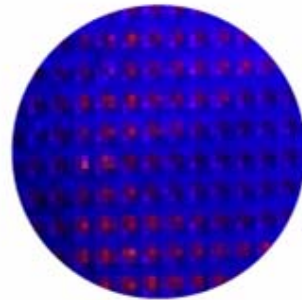


Bluetooth Traffic Monitoring Technical Attributes and Applications

**NATMEC
June 23, 2010**

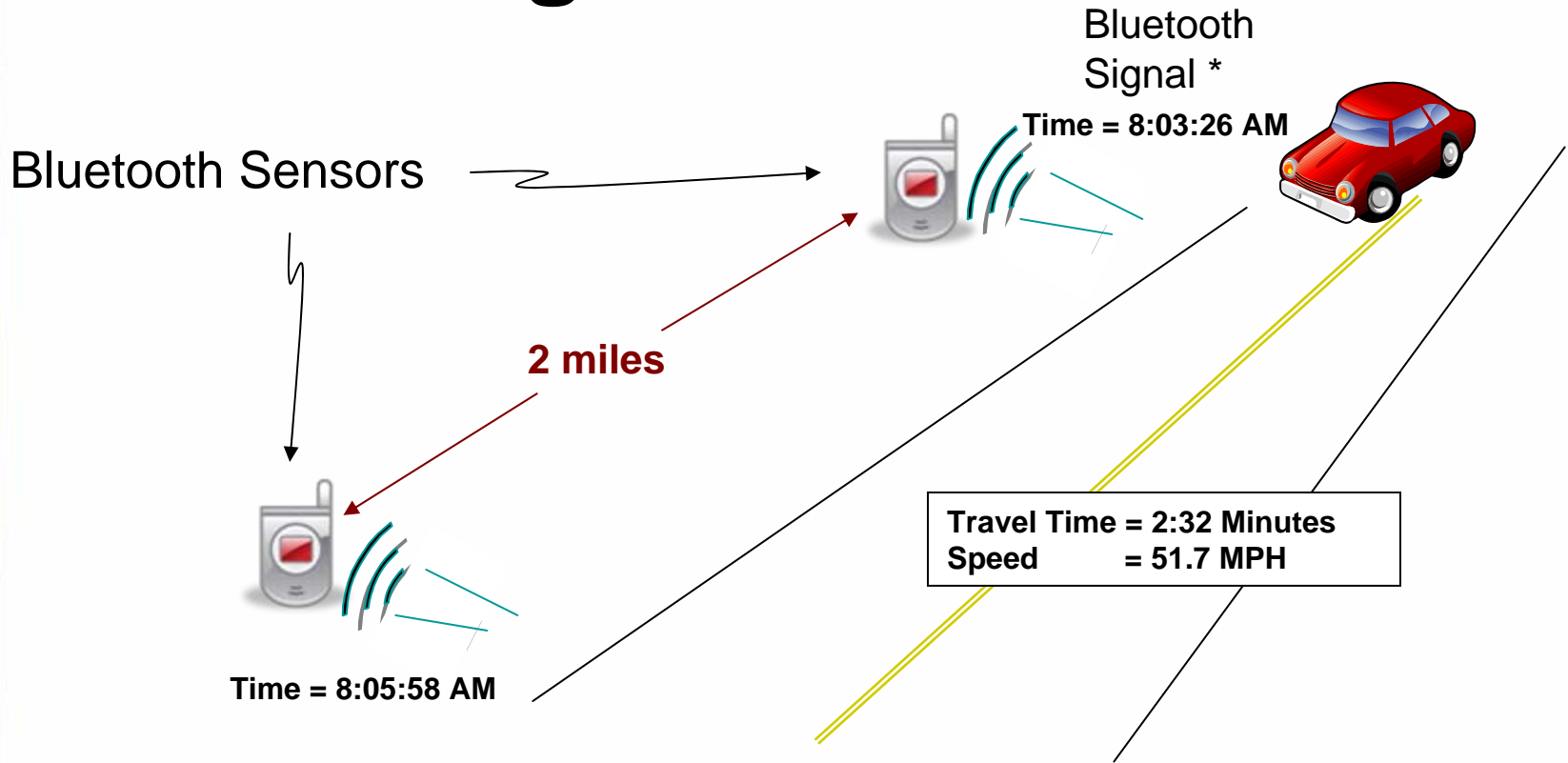
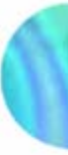
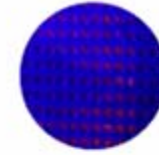




What is Bluetooth?

- **IEEE Wireless Data Communication Standard**
 - License Free Spectrum - ~2.4GHz
 - Cable Replacement Technology
 - Ubiquitous – worldwide proliferation
- **Where is it found?**
 - Cell phones / PDAs / PNDs / MP3 players
 - Laptops / Games / Cameras
- **Essential characteristics**
 - Three power ranges 100m / 10m / 1m
 - Anonymous ID / Privacy Protection / Voluntary
 - Approximately 1 in 20 sampling rate is the US

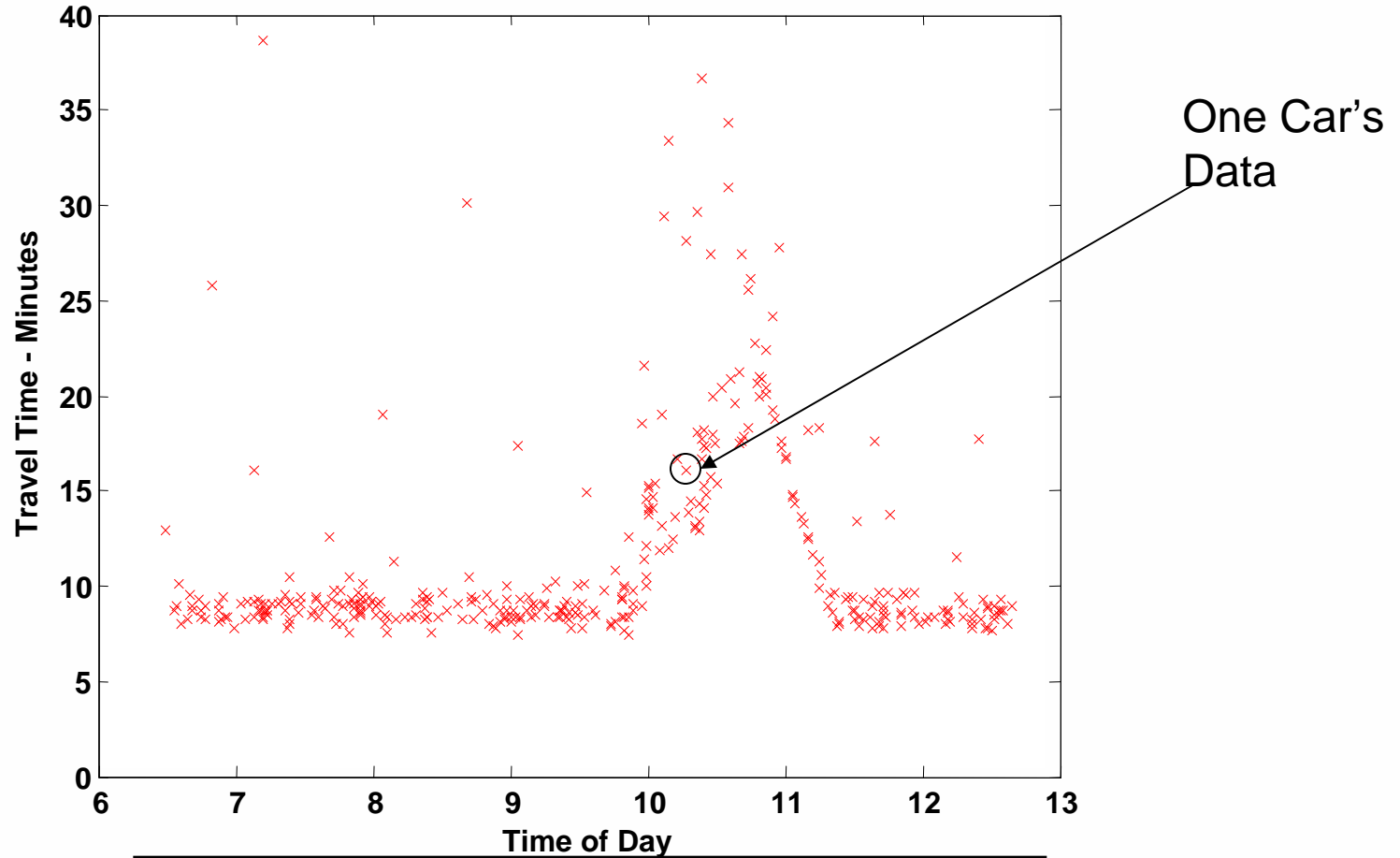
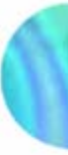
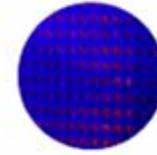
Bluetooth Traffic Monitoring



* Bluetooth signals come from cell phones, PDAs, laptops, GPS, car radios...

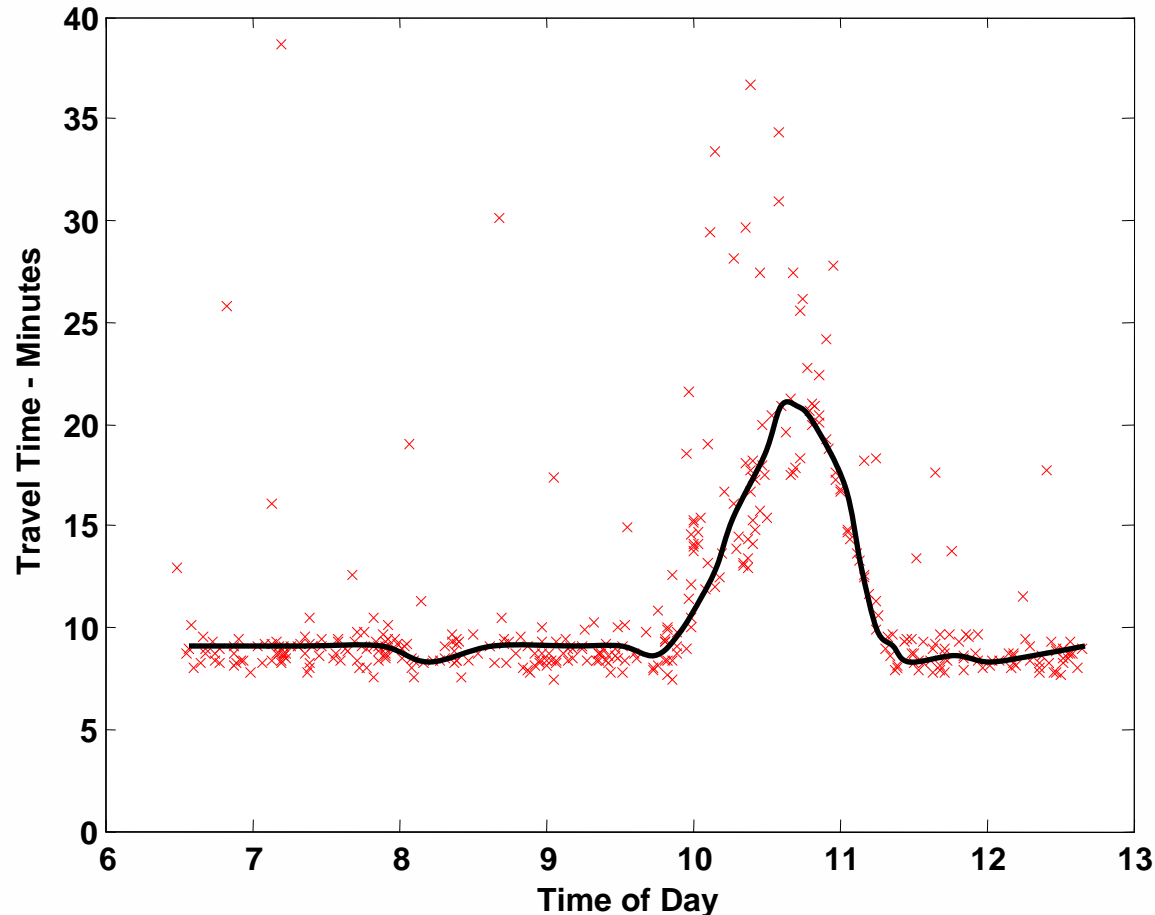
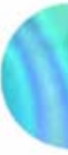
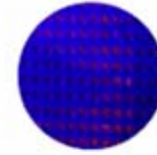
** Provisional patent received

Data from many cars ...



Actual Travel Time Data from I-95 Northbound on April 2

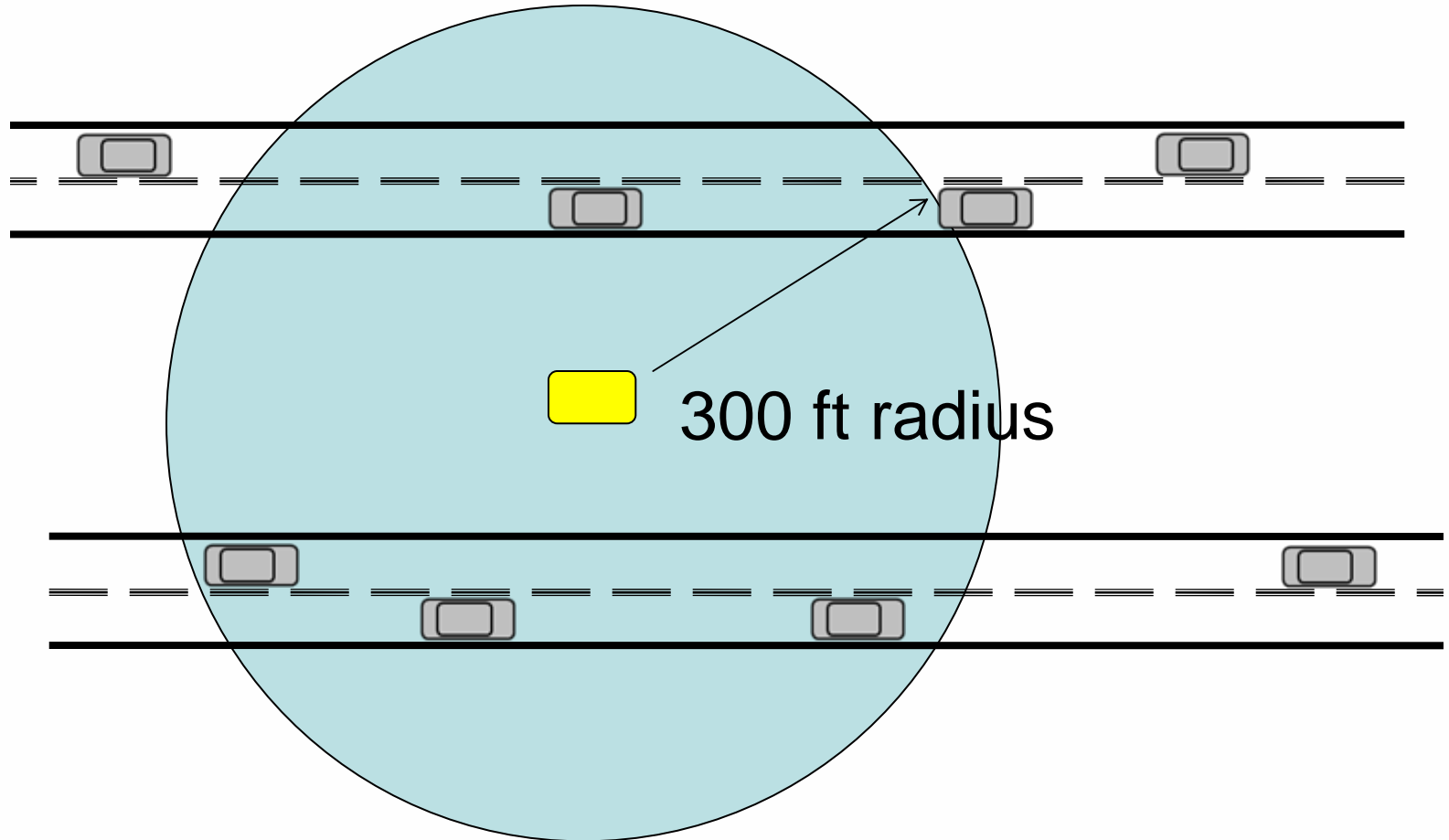
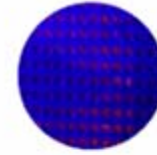
Data from many cars ...



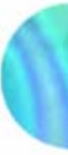
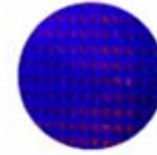
6/30/2010

Actual Travel Time Data from I-95 Northbound on April 2

Bluetooth Detection Range



Typical Temporary Deployment of a Bluetooth Sensor





Conventional
Detectors

GPS Fleet
Tracking

Cell Phone
Geolocation

Toll Tag
Tracking

Bluetooth Traffic Monitoring Advantages

- ✓ **Privacy guarantees**
- ✓ **Direct Travel Time measurement**
- ✓ **All roadways at any time of day**
- ✓ **Flexibility of deployment**
- ✓ **Validated against ATRs, Toll Tags, and Floating Car**
- ✓ **Ubiquitous – worldwide proliferation**



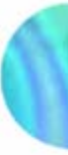
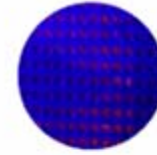
Privacy and Legal Issues

- Bluetooth IDs inherently anonymous
 - No user account information
 - Compliant to IEEE standards
 - No packet sniffing
- Federal Rules and State Legislation
 - FCC anti-eaves dropping rules
 - State legislation against use of personal data

Application Potential

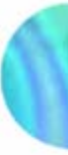
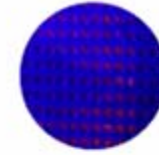
- Bluetooth applications:
 - Freeway travel time (VM)
 - Arterial travel time and Performance Measures (M)
 - Traffic signal studies (M)
 - Pedestrian travel time (E)
 - Airports, Evacuation Modeling, Transit
 - O&D studies (R&D)

Ongoing Applications

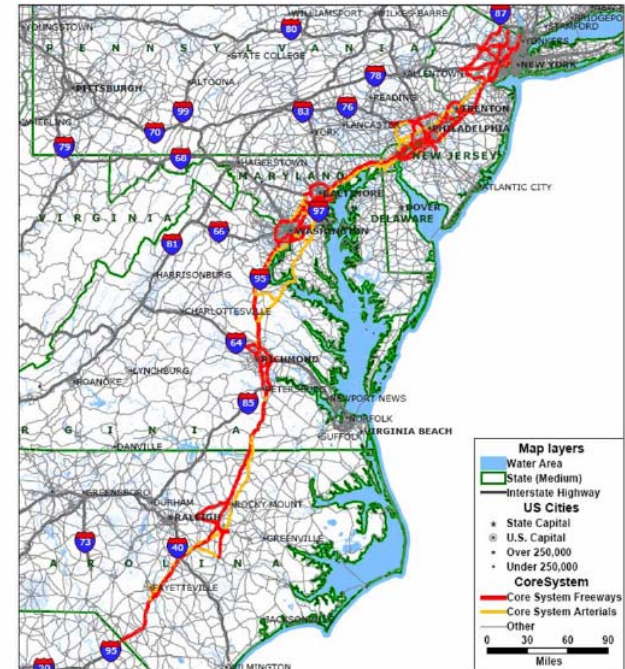


- **Vehicle Probe Project**
- Bluetooth Sampling Rate
- Dynamic Message Sign Evaluation Pilot
- Short Term Travel Time Forecast
- Special Event Pedestrian Traffic Monitoring

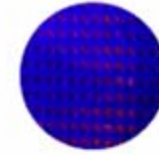
Vehicle Probe Project



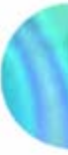
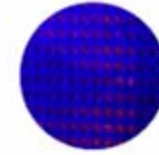
- Validation of Travel Time data provided by INRIX to I-95 member states since July 2008
- Participating states:
 - Delaware
 - Maryland
 - New Jersey (entire limited access road network)
 - North Carolina (entire interstate system)
 - Virginia
 - Pennsylvania



Safety Issues in Deployment



Validation Effort




- Six states
- 16 evaluation reports
- 21 deployments, 206 days sensors on the road
- 505 centerline mile (454 mile freeway, 51 mile arterial)
- 33,461 hour worth of ground truth data resulting from 3.8 million Bluetooth observations

State	Deployment	TMC Type	Start Time	End Time	No. of TMC	Total Length	Total BT Records	Total BT Hours
DE	1	F	9/4/08 11:35	9/9/08 18:25	3	6.2	4182	348
		A	9/4/08 13:05	9/9/08 15:50	2	2.8	2914	242
	2	F	2/3/09 13:05	2/9/09 21:15	10	13.5	16929	1410
	3	F	8/11/09 13:25	8/22/09 21:05	7	10.3	21364	1780
		A	8/11/09 13:10	8/23/09 2:00	2	2.5	5875	489
4	F	4/26/10 11:00	5/4/10 10:55	9	13.4	14004	1167	
MD	1	F	7/30/08 19:35	8/7/08 19:55	26	33.6	4015	334
		A	7/30/08 20:40	8/7/08 19:20	23	25.1	4877	406
	2	F	3/5/09 11:20	3/17/09 21:30	9	20.1	15058	1254
	3	F	2/2/10 10:25	2/10/10 16:15	10	13.9	9483	790
A		2/2/10 11:20	2/9/10 19:50	2	3.0	814	67	
NC	1	F	10/24/08 9:25	11/5/08 14:35	13	40.5	20888	1740
		A	10/28/08 15:05	11/6/08 17:35	5	10.9	2179	181
	2	F	7/10/09 9:20	7/21/09 10:15	10	43.8	29863	2488
3	F	3/23/10 10:20	4/3/10 20:50	10	19.5	18494	1541	
NJ	1	F	9/15/08 13:20	10/3/08 13:45	12	28.0	15487	1290
	2	F	4/8/09 15:05	4/20/09 23:50	10	15.8	18424	1535
	3	F	6/3/09 10:15	6/15/09 11:35	10	63.3	29678	2473
	4	F	9/8/09 11:25	9/17/09 12:15	10	17.3	25816	2151
	5	F	10/1/09 11:55	10/13/09 19:20	10	13.7	30724	2560
	6	F	5/25/10 12:05	6/3/10 12:40	6	10.1	12332	1027
PA	1	F	1/6/10 11:25	1/17/10 16:35	8	9.2	22971	1914
		A	1/6/10 12:20	1/17/10 1:30	2	5.9	5170	430
VA	1	F	7/22/08 19:15	7/24/08 19:15	24	37.7	4321	360
	2	F	11/18/08 10:20	11/25/08 18:15	10	16.5	18138	1511
	3	F	5/7/09 9:45	5/18/09 21:20	9	13.8	17819	1484
	4	F	11/5/09 9:40	11/16/09 21:10	8	13.6	24513	2042
		A	11/5/09 11:20	11/15/09 22:35	2	1.0	5371	447

Automated Evaluation Tool

University of Maryland, Traffic Information Analysis

Data handling Reports & charts



195 Corridor Coalition Vehicle Probe Project Data Evaluation Tool

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Ali Haghani, Masoud Hamedi

Match and Filter

Matching and Filtering

Match Bluetooth records (Batch) Upload matched records

Filter Bluetooth observations 1.5 * Sigma Analyze

Aggregate Bluetooth observations Two minute aggregation

Add matched observations to DB Deployment number: 99

Generate Inrix records based on BT Generate Inrix path records

Aggregate generated Inrix records Aggregate Inrix path records

Add aggregated records to database Add aggregated path records

Report and statistics:

DMS Data Processing

Aggregate

GPS Data

Generate the match from GPS data Sort and aggregate GPS data

University of Maryland, Traffic Information Analysis

Data handling Reports & charts

- TMC based report for Bluetooth and Inrix
- TMC based report for drive test
- Filter Comparison
- Detector data
- Path analysis
- DMS study

Database stats

195 Corridor Coalition Vehicle Probe Project Data Evaluation Tool

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Ali Haghani, Masoud Hamedi

Report Generator

TMC based reports - Bluetooth vs Inrix

TMC Type: All Freeway Arterial

TMC length range: Min Max

Shift Inrix Data: No 5 Min

Recalculated Inrix: Yes No

Inrix Score: All Score = 30 Score <= 20 Score >= 20

Filter Bluetooth records: Max COV

Band around mean: by standard dev by standard error

States: All states

State	Dep
DE	1
DE	2
DE	3
DE	9
MD	1

Select TMC

TMC	State	Type
103+04107	DE	F
103-04103	DE	F
103-04110	DE	F
103-04763	DE	A

Date Range: 1/1/2000 12:00 AM to 1/1/2010 12:00 AM

Graph time labels: UTC EST Show data

TMC Selection: Add to selection, Add all TMC's

TMC Report | Group TMC report | Cover reports | Band Report

Report overall average error for TMC's

Report overall average error for speed bins

Average Error / Speed Bin - TMC by TMC

Date filter doesn't apply to the above reports



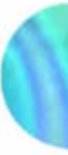
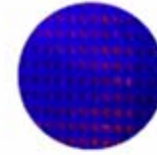
TMC 103-04107 on Virtual Earth

Zoom to end point 1 | Zoom to end point 2

Database stats

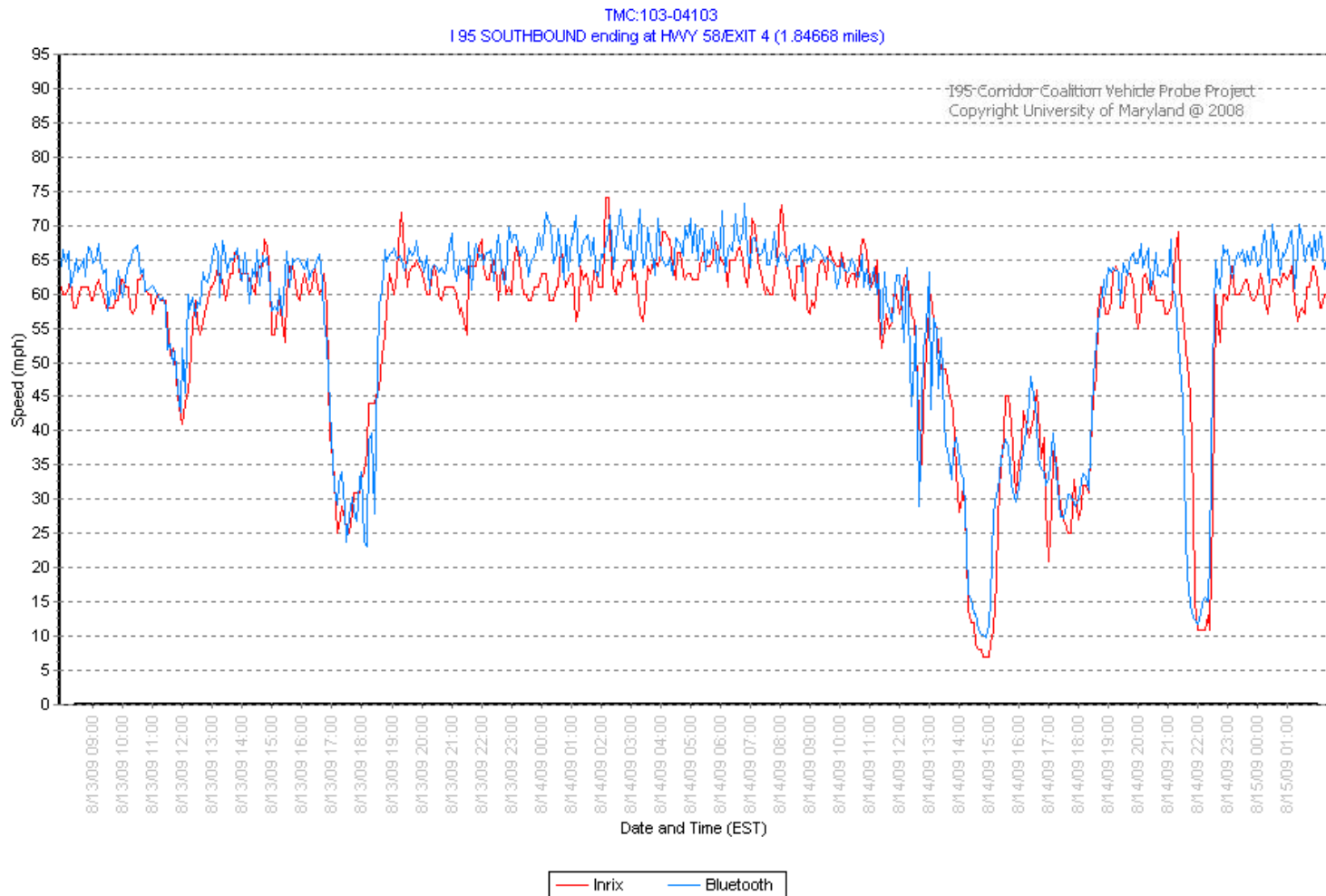
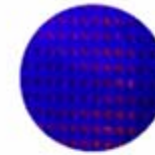
USState	Deployment	TMCType	Start_Time	End_Time
			Total_Deployment_Days	TMC_COUNT
			Total_BT_Records	Total_BT_Hours
DE	1	F	9/4/2008 11:35:00 AM	9/9/2008 6:25:00 PM
	5	3	6.20428 4182 348	
DE	1	A	9/4/2008 1:05:00 PM	9/9/2008 3:50:00 PM
	5	2	2.763698 2914 242	
DE	2	F	2/3/2009 1:05:00 PM	2/9/2009 9:15:00 PM
	6	10	13.46 16929 1410	
DE	3	F	8/11/2009 1:25:00 PM	8/22/2009 9:05:00
PM	11	7	10.33 21364 1780	
DE	3	A	8/11/2009 1:10:00 PM	8/23/2009 2:00:00
AM	12	2	2.54254 5875 489	
DE	9	F	8/11/2009 2:00:00 PM	8/23/2009 11:30:00
AM	12	1	1.71 3427 285	
MD	1	F	7/30/2008 7:35:00 PM	8/7/2008 7:55:00 PM
	8	26	33.613553 4015 334	
MD	1	A	7/30/2008 8:40:00 PM	8/7/2008 7:20:00 PM
	8	23	25.107969 4877 406	
MD	2	F	3/5/2009 11:20:00 AM	3/17/2009 9:30:00

Features

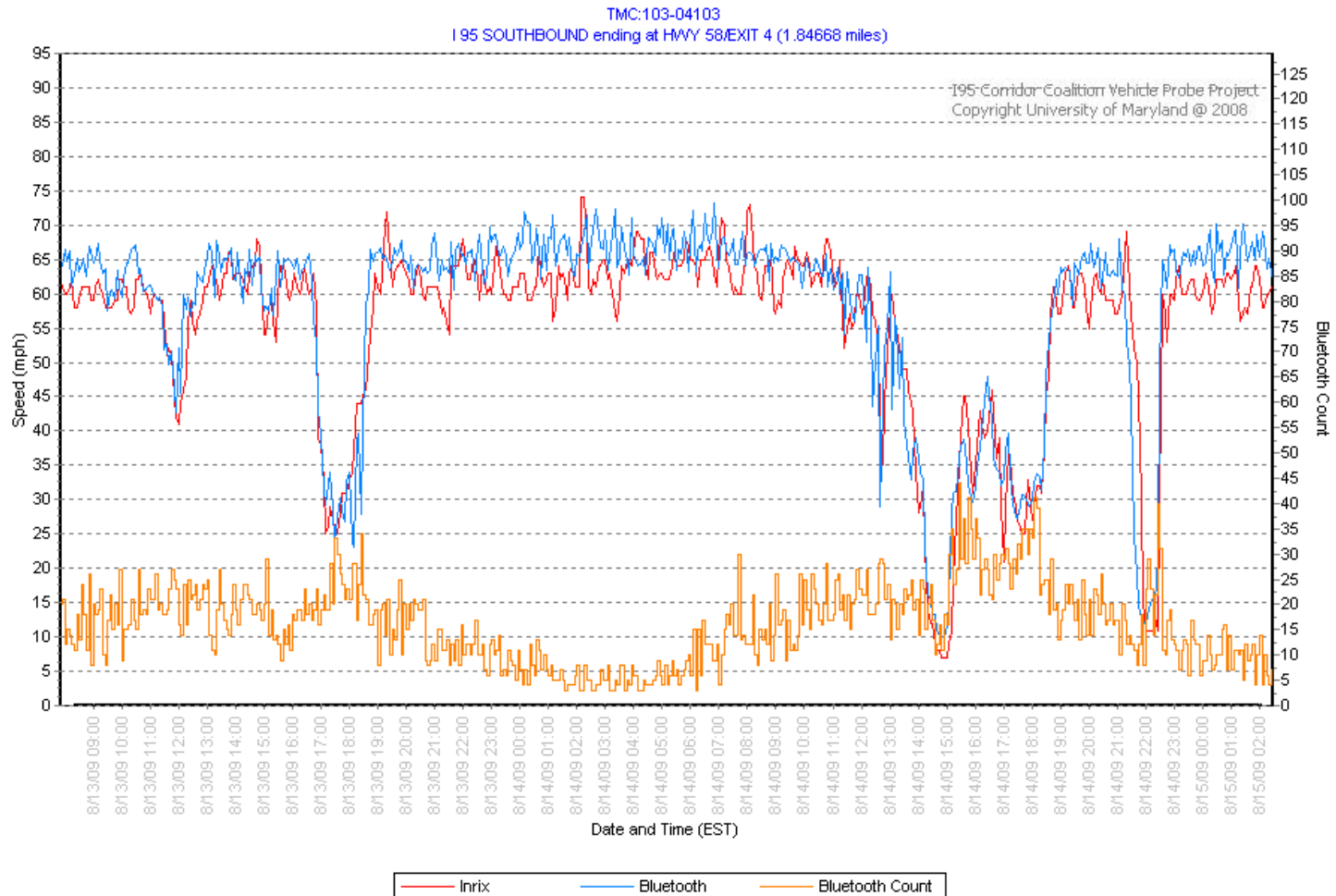
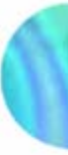
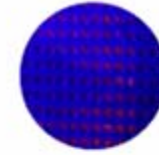


- Internet accessible
- Outlier filtering
- Path data analysis
- Evaluation report generator
- Graph generator
- Data Import and export (XML, CSV)
- Bluetooth penetration rate analysis
- Bluetooth OD analysis and report
- Statistics report
- TMC mapping
- Data mining
- Programming language C++, Database Microsoft SQL Server

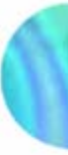
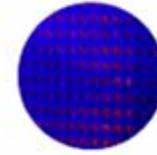
Bluetooth and INRIX Speed Comparison



Bluetooth and INRIX Speed Comparison with Bluetooth Observation Counts

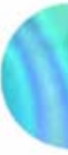
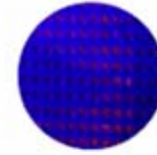


Ongoing Applications



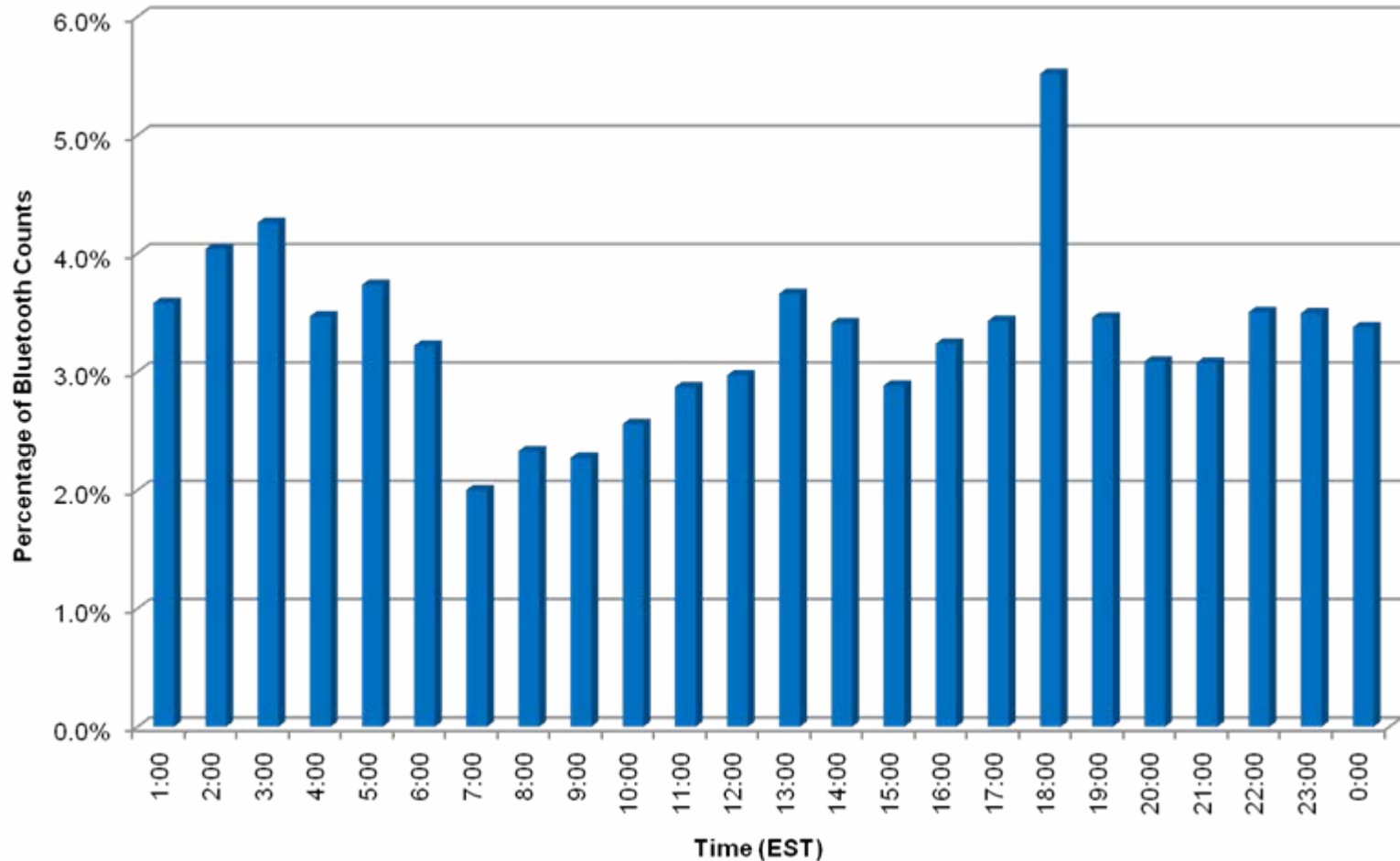
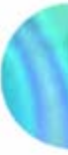
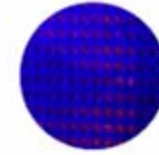
- Vehicle Probe Project
- **Bluetooth Sampling Rate**
- Dynamic Message Sign Evaluation Pilot
- Short Term Travel Time Forecast
- Special Event Pedestrian Traffic Monitoring

Bluetooth Sampling Rate

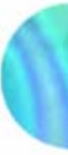
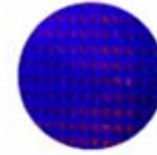


- Bluetooth sensors sample a fraction of vehicles in the traffic stream, so it is important to understand what percentage of total traffic volume is being sampled
- Secondary source of traffic surveillance is required to measure the sampling rate
- Wavetronix sensors in Delaware and CHART data in Maryland was used to study the sampling rate

Typical Hourly Bluetooth Sampling Rate

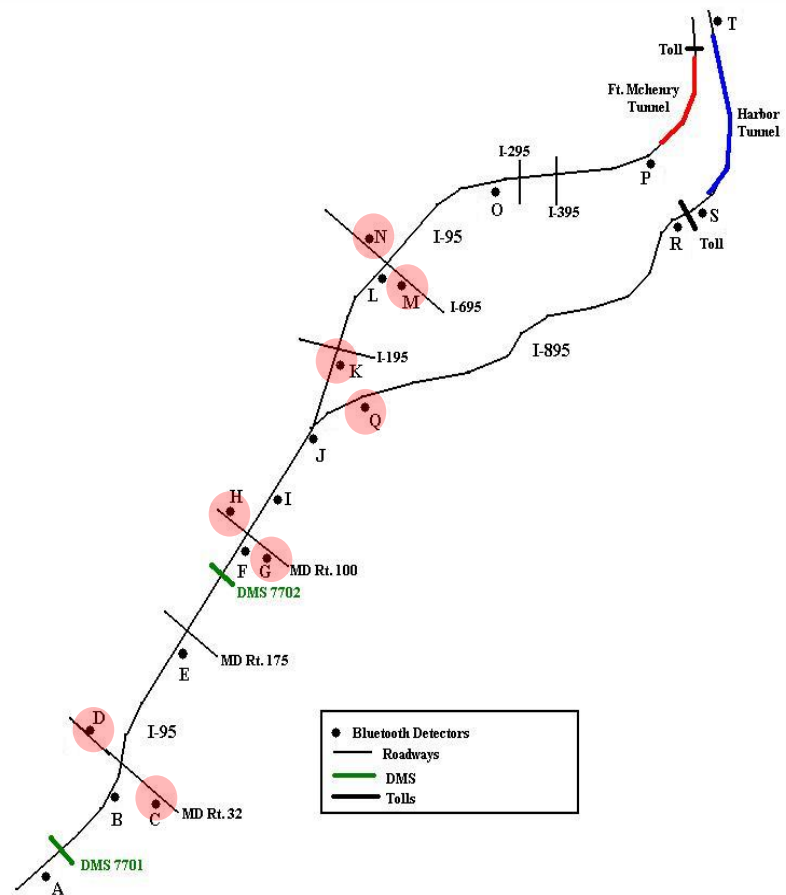
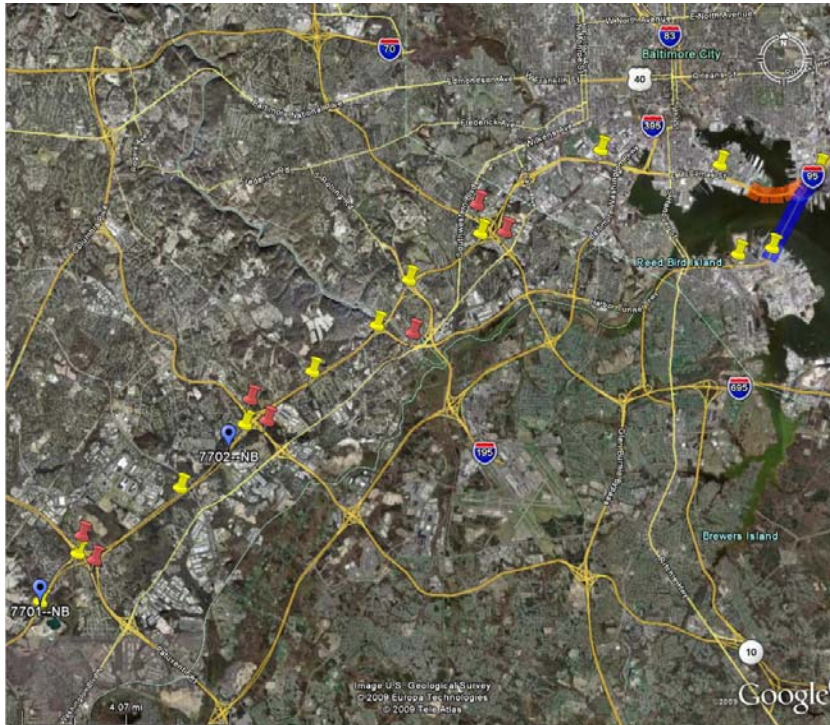
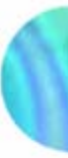
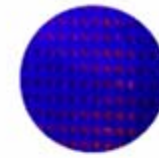


Ongoing Applications

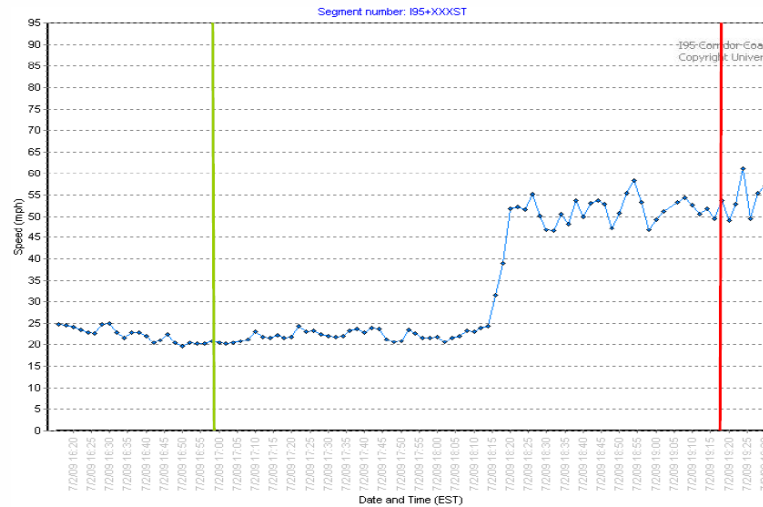
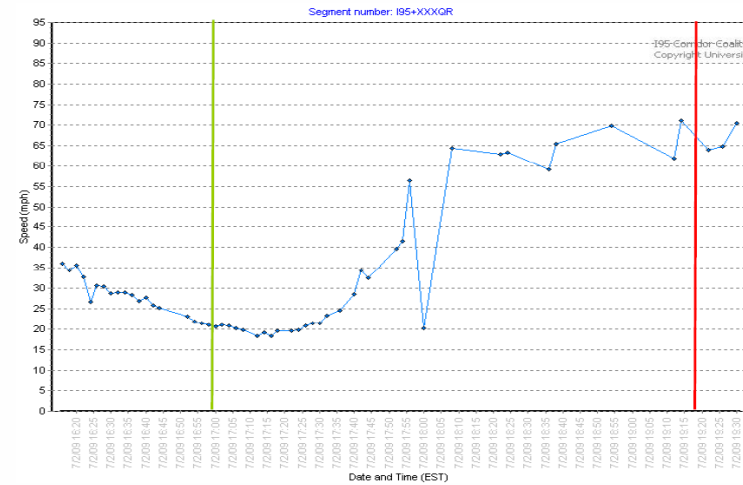
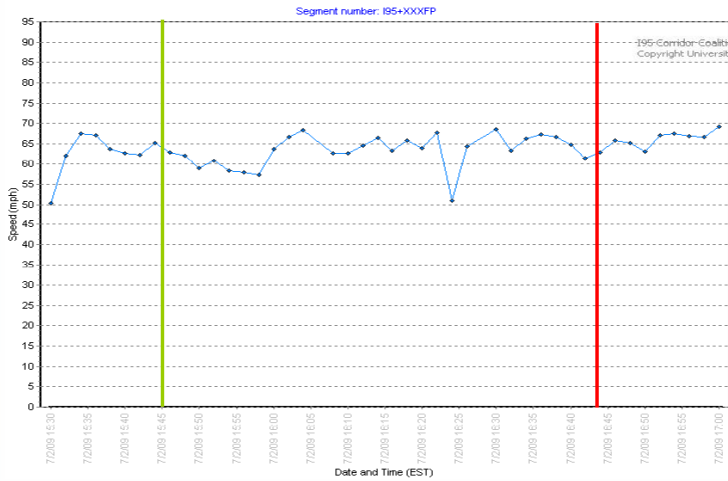
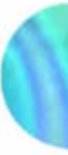
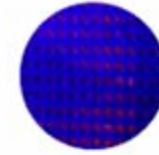


- Vehicle Probe Project
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- **Dynamic Message Sign Evaluation Pilot**
- Short Term Travel Time Forecast
- Special Event Pedestrian Traffic Monitoring

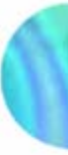
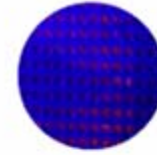
DMS Evaluation Pilot



DMS Evaluation Pilot

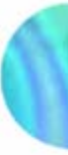
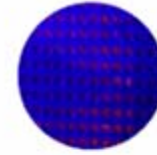


Ongoing Applications



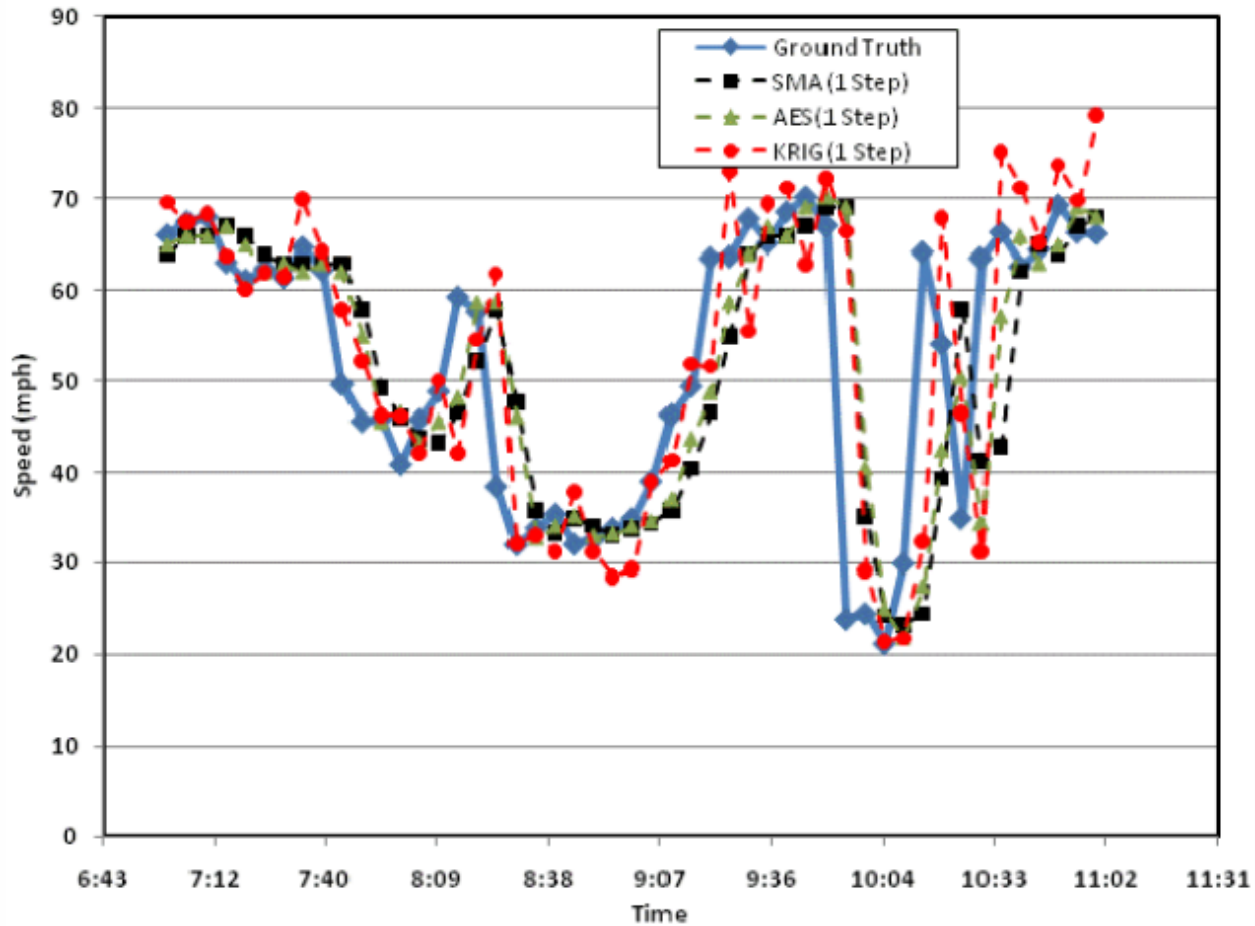
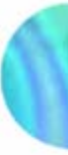
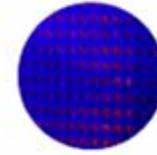
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Short-Term Travel Time Forecast

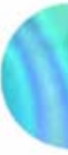
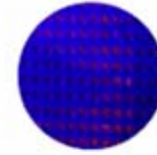


- Real time travel time estimates from Bluetooth are used for short-term forecasts
- Moving average methods are widely used for this purpose
- Three moving average methods are considered
 - Simple Moving Average w/ equal weights
 - Adaptive Exponential Smoothing
 - Kriging w/ optimal weights

Short-Term Travel Time Forecast (5 minute predictions)

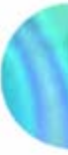
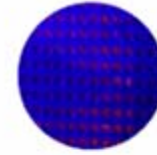


Ongoing Applications



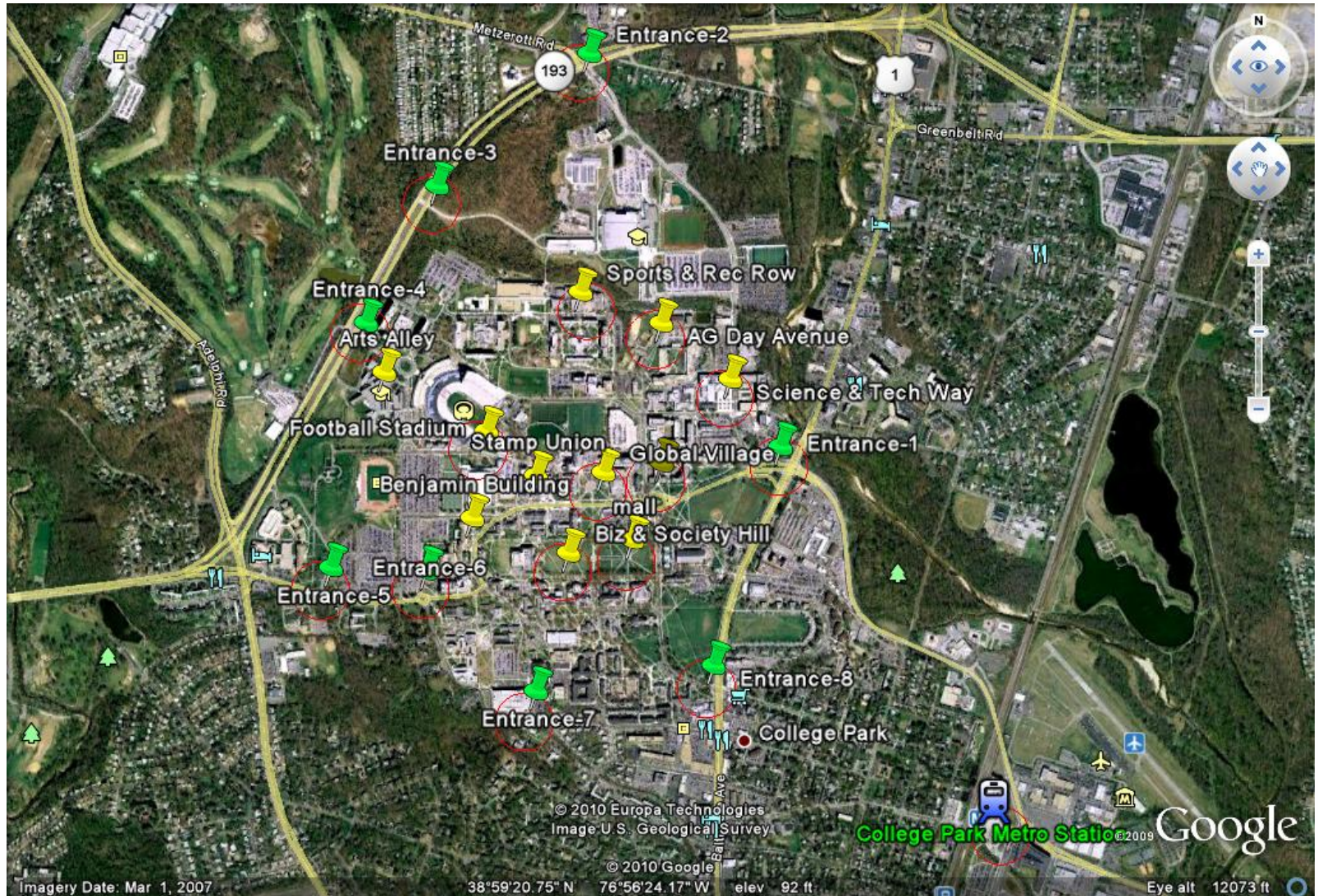
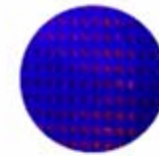
- Vehicle Probe Project
- Bluetooth Sampling Rate
- Dynamic Message Sign Evaluation Pilot
- Short Term Travel Time Forecast
- **Special Event Pedestrian Traffic Monitoring**

Special Events Pilot

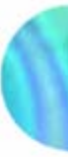
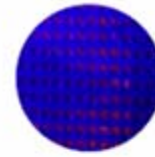


- **Maryland Day Traffic Patterns (April 24, 2010)**
 - Descriptive trip analysis
 - Pedestrian route choice
 - Event planning
 - Evacuation plans

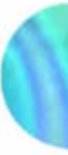
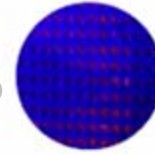
Special Events Pilot



Special Events Pilot

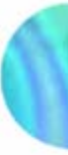
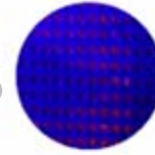


Papers and Presentations



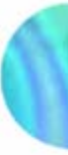
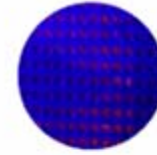
- Kaveh Farokhi Sadabadi, Masoud Hamed, Ali Haghani, **“Real-Time Travel Time Estimation: Filtering Raw Data in an Automatic Vehicle Identification Setting”**, Paper presented at the ITS America Annual Meeting, Washington, DC, June 2009.
- Kaveh Farokhi Sadabadi, Masoud Hamed, Ali Haghani, **“Real-Time Short-Term Freeway Travel Time Prediction Under an AVI Setting”**, Paper presented at the 2nd International Symposium on Freeway & Tollway Operations, Honolulu, Hawaii, June 2009.

Papers and Presentations



- Kaveh Farokhi Sadabadi, Masoud Hamedi, Ali Haghani, **“Evaluating Moving Average Techniques in Short-Term Travel Time Prediction Using an AVI Dataset”**, Presented at the 89th Transportation Research Board annual meeting, Washington, DC, January 2010.
- Ali Haghani, Masoud Hamedi, Kaveh Farokhi Sadabadi **“Freeway Travel Time Ground Truth Data Collection Using Bluetooth Sensors”**, Presented at the 89th Transportation Research Board annual meeting, Washington, DC, January 2010.
- Masoud Hamedi, Ali Haghani, Kaveh Farokhi Sadabadi **“Using Bluetooth Technology for Validating Vehicle Probe Data”**, Proceedings of 16th ITS World Congress, Stockholm, Sweden, September 2009.

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