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Convergence of Vehicle and Infrastructure Data for Traffic and Demand Management

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National Renewable Energy Laboratory

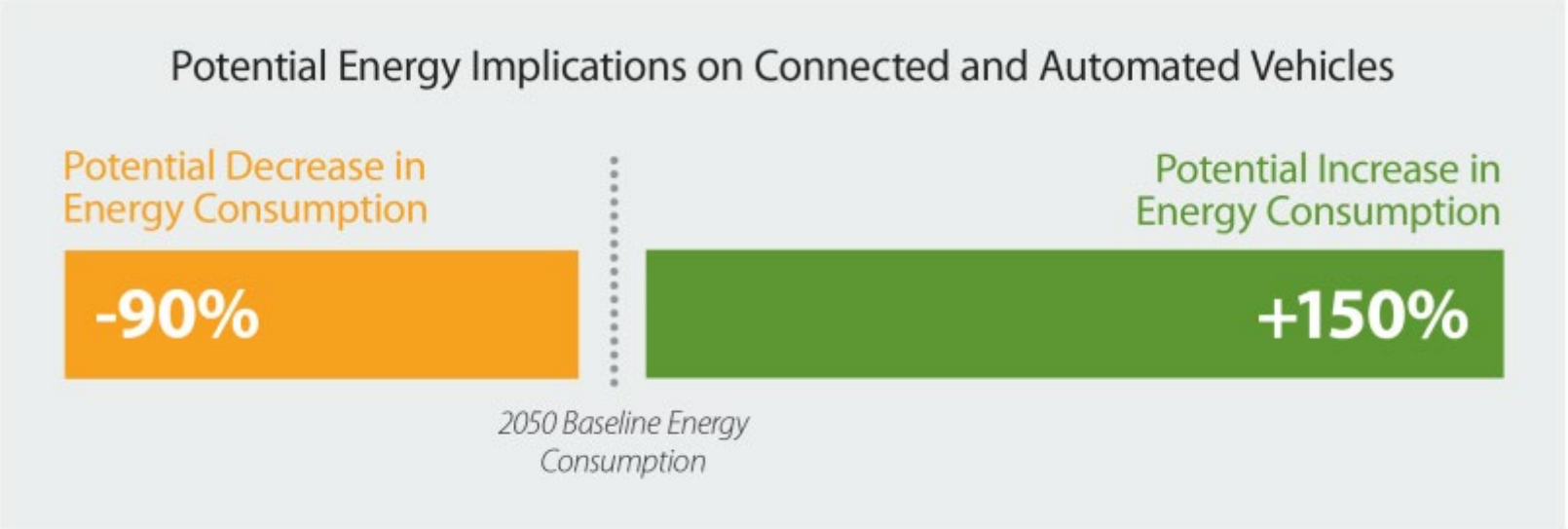
November 16, 2015

New Directions in Mathematical Approaches for Traffic Flow Management workshop
Los Angeles, California

NREL/PR-5400-65504

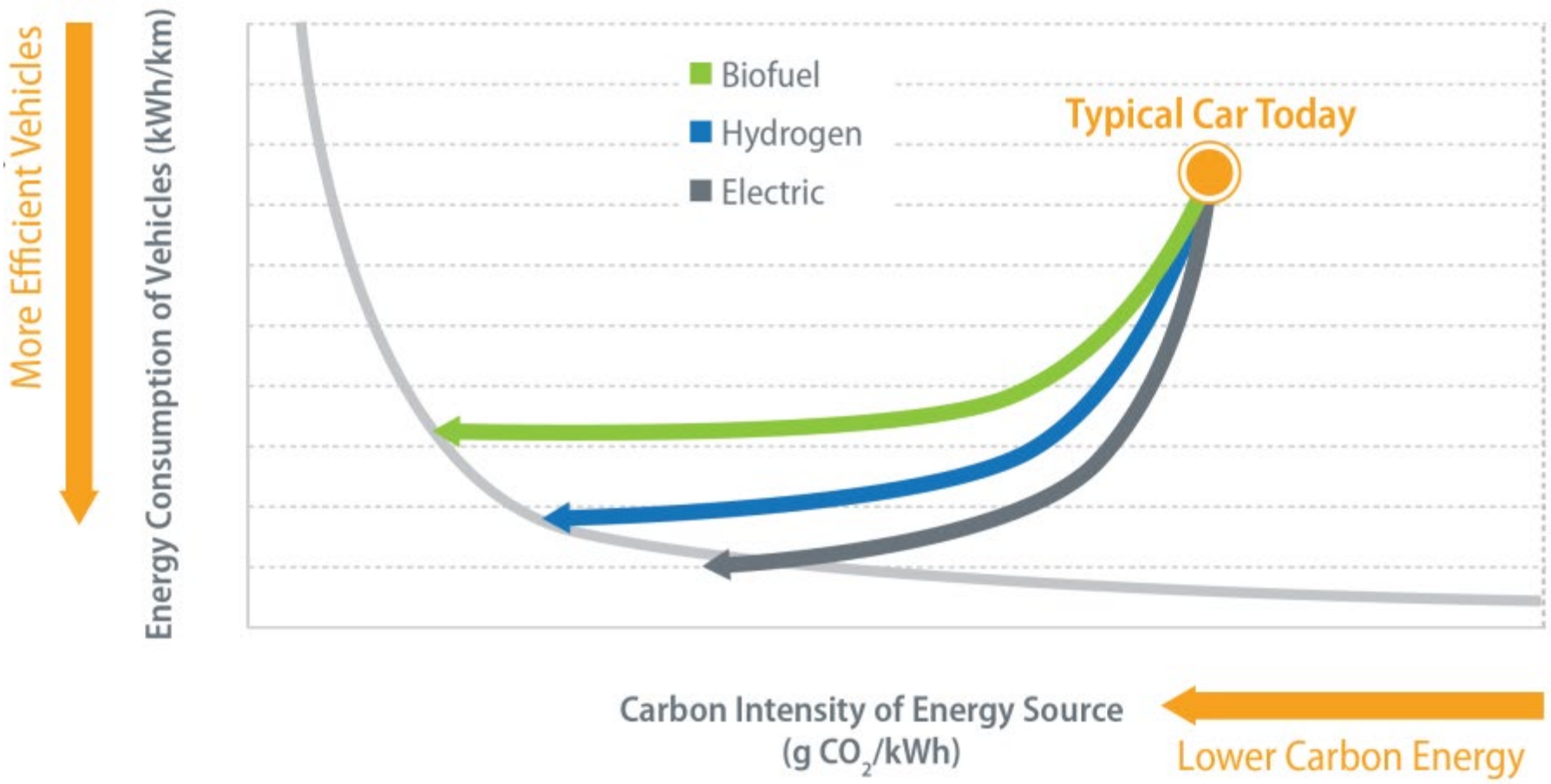
Connectivity/Automation Will Transform Transportation

- Vehicle connectivity and automation can substantively impact the effectiveness of investments in increased fuel economy and low-carbon fuels
- Huge business around increasing vehicle and transportation asset utilization and right-sizing of mobility technologies
- Increased pressure for transportation infrastructure managers to do more with less



Source: Brown, A.; Gonder, J.; Repac, B. (2014). "An Analysis of Possible Energy Impacts of Automated Vehicles." Springer Book Chapter.

Getting the CO_2 Out – Pathways to 2050



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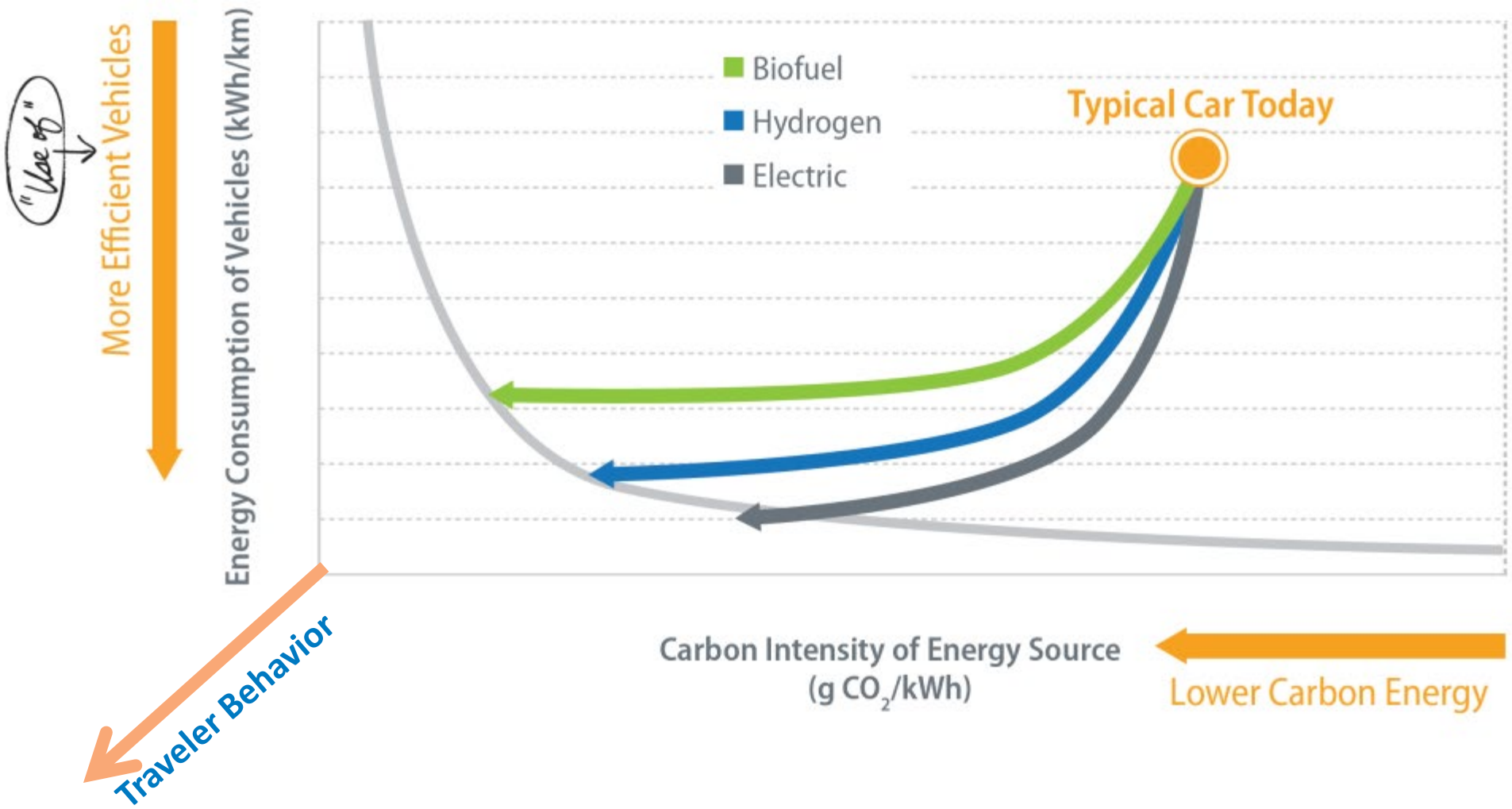
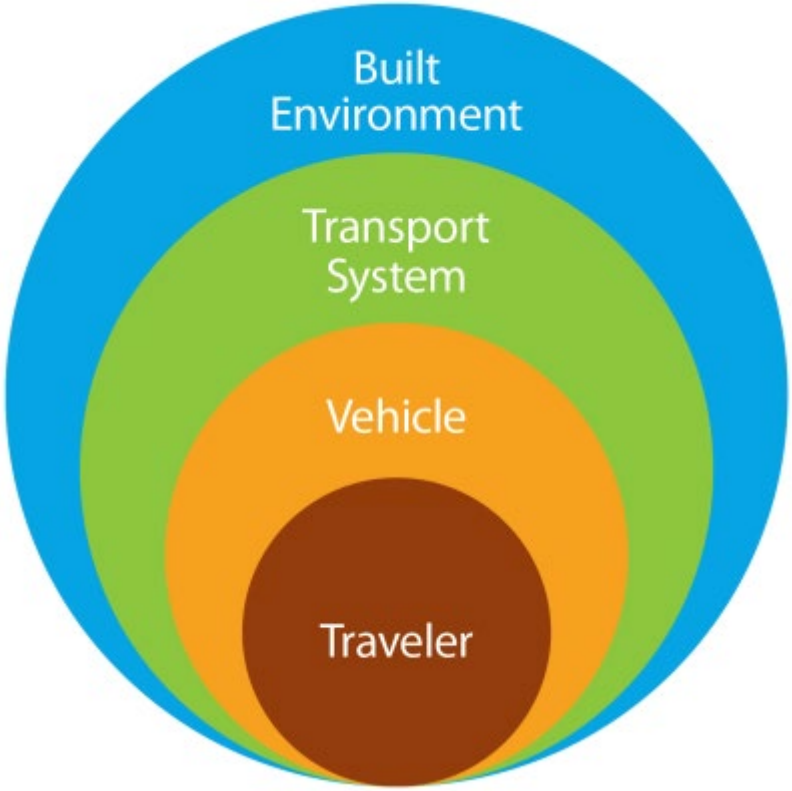


Starting with the Traveler

We need to approach sustainable transportation as a network of travelers, services, and decision points connected by communication technology and decision-making tools—rather than just by vehicles and roads—to significantly reduce related energy consumption.



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The Connected Traveler

ARPA-E TRANSNET

The Connected Traveler

The Market Opportunity

American travel time increased by

6.9 billion hours

. . . increasing gasoline consumption by

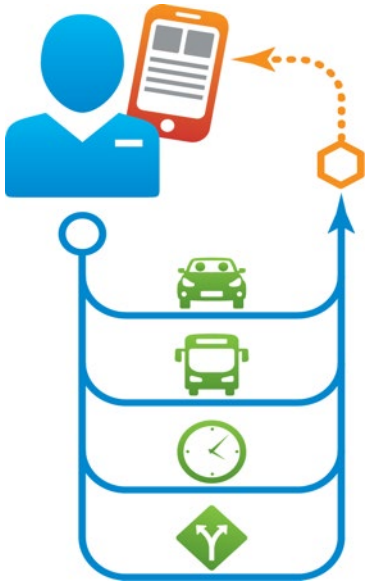
3.1 billion gallons

. . . resulting in a congestion cost of

160 billion dollars

Source: Texas A&M Transportation Institute 2015 Urban Mobility Scorecard

The Project



The Team

UC DAVIS
UNIVERSITY OF CALIFORNIA

KU
THE UNIVERSITY OF KANSAS

metropia

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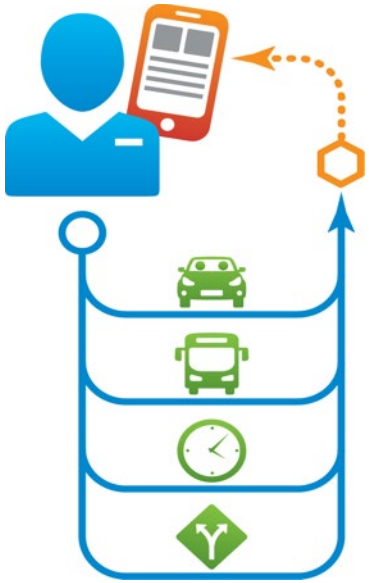
Texas Transportation Institute

UNIVERSITY of WASHINGTON

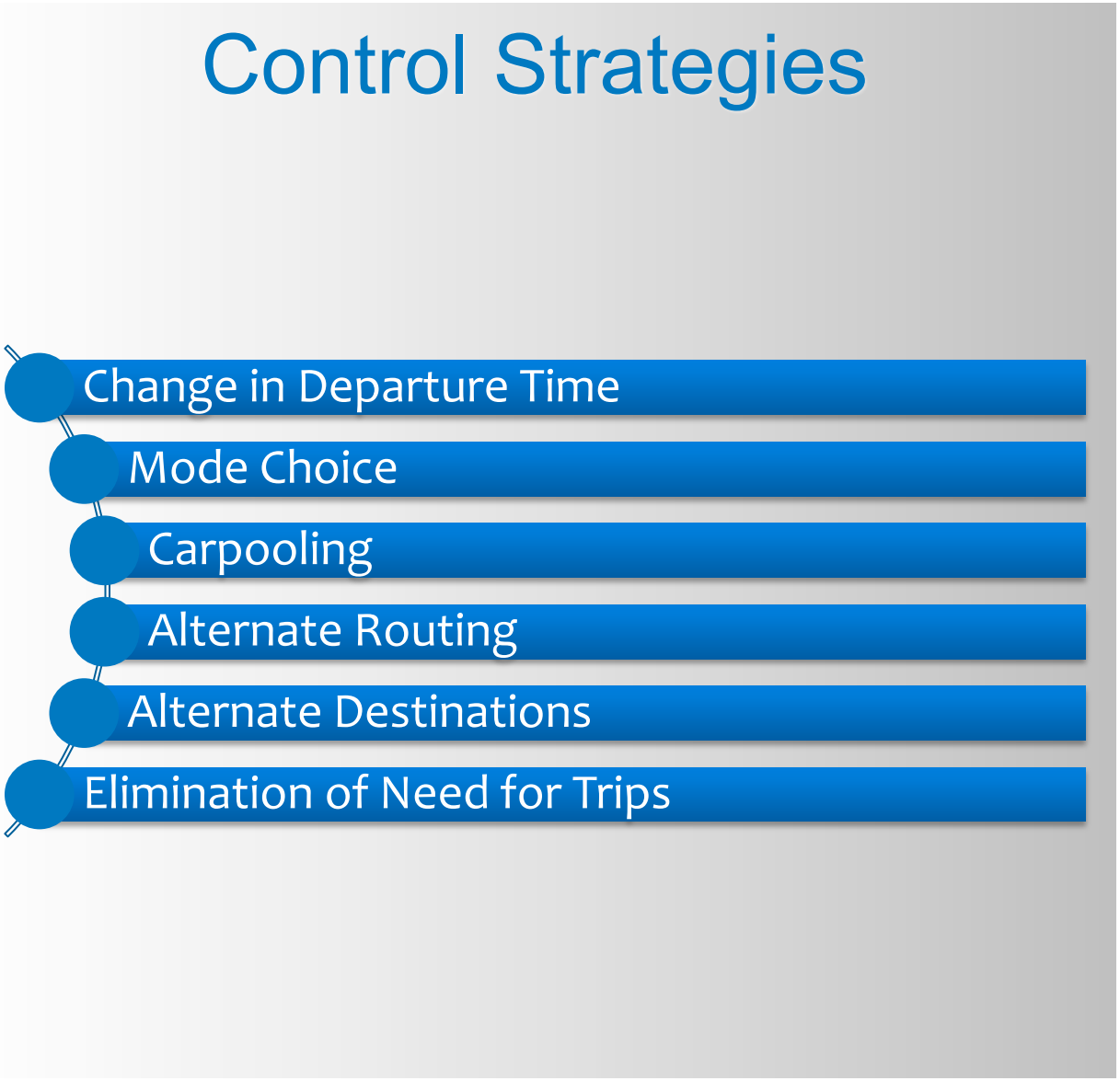
Connected Traveler Project Overview



- Multi-disciplinary undertaking that will seek to validate potential for transformative transportation system energy savings by incentivizing efficient traveler behavior
- Control architecture will be developed that incorporates adaptive learning, refined incentives, and control strategies to provide high certainty of adoption
- Metropia platform will allow for real-world validation of traveler behavior and assist in refining incentives and control strategies
- NREL Transportation Secure Data Center and related tools will be used to determine individual energy consumption
- Individual energy impacts will be extrapolated to estimate transportation system energy consumption*

**Additional system model development may be required to refine this to a margin of error that can be used by transportation practitioners*

Framing and Refining Control Strategies



Framing effects of incentives and benefits will be investigated and refined

Additional control strategies will be investigated to allow for additional savings opportunities and incorporation of new mobility opportunities

Phase I

- Change in departure time
- Alternate routing
- Alternate destinations

Phase II

- Mode Choice
- Carpooling
- Elimination of Trips

Framing and Refining Control Strategies

Incentive Spectrum

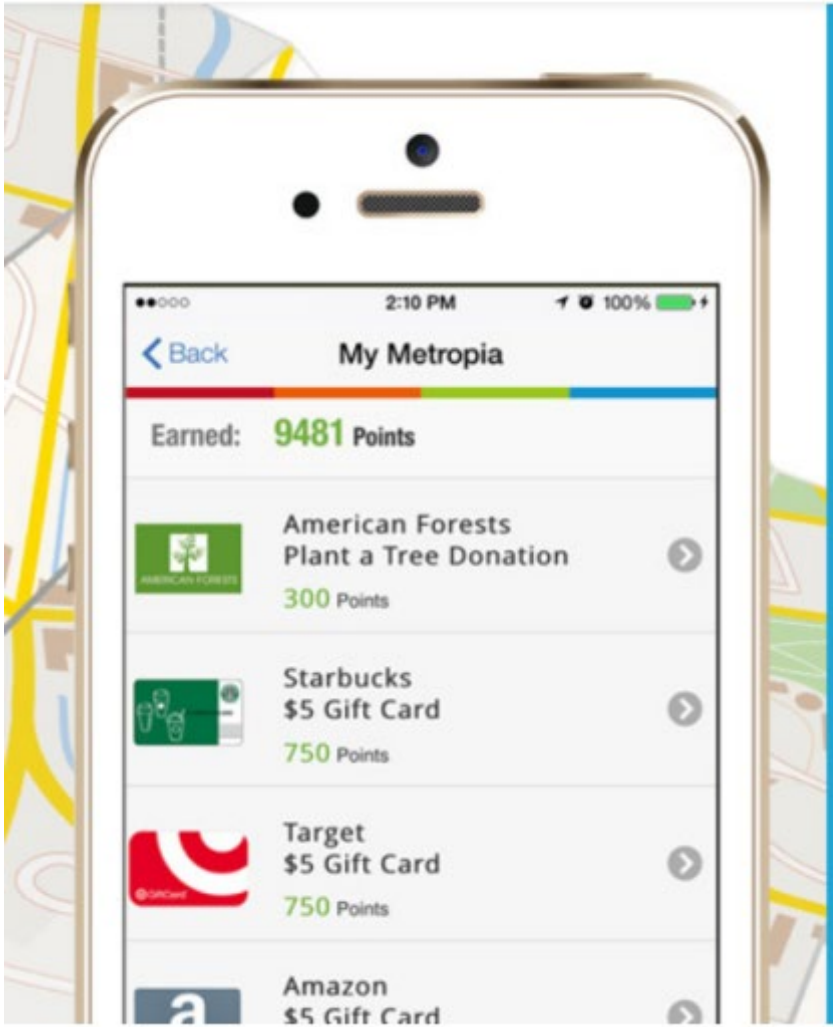
- Navigation Service
- Travel Time Minimization
- Predictive Analytics
- **Points, Points, Points**
- Products – ex. Starbucks coupon
- Services – ex. Transit pass or discount
- Charity – ex. Plant a tree

The incentives for using the app and accepting its suggestions for routing, mode, time diversions is a set of incentives

Traditional incentives include rewards as navigation services, route selection to minimize delay, and predictive analytics.

Non-traditional incentives include using the app in a method similar to credit cards or frequent traveler programs. Points are earned toward products, services, and even donations to charities.

Small Nudges to Sustainability



Avoiding traffic is its own reward (but we're throwing in others just for fun)

Metropia incentivizes and rewards you for making responsible driving decisions. Earn maximum rewards for using our traffic-free routes and choosing less-congested times to commute.

You can redeem your reward points for:

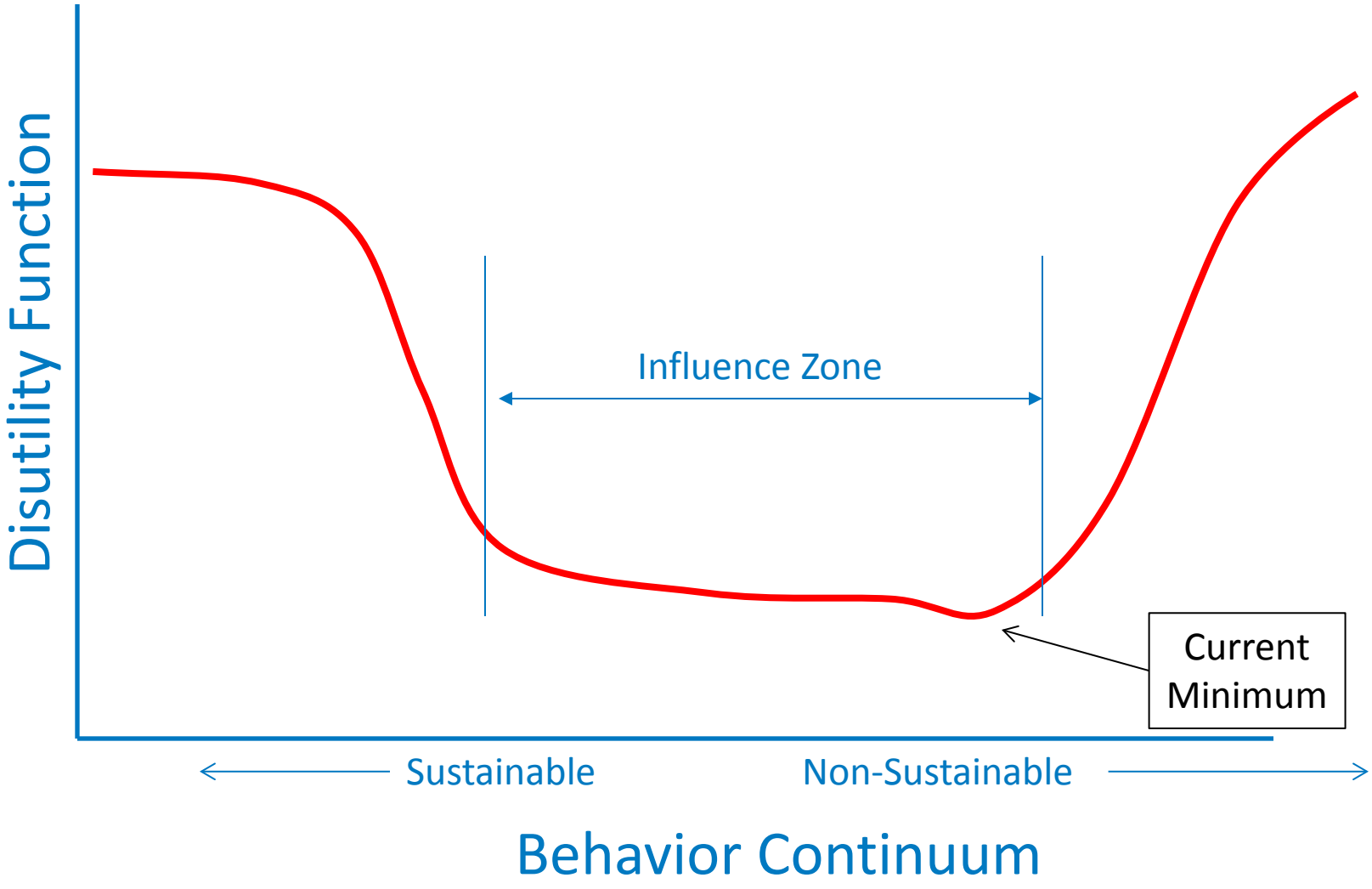
» Gift cards to your favorite stores & restaurants

» Free passes to special events and activities

» Planting a tree with American Forests

www.metropia.com

Nudging Personal Behavior toward Sustainability



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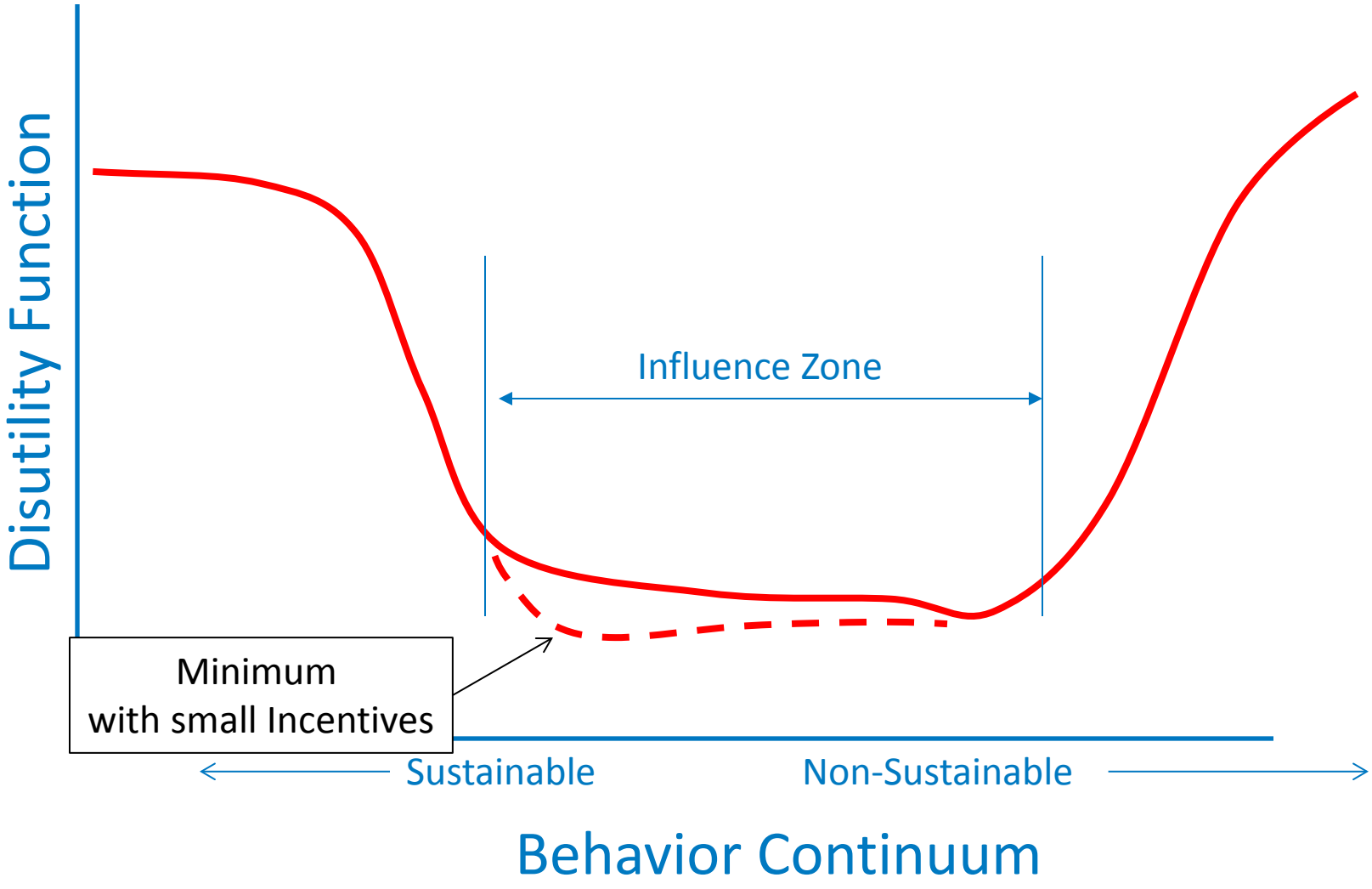
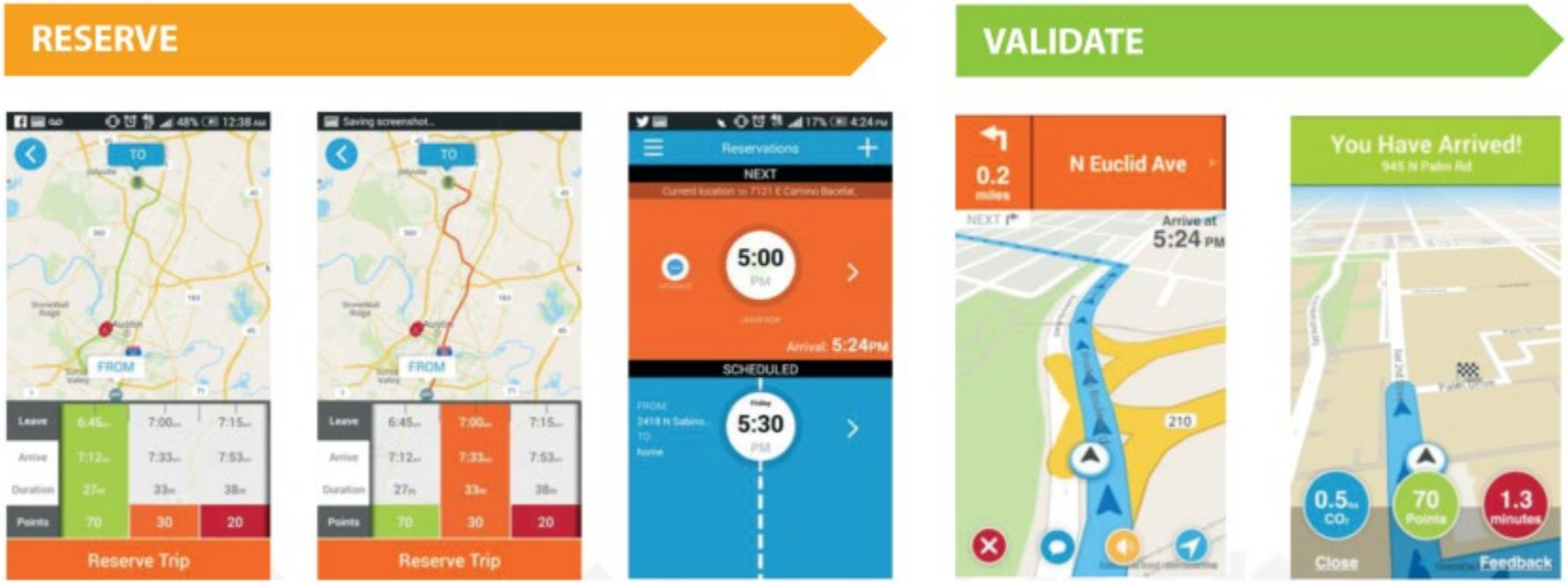


Engage Broader Community Participants

www.metropia.com

Validating and Optimizing Traveler Behavior

- Adaptive learning will be applied to refine control strategies bases on energy savings potential and likelihood of adoption by traveler
- Project will leverage Metropia platform to validate incentive effectiveness and hone control strategies



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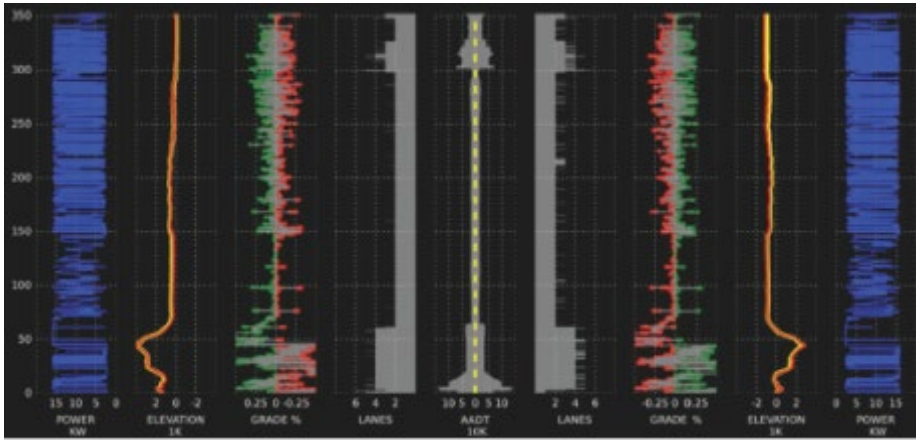
Iterating a Baseline for Energy Consumption

Accessing Diverse Transportation Data Sets

NREL's Transportation Secure Data Center houses data from travel surveys and studies conducted using GPS devices. It features millions of data points—second-by-second GPS readings, vehicle characteristics (if applicable), and demographics—for all modes of travel.

Leveraging Existing Tools to Estimate Energy Impact

- DRIVE
- FAST Sim
- FleetDNA



Example of TSDC Analysis

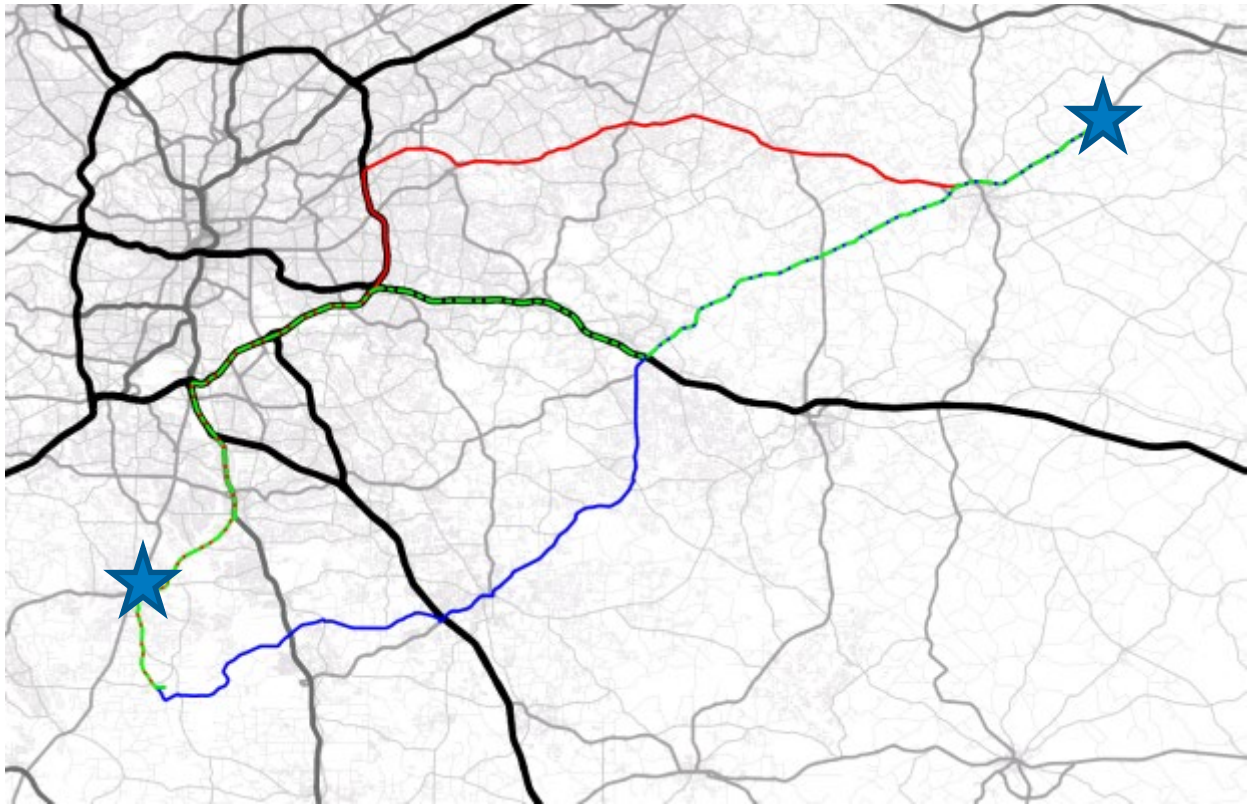
Integration of TomTom infrastructure details with road load equation to estimate instantaneous power demand (blue) for a Chevy Volt at a constant speed given instantaneous grade. Average annual daily traffic is visualized in the center indicating vehicle count.

Source: NREL

Example: Eco-Routing to Enhance PHEV Performance

Aggregate Energy Savings Potential of 4.6%

- Demonstrated ability to model vehicle speed/acceleration profiles relative to road type
- Constructed high-level powertrain model employing cycle metrics and vehicle state as inputs
- Applied model using real-world distribution of origin/destination



Route	A	B	C
Distance, mi	81.6	76.2	67.6
Duration, min	107	107	113
Avg Elec Rate, Wh/mi*	0.83	0.89	1.0
Avg MPG*	0.45	0.50	1.0
Cost, $*	1.0	0.89	0.59

Project Timeline – Key Milestones

Year 1	
Q1	• Tech to Market Plan completed • Target city identified • Phase I control architecture development begins
Q4	• Energy estimation for Phase I control strategies completed

Year 2	
Q5	• Initial control strategies implemented in Metropia app • Phase II control architecture development begins
Q6	• Sensitivity analysis for control strategies completed
Q7	• Integrate Phase I/II control strategies and incentives into Metropia app • Energy estimation of all control strategies complete • System energy estimation performs within 10% accuracy
Q8	• Development of learning algorithm completed

Year 3	
Q9	• Updated Metropia application deployed to mobile app markets (e.g. iOS app store)
Q10	• Project close-out

Project Team

Lead: H. Michael Zhang, Ph.D.
Professor of Civil and Environmental Engineering

Lead: Derek Reed, Ph.D.
Associate Professor and Director Graduate Studies, Applied Behavioral Sciences

Lead: Vassilis Papayannoulis, Ph.D.
Principal

Lead: Stan Young, Ph.D.
Advanced Transportation and Urban Scientist

Lead: Jeff Shelton
Research and Implementation Lead

Lead: Cynthia Chen, Ph.D.
Associate Professor and Director of Transportation-Human Interaction and Knowledge Network (THINK) Lab

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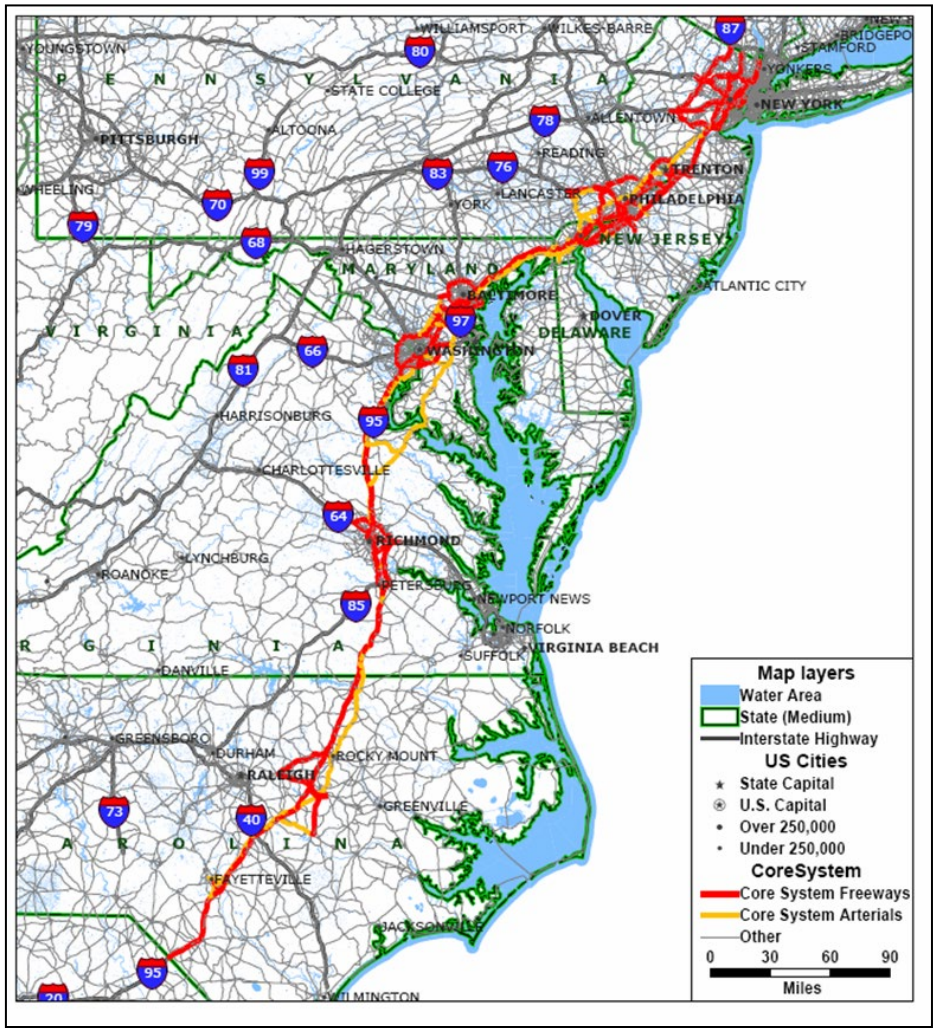
Performance from Large Data Sets: Nationwide Real-time Volumes

I-95 Vehicle Probe Project

- **Phase I (2008-2014)**
  - First Probe-based Traffic System
  - Specifications-based, validated
  - Licensing - one buys, all share
  - Began 2.5K miles, grew to 40K
  - Travel time on signs, 511 systems, operational awareness, performance measures
- **Phase II (2014 forward)**
  - All of the above
  - Better quality, less cost
  - Data market place (Multiple-vendors)
  - Emphasis on arterials and latency
  - 42.5K miles and growing
  - Map-21 Performance Measures



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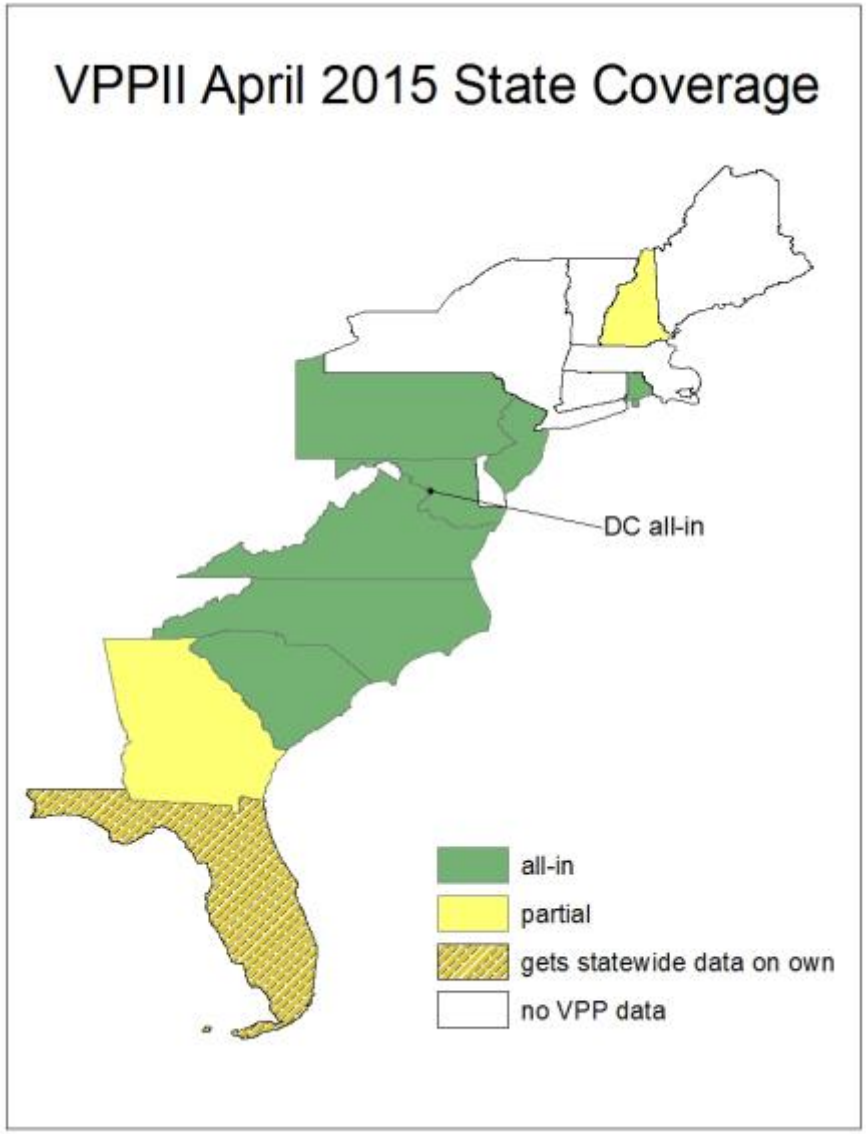
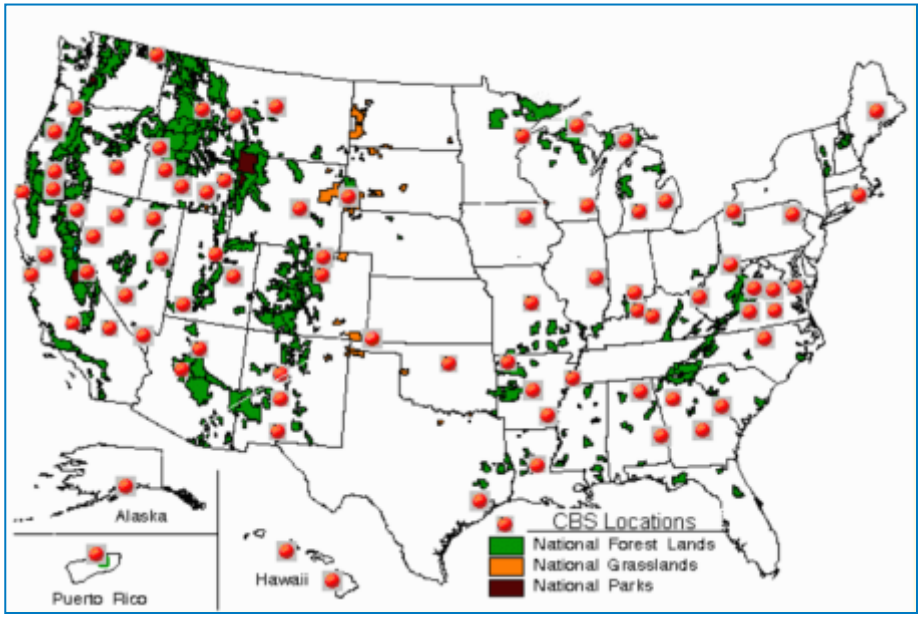


Real-Time Volume and Turning Movements

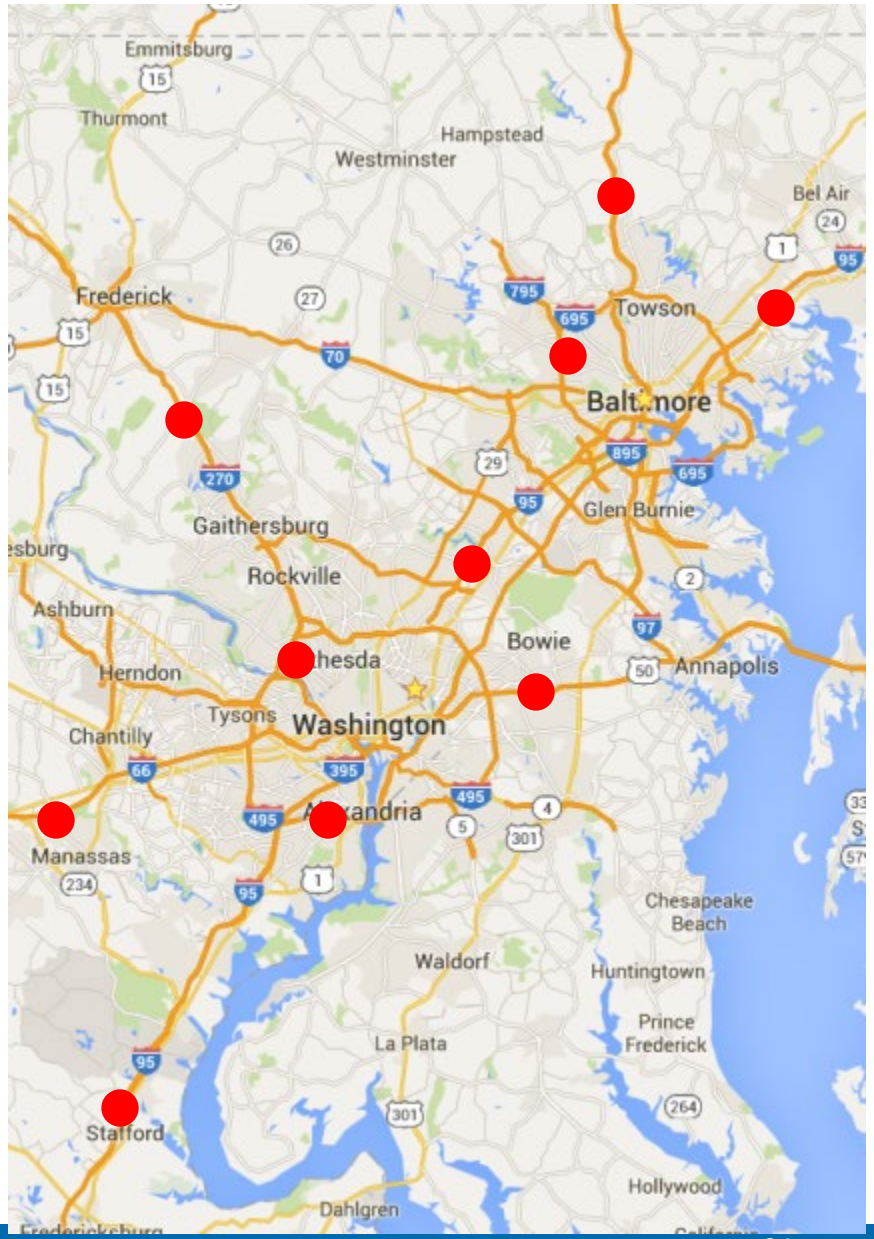
- **Objective: Accelerate the timeframe viable real-time volume and turning movement data is available as a probe data service**
- **Partners**
  - I95 Corridor Coalition
  - Univ. of MD, INRIX, HERE, & TomTom & NREL
- **Approach**
  - Calibration/validation test bed
  - Focus group to refine product
  - Vendors develop, test, and report
- **Goal is nationwide 24/7/365 volume and turning data on NHS**
- **Commence Jan 2016**



http://www.fs.fed.us/t-d/programs/gps/clickmap/cbsmap.htm

Operations Concept

- Network of calibration sites using existing sensors
- Determine proportionality coefficient/s
  - $V = \alpha S_1 + \beta S_2 + \partial S_3 \ldots$



Benefits of real-time volume

- **Monitoring traffic during major events**
- **Accurate performance measures**
- **Diversion routes**
  - Impact to travel time and volumes
  - Traveler information
- **Volume Heat Maps**
- **Signal timing applications**
- **Work zones management**

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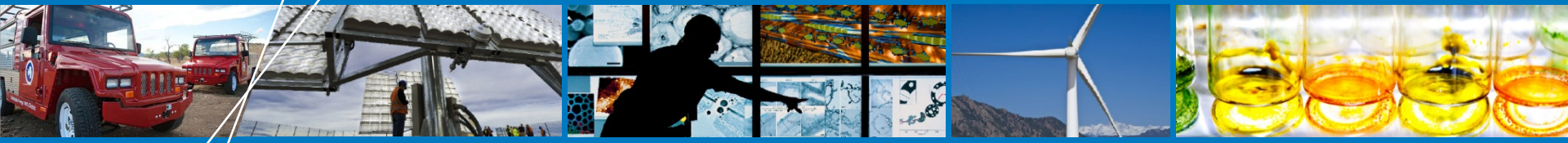


Performance from Large Data Sets: Arterial Performance Assessment

Prevailing Practice

- **Limited Data Collection**
  - Traffic counts from a single day
  - Travel time from minimal floating car runs
- **Modeled – not measured**
  - Synchro used to established timing
  - Tweak in the field with roadside observation
- **Ongoing performance assessment**
  - Number of complaint calls
  - Broad-based data too expensive

Enabling Arterial Management Systems

Re-identification

High-Res Signal Data

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

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

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

Not one or the other… but both!

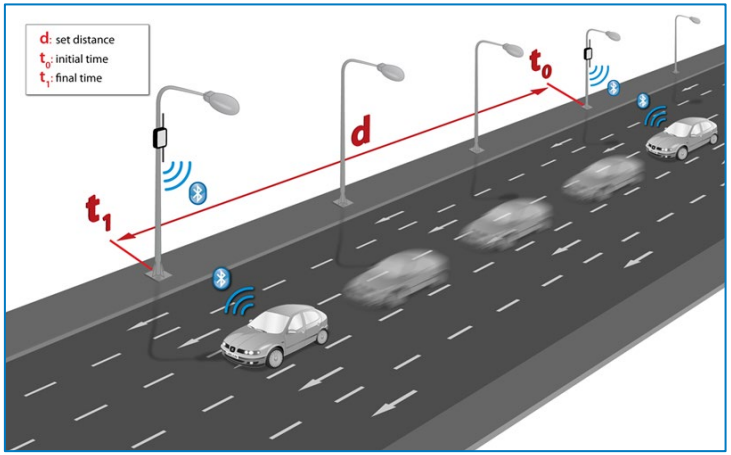
Emerging Arterial Performance Measures

- **Travel Time and Travel Time Reliability – based on sampled travel time sources**
  - Enabled by re-identification data, later outsourced probe data and connected vehicle data as it matures
  - Fundamentally linked to the statistical distribution of travel time
- **Percent Arrivals on Green**
  - Measures when vehicles arrive with respect to phase
  - Visualized via Purdue Coordination Diagram tools
- **Capacity Utilization**
  - Frequency of split failures
  - Based on Green Occupancy Ratio (GOR) & Red Occupancy Ratio (ROR)

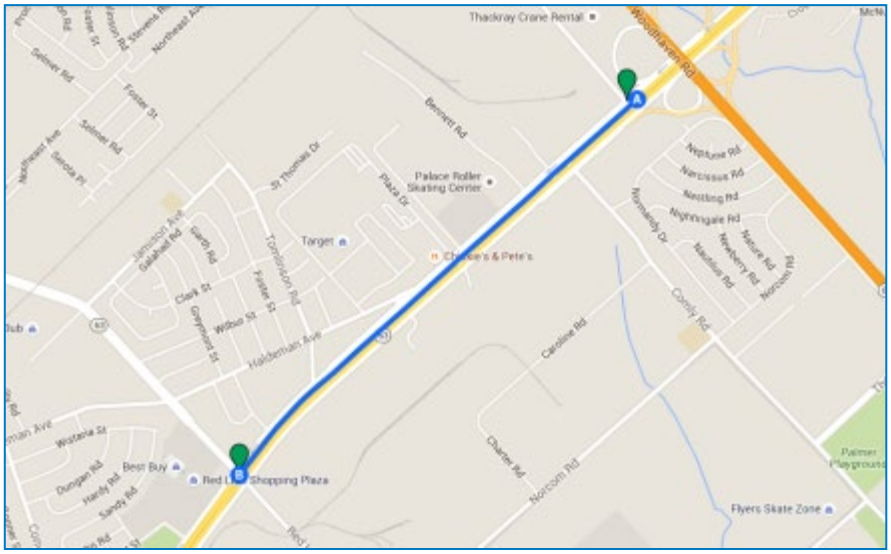
Travel Time and Travel Time Reliability

- **Based on direct measures of travel time**
- **Reflects quality of corridor progression**
- **Directly reflects traveling public**
  - Measures efficiency & travel predictability
- **Can be applicable to other modes of travel**
  - Freeway, transit, air, etc.

Car	MAC address	Entry Time hh:mm:ss	Exit Time hh:mm:ss
1	12-34-56-78-9A-BC	13:10:05	13:15:37
2	48-2C-6A-1E-59-3D	13:10:10	13:15:25

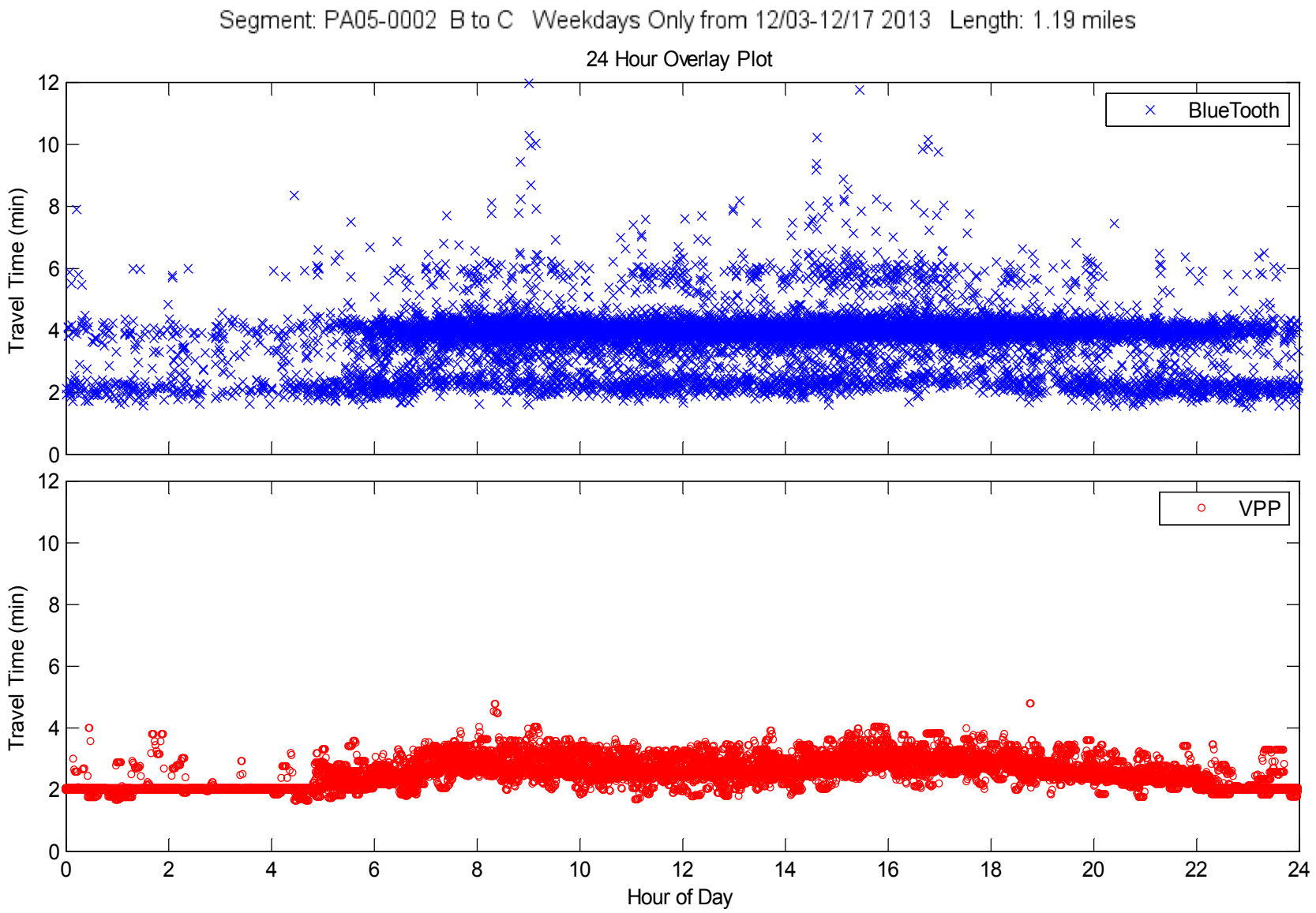


Sample Re-identification Data

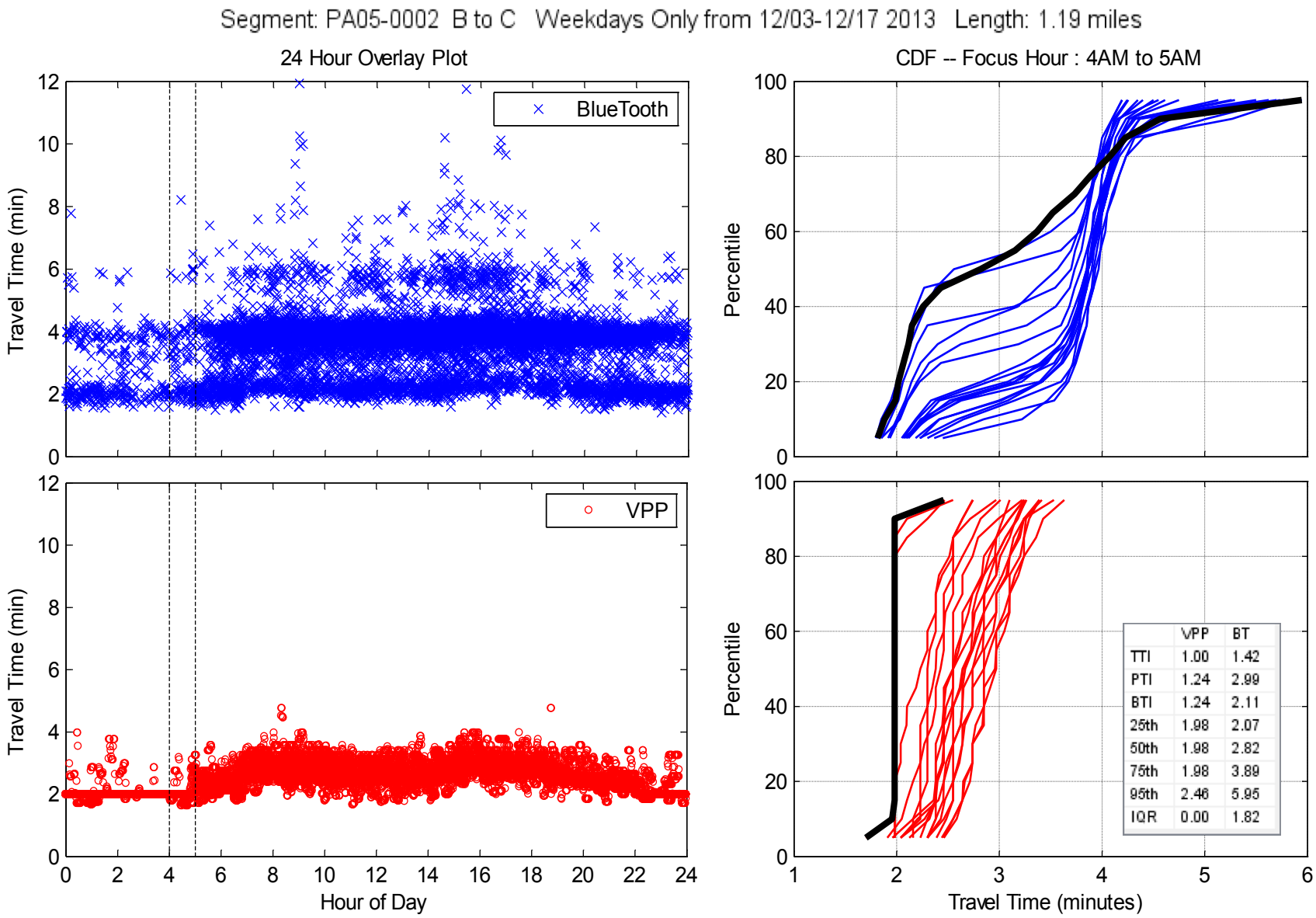


- **US1 - PA**
- **North of Philadelphia**
- **Southbound**
  - 1.2 miles, 6 (3/3) lanes
  - AADT >24K
  - 4 signalized intersection
  - 45 mph speed limit
- **Date collected Dec 3-17, 2013**

Re-id Travel Time Data Fidelity



CFD Statistical Performance Measures



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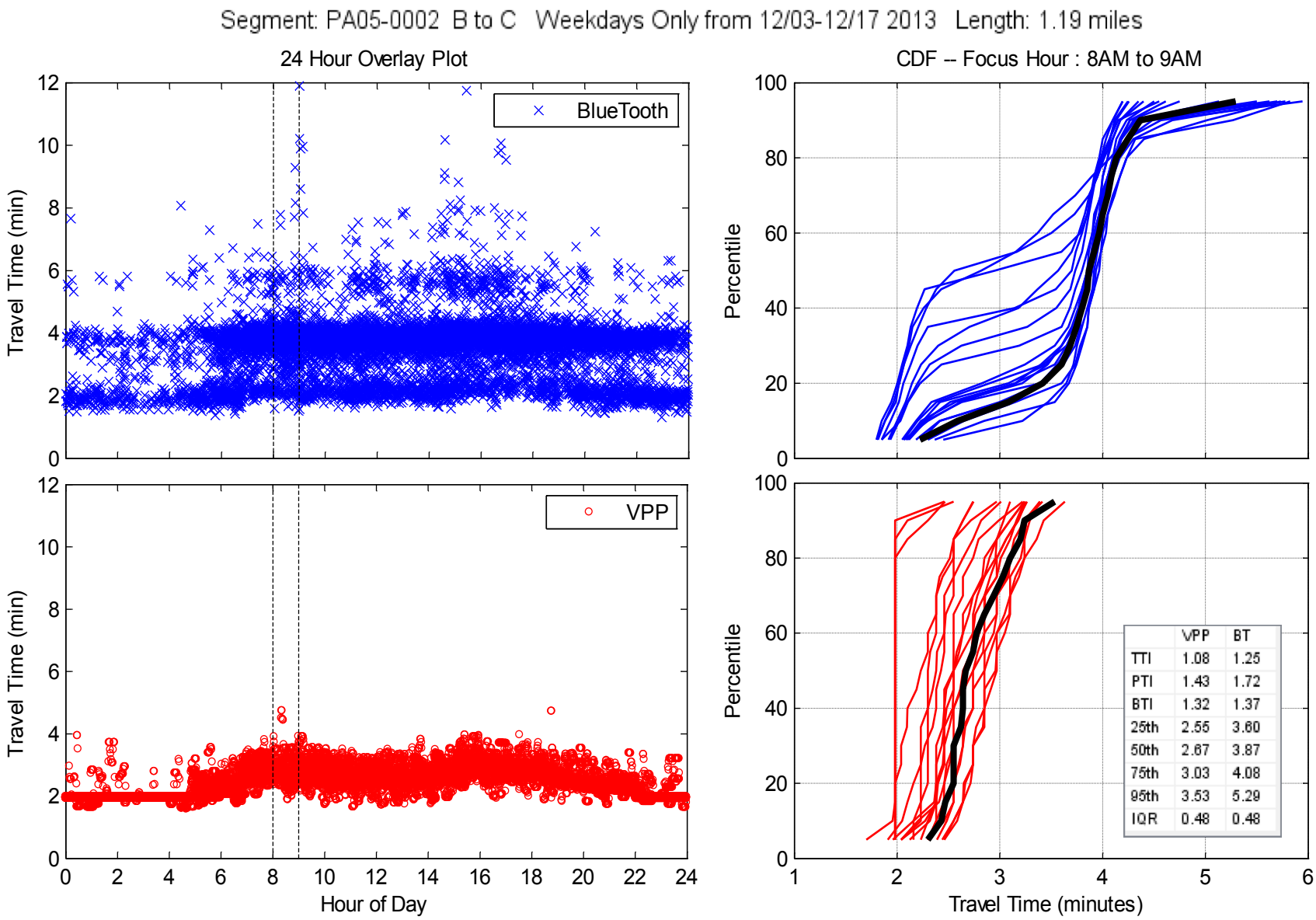
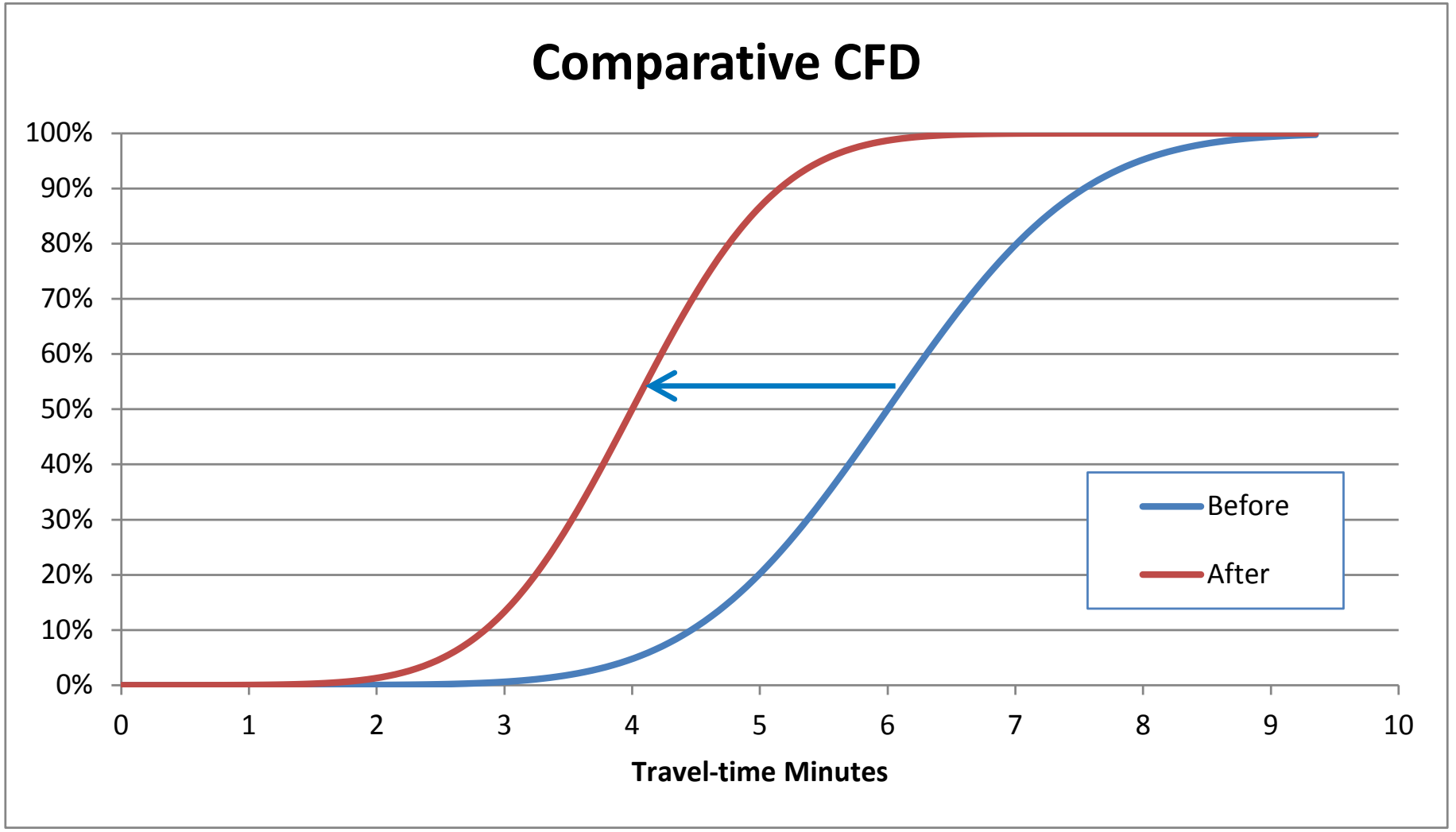
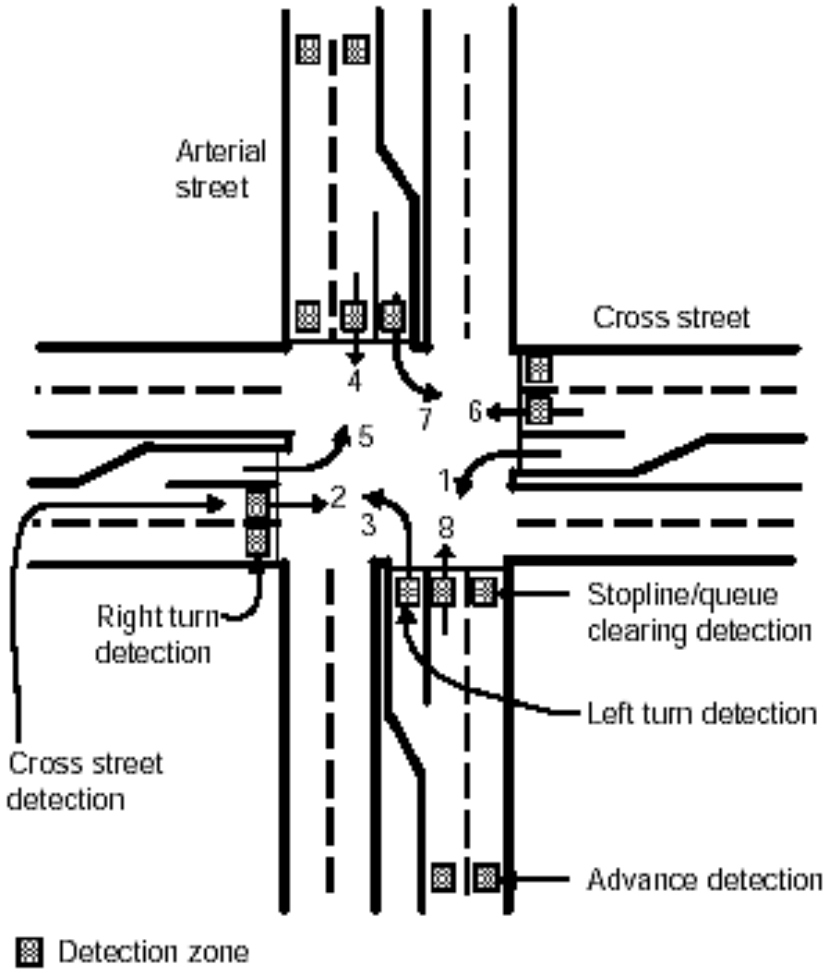


Travel Time Distribution



High Resolution Signal Data

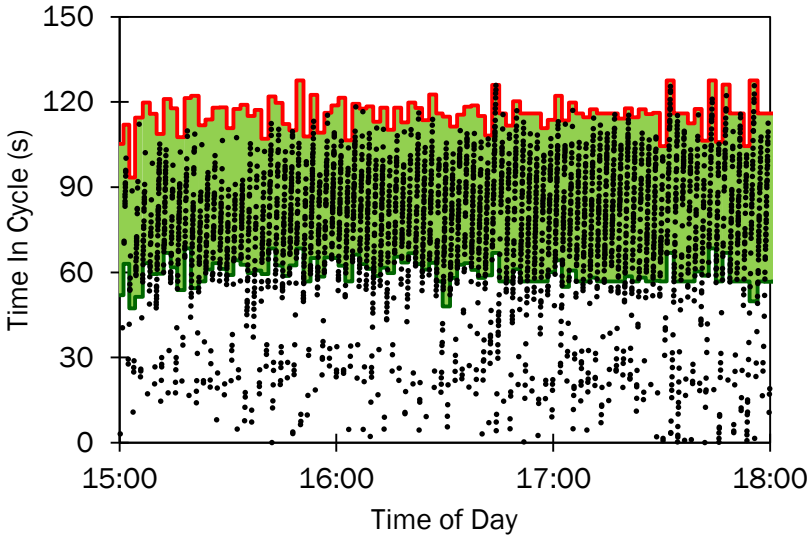
- **Logging of sensor and phase information**
- **Data forwarded periodically to central server**
- **Applications**
  - Purdue Coordination Diagram
  - Red-Occupancy Ration / Green Occupancy Ratio
  - Volume / Demand Analysis (per movement)
  - Streamlined Maintenance

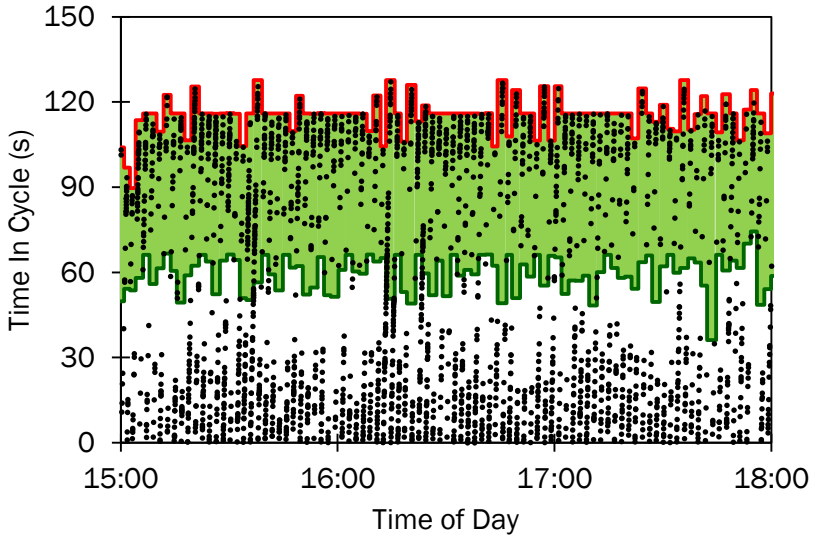


Picture Source: FHWA

Percent Arrivals on Green

Purdue Coordination Diagram





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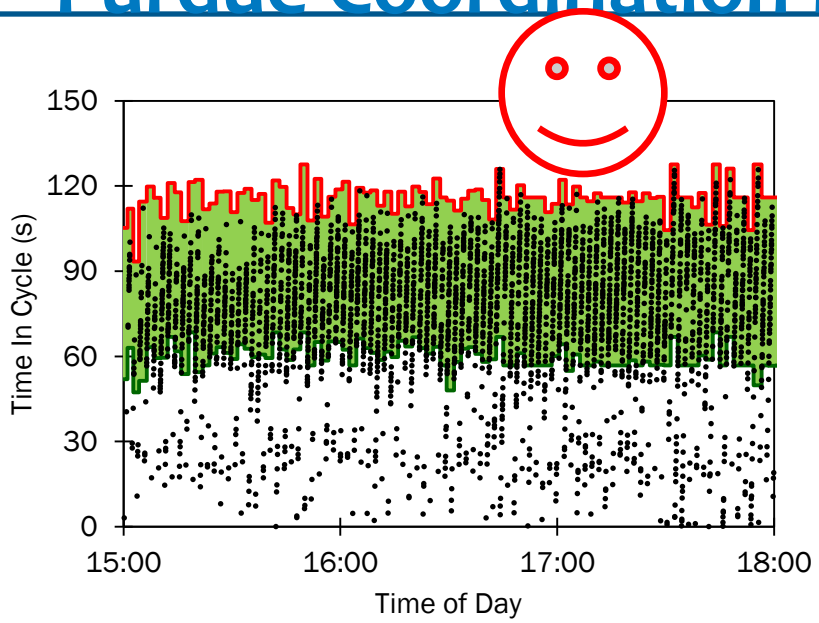
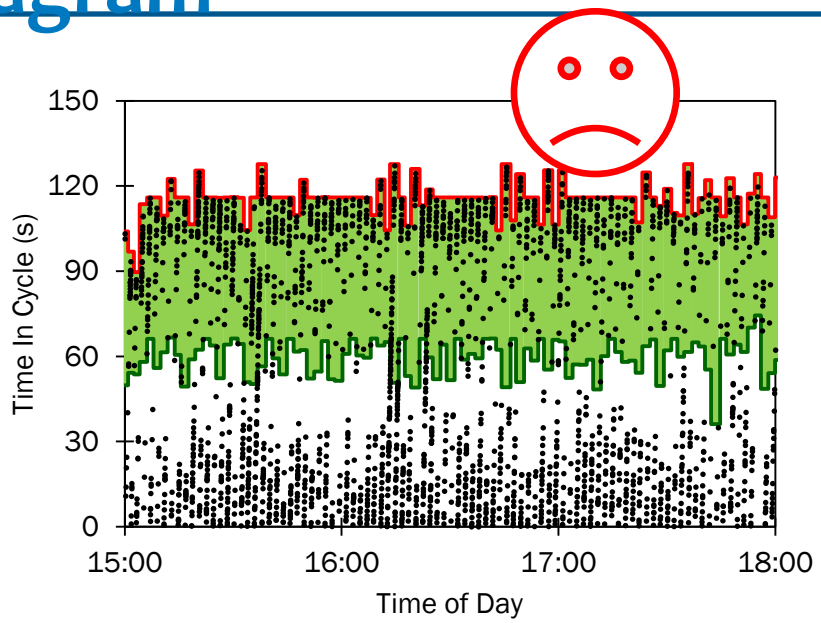
Percent Arrivals on Green

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

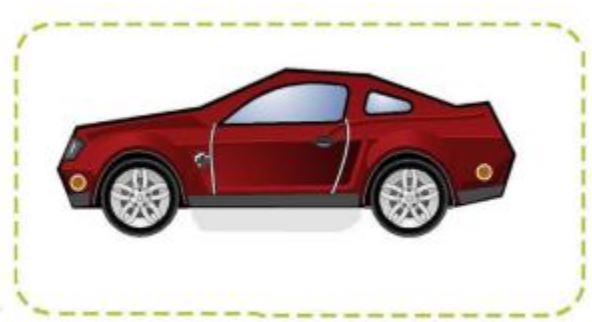
Published December 23, 2013 10:04 pm

Opportunity for Scaling

- **Re-identification & Hi-Res**
  - Enabled by low-cost communications
  - Leveraged by centralized processing
  - Provides comprehensive performance measurement
- **Still requires hardware in the field**
  - Rollout anticipated over the next decade
- **Opportunity –**
  - Can this be scaled nationwide in another way?

Nodes on the IoT Super Highway

- Car Companies connect to vehicles for vehicle monitoring / sales and lease information



- In dash navigation systems & infotainment systems provide media and report on vehicle condition.

- The smart phone is the generic IoT that provides all of the above – even when not in the vehicle.

All becoming independent notes on the IoT!!!

The spy in your pocket …. Multi-layers of reporting

Phone Manufacturer – Hardware Layer
Samsung / LG / Nokia / Iphone

Operating System Layer
Android / Iphone

Telecommunications Carrier Layer –
AT&T Mobile/Verizon/Tmobile/Sprint

Application Software
Maps – Google, Mapquest, Etc.
Traffic apps. – Waze, Uber, Lyft
Any other location enabled software

Traffic Probe Data

Similar with the Vehicle ….

Vehicle Manufacturer

OEM Suppliers

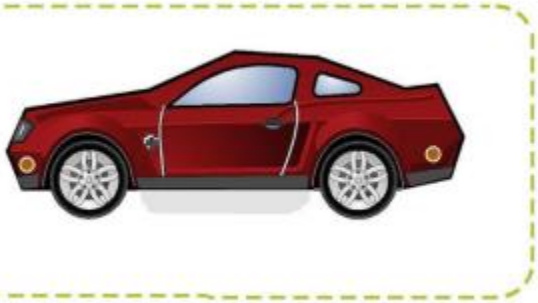
Infotainment Ops Systems

Infotainment Apps

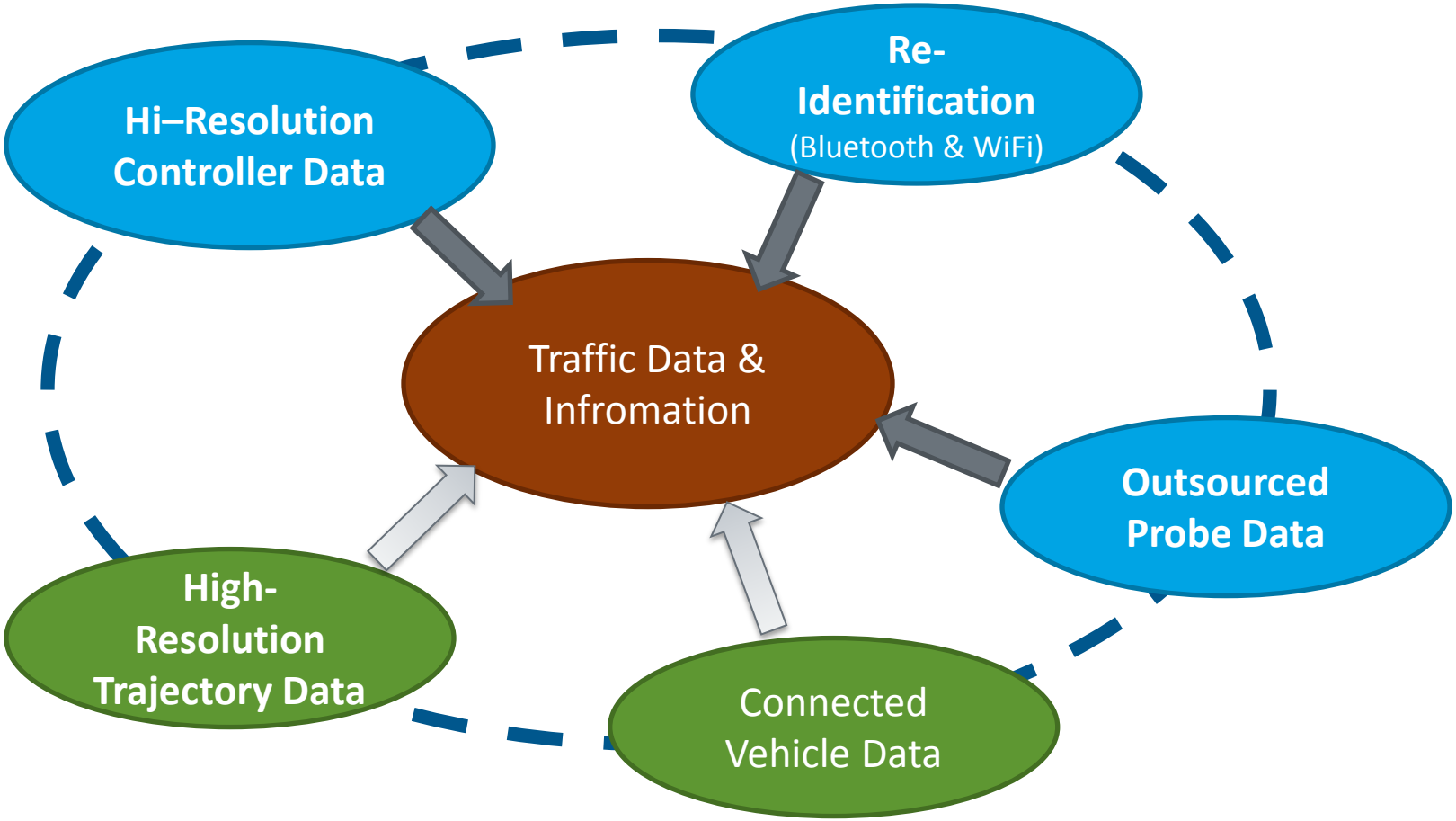
Insurance Companies – Behavioral Based Insurance

Security Companies

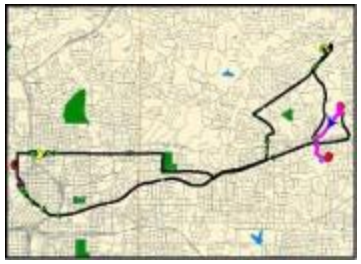
Tolling Applications / RFID



Convergence and Maturation of Data Sources



Transportation Secure Data Center (TSDC) Rationale



High-resolution survey data (e.g., GPS travel profiles, geo-coded trip ends)

- Very valuable for research
- Misuse could violate participant privacy

Secure data center makes data available for legitimate research while preserving privacy

- Maximizes value from limited public funds
- Benefits data providers and users
  - Takes care of archiving and responding to data requests
  - Data accessible from a central location

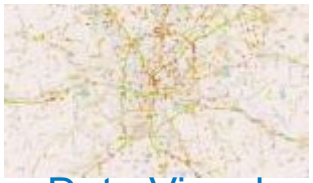
* See this 2007 National Research Council report: http://books.nap.edu/openbook.php?record_id=11865

The TSDC has been supported since 2009 by NREL, U.S. DOT and U.S. DOE

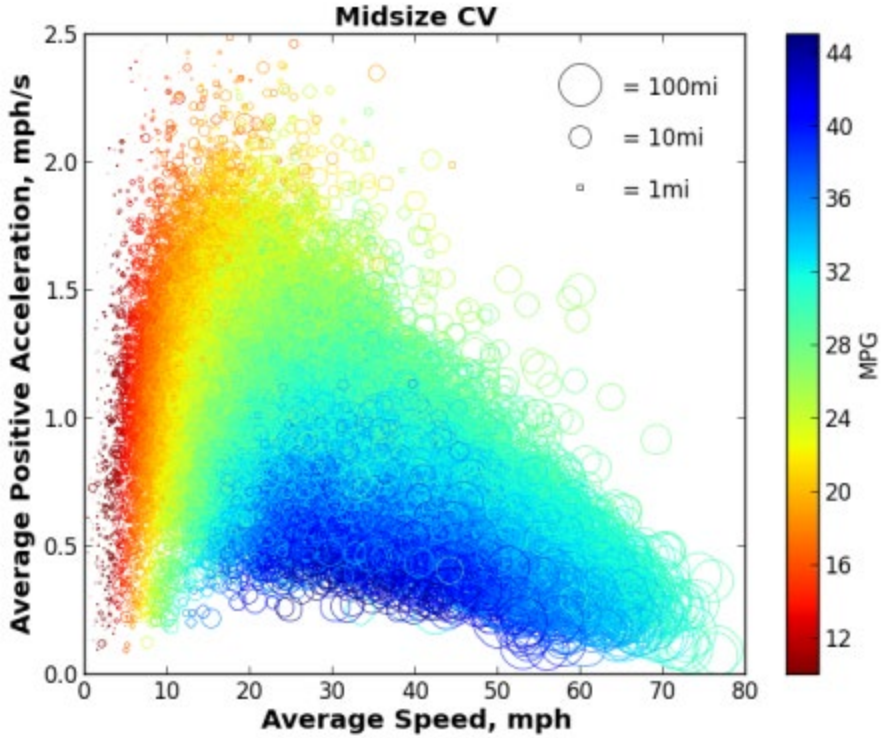
- Department of Transportation, Federal Highway Administration
- Department of Energy, Vehicle Technologies Office

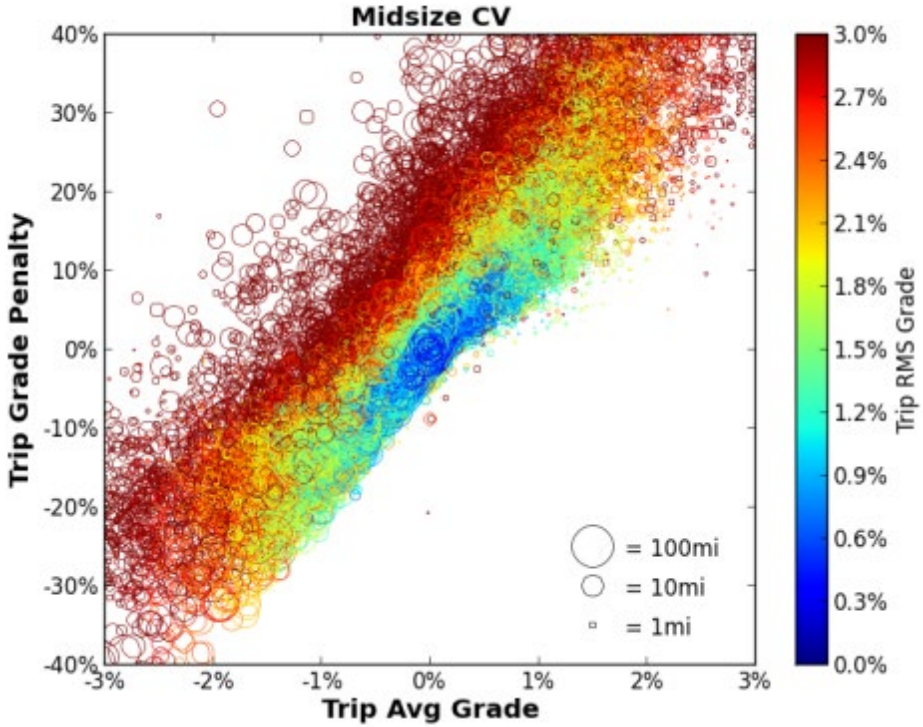
Related Real-World Analysis Efforts Using TSDC Data

- Large distribution of real-world GPS travel profiles, including speed, acceleration, distance, time of day, stop duration, etc.
- E.g., previous analysis explored fuel economy sensitivity to speed/acceleration characteristics and road grade using hundreds of thousands of GPS drive cycles in NREL TSDC



Data Visual





GPS = Global Positioning System; CV = Conventional Vehicle

Feasibility Test of High-Res Trajectory Data

- Is data prevalent enough to assess all roadways?
- Can arterial performance measures (travel time and reliability, coordination, and capacity) be calculated?
- Is it as accurate as prevailing methods?
- Can the method be scaled nationally?
- Can arterial performance management be enabled in one year, at 1/100 of the cost?

Thank **You**

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