There's Energy in the Air: Reducing Fuel Consumption Through Connectivity

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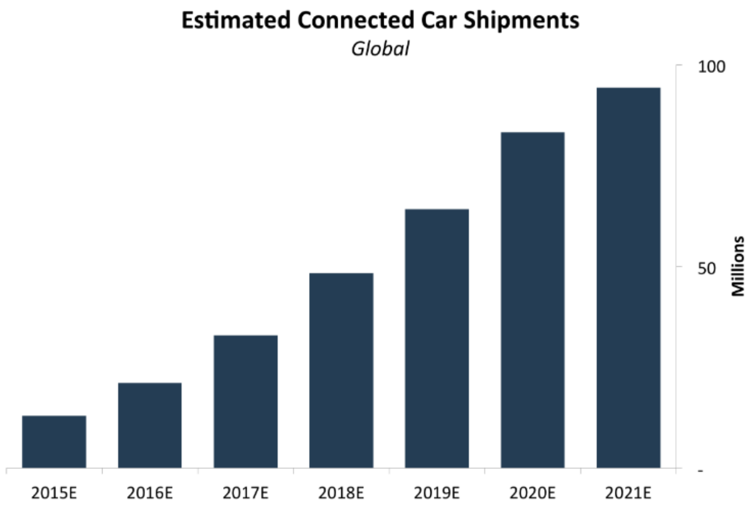
The NEXTCAR Program

- Next-Generation Energy Technologies for Connected and Automated on-Road Vehicles
- 3 year program funded by ARPA-E
- Rapid growth in connectivity and autonomy in vehicles
- Develop next generation of vehicle dynamics and powertrain control technologies
- Technologies developed must be deployable at scale – dedicated Tech To Market (T2M) phase



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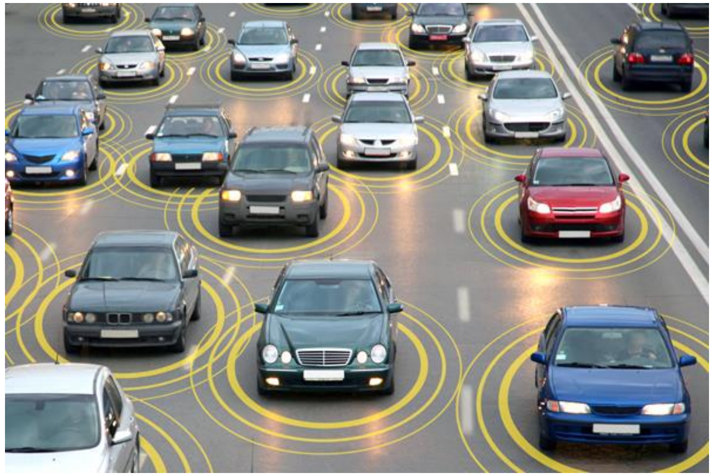

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NEXTCAR Program Objectives

- Reduce energy consumption of a 2016 baseline LD, MD or HD vehicle by at least 20%
- No extensive powertrain architecture or hardware changes
- No compromise in emissions, safety or drivability
- System cost <$1000 f $0
- Synergy between pure connectivity (DOT AERIS) and powertrain or regulation driven (CAFE and NHTSA/EPA) approaches

Teams & Approaches

- Total of 11 teams – Universities (9), GM and SwRI
- LD, MD, class 8 trucks, UPS delivery vehicles as well as plug-in hybrid electric bus
- Key technologies:
  - Machine learning
  - Cloud computing
  - Model predictive control
  - Cylinder deactivation
  - Eco-routing/Eco-AND
  - Platooning
  - Speed harmonization…

Model Predictive Control for Energy-Efficient Maneuvering of Connected Autonomous Vehicles (CAVs)

SwRI NEXTCAR Team

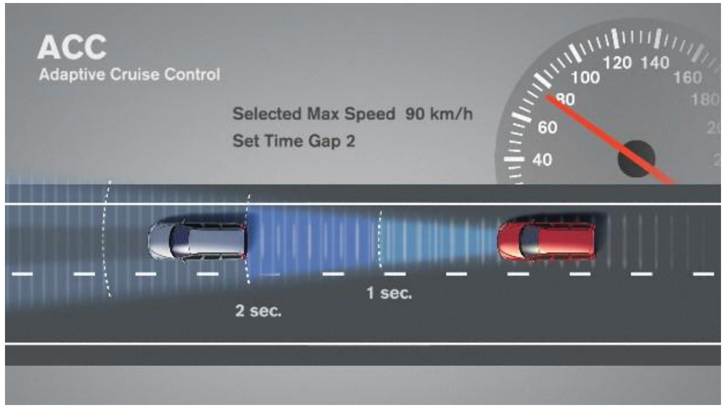
Powertrain Engineering

Intelligent Systems

TOYOTA

SwRI NEXTCAR Vehicle

- Toyota Prius Prime 2017
  - Plug-in HEV
  - 1.8 L 4-cylinder engine
  - 42% BTE, 13:1 CR, ECVT
  - 8.8 kW-hr battery, 25 mile pure electric range
  - 54 mpg in hybrid mode
  - 133 mpge combined
- Dynamic radar cruise control
- Camera and sonar
- Add-on
  - Dedicated Short Range Communication (DSRC) radio for connectivity

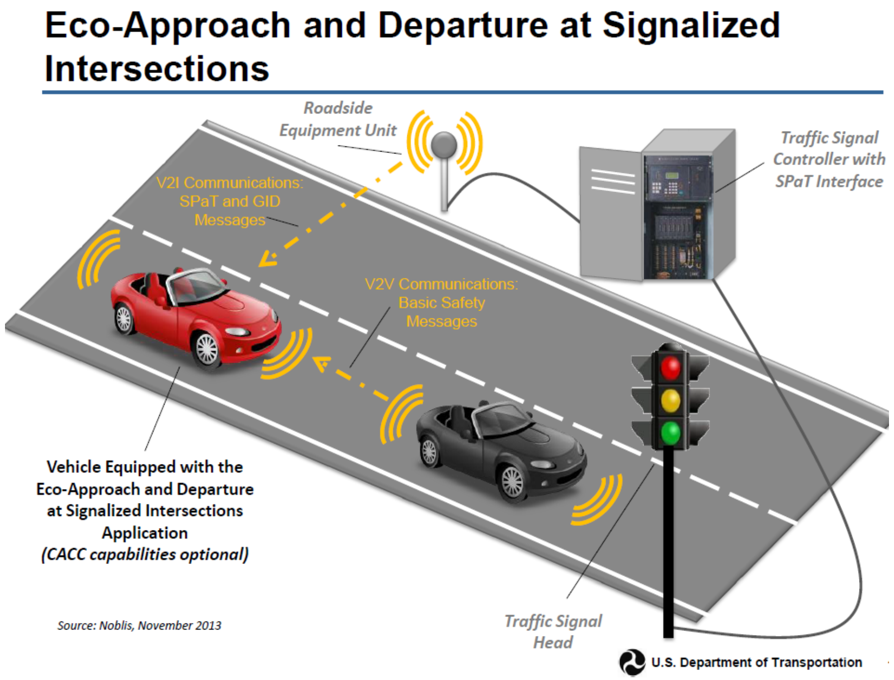


Approach Overview - I

- Trip Energy
  - Operates at *macroscopic* level (entire route)
  - Connectivity → coarse info about traffic congestion, grade, signals, school zones, charging opportunities etc.…
  - Energy efficient route selection specific to powertrain
  - Smarter power split planning based on route info and charging opportunities

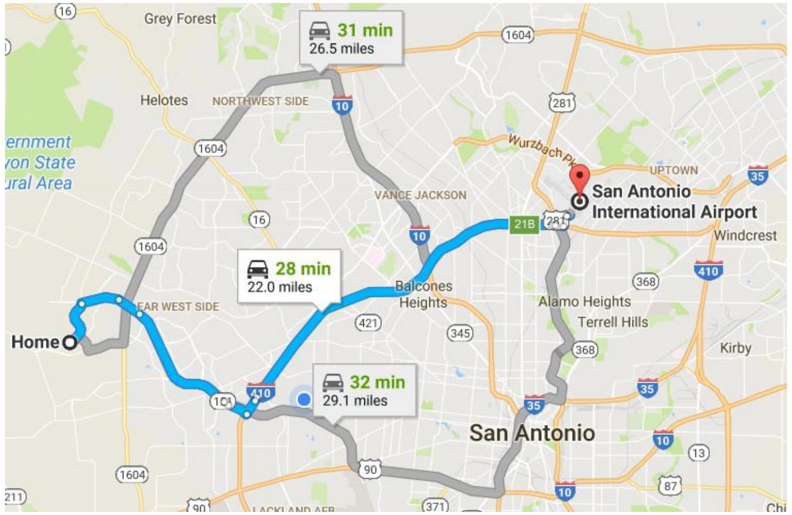
Approach Overview - II

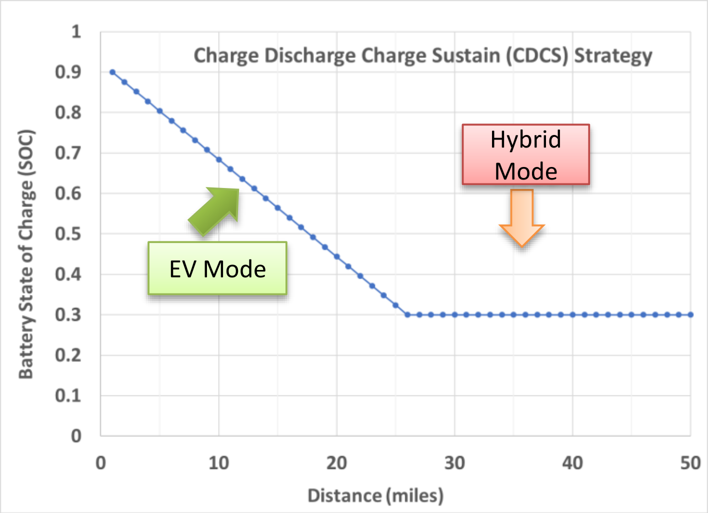
- Driving Power
  - Operates at *mesoscopic* level
  - Leverages neighboring CAVs and V2I (Vehicle to Infrastructure) info
  - Info more accurate but restricted foresight
  - Better prediction of localized traffic behavior
  - MPC for smarter power split and velocity optimization



Trip Energy - Conventional

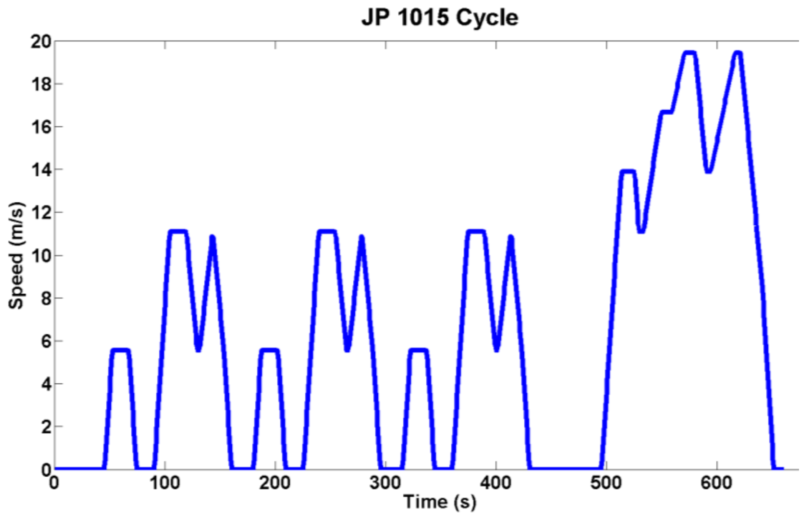
- Hybrid example
  - Conventional route selection based on least travel time
  - Power split on current vehicle based on Charge Deplete Charge Sustain Strategy (CDCS)
  - CDCS not optimal under all conditions (ex: highway then urban)
  - Preliminary results show significant reduction of total energy consumption

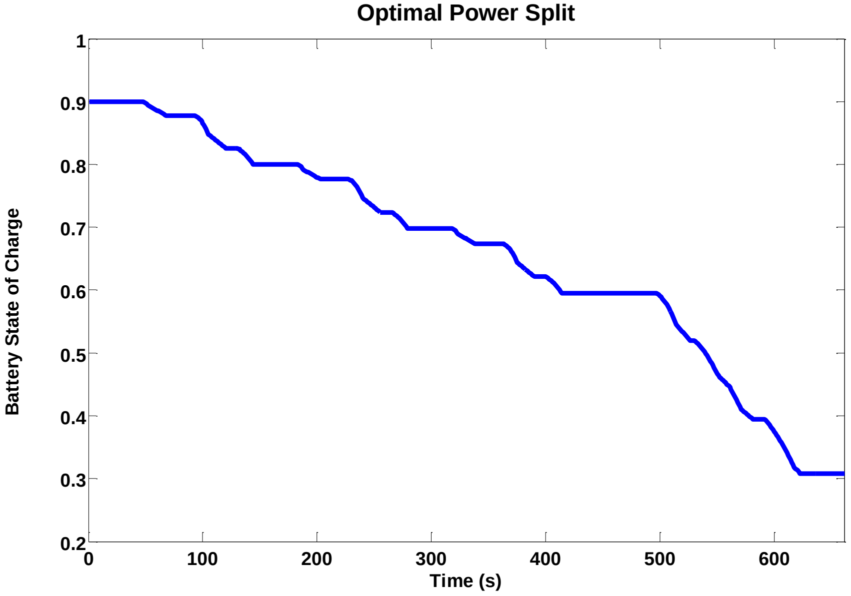




Trip Energy - Optimized

- Japanese JP1015 cycle simulation study
- Global optimizer used to calculate optimal power-split
- Battery SOC allowed to vary from 0.9 to 0.3
- Cost function is total energy consumption on given cycle
- Optimal power split different from CDCS
- Not everything goes according to plan !



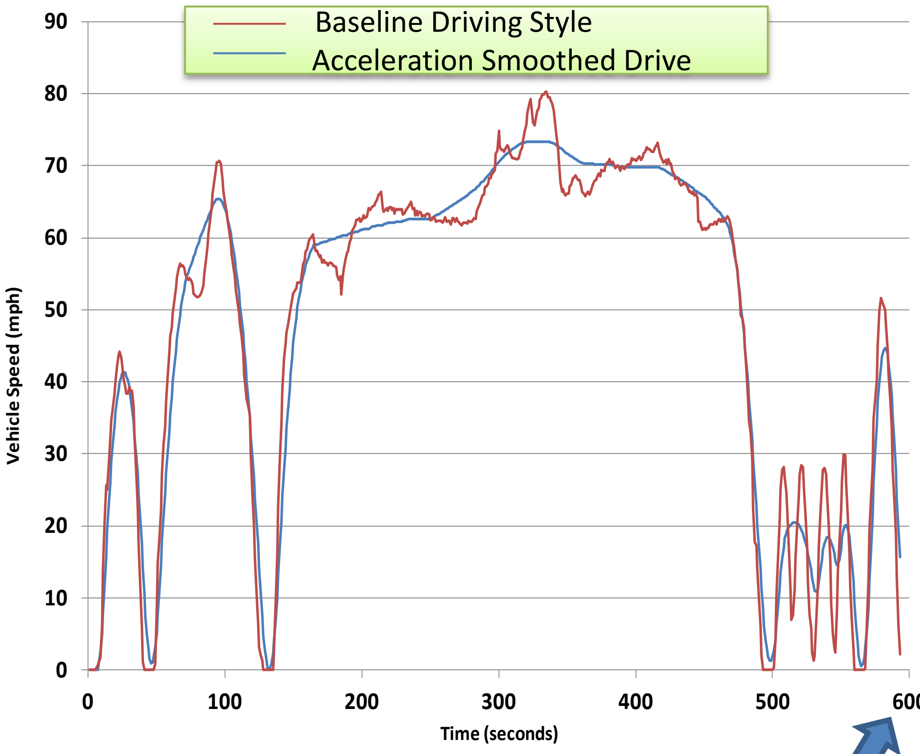


Driving Power Optimization

- ECO-Approach & Departure
  - Minimal or no stops at signalized intersections
  - Signal Phasing and Timing (SPaT) info from traffic lights
- Info from neighboring CAVs (~1 km horizon)
- Velocity optimization based on current traffic and Vehicle To Infrastructure (V2I) information
- Minimize or smooth aggressive tip-ins and other surges in power demand

Impact of Acceleration Smoothing

- Simulation studies by University of Michigan in collaboration with EPA
- Modified velocity trace generated for various cycles
- MPC applied with preview ranging from 1.5 seconds to 20 seconds
- Actual test done at SwRI chassis dynamometer
- Certification style fuel economy measurements
- Significant benefit in energy consumption ~ 10%



Vehicle covers same distance in the same amount of time for both driving styles

Traffic Simulator Overview

- What does it do?
  - Simulate traffic patterns
  - Simulate neighboring CAVs
  - Simulate V2X infrastructure
  - Integrate with CAV-HIL
- Why is it important?
  - Generate repeatable driving scenarios
  - Evaluate robustness of control algorithms

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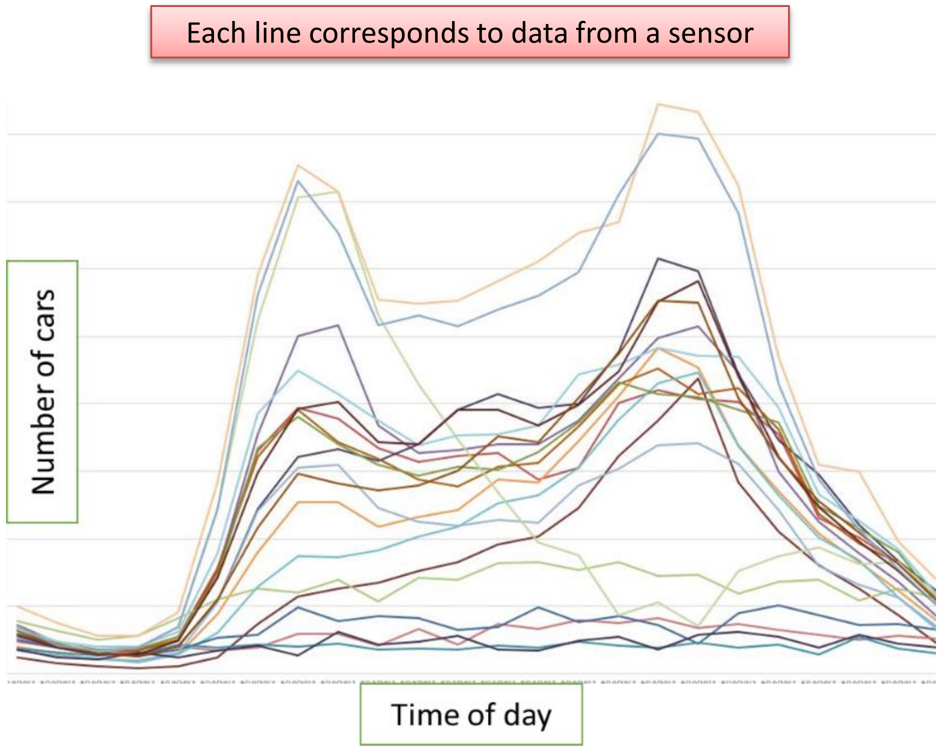
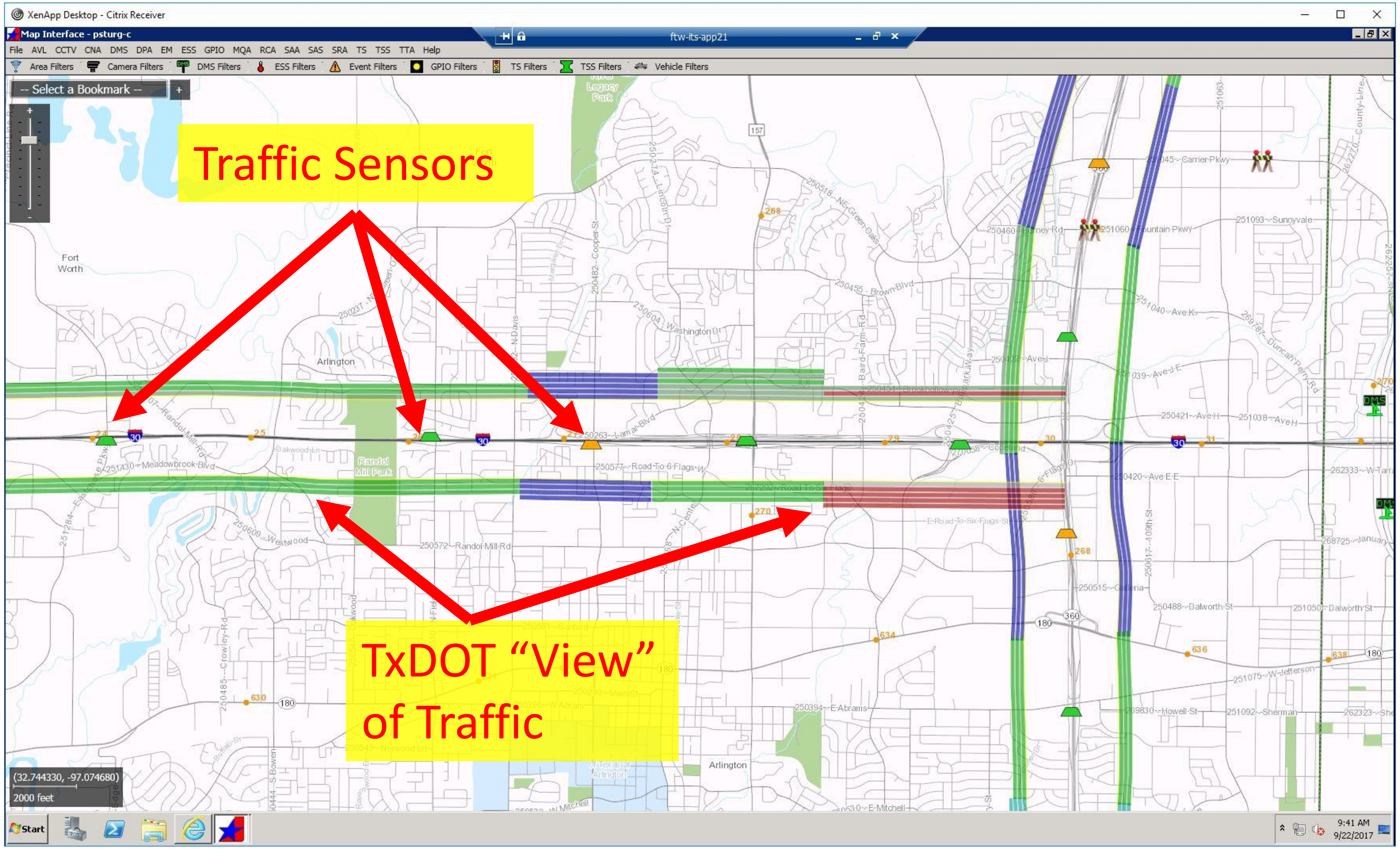
Real Time Traffic Simulation

- SwRI has close collaboration with Texas Department of Transportation (TxDOT)
- Traffic simulation built with real data from traffic sensors from TxDOT
- Highway and surface streets
- *Dynamic* simulation – reacts to changes from test vehicle
- Ability to program driver behaviors – ex: aggressive

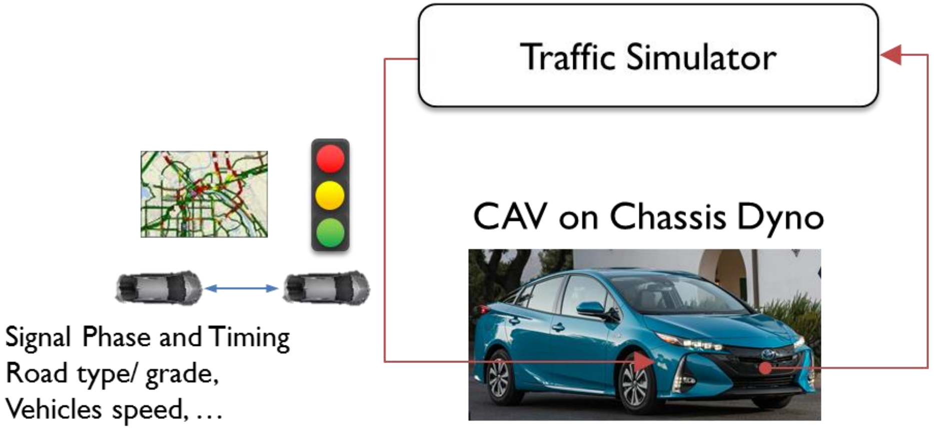


Real Time Traffic Simulation



SwRI CAV Hardware-In-the-Loop Dyno

- Traffic simulator integrated with SwRI chassis dyno to create a unique "CAV" test platform
- Simulate neighboring vehicles, infrastructure and sensors like DSRC, GPS, radar and sonar to mimic real world driving scenarios
- Enables rapid development and testing of algorithms in a controlled environment – robustness and repeatability



Co-optimized Vehicle & Powertrain Control

Summary

- Improve energy consumption by 20% over 2017 Prius Prime
- No significant modifications on hardware
- Develop next generation of vehicle dynamics and powertrain control technologies for CAVs
- Merge efficiency improvements via powertrain based approaches with connectivity driven approaches
- Algorithms being developed applicable to other powertrain architectures – not just hybrid system
- CAV HIL– enabling tool for rapid algorithm development and testing in controlled environments
- Tech-to-Market – partner with OEMs, suppliers and regulators

Questions?

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