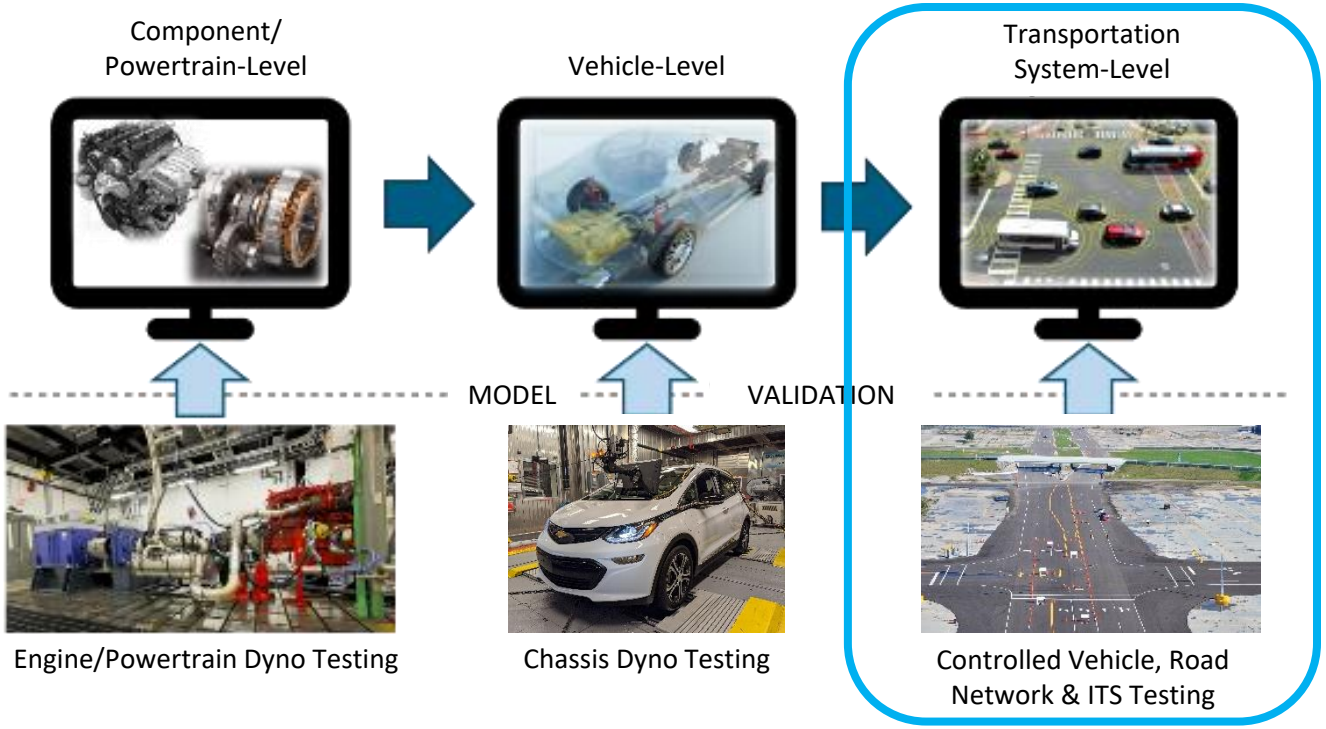
Validation of Connected and Automated Mobility System Modeling and Simulation



Jeffrey Rupp, Principal Investigator

American Center for Mobility

June 2, 2020

2020 DOE Vehicle Technologies Office

Annual Merit Review – Project ID: EEMS082

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CONNECTED. AUTOMATED. VALIDATED.

Overview

Timeline

- Start: October 1, 2019
- End: December 31, 2021[1]
  - ~ 10% complete (milestone basis)

Budget

• Total	$7,633,143
• DOE	$6,103,138
• 20% Cost Share	$1,530,005
• BP1: 2020	$5,025,594
• BP2: 2021	$2,607,549

Premise

- New Connected and Automated Vehicle (CAV) technologies have the potential for many future benefits

EEMS[2] Barriers

- *(Accurately predicting) the value and productivity derived from new mobility technologies*
  - Large scale physical testing of CAVs can be impractical (cost and time)
- *Computational difficulty of accurately modeling and simulating large-scale transportation systems*
  - Models and simulation are, by definition, a simplification of the real world

Partners

- American Center for Mobility
- Michigan Tech Research Institute
- Michigan Technological University
- Note: four national laboratories are also collaborating

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[1]*Excluding potential COVID-19 extension* [2]*U.S. DOE Office of Energy Efficient Mobility Systems (EEMS)*

Michigan Tech Research Institute Michigan Tech

Relevance

Project: Validation of Connected and Automated Mobility System Modeling and Simulation

Objectives

- Translate Lab algorithms into vehicle and infrastructure controls
- Conduct physical testing at a manageable scale
- Compare test results with simulation
- Interactively develop better models
- Integrate testing and simulation to expand the set of models that can be assessed

Impact on Barriers

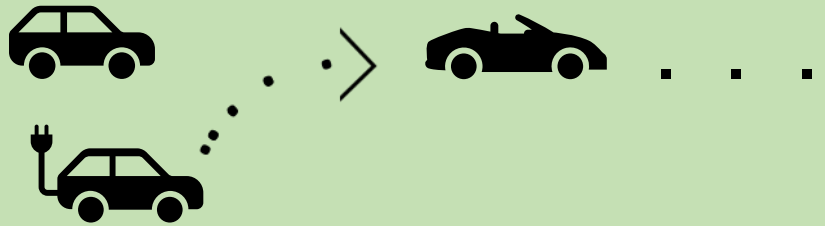
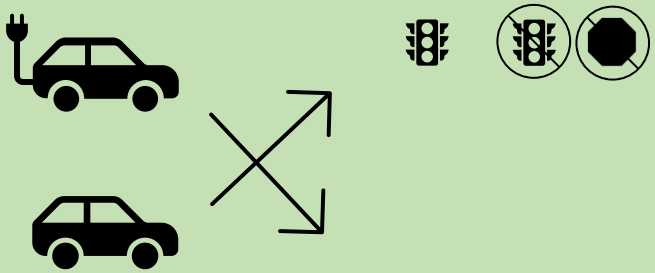
- Validated simulation reduces need for physical testing at large scale
- Interactive development of a model with the author improves its accuracy
- Validated models can provide a valuation of proposed technology with reasonable cost and time

EEMS Strategic Goal #1

- *Develop new tools, techniques, & core capabilities to understand & identify the most important levers to improve the energy productivity of future integrated mobility systems*

Approach

1. Translate Lab algorithms into vehicle and infrastructure controls
2. Build physical vehicles and infrastructure for testing of algorithms
3. Test vehicles with lab algorithms and models in coordinated scenarios at a specialized track
4. Compare results and modify accordingly

Energy Efficiency – Study Cases	
Speed Harmonization	
Merging	
Intersections	

Approach

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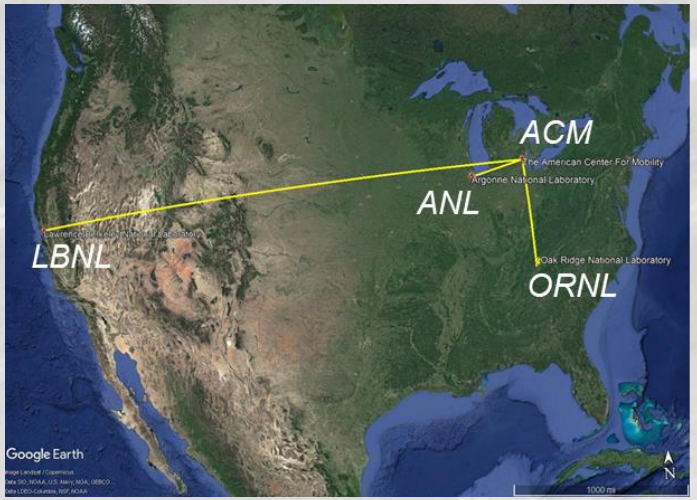

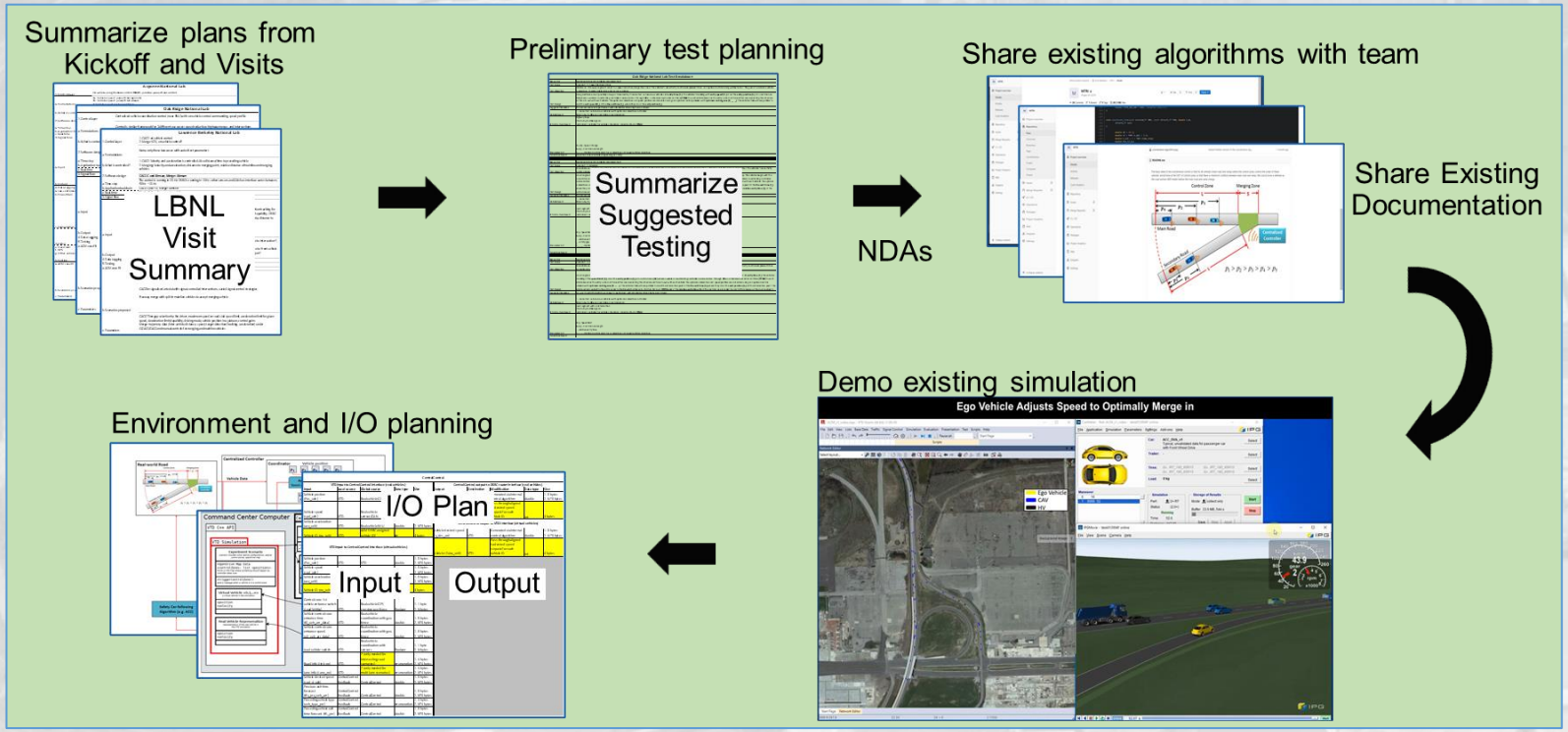

Approach

1. Translate Lab algorithms in order to control the vehicles and infrastructure
2. Build physical vehicles and infrastructure for testing of algorithms
3. Test vehicles with lab algorithms and models in coordinated scenarios at a specialized track
4. Compare results and modify accordingly

Automated Test Platforms

Approach

1. Translate Lab algorithms in order to control the vehicles and infrastructure
2. Build physical vehicles and infrastructure for testing of algorithms
3. Test vehicles with lab algorithms and models in coordinated scenarios at a specialized track
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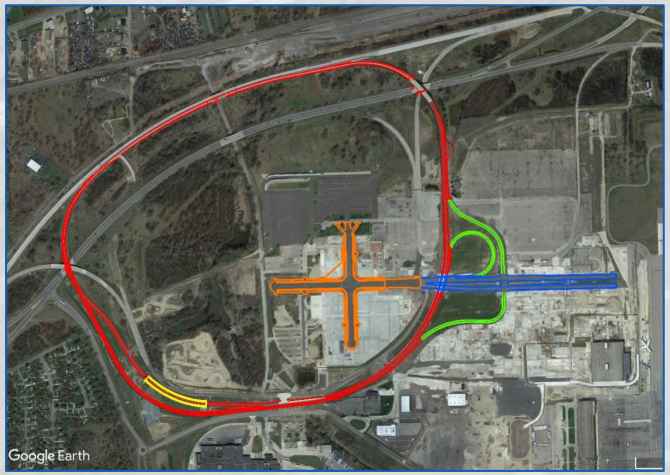


Full test facility

Speed Harmonization

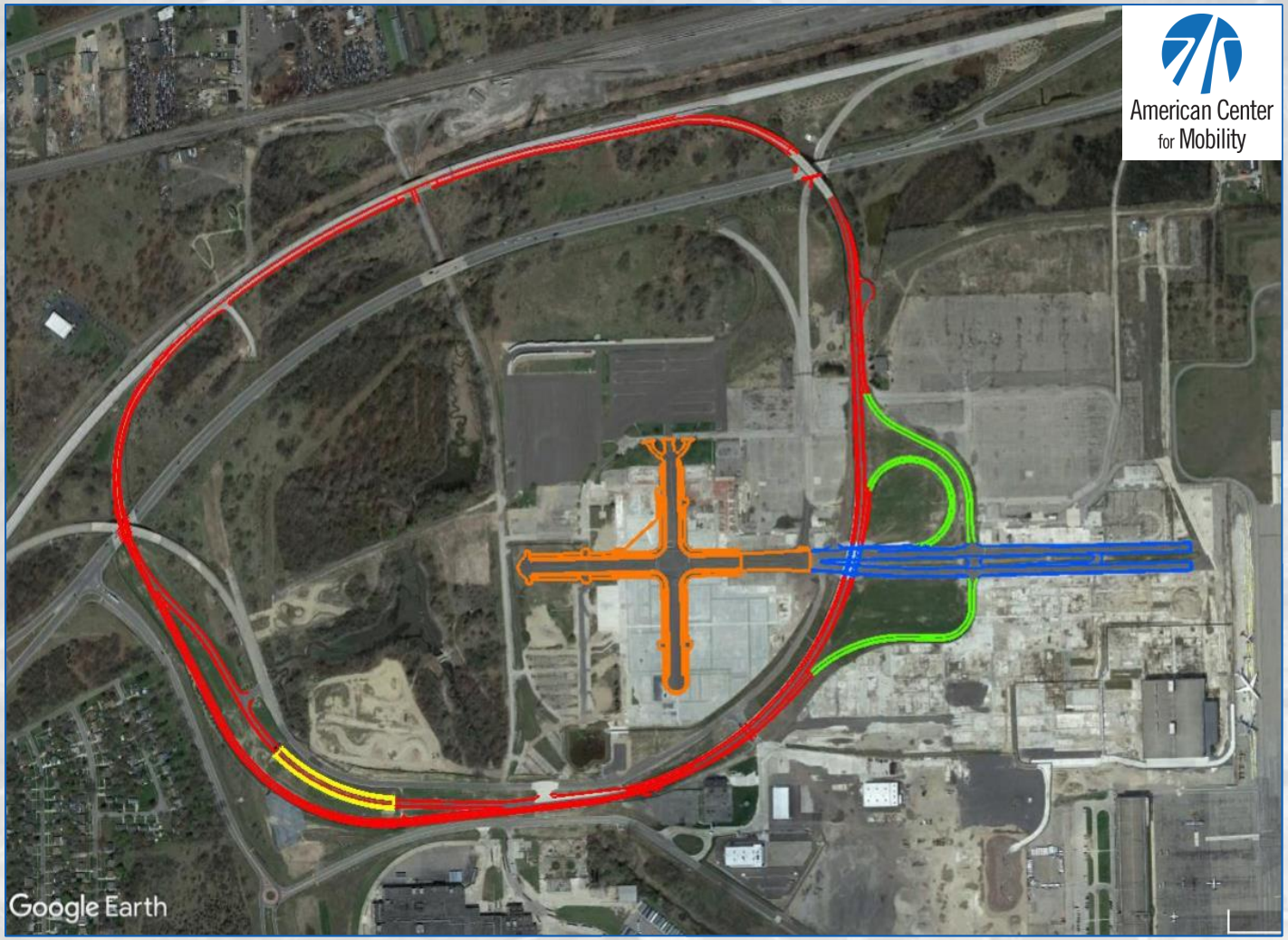
Merging

Intersections

Approach

ACM, unlike other CAV test facilities:

- Naturalistic environments, not a converted automotive manufacturer test track
- Large scale, high speed
- Highway – 2.3 miles:
  - 6 hills
  - +4.3% max, -3.6% min grades
- Overpasses, underpass, tunnel
- Merges: 24+ configurations
- Intersections: 62+
  - 2+ Smart, fully integrated
- Irregularities provide real world transient challenges – *no easy miles*



Highway loop, Tunnel, 6x6 Intersection, Boulevard, Ramps

Approach

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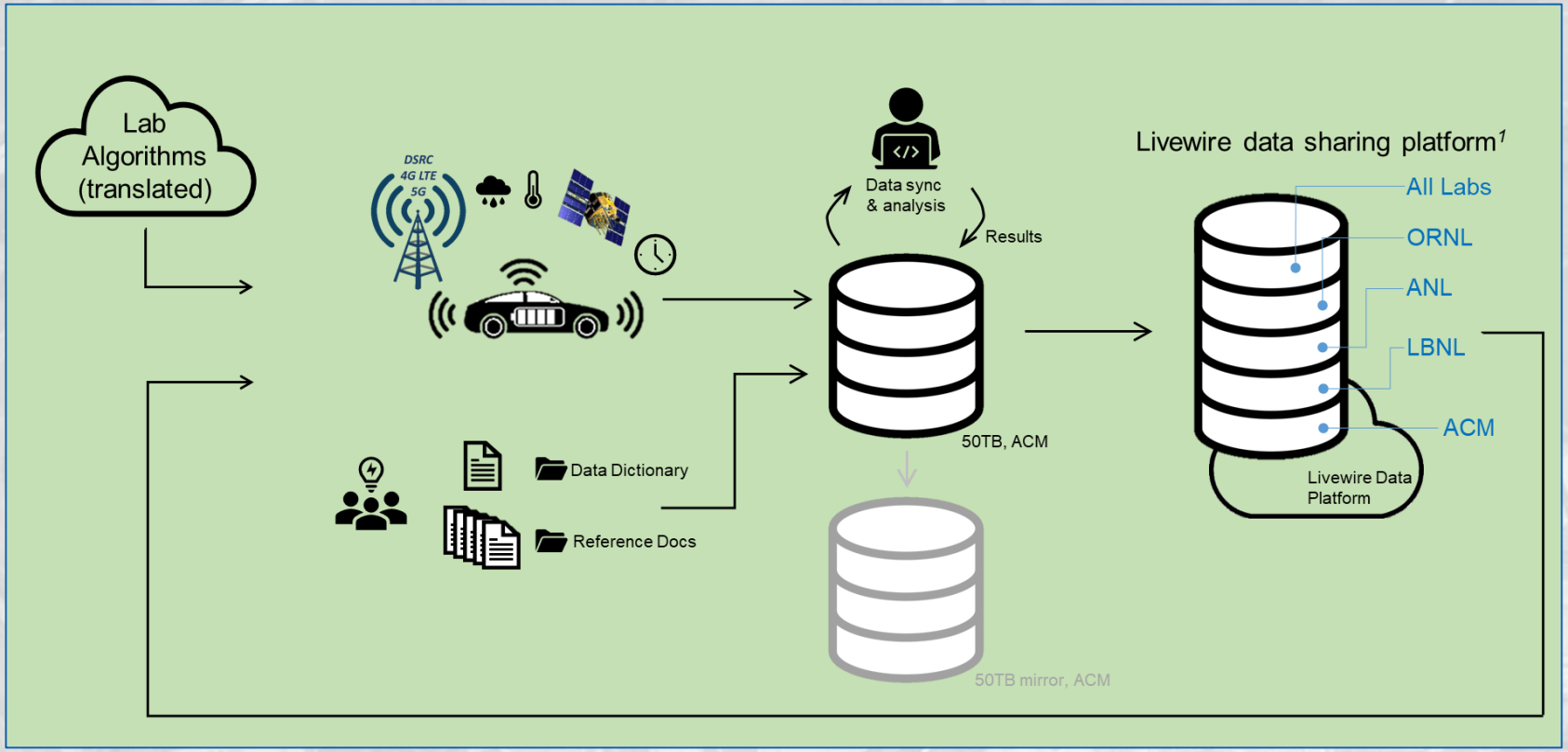


Milestones

1. Translate Lab algorithms in order to control the vehicles and infrastructure
2. Build physical vehicles and infrastructure for testing of algorithms
3. Test vehicles with lab algorithms and models in coordinated scenarios at a specialized track
4. Compare results and modify accordingly

Milestones	Budget Period 1[1] (BP1)					BP2			
	2019	2020				2021			
	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Integrate National Laboratory model criteria	Task 1.1				2.1		3.1		
Design Experiments Complete	1.2								
Test Vehicle Setup	1.3, 1.5								
Conduct Experiments				1.4, 1.6					
Experiment complete (Go/No Go)		Speed Harmonization			1.7, 1.8				
Design Experiments Complete					2.2		3.2		
Test Vehicle Setup					2.3, 2.5		3.3, 3.5	Intersections	
Conduct Experiments						2.4, 2.6		3.4, 3.6	
Experiment complete					Merging		2.7, 2.8		3.7, 3.8

[1]*Excluding potential COVID-19 extension*

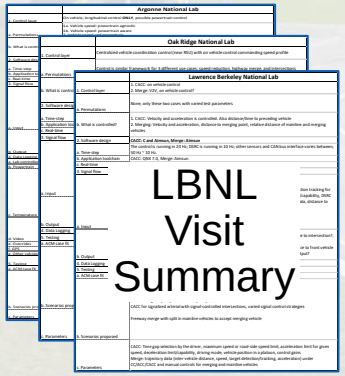
Progress & Accomplishments Summary

- Started Model Integration
- Vehicle Design Complete, Build Underway
- Build of Virtual Test Track Underway
- Vehicle-to-Infrastructure Communication Shakedown Begun
- Energy Model Correlation Underway
- Data Flow Established
- Connected Vehicle Infrastructure Evolving

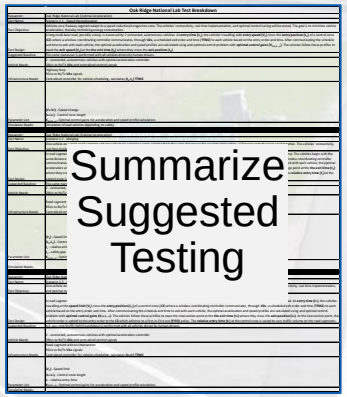
Project Progress & Accomplishments:

Started Model Integration (within collaboration framework)

Summarize plans from Kickoff and Visits

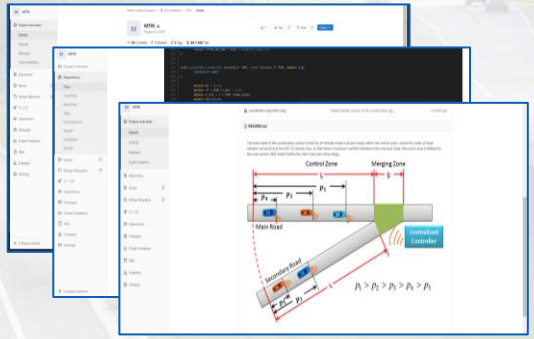


Preliminary test planning



NDAs

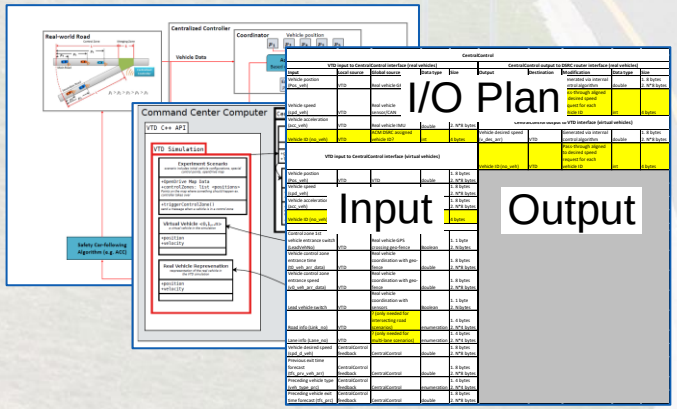
Share existing algorithms with team



Share Existing Documentation

Demo existing simulation

Environment and I/O planning



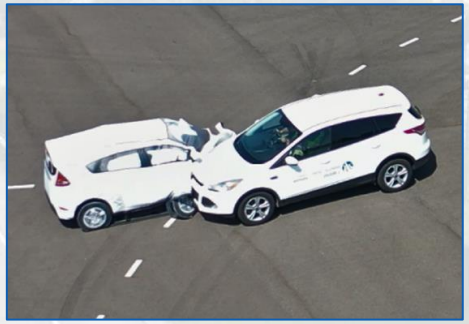
Project Progress & Accomplishments:

Vehicle Design Complete, Build Underway

Volt (2x, Hybrid)

Bolt (2x, BEV)

Pacifica (ICE)



Self-Guided Target

Virtual Vehicles (15-100x)

Five Automation Strategies

1. By-wire control driven by Lab algorithm (translated) in MicroAutoBox (MABx)
2. Add perception overlay with human behavior emulator (comfort, safety)
3. Robotic target for high risk maneuvers
4. Virtual vehicles for higher traffic volume
5. Human-driven for naturalistic interaction

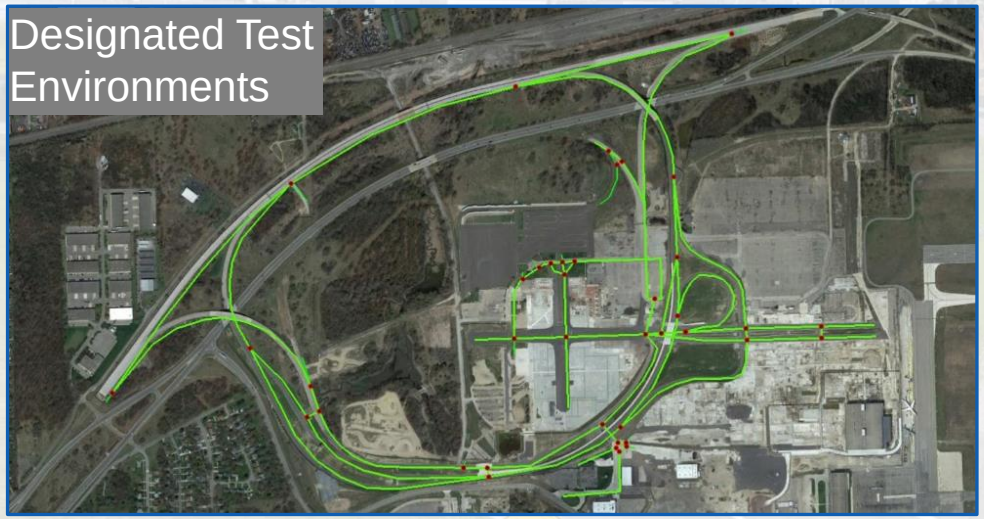
Automation Specifications

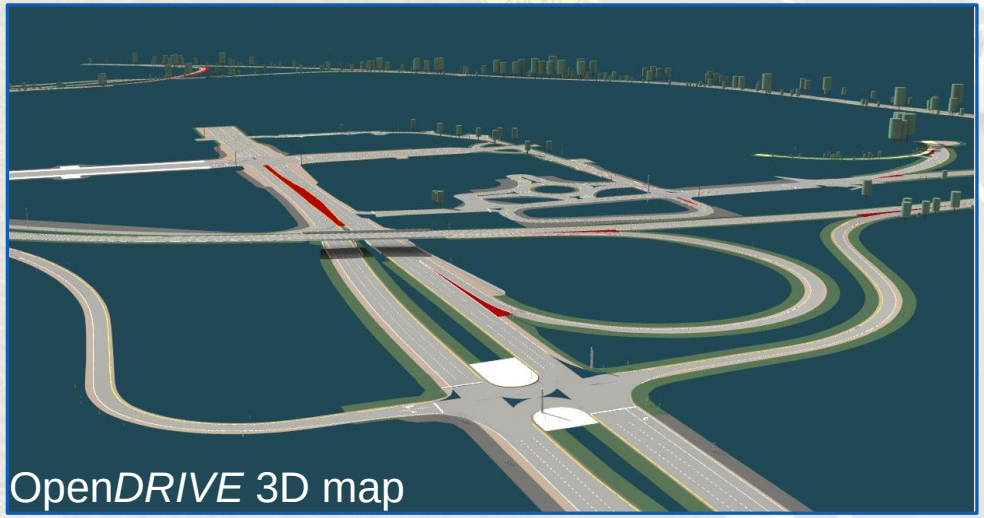
1. Basic: (2 Volts, 1 Bolt)
   - By-wire: throttle, brake, steering
   - Communication: DSRC, 4G cellular
   - Sensing: GNSS/INS/RTK, Fwd long range radar
2. Advanced, add: (1 Bolt, 1 Pacifica)
   - Sensing: 360° lidar, Side/Rr short range radars
   - Control: open source ROS/Autoware, Livetraffic[1]

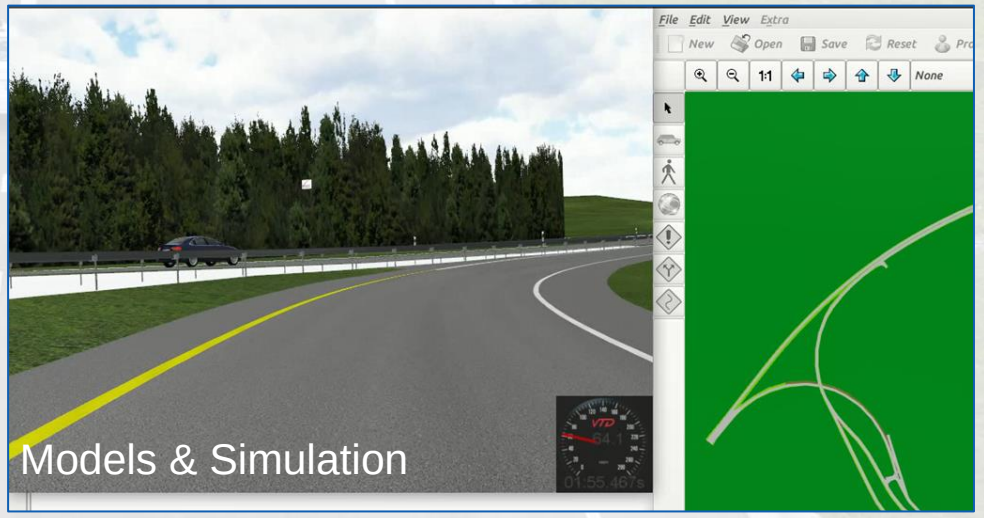
[1]AutonomouStuff *Dedicated Short Range Communication (DSRC), Global Navigation Satellite System (GNSS), Inertial Navigation System (INS), Real-Time Kinematic (RTK), Robot Operating System (ROS)*

Project Progress & Accomplishments:

Build of Virtual Test Track Underway







Project Progress & Accomplishments:

Build of Virtual Test Track Underway

Designated Test Environment

High Def. 3D point cloud

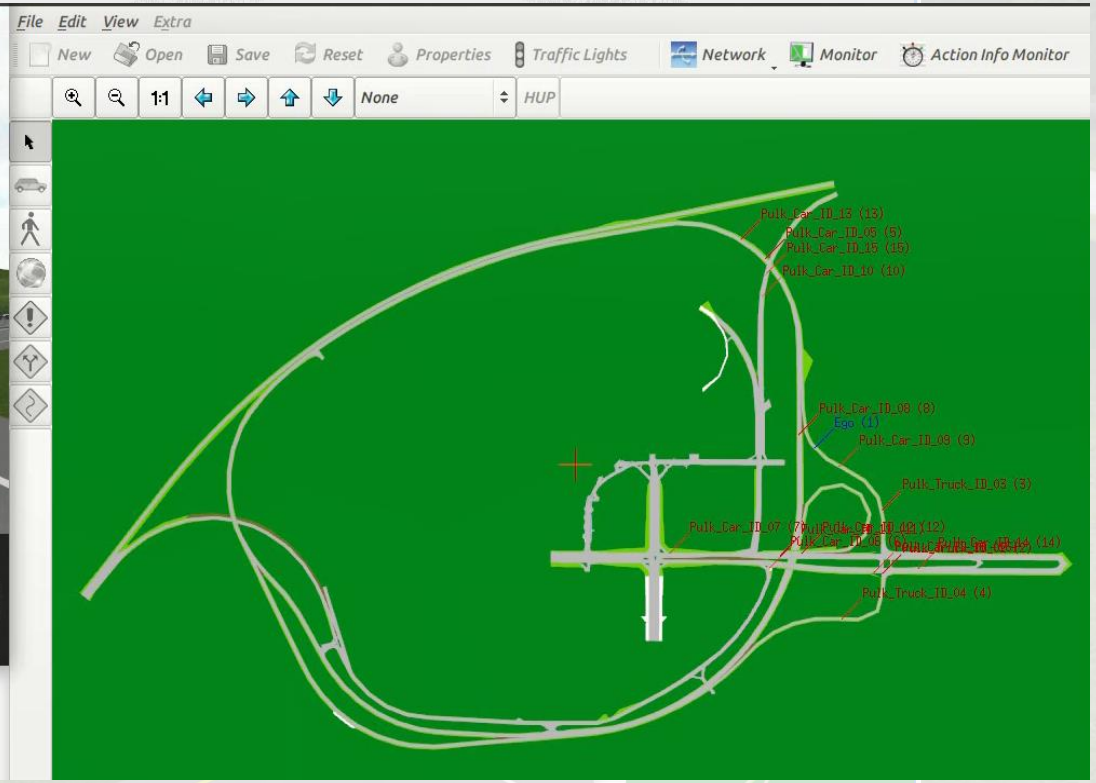
Tools:

- MSC Virtual Test Drive

Application allows:

- Data flow out and vehicle control back in
- Real time communication

VIDEO



OpenDRIVE® 3D map

Model & Simulation

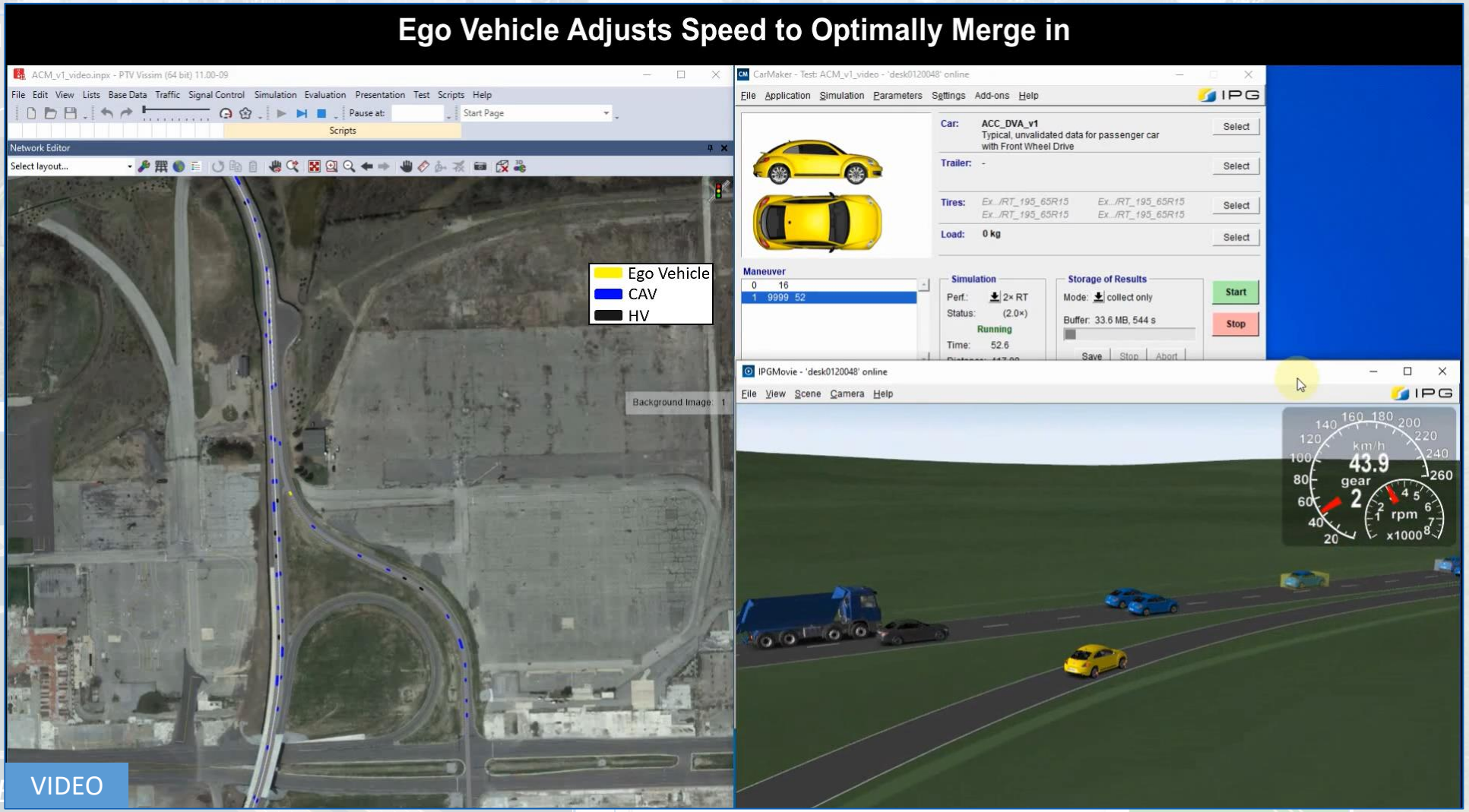
Project Progress & Accomplishments:

Build of Virtual Test Track Underway

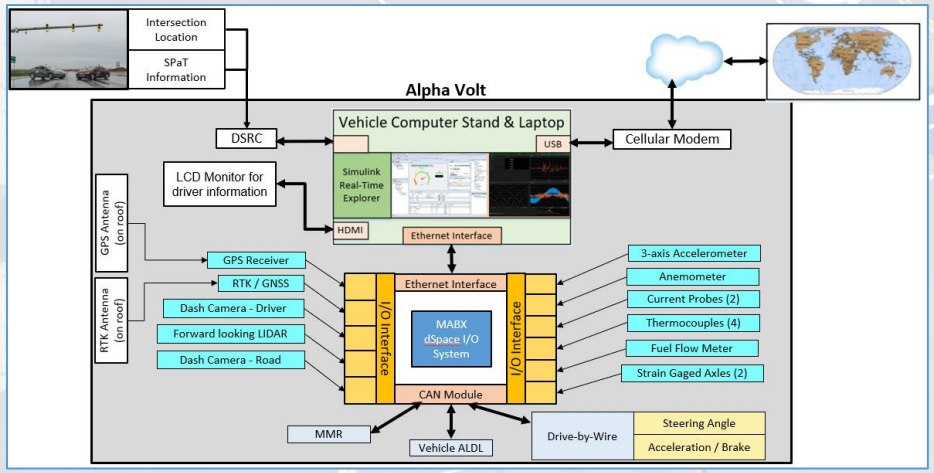
Tools:

- PTV Vissim
- IPG CarMaker

Case 2 Merging simulation, courtesy of ORNL, project "Virtual and Physical Proving Ground for Development and Validation of Future Mobility Technologies"

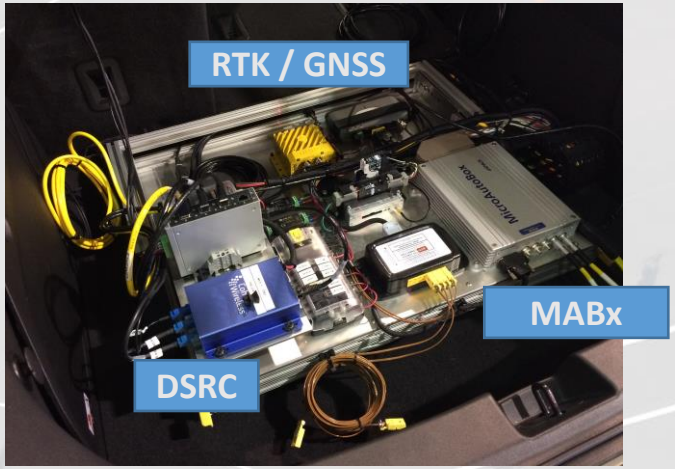


Vehicle-to-Infrastructure Communication Shakedown Begun

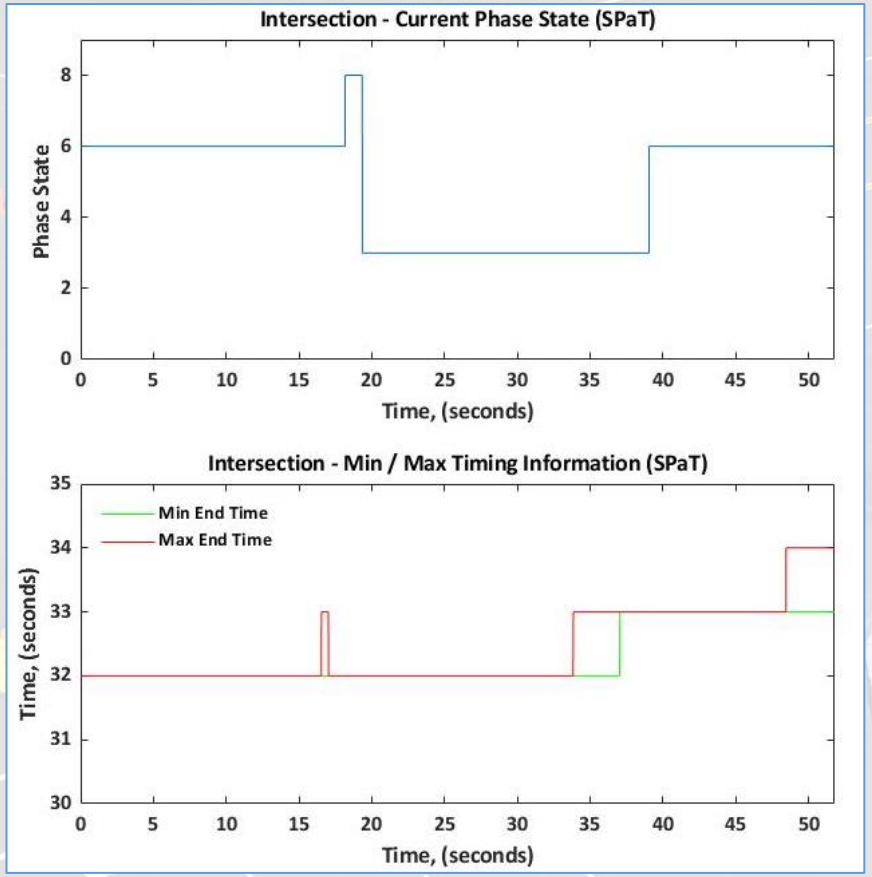


Planned Instrumentation and Connectivity

Preparing vehicles to receive Signal Phase and Timing (SPaT) messages from intersection



Components Installed in Vehicle

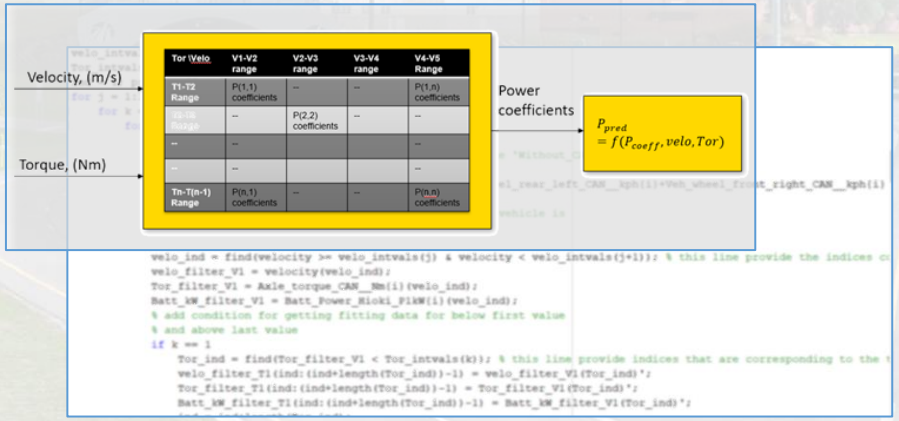


SPaT Messages Read By Volt

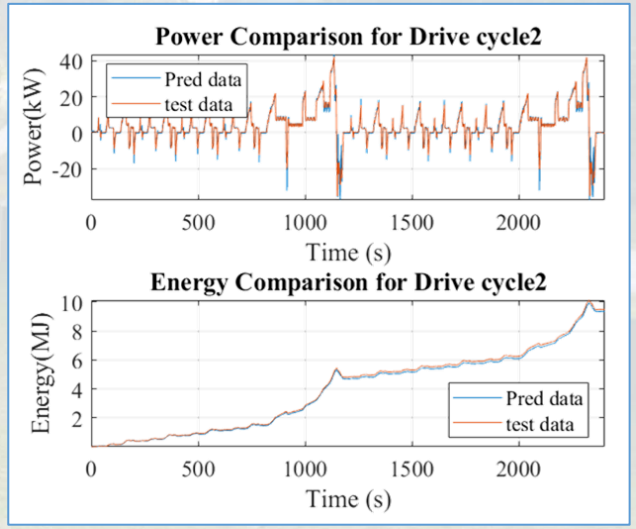
Project Progress & Accomplishments:

Energy Model Correlation Underway

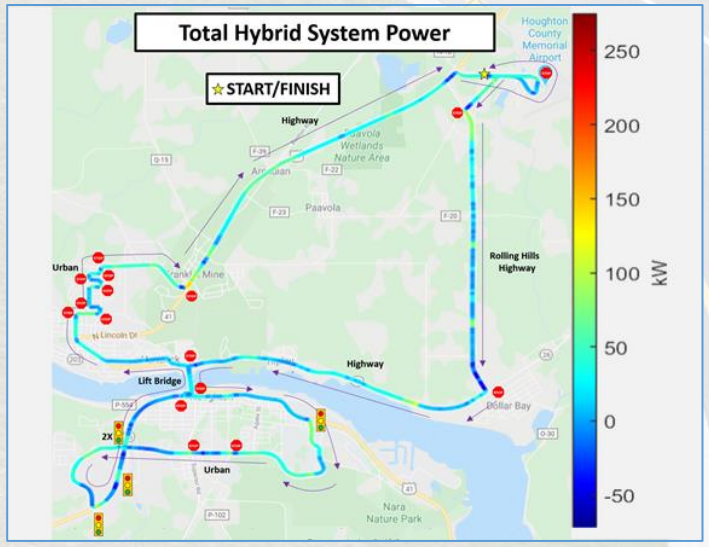
1) Energy model created using Pacifica vehicle speed and axle torque

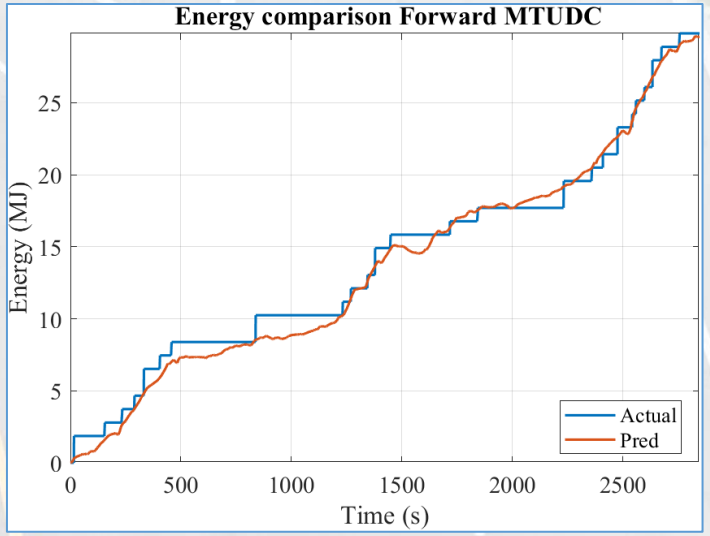


2) Pacifica energy predictions correlated to ANL drive cycle test results



3) Model applied to Volt on MTU drive cycle



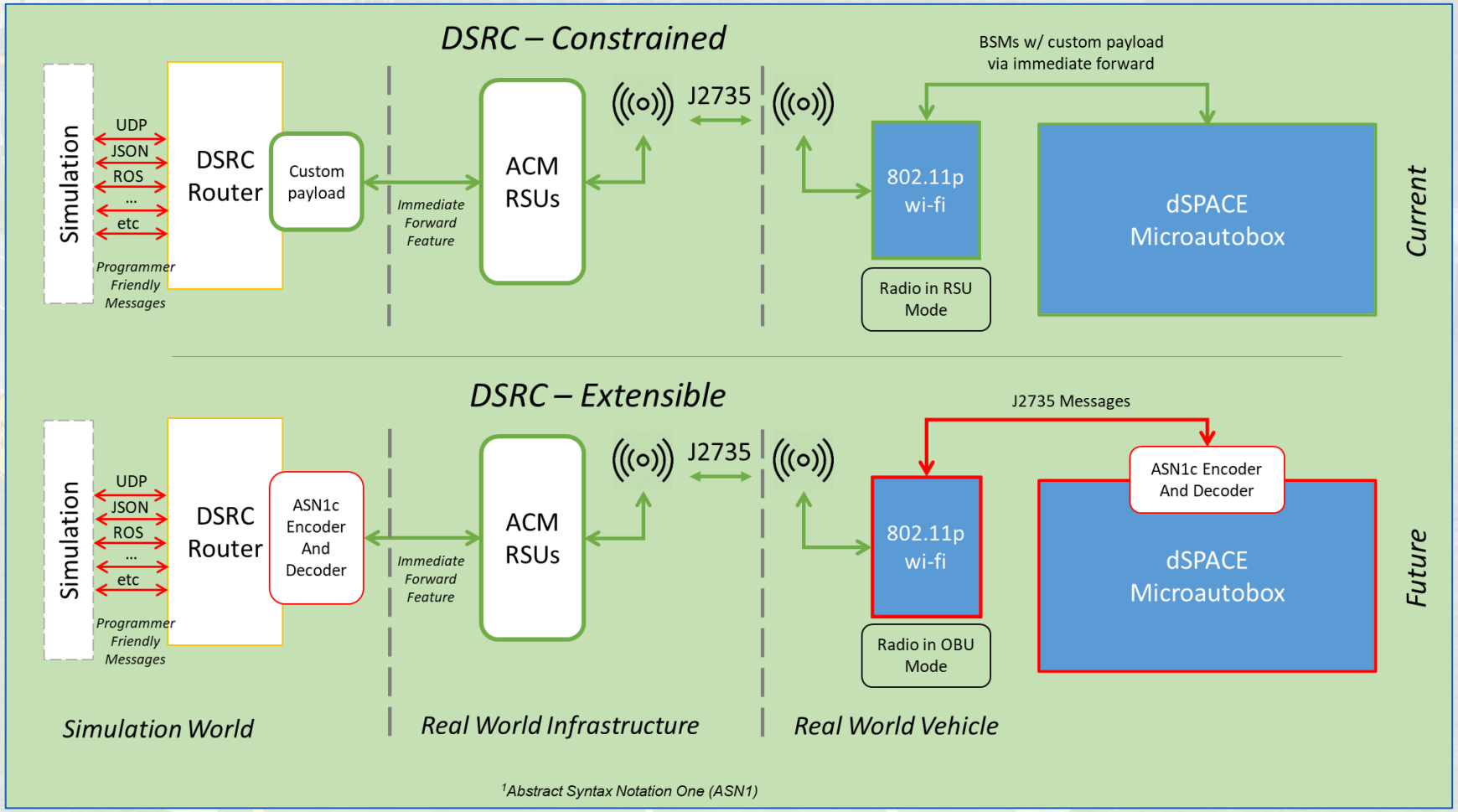


4) Predictions correlated to test data from Volt on MTU drive cycle

5) Next – simulate Bolt and Pacifica over the virtual test track then correlate with physical data

Connected Vehicle Infrastructure Evolving

- Algorithm evaluations include real world and synthetic vehicles
- Synthetic vehicles generated in simulation transmit basic safety messages through test facility infrastructure
- Implementing automotive DSRC standard, SAE J2735 (2016)
- Developing ASN1C[1] messaging standard for encoding / decoding



[1]Abstract Syntax Notation One Compiler (ASN1C)

Response to Previous Year Comments

The 2020 Annual Merit Review is the first year of review for this project

Team Collaboration & Coordination

Partners

American Center for Mobility

PI, PM, Test Facility

Michigan Tech Research Institute

Virtual Traffic, Data Analysis, Robotic Control

Michigan Technological University

Algorithm Translation, Data Analysis, Vehicle Control

Collaborating (Separately Funded)

Oak Ridge National Laboratory

Argonne National Laboratory

Berkeley Lab

NREL Transforming ENERGY

Algorithms, Models, Simulation, Vehicle Characterization, Livewire

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Michigan Technological University (1885) — Algorithm Translation, Data Analysis, Vehicle Control

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Oak Ridge National Laboratory; Argonne National Laboratory; Berkeley Lab; NREL Transforming ENERGY

Algorithms, Models, Simulation, Vehicle Characterization, Livewire

- ★ ORNL engineer, representing all Labs, collocated at ACM for project duration
- ★ Special consultant team support, appointed by U.S. DOE
- MTU/MTRI team collocated at ACM during development and testing
- Weekly meetings – Quad chart-driven (Progress, Goals, Lessons, Help Needed)

Remaining Challenges and Barriers

Remaining Technical Challenges

- Implementation of multiple realistic vehicles in simulation
- Conversion, extraction, partitioning of models to work in distributed real-world environment
- Enable message encoding-decoding across network of infrastructure, and virtual and physical vehicles utilizing standard DSRC message protocols
- Develop test cases for successful acceptance of algorithms in transition to test platforms
- Identify potentially confounding variables in simulation and approach to limit impact in design of experiments
- Quantify sensitivity of models to input parameters
- Estimate variability of hardware components
- Quantify the statistical power of empirical tests as a function of the number of trials

Planned and Future Research

Planned

Budget Period 1 (2020)

- Develop project-specific DSRC message protocols to enable virtual traffic communication with physical vehicles
- Implement encoder-decoder software on all test components: infrastructure, virtual and real vehicles
- Evaluate DSRC message delays and bit error rates
- Validate algorithms in evaluation system through acceptance test case
- Complete automated vehicle builds
- Run experiments related to Speed Harmonization test case

Planned

Budget Period 2 (2021)

- Run experiments related to Merging test case
- Run experiments related to Intersections test case

Future

- Extend scope to include new use cases:
  - Highway corridor (public smart roadway)
  - Dynamic wireless power transfer roadway
  - Traffic-aware intersection
  - Impact of congestion
  - Cyber-security issues
  - Interactions with vulnerable road users
- Include additional complexity related to weather effects – simulation and artificial

Any proposed future work is subject to change based on funding levels

Summary

Project: Validation of Connected and Automated Mobility System Modeling and Simulation

Objectives

- Translate Lab algorithms into vehicle and infrastructure controls
- Conduct physical testing at a manageable scale
- Compare test results with simulation
- Interactively develop better models
- Integrate testing and simulation to expand the set of models that can be assessed

Approach

- Translate Lab algorithms into vehicle and infrastructure controls
- Build physical vehicles and infrastructure for testing of algorithms
- Test vehicles with lab algorithms and models in coordinated scenarios at a specialized track
- Compare results and modify accordingly

Accomplishments

- Completed vehicle design, build underway
- Started model integration within collaboration framework
- Vehicle-to-infrastructure shakedown tests kicked off
- Connected vehicle infrastructure evolving
- Energy prediction model correlation underway

Planned & Future

Planned:

- Virtual traffic integration
- Speed harmonization, Merging, Intersection tests

Future:

- Public highway corridor
- Dynamic wireless power transfer roadway
- Traffic-aware intersection
- Congestion, Cyber, VRUs
- Weather

Any proposed future work is subject to change based on funding levels

Technical Backup Slides

Technical Backup Slides

- None