OAK RIDGE National Laboratory

ORNL Connected and Automated Vehicle (CAV) Testbed

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Project ID: EEMS067

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2019 Annual Merit Review

ORNL is managed by UT-Battelle, LLC
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U.S. DEPARTMENT OF ENERGY

OAK RIDGE National Laboratory

Overview

Timeline

- Start Date: Oct 1, 2018
- End Date: Sept 30, 2021
- Percent Complete: 10 %

Barriers and Technical Targets

- Modeling and simulation environments are not all inclusive for all scenarios.
- Lack of standard co-simulation tools or hooks.
- Computational Requirements of complex environment simulation.

Budget

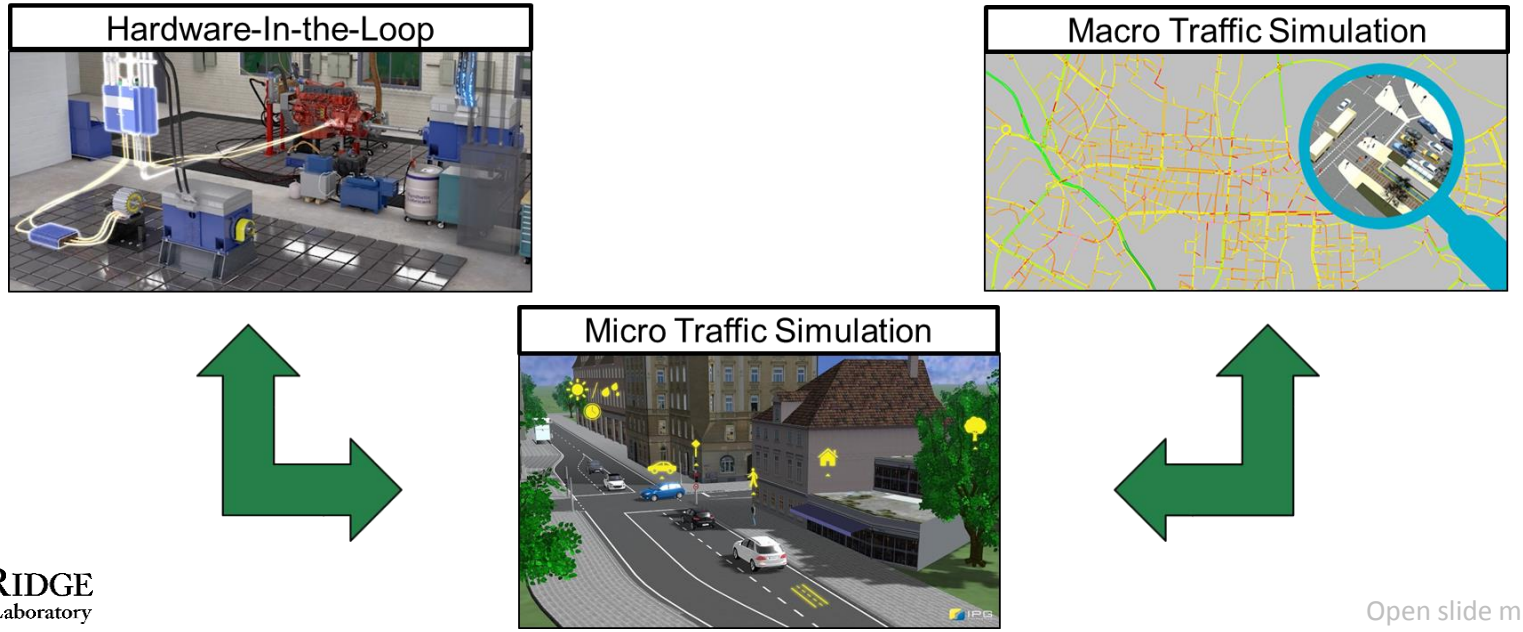
- Total Budget
  - DOE Share $3,100K
- Funding for FY 2019
  - $1,100K
- Funding for FY 2020
  - $1,000K

Partners

- Collaborations
  - National Renewable Energy Laboratory (NREL)
  - Lawrence Livermore National Laboratory (LLNL)
  - University of Michigan (UoM)
  - American Center for Mobility (ACM)
  - IPG Automotive

Relevance / Project Objectives

- **Relevance:** Currently there are many toolsets and toolchains being utilized to simulated Connected and Automated Vehicles (CAVs), each with their own benefits and features, but none able to cover all applications.
- **Objective:** Create the beginnings of an agnostic standardized framework to allow for validation of EEMS and SMART Mobility models, tools, and data sets utilizing various combinations of modeling, simulation, Hardware-in-the-Loop (HIL), and vehicle-level testing. This architecture will consider and allow for the integration of both DOE and Industry standard software and toolsets.



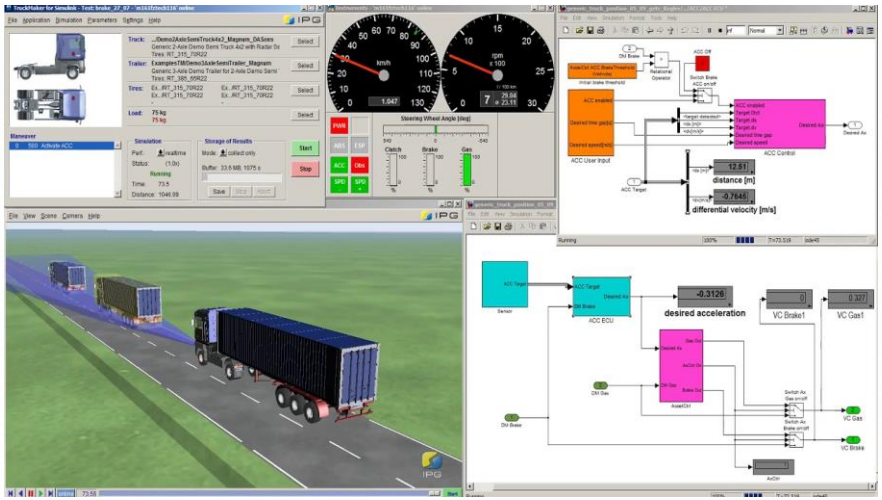
Milestones

Date	Milestone and Go/No Go	Status
March 2019	Establish HD truck platooning models based on ORNL/NREL/LLNL data for use in platooning integration. (Subtask 1.2)	Delayed – Expanded to Include High Fidelity Options
June 2019	Complete integration of V2X communications hardware into virtual-physical framework. (Subtask 2.1)	On Track
September 2019	Establish virtual-physical standardized framework. (Subtask 1.1)	On Track
December 2020	Demonstrate real-time merging algorithm in a HIL laboratory with a single real vehicle. (Subtask 2.3)	On Track
March 2020	Demonstrate a working virtual replica of the ACM facilities including V2I integration. (Subtask 2.2)	On Track
Jun 2020	Integrate freight operations and routing scenarios into traffic simulations based on real-world data. (Subtask 1.3)	On Track
September 2020	Demonstrate the proving grounds integrations of other DOE developed traffic simulation tools showing the platforms agnostic characteristics. (Subtask 1.1)	Not Started

Approach

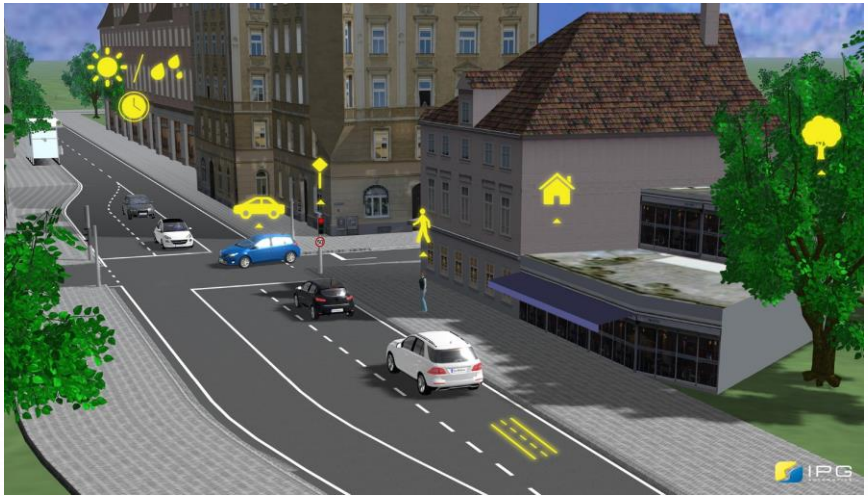
"Virtual-Physical" Proving Ground – Task 1

- Close the gap in the ability to accurately verify the large-scale energy benefits and emissions impacts of CAV technologies in considering physical powertrain hardware subjected to virtual traffic conditions.
- Integration of micro- and mesoscopic-level vehicle/traffic simulation tools with advanced HIL-enabled laboratories to investigate the impact on energy efficiency of CAVs and other advanced transportation technologies currently not being tested in laboratory settings.



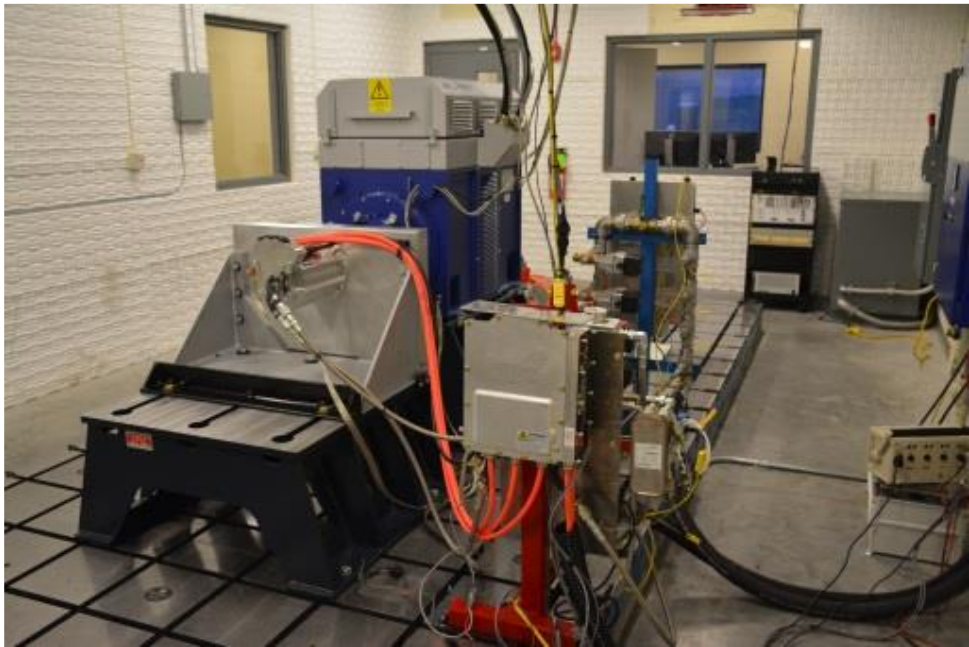
Communication (V2X) Modeling, Development, and Validation – Task 2

- Provide a platform to couple laboratories to real-time, high-fidelity, traffic simulations while subjecting actual powertrain(s) to emulated real-world traffic conditions utilizing Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communication.
- Development of control strategies and algorithms specifically targeted at advanced vehicle technologies, central traffic controllers, as well infrastructure controls.



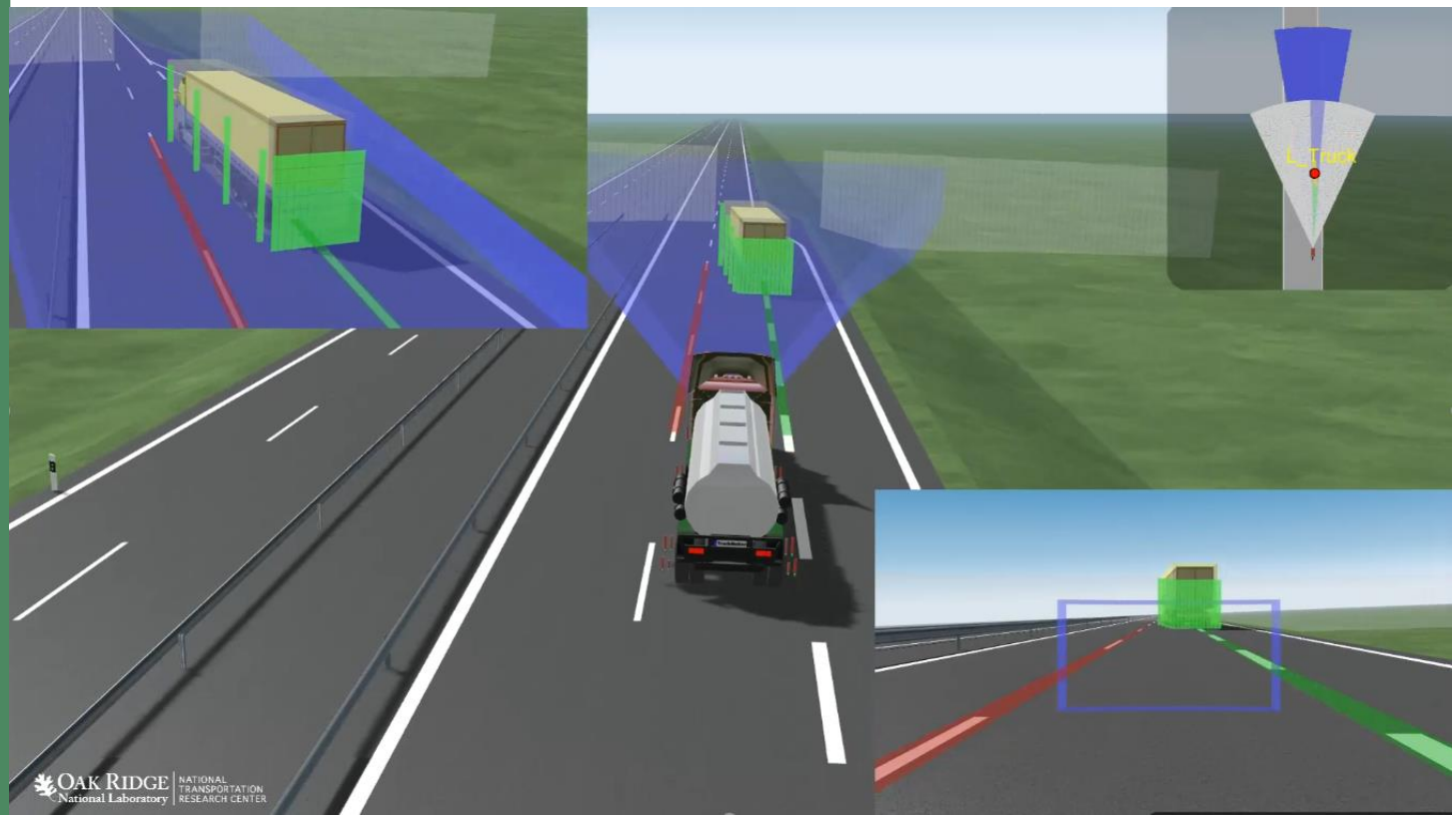
Accomplishments Task 1 – Virtual Urban Test Platform with Electric Drive Hardware-in-the-Loop (HIL) Platform

- A UQM 120kW Electric Drive unit has been integrated into a virtual urban environment.
- The electric drive unit is utilizing the ORNL HIL system allowing for the UQM motor to control the vehicle in real-time.
- The environment includes vehicle longitudinal and lateral dynamics, autonomous traffic objects, traffic lights, speed limits, and intersections.



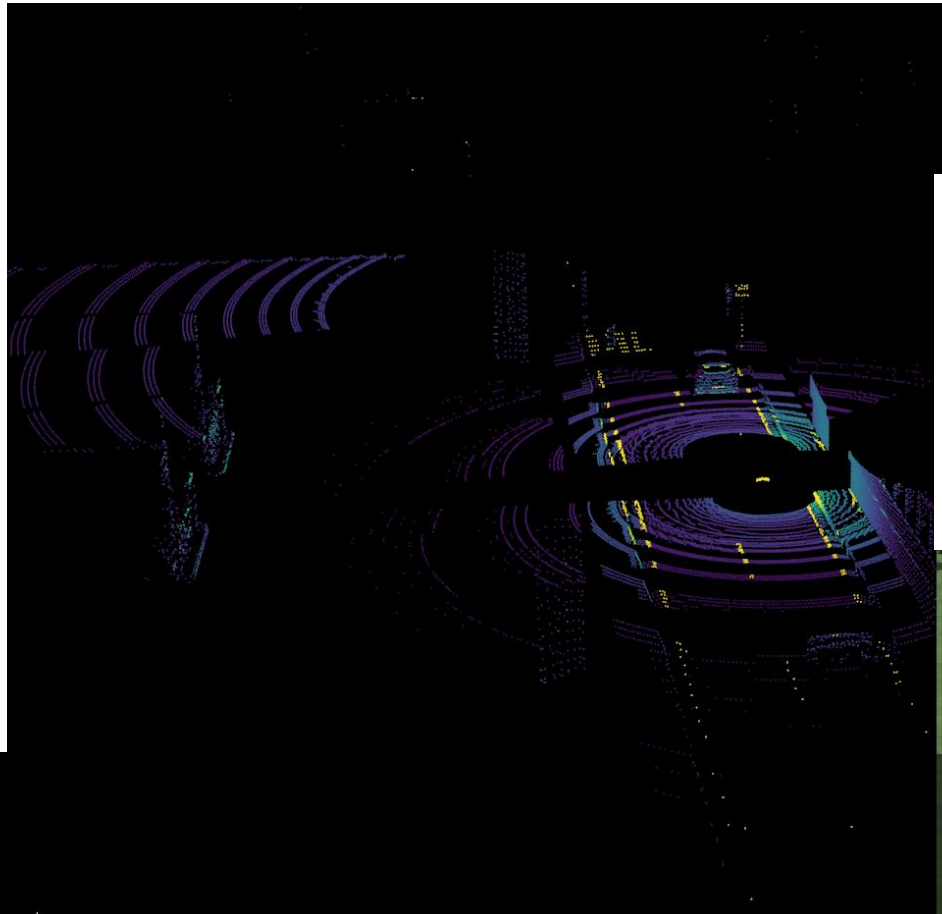
Accomplishments Task 1 – Virtual Platooning with Ideal Sensors and Aerodynamics

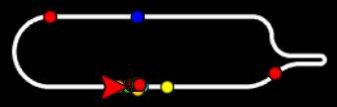
- Currently the controls and coordination for two platooning trucks has been completed, the control is based on the feedback from the lidar and radar sensors.
- The Sensors models utilized idealized techniques to emulated sensor behaviors.



Accomplishments Task 1 – Integration of Physics Based Lidar Simulation

- The raw signal interface for the Lidar simulates the propagation of light through the rendered scenario. Ray tracing algorithms are used to scan each point and provides info such as time of flight , intensity and echo pulse width.





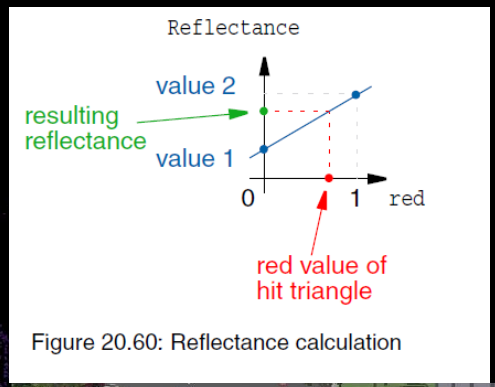


Figure 20.60: Reflectance calculation

Vhcl.sRoad: 335m

Accomplishments Task 1 – Integration of Physics Based Radar Simulation

- Simulates the propagation of the electromagnetic waves using ray tracing and interacting with the 3D rendered geometry of the environment.

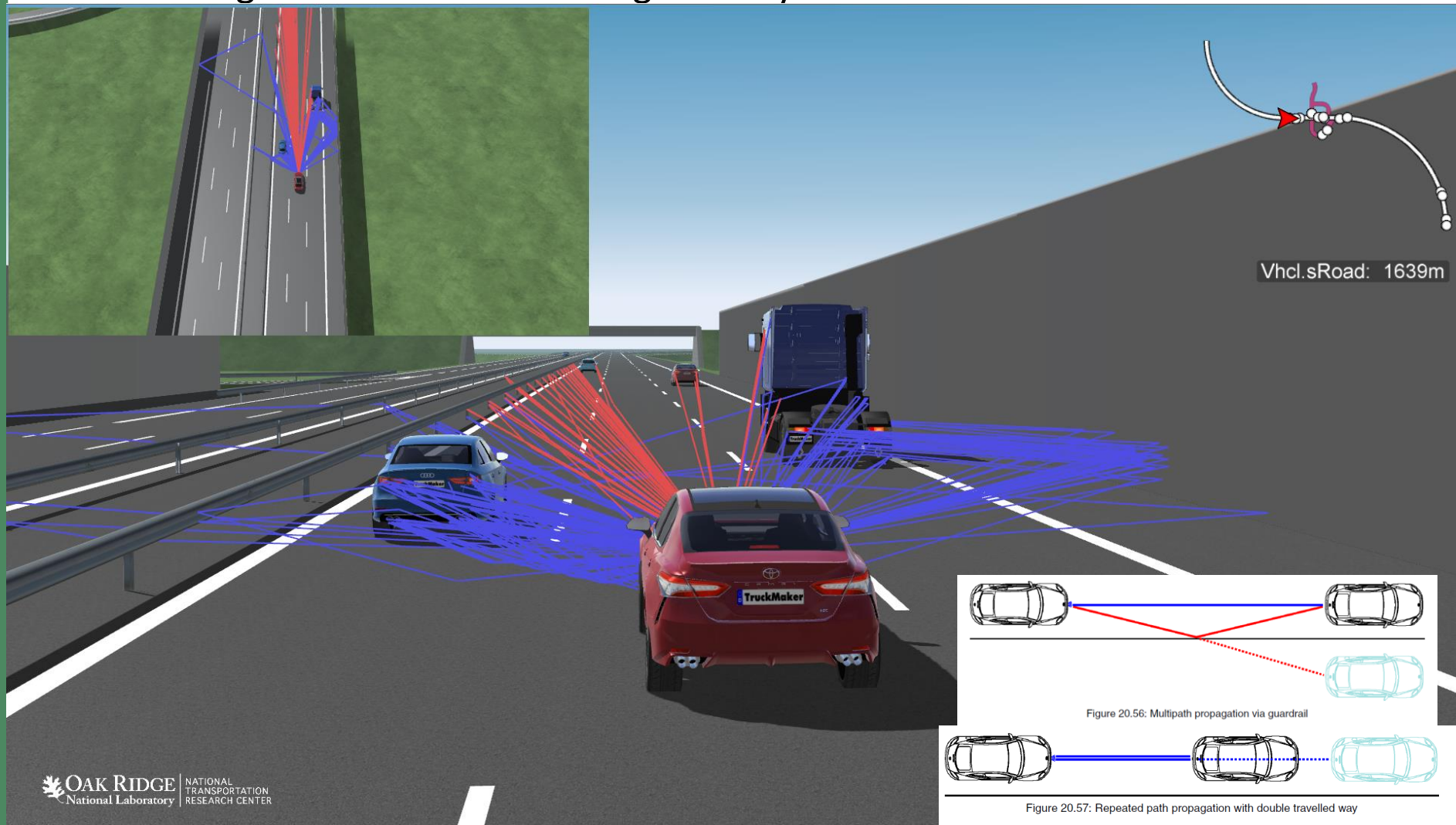
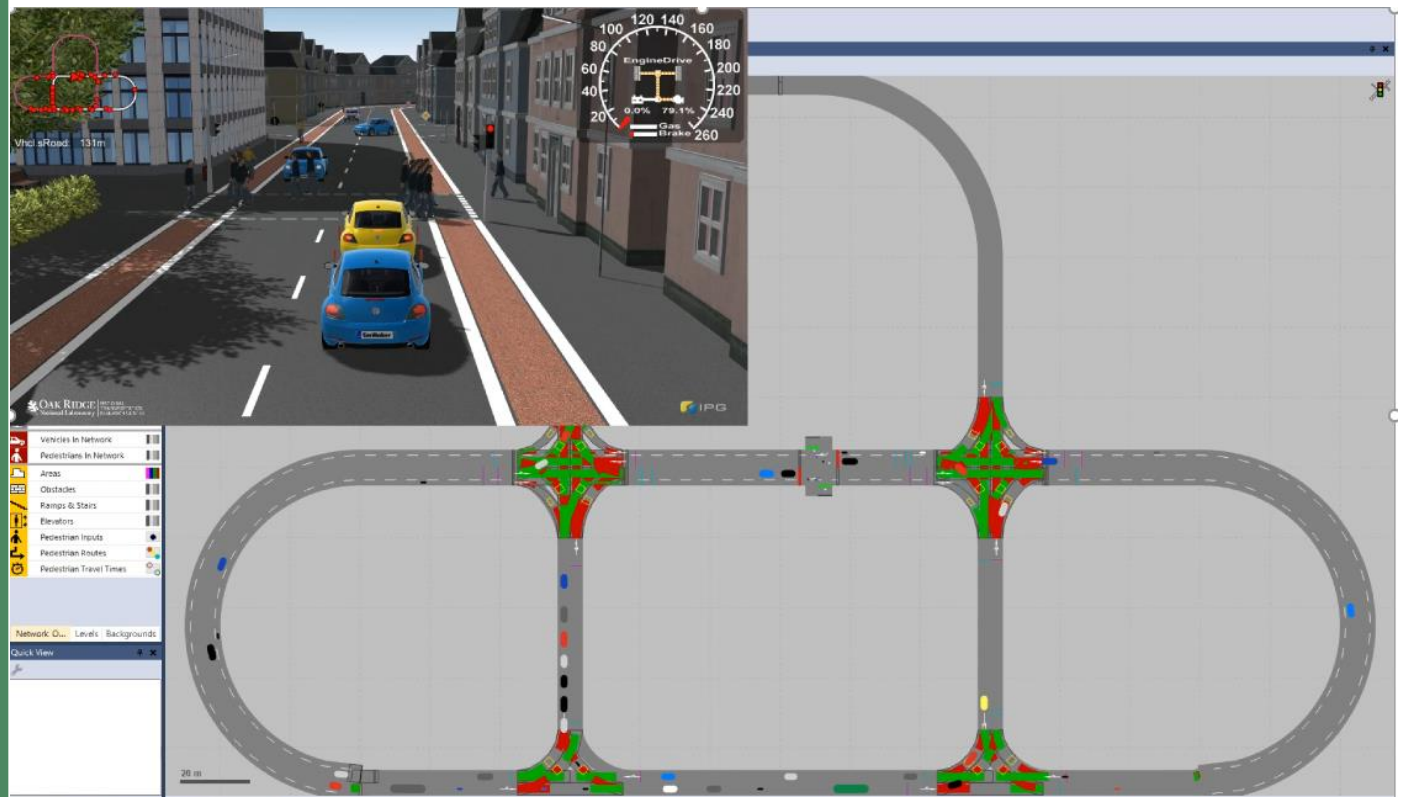


Figure 20.56: Multipath propagation via guardrail

Figure 20.57: Repeated path propagation with double travelled way

Technical Progress Task 1 – Co-Simulation of Agent and Physics Based Models in Real-Time Simulation

- Working with IPG Automotive a Co-Simulation bridge between CarMaker's vehicle dynamics-based environment and Vissim's agent-based traffic control environment has been created.
- ORNL is using this link to apply HIL techniques to agent-based models that are part of SMART in order to get realistic energy consumption utilizing hardware.

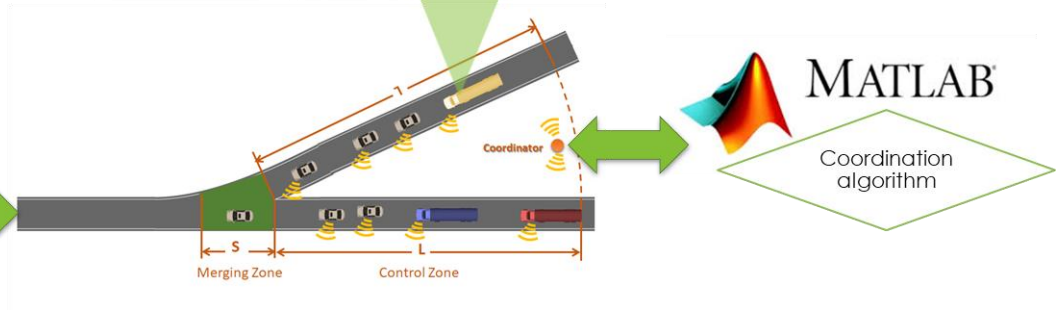


Technical Progress Task 2 – Microscopic Traffic Model with Real-Time Coordination Algorithm

- ORNL has created a digital twin of the Tennessee I-75/I-40 Corridor in Vissim's microscopic traffic simulation environment.
- This environment has been connected to a centralized coordinator controller in the form of a dSpace RT box, that controls autonomous vehicles on one of the merger ramps.
- Utilizing a coordination algorithm in MATLAB, the team is investigating the speed at which the merging algorithm can be executed.

Digital Twin of I-75/I-40 Corridor

dSpace Real-Time PC



Response to Previous Reviewer's Comments

- This project is new for FY 2019.

Collaborations

NREL NATIONAL RENEWABLE ENERGY LABORATORY	On track platooning data to improve IPG aerodynamic models and correlate fuel consumption effects of platooning.
Lawrence Livermore National Laboratory	Aerodynamic data from wind tunnel testing to improve IPG aerodynamic models utilized in the virtual-physical proving ground platooning work.
American Center for Mobility	High fidelity mapping of the ACM facility is being provided to ORNL to allow for a digital twin to be generated and utilized in year 2 and 3 of the project.
UNIVERSITY OF MICHIGAN	Working with ORNL to introduce Internet-in-the-Loop approach to test facilities. Allowing for multiple non-collocated test cells to run in a single virtual environment.
IPG	Providing support for the co-simulation bridge allowing for Car/TruckMaker to be ran in real-time with Vissim.

Remaining Challenges and Barriers

- A primary challenge for this project is discovering a way to determine what approach is the correct one for varying applications. Some applications require co-simulation of various tools, some require HIL techniques and Real-Time hardware, and others are satisfactory with a single simulation tool.
- Determining the computational requirements for these various applications is also a major challenge as well as a barrier to some applications. To be able to run the most demanding sensor simulations (ie Lidar and Radar) on HIL applications requires both an extremally powerful PC to apply ray tracing techniques utilizing GPU calculation, and a powerful Real-Time node.

Proposed Future Research

- Remainder of FY19
  - Continue working with NREL and LLNL to add realistic aerodynamic properties to the platooning work.
  - Complete HIL integration of V2X communication hardware into the virtual framework.
  - Finish links for more standardized sim tool swaps.
- FY 2020 Future Work ("Any proposed future work is subject to change based on funding levels.")
  - Demonstrate a fully functional Real-Time capable merging algorithm in a HIL laboratory.
  - Demonstrate a working digital twin of the ACM facility for use in HIL applications of the "virtual-physical" proving ground.
  - Demonstrate integration of DOE developed tools into the "virtual-physical" proving ground (e.g. SUMO, LBNL BEAM, ANL Autonomie).

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Summary

Relevance

- Create an agnostic standardized framework to allow for validation of EEMS and SMART Mobility models, tools, and data sets utilizing combinations of modeling, simulation, HIL, and vehicle-level testing.
- This architecture will consider and allow for the integration of both DOE and Industry standard software and toolsets.

Technical Accomplishments

- Virtual-Physical urban environment running fully utilizing HIL on an electric drive platform.
- Virtual Platooning environment includes physics-based radar and lidar sensor emulation.
- Agent Based Model with Real-Time Coordination Algorithm integrated into ORNL's HIL environment for testing.

Approach

- "Virtual-Physical" Proving Ground
- Communication (V2X) Modeling, Development, and Validation

Future Work

- FY 2019:
  - Continue working with NREL and LLNL to add realistic aerodynamic properties to the platooning work.
  - Complete HIL integration of V2X communication hardware into the virtual framework.
  - Finish links for more standardized tool swaps.
- FY 2020:
  - Integrate the ACM facility into the environment.

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Reviewer Only Slides

Critical Assumptions and Issues

- Currently there are many different forms of simulation, tools, and approaches to test the varying aspects of CAVs. Due to this wide variety it is extremely difficult to settle on a tool chain and set of software for full scale testing. This is compounded on the fact that some tools are extremely expensive.
- The other issue is that in order to fully simulate a vehicle in a virtual environment and within a traffic network there are multiple simulation tools required. This requires multiple computers, real-time boxes, or a clusters setup to run.
- The computational resources required to run the various tool sets vary from one to the other. It makes it difficult to dedicate purpose built machines. Also with the many of the tools leveraging raytracing and video game engines the GPU requirements are higher than before.