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AUTOMOTIVE CONFERENCE 2024
India

November 19th , Pune

Tech Talk: Virtual Vehicle: Transforming Vehicle Engineering Through Simulation

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AMZ Racing, ETH Zurich

What do you think is the record-breaking time set by AMZ Racing for going from 0 to 100 km/h?

a) $1.5\ s \leq t < 2\ s$

b) $1\ s \leq t < 1.5\ s$

c) $0.9\ s \leq t < 1\ s$

d) $t < 0.9\ s$

Panel Members

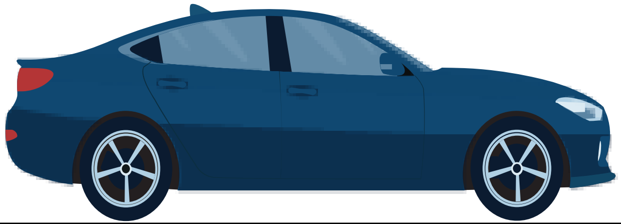
Moderator: Sree Varshini

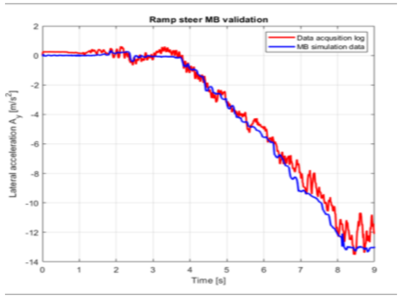
Veer Alakshendra

Abhisek Roy

Rahul Choudhary

Key takeaways





System Level Modelling → Validation & Testing → Large-Scale Studies

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d) $t < 0.9\ s$

0 to 100 km/h in ***0.956*** seconds

AMZ Racing World Records

0 to 100 km/h in ***1.513*** seconds

0 to 100 km/h in ***0.956*** seconds

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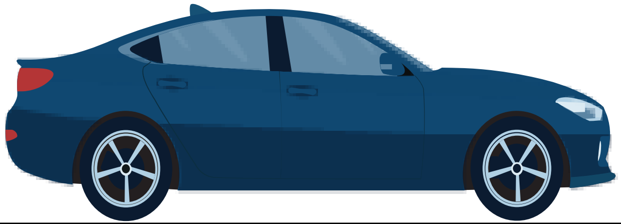
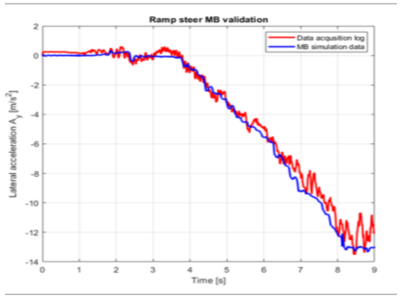
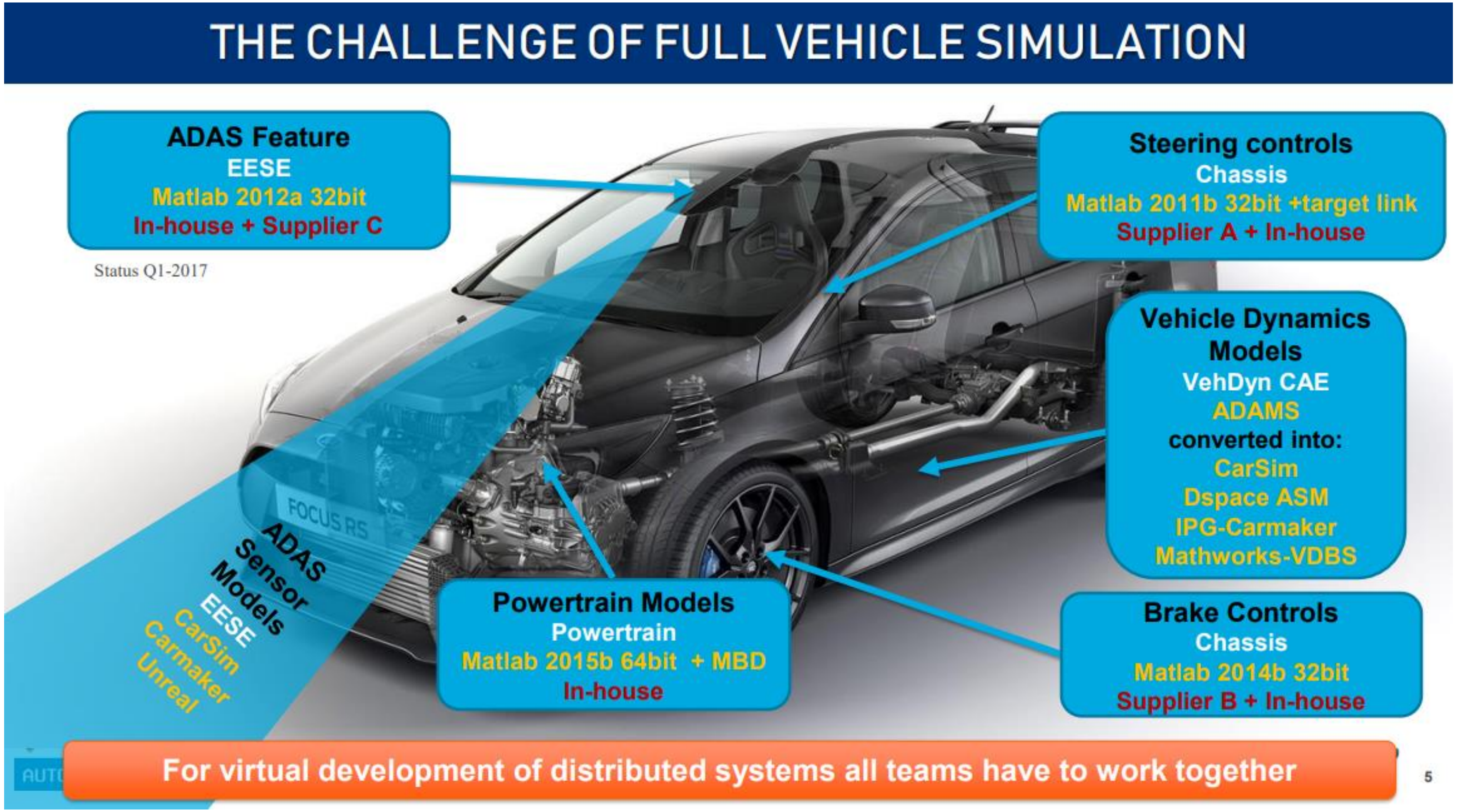
Key takeaways





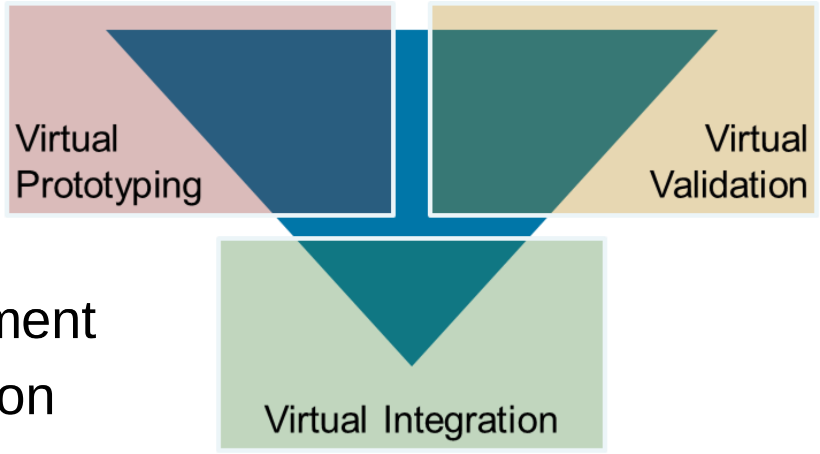
System Level Modelling → Validation & Testing → Large-Scale Studies

Challenges: Ford: Model-Based Agility with FASST



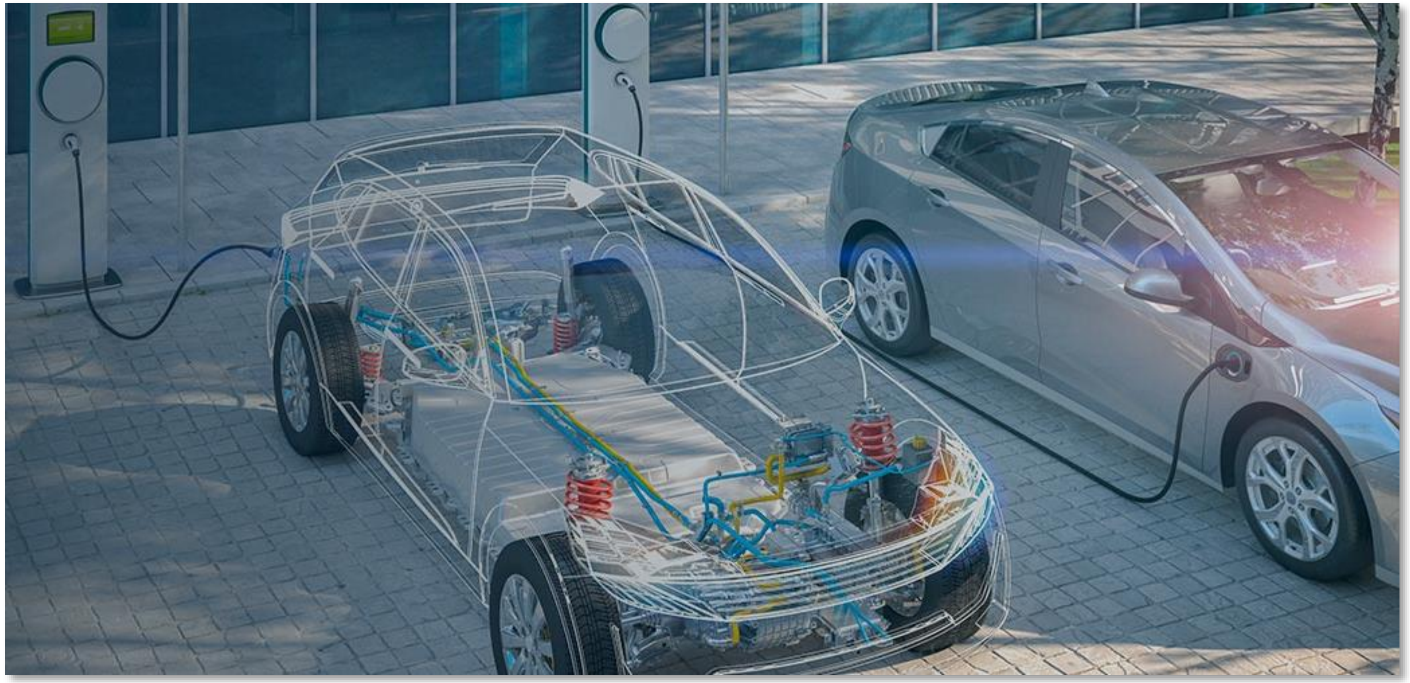
Link to article

Challenges: MathWorks observations

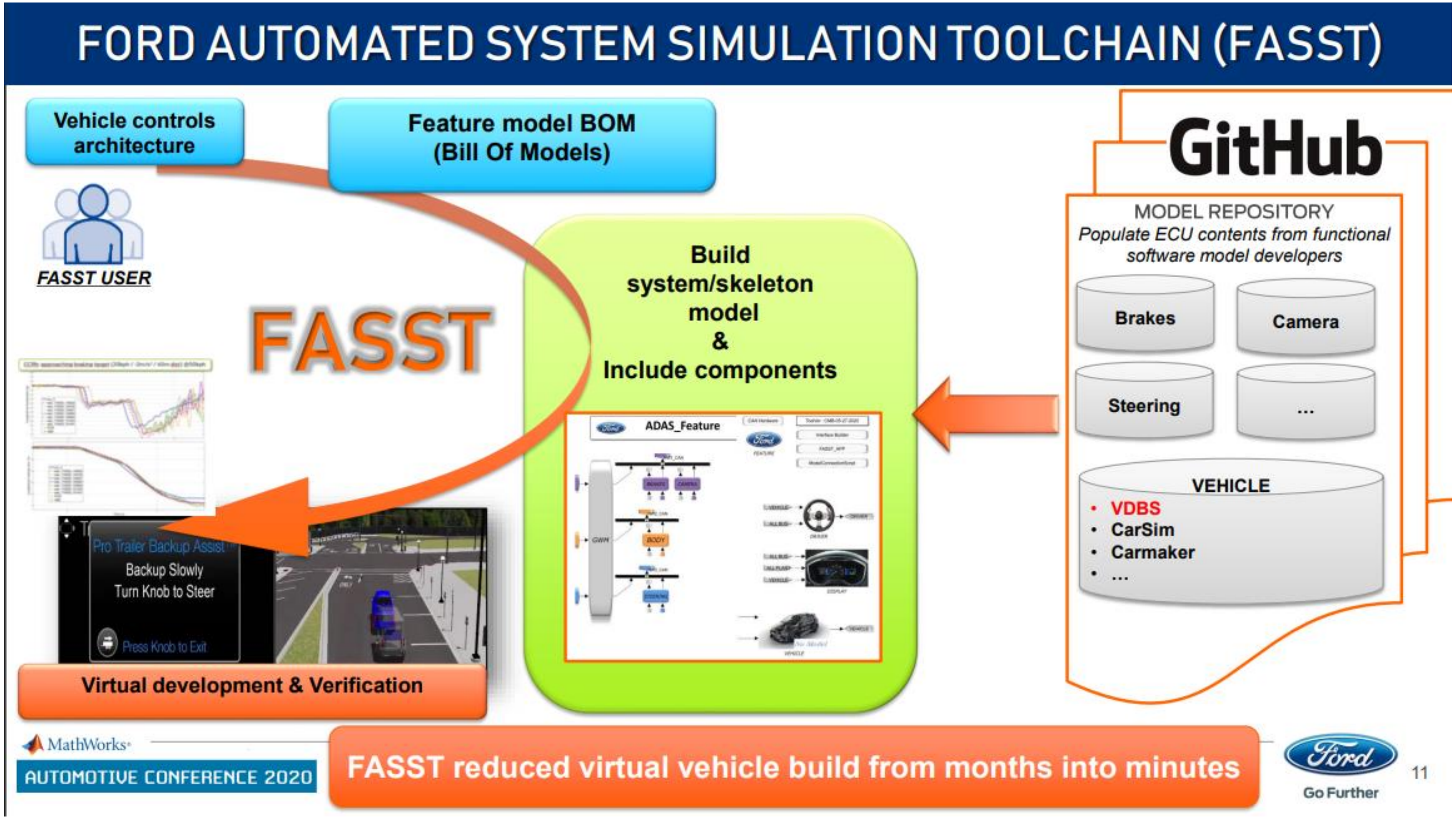


- Companies are deepening virtual development
  - Increasing reliance on system-level simulation for development
  - Using physical prototypes for confirmation and final validation
  - Focus on powertrain, vehicle dynamics and ADAS / AD

- Common challenges
  - Integration of both **physics** and **software** models
  - Access to “right level” **fidelity** models across organization
  - Deploying models to users who **aren’t tool experts**

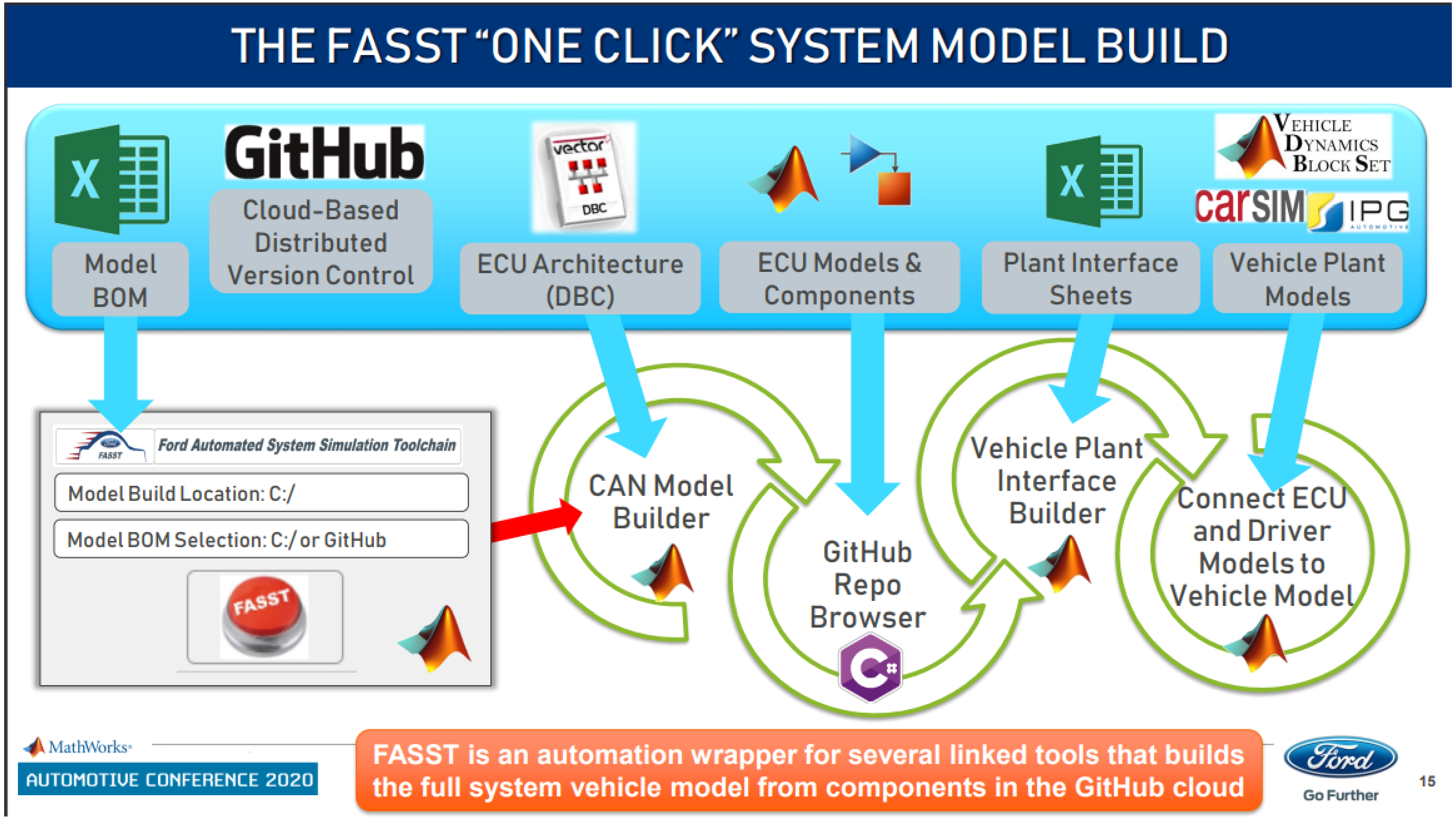


Ford: Model-Based Agility with FASST



[Link to article]

Ford: Model-Based Agility with FASST



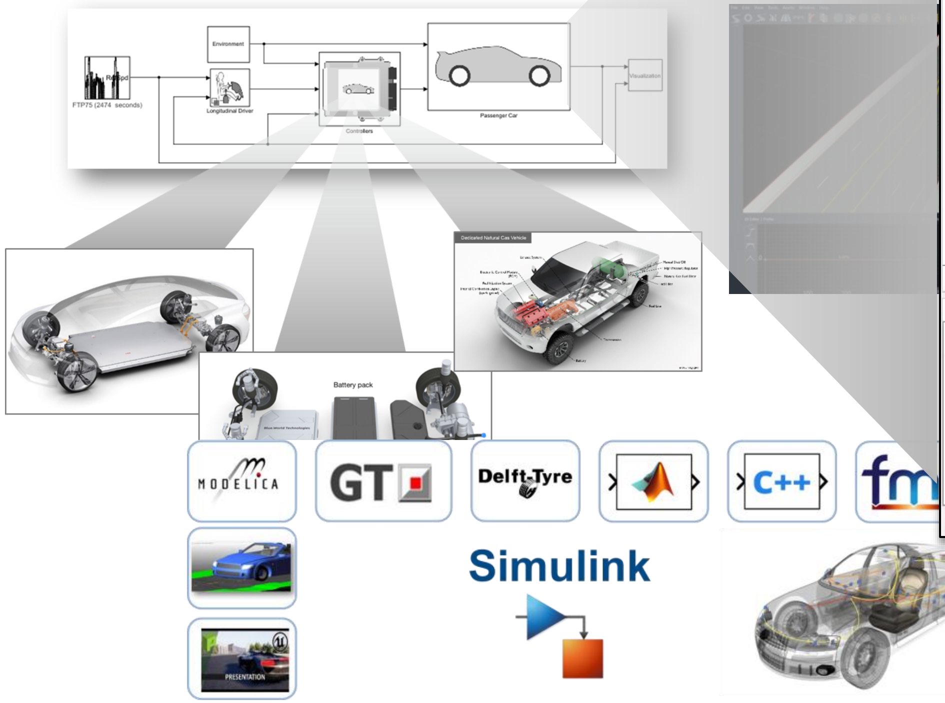
[Link to article]

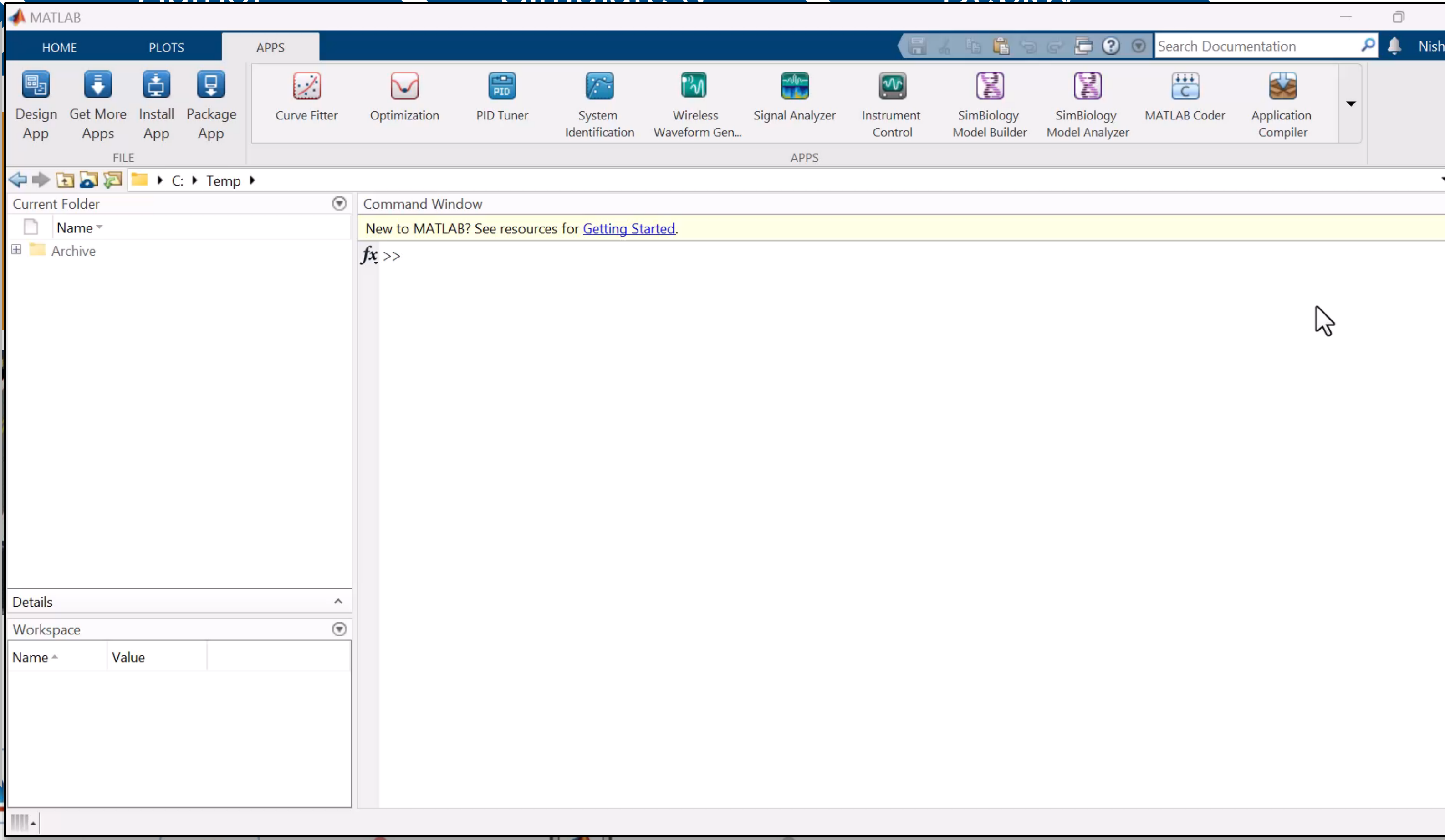
Process to build Virtual Vehicle

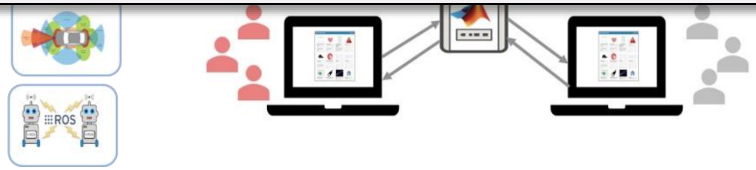
Create Vehicle | Integrate Software | Author | Simulate & | Deploy

Vehicle Templates
Subsystem Libraries
Modeling Guidelines

C/C++ Interface
Reduced Order Models
FMU Integration







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Motivation and Methodology

Maintain accessibility for future use by the team members

Maximize performance

- Redesign motor controller
- Achieve desired performance at 100 km/h
- Target 20 Nm torque on the front axis and 40 Nm on the rear wheels.

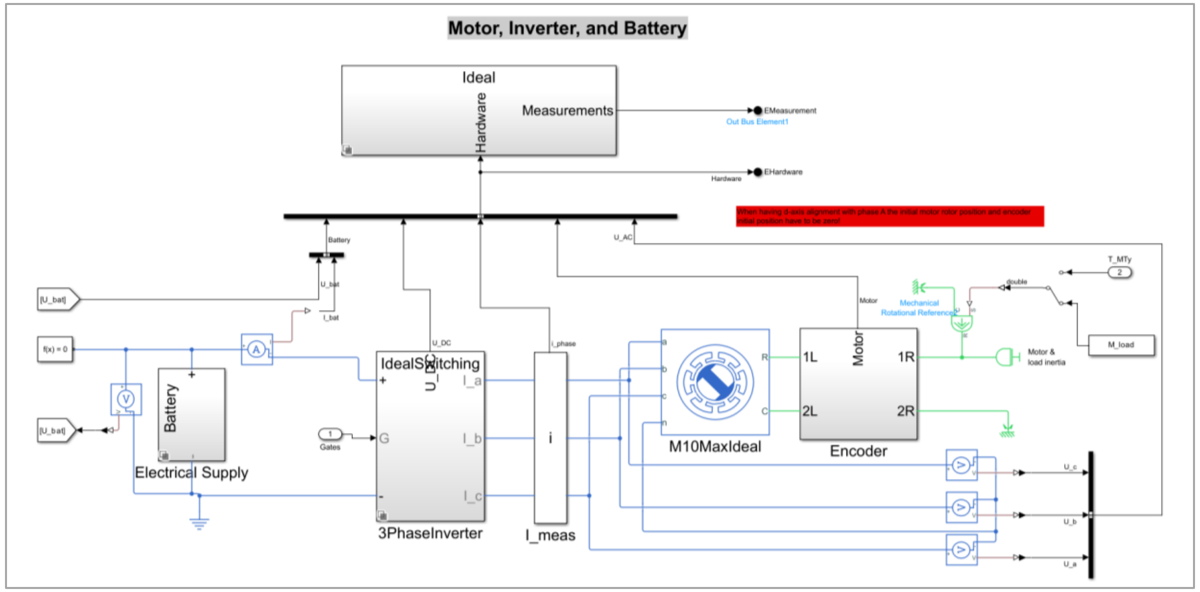
Identify errors and safeguard the hardware

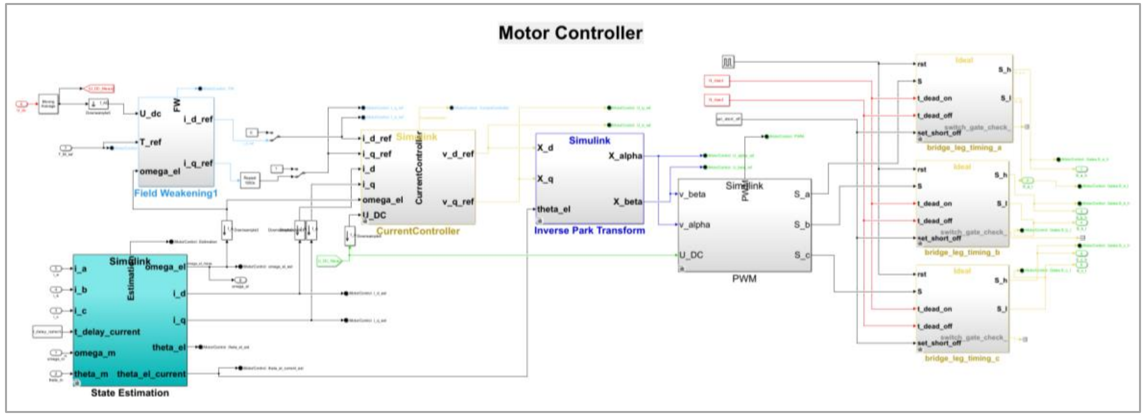
Goal → Requirements Powertrain → System Modelling of Powertrain → Controller Implementation → Controller Verification in Simulation

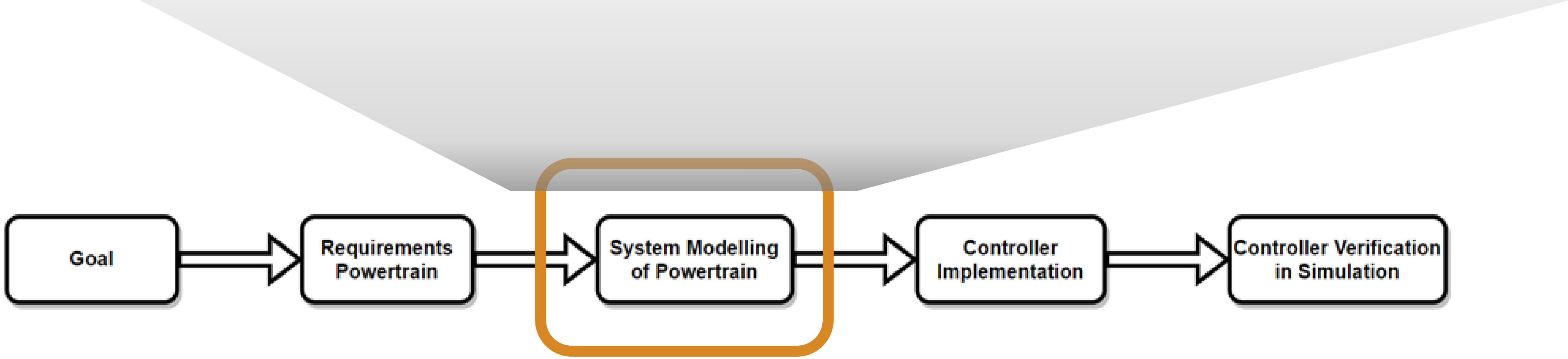
[How AMZ Racing Designed the Motor Controller to Achieve 0 to 100 km/h in 0.956 Seconds]

System Modeling of Powertrain

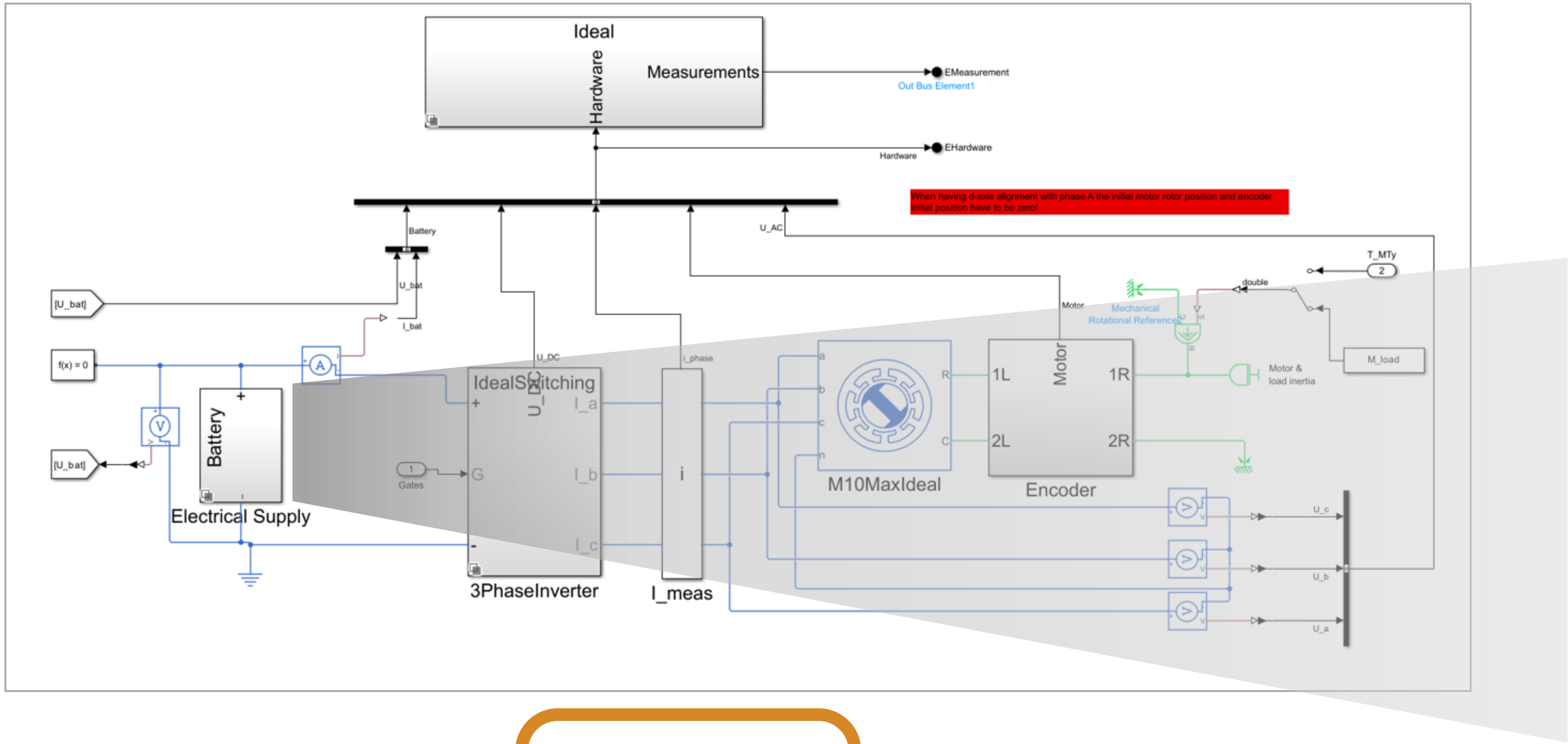
Inverter, Battery, Motor, Motor Controller



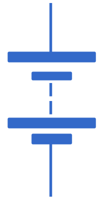




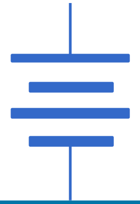
System Modeling of Powertrain
Battery, Motor, Inverter



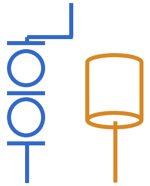
Different Model Fidelities



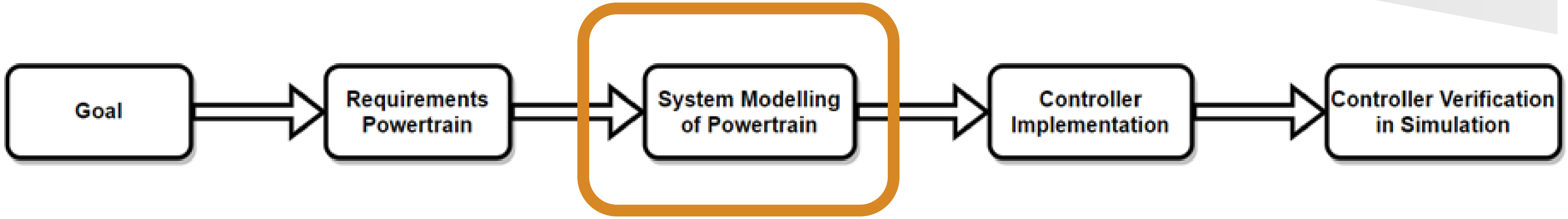
Battery (Table-Based)



Battery (Equivalent Circuit)



Battery (Single Particle)



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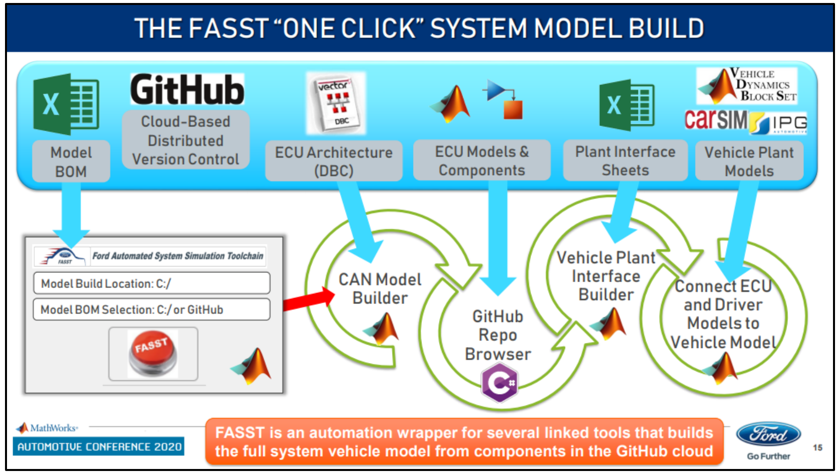
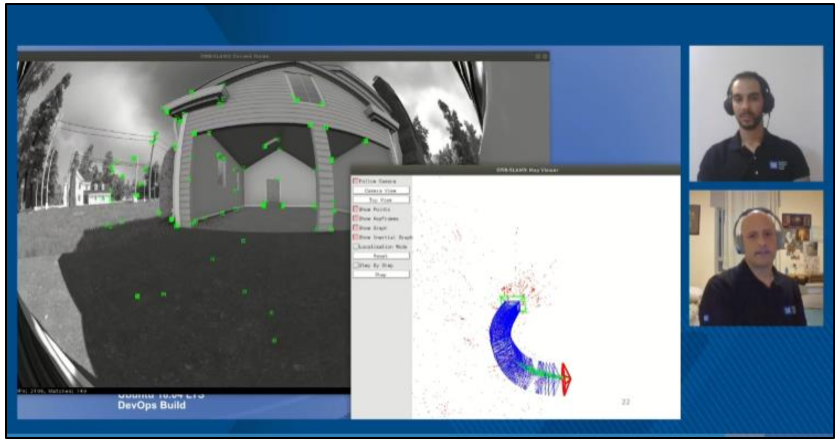
How Are Companies Building Virtual Vehicles with MathWorks?

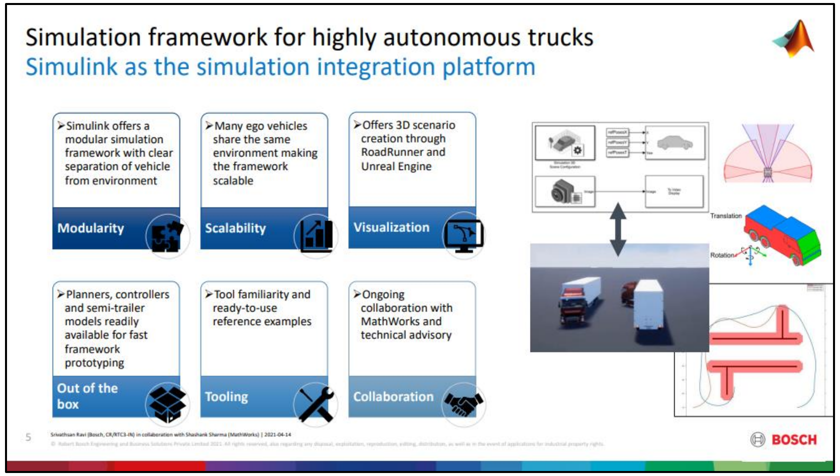
- Different virtual vehicles are built for different use cases
- Common themes are the automation of model creation, simulation and analysis



[Ford: Build Virtual Vehicle in minutes]



[GM: Autonomous parking development]



[Bosch: Autonomous truck development]

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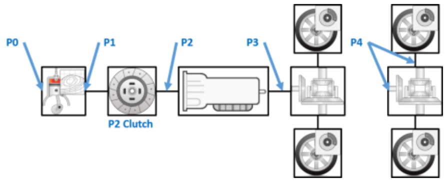
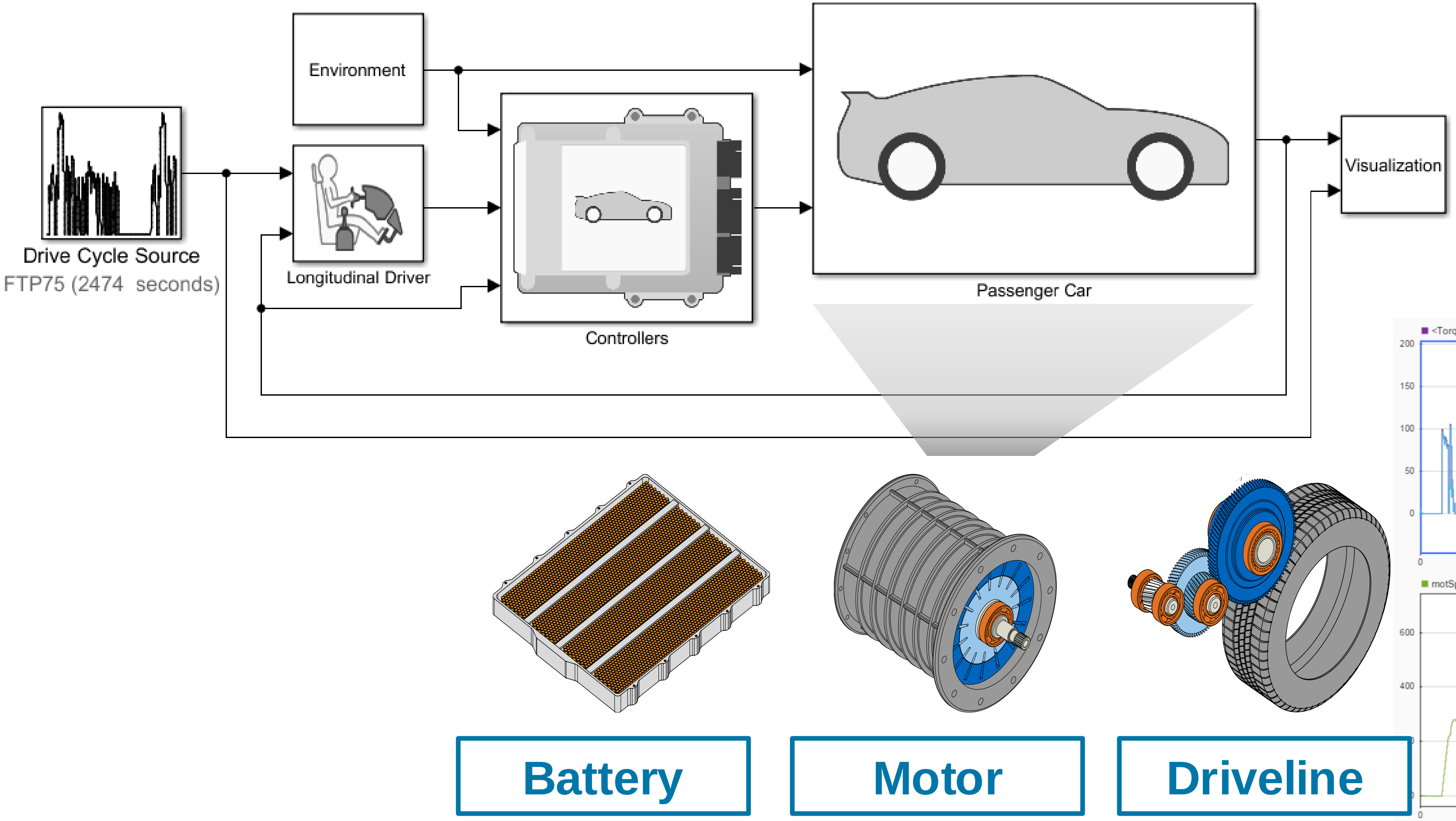
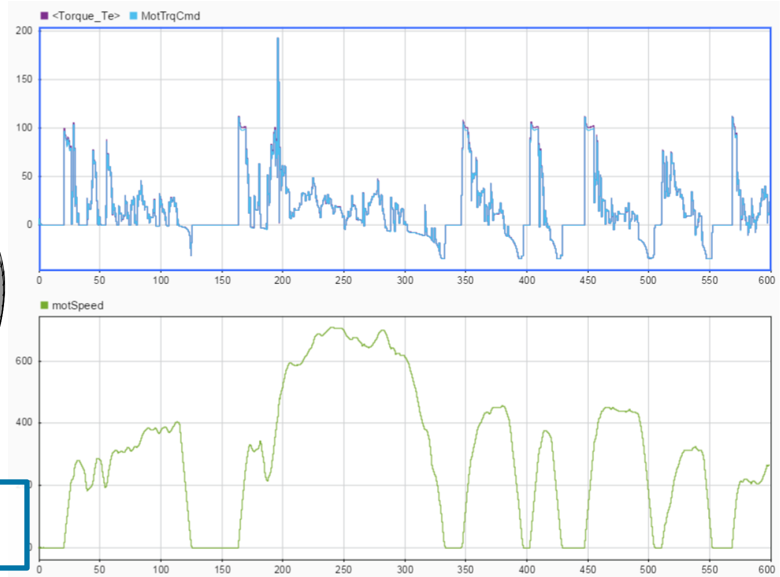
System Level Model of the Vehicle



- Component Selection?
- Component Sizing?
- Trade-off Studies?

- Detailed Component Modeling and Control Design?



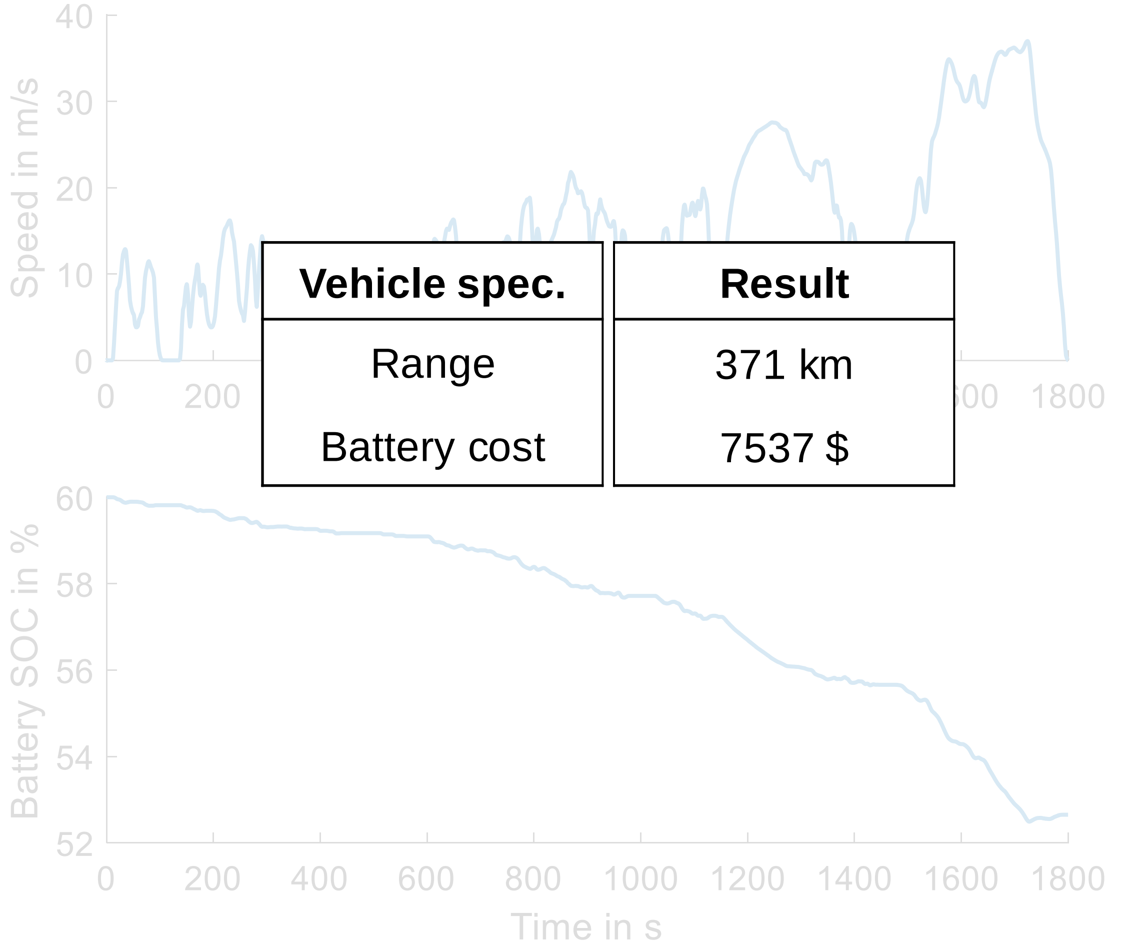


EV Reference Application

Overview vehicle model

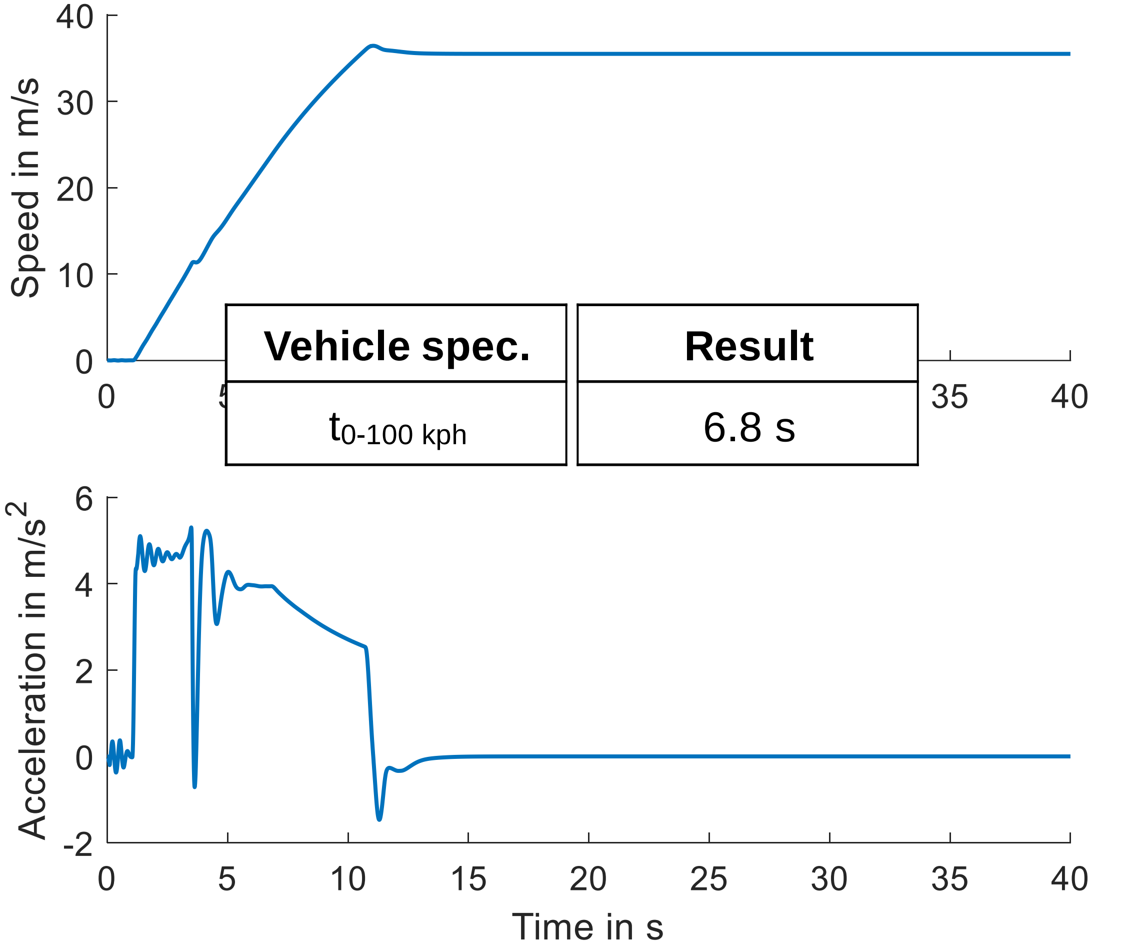
Initial assessment, mid-size electric passenger car

Drive cycle simulation (WLTP)



Vehicle spec.	Result
Range	371 km
Battery cost	7537 $

Acceleration simulation (WOT)



Vehicle spec.	Result
$t_{0\text{-}100\ kph}$	6.8 s

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Optimize Vehicle Performance

Given the vehicle model, define the optimization problem:

- Objective:

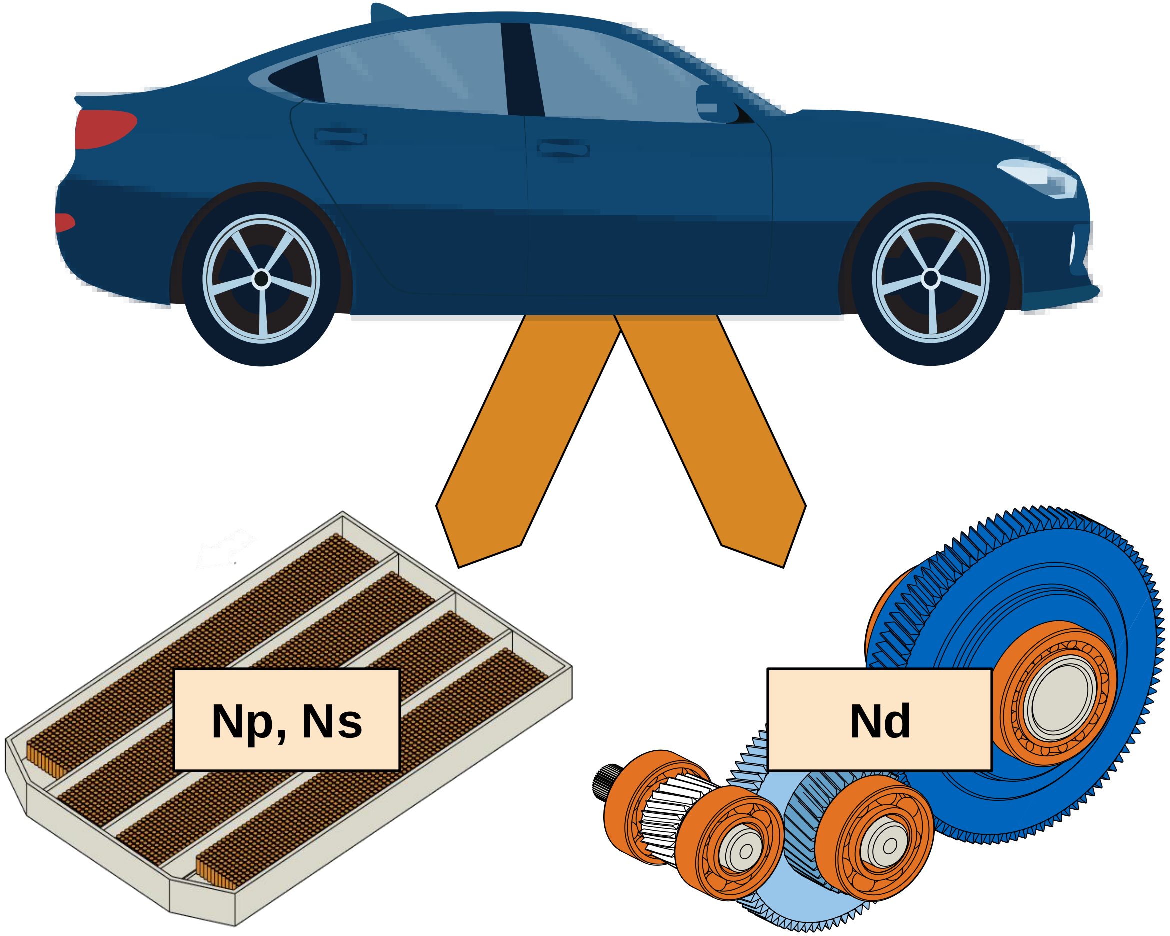
  minimize $f(x) = w_1 * Cost - w_2 * Range$

- Constraints:

  g_1: DriveCycleFault ≤ 0
  g_2: Range $\geq$ 400 km
  g_3: $t_{0\text{-}100\ kph} \leq 7$ s

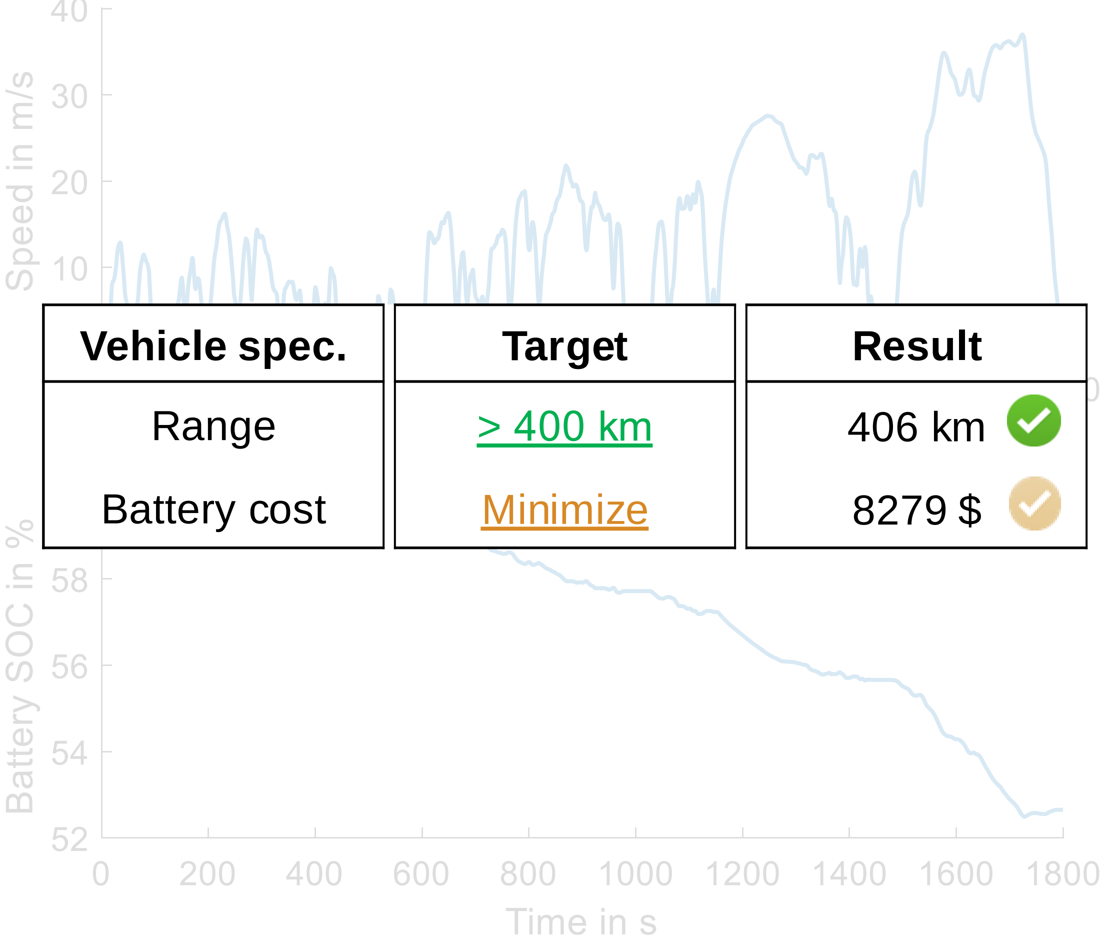
- Design variables

  x_1: $10 \leq Np \leq 50$ (Integer)
  x_2: $80 \leq Ns \leq 140$ (Integer)
  x_3: $7 \leq Nd \leq 10$ (Continuous)



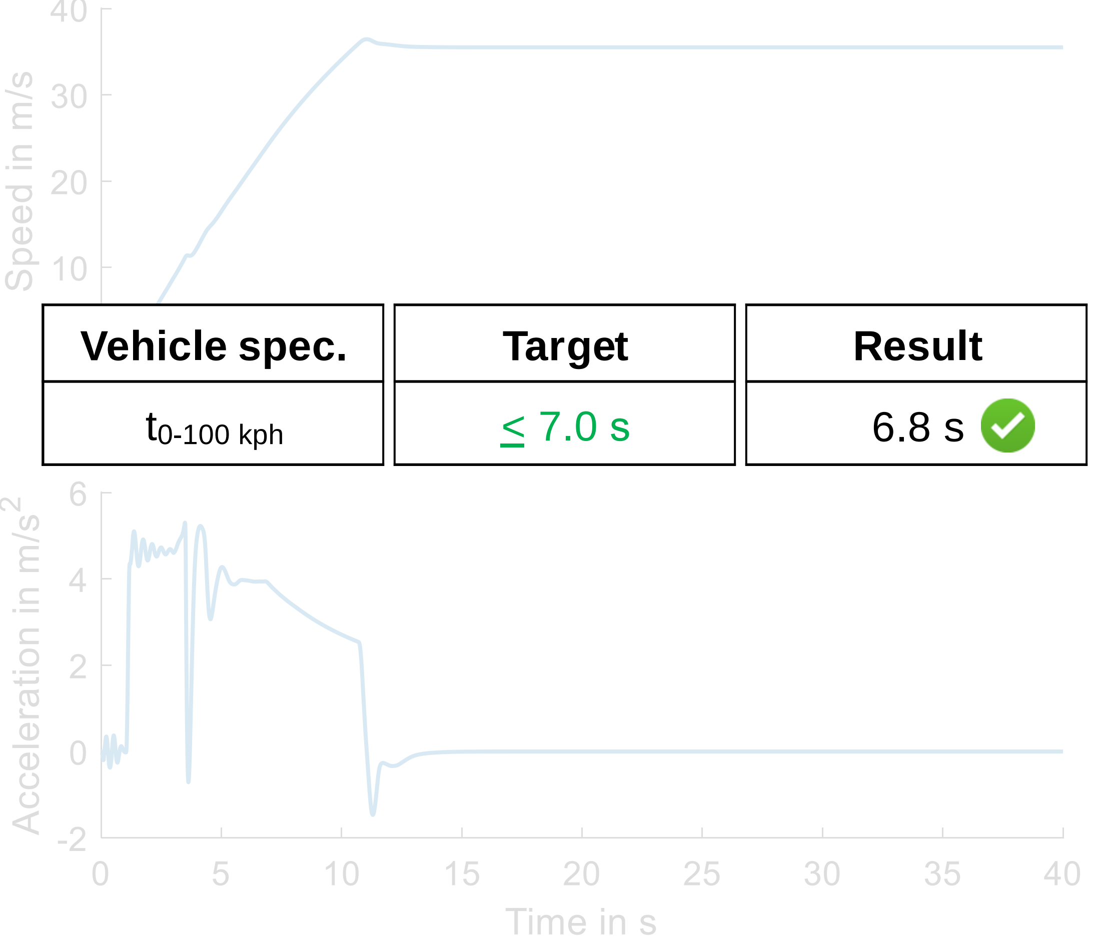
Optimization Results

Drive cycle simulation (WLTP)



Vehicle spec.	Target	Result
Range	≥ 400 km	406 km ✔
Battery cost	Minimize	8279 $ ✔

Acceleration simulation (WOT)



Vehicle spec.	Target	Result
$t_{0\text{-}100\ kph}$	≤ 7.0 s	6.8 s ✔

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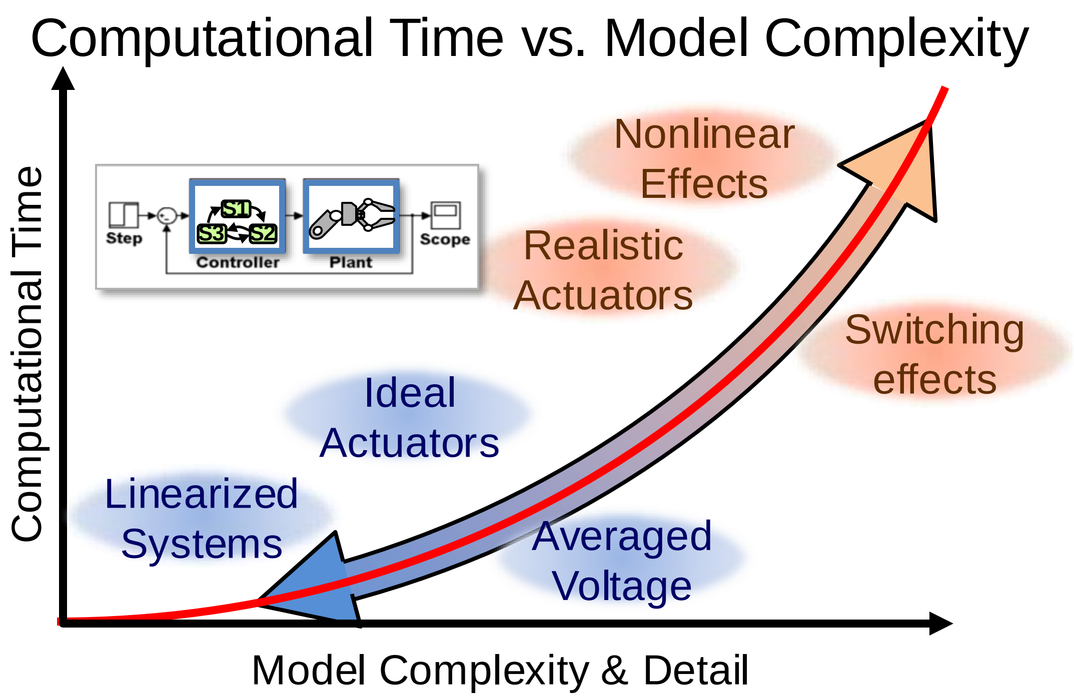
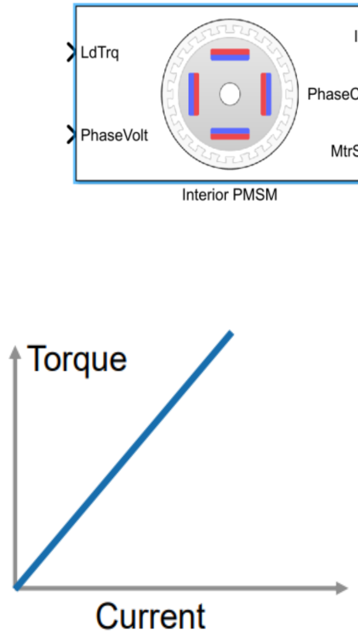
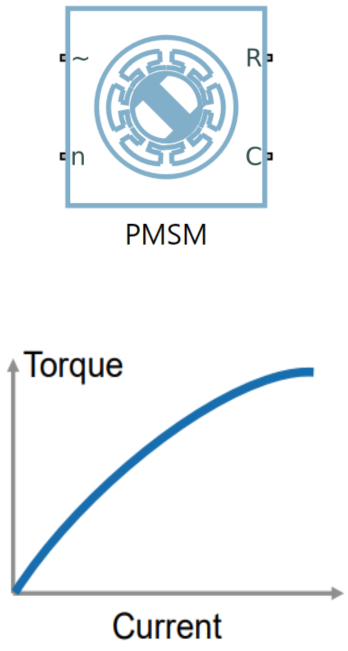
Selecting Model Fidelity



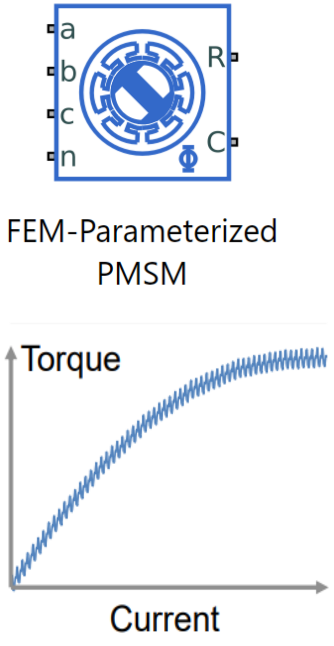
Configure your model to balance simulation speed and model fidelity.



Lumped Parameter



Saturation



Saturation + Spatial Harmonics

Selecting Model Fidelity

System-Level Behavior	Component Validation	Component Design

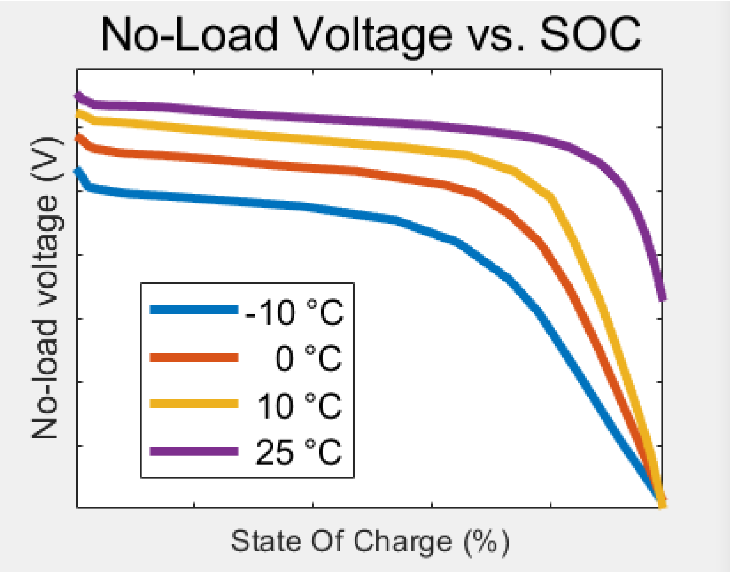
Low Fidelity **Charge/Discharge Characteristic** High Fidelity

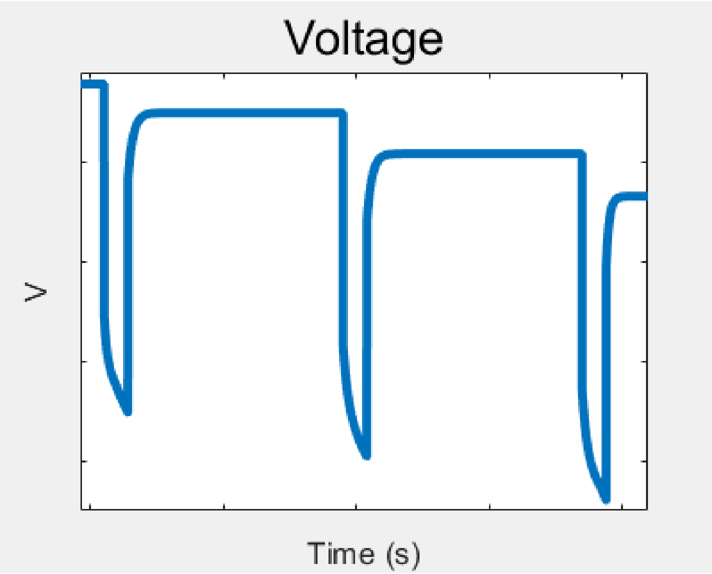
Infinite Charge

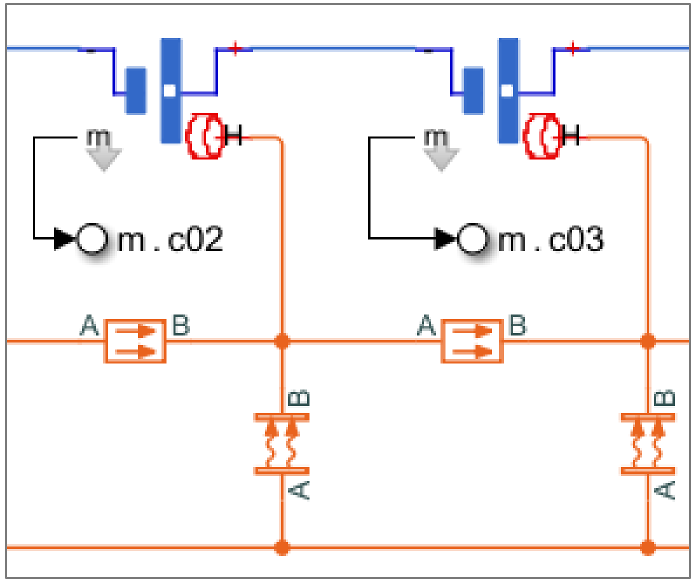
Finite Charge, Fade, Temperature Dependent

Charge Dynamics

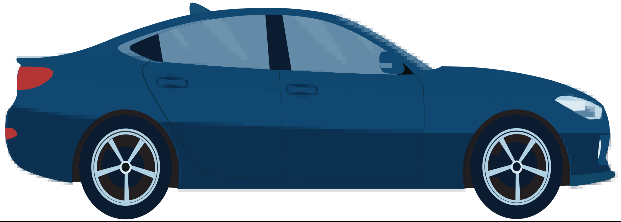
Cell Behavior

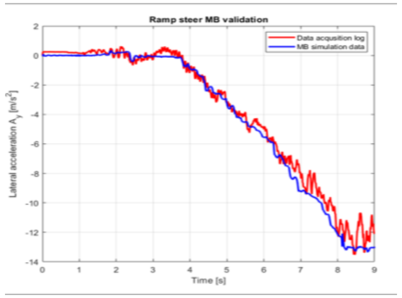






Key takeaways





System Level Modelling → Validation & Testing → Large-Scale Studies

Virtual Vehicle
Virtualization and Virtual Vehicles System-level models Powertrain Systems-Optimization

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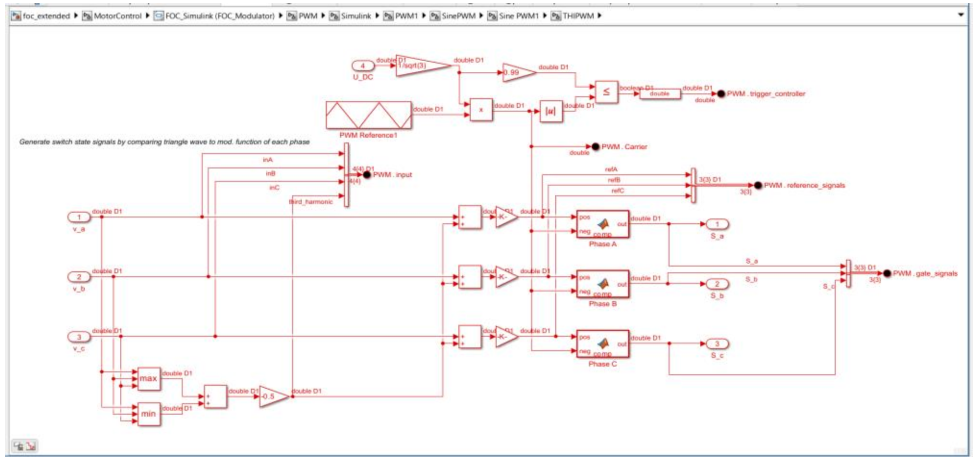
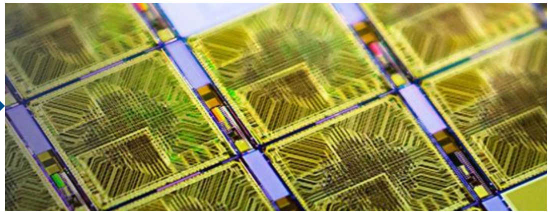
AMZ Racing Motor Control Deployment and Testing

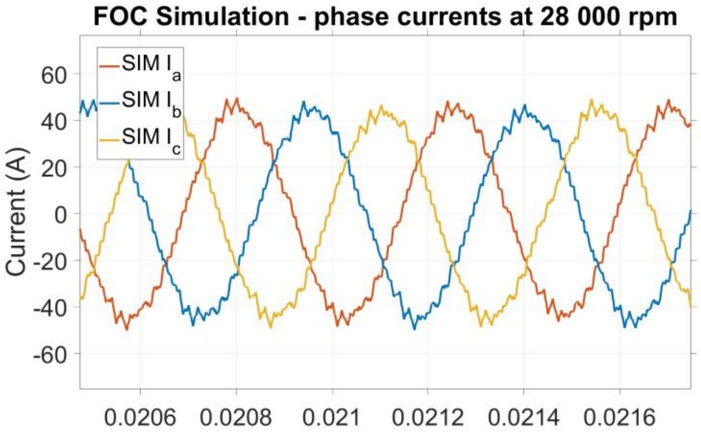


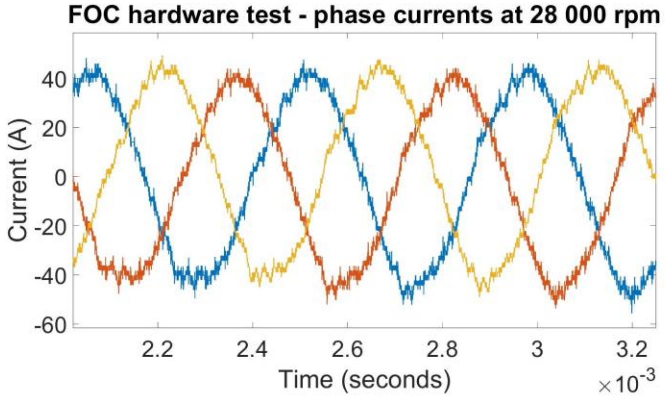
Simulink FOC Motor Controller Model

HDL Code



AMD FPGA

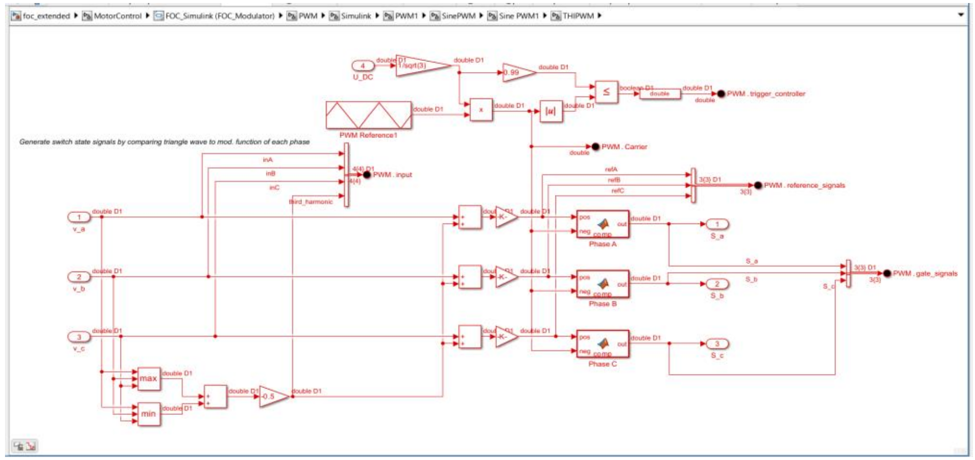




Comparison of FOC simulation and hardware test

- Accuracy of the simulation model
- Realistic representation of the hardware
  - Controller gains

AMZ Racing Motor Control Deployment and Testing



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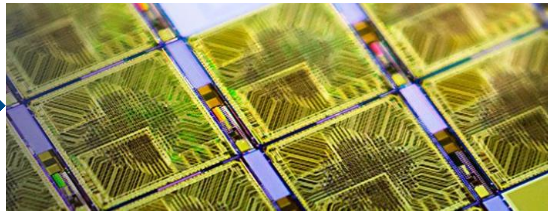
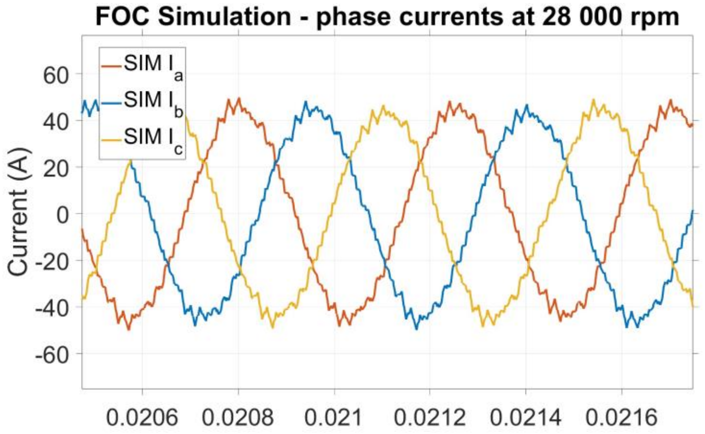
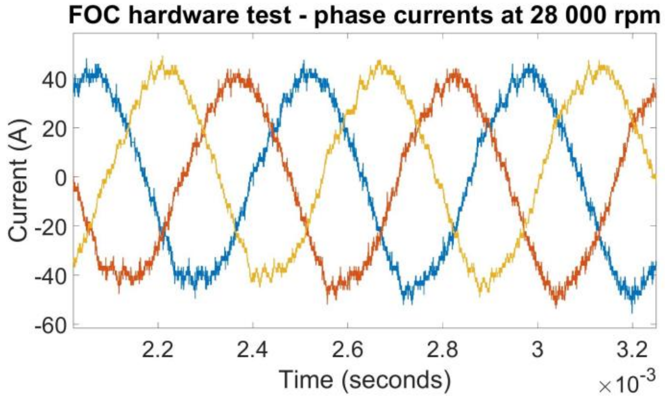
HDL Code

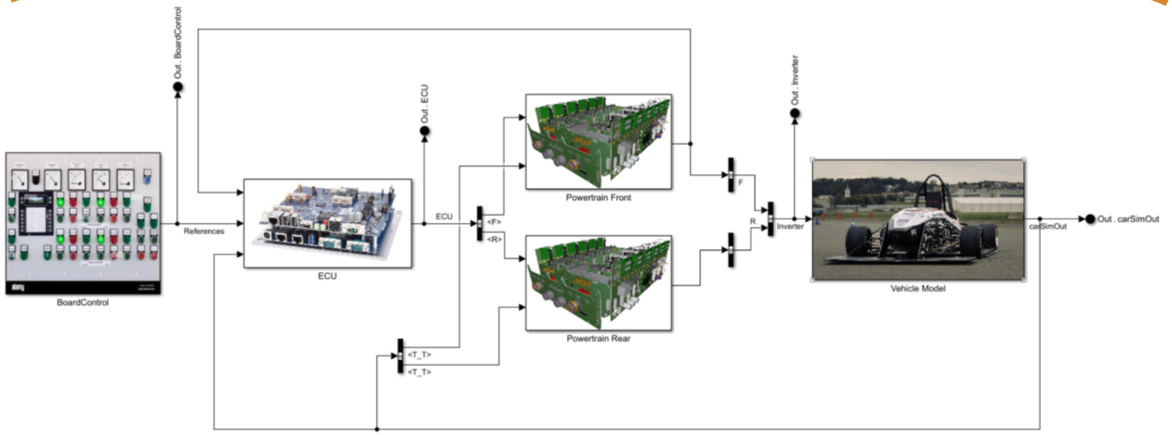


AMD FPGA





Comparison of FOC simulation and hardware test



Implementation of the HIL simulation running on the Speedgoat machine

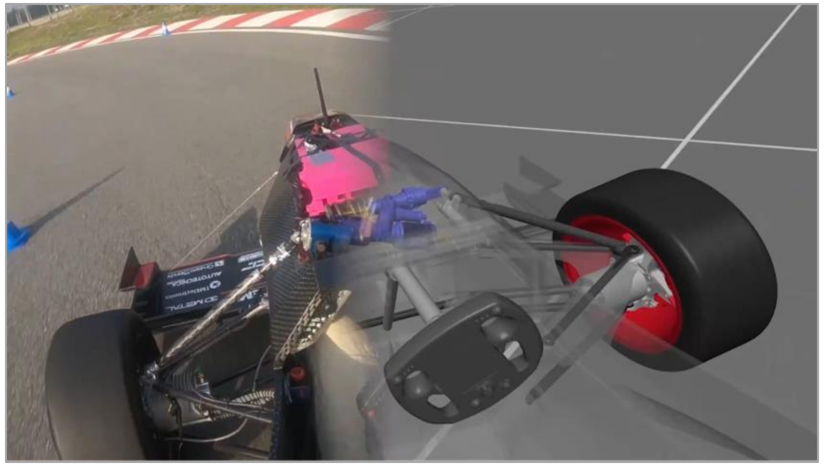
Validation and Testing

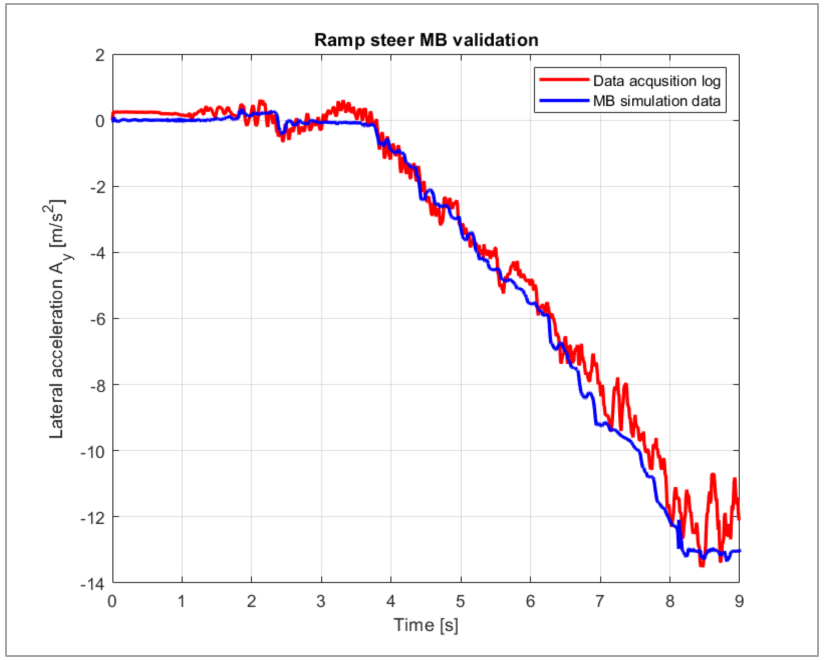
Vehicle Dynamics

Simulation

Driver-in-the-Loop

Track Test





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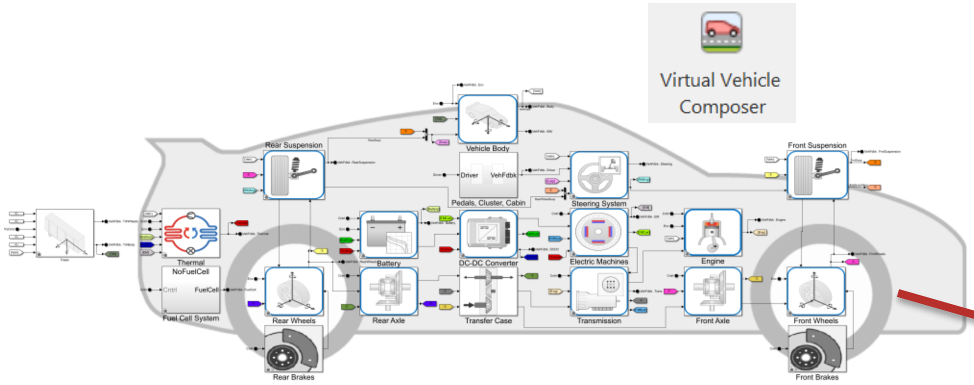
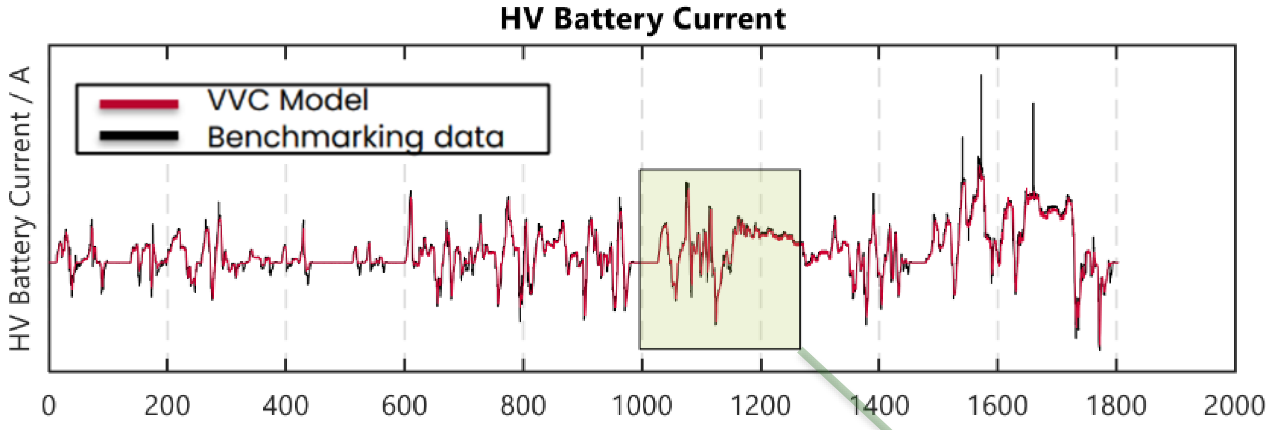
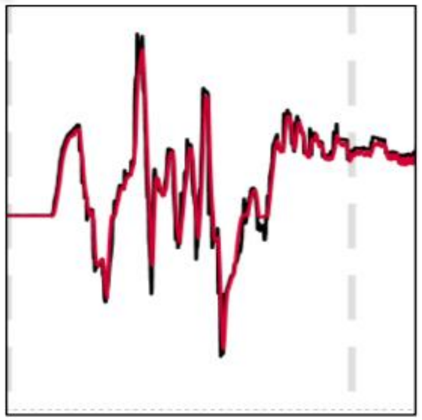
FEV parameterizes and benchmarks VVC generated vehicle models



Powertrain Blockset model built using Virtual Vehicle Composer (VVC) app





Benchmarking data

FEV

"As a new user of Virtual Vehicle Composer and Powertrain Blockset, we were able to quickly configure, parameterize & generate a model that matched our real-world vehicle test data within a few percent RMSE"

– *Ahmed Uddin*, *FEV Engineering Manager*

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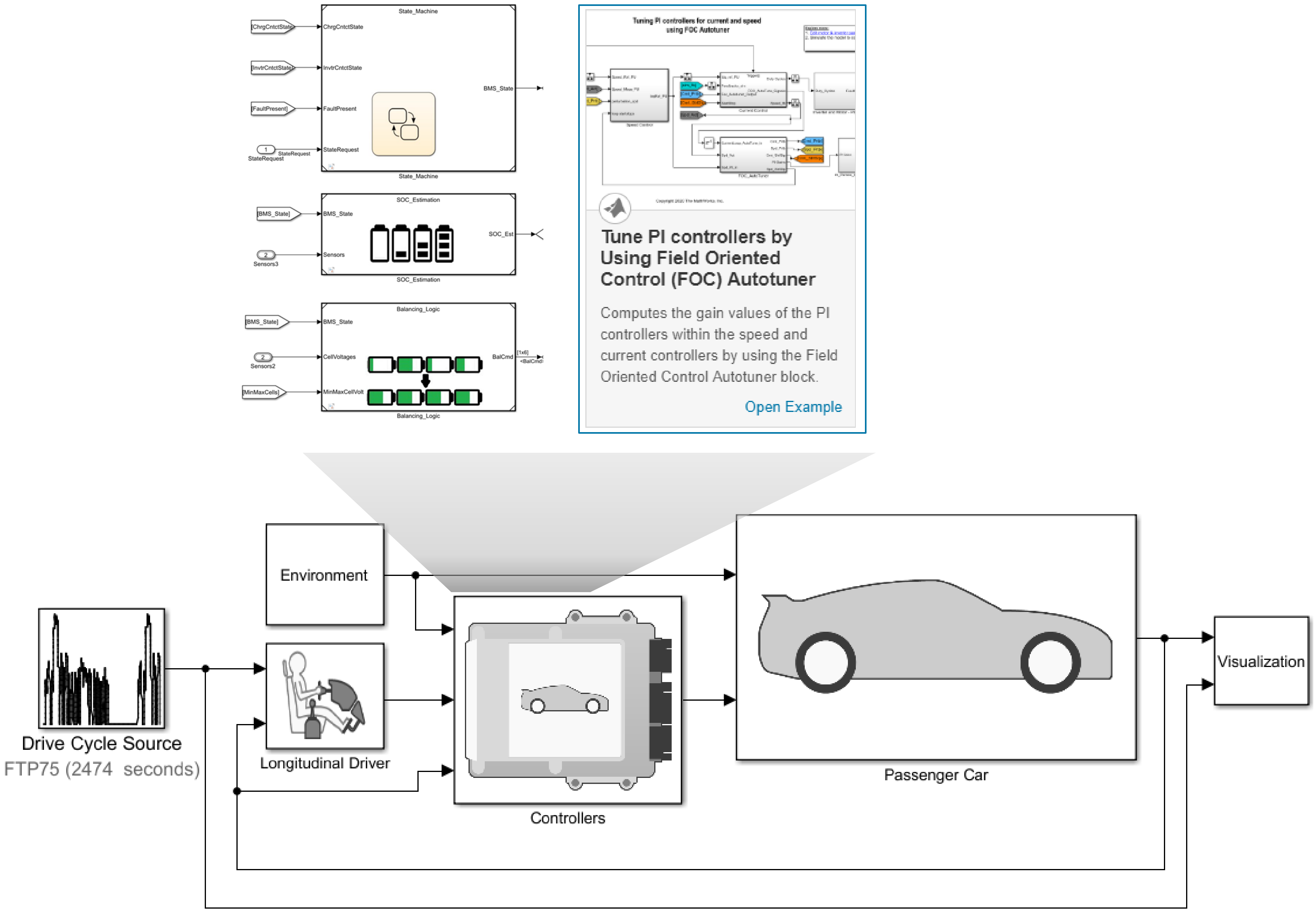
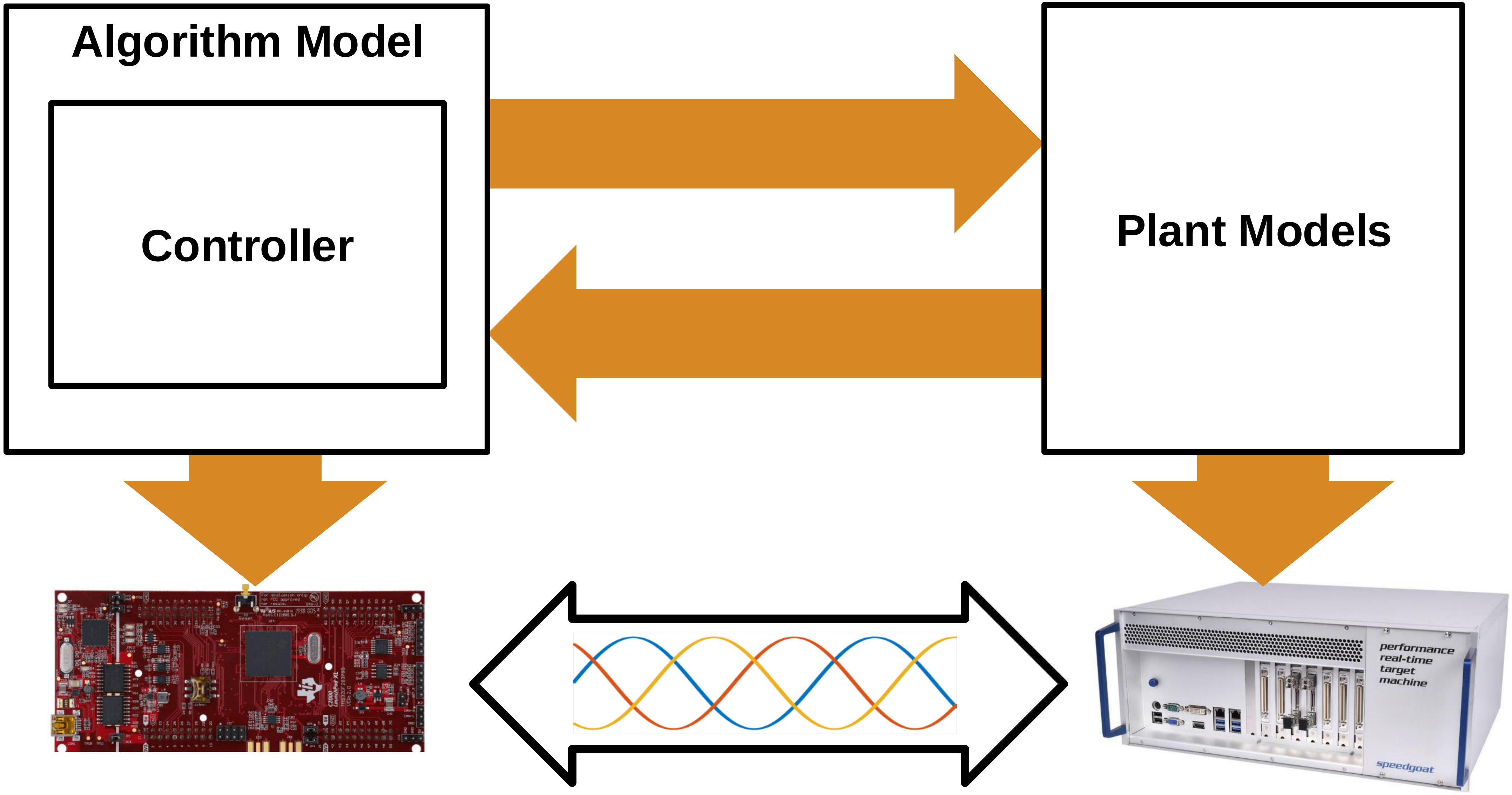
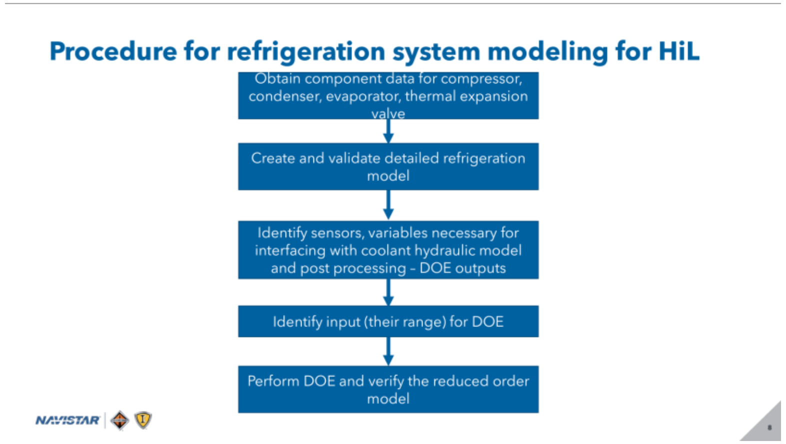
Validation Workflow



Hardware-in-the-Loop Validation

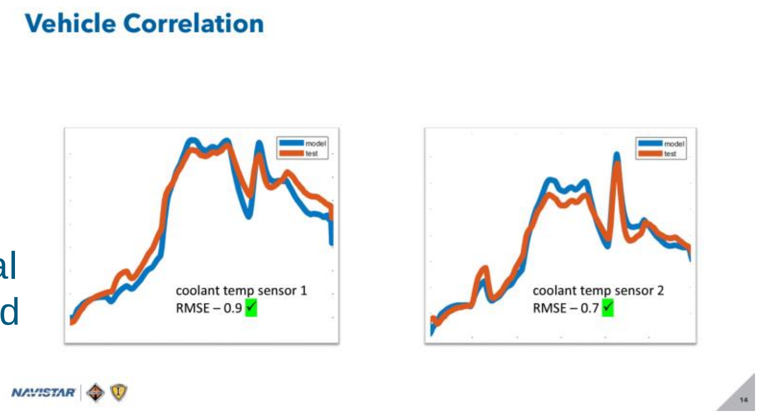


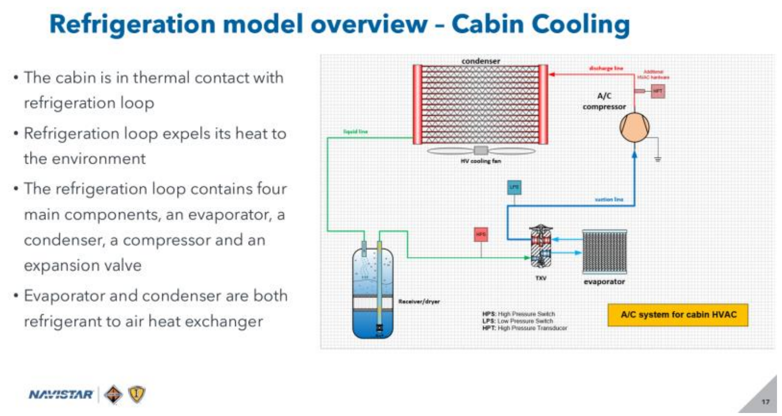
Navistar uses a data-driven approach to perform HIL simulations of the thermal management system for electric trucks



Generate data-driven Model of the chiller system

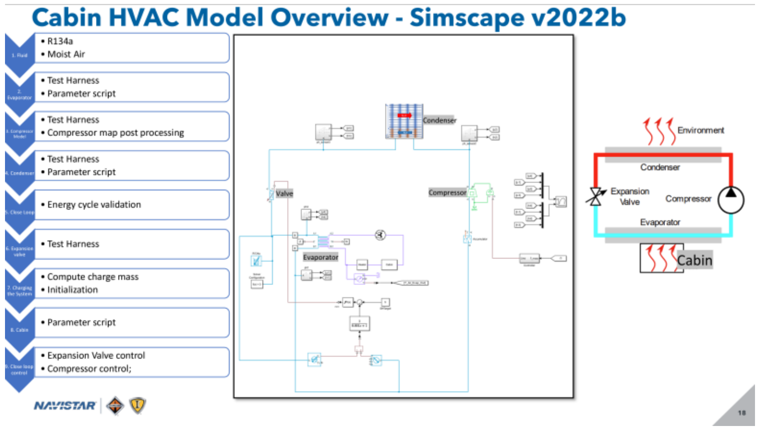
Simscape based thermal System model correlated well with the vehicle





Workflow extended to The refrigeration system in cabin cooling

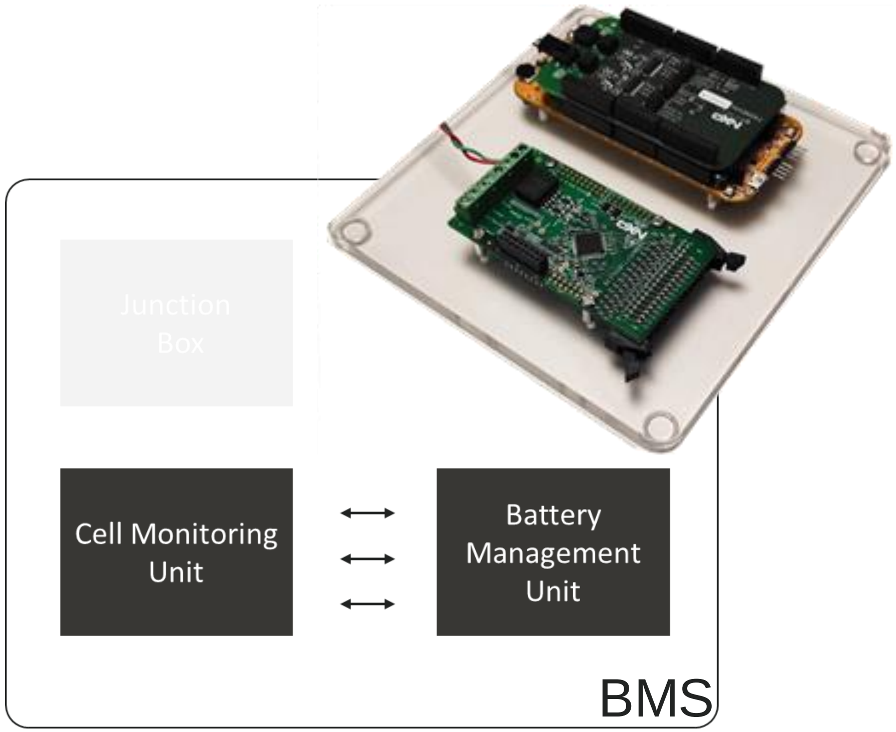
Building real-time model of cabin cooling system in Simscape Fluids



Link to Article

HIL Testing of BMS hardware

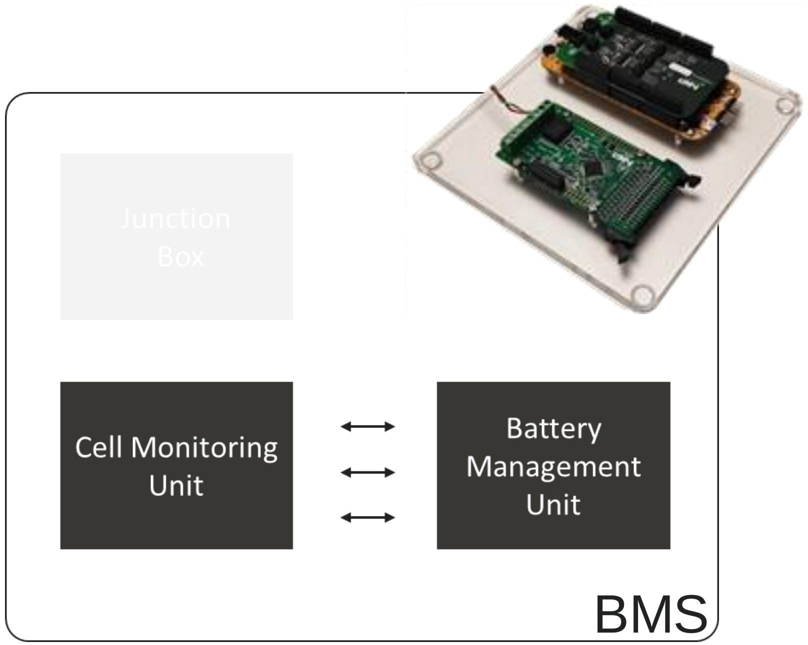
BMS HIL System



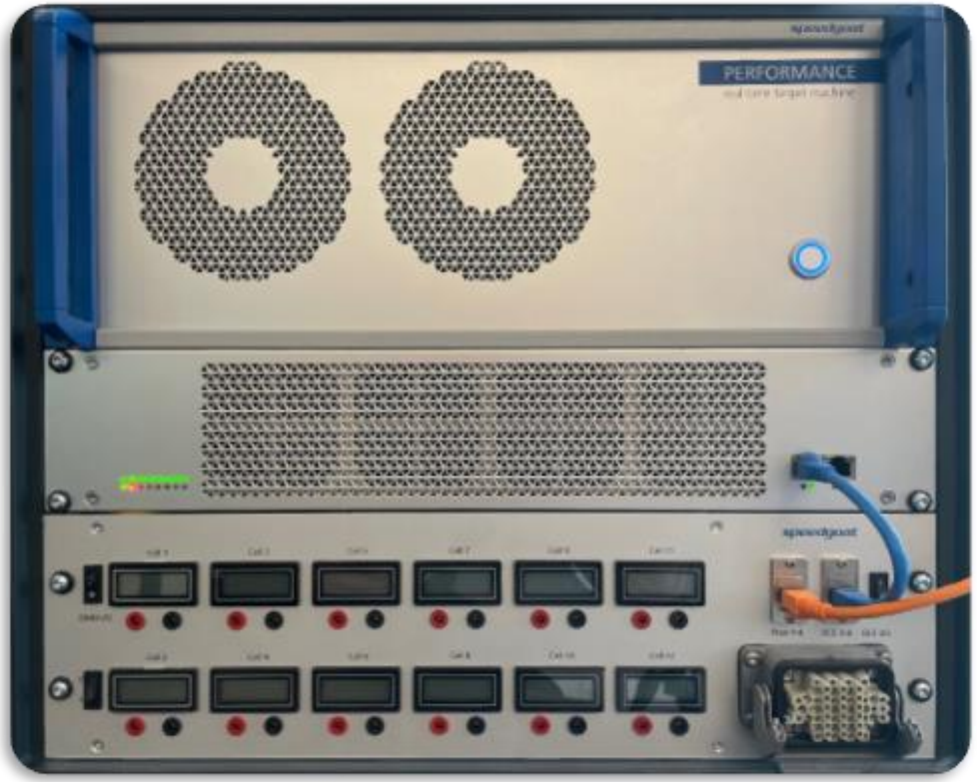
BMS HIL System

HIL Simulator

Performance real-time target machine



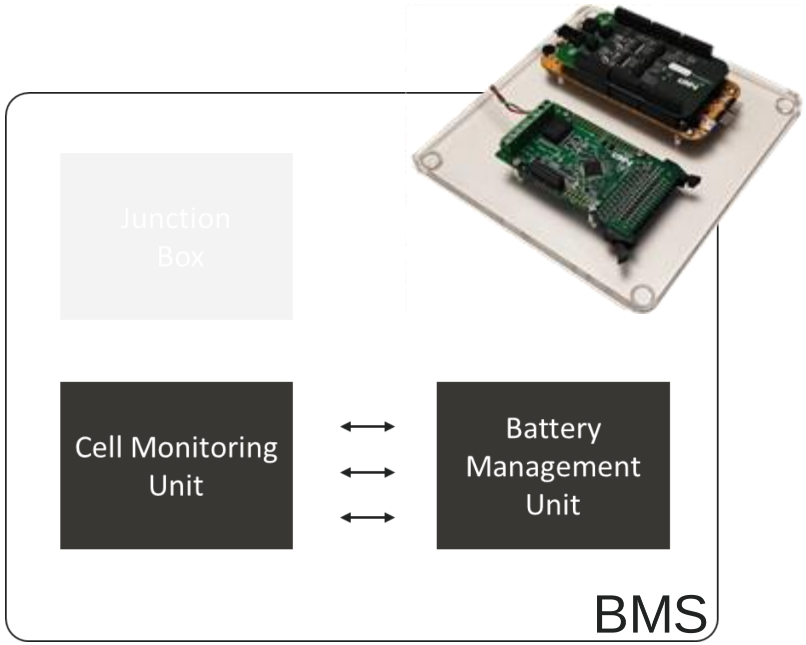
BMS HIL System



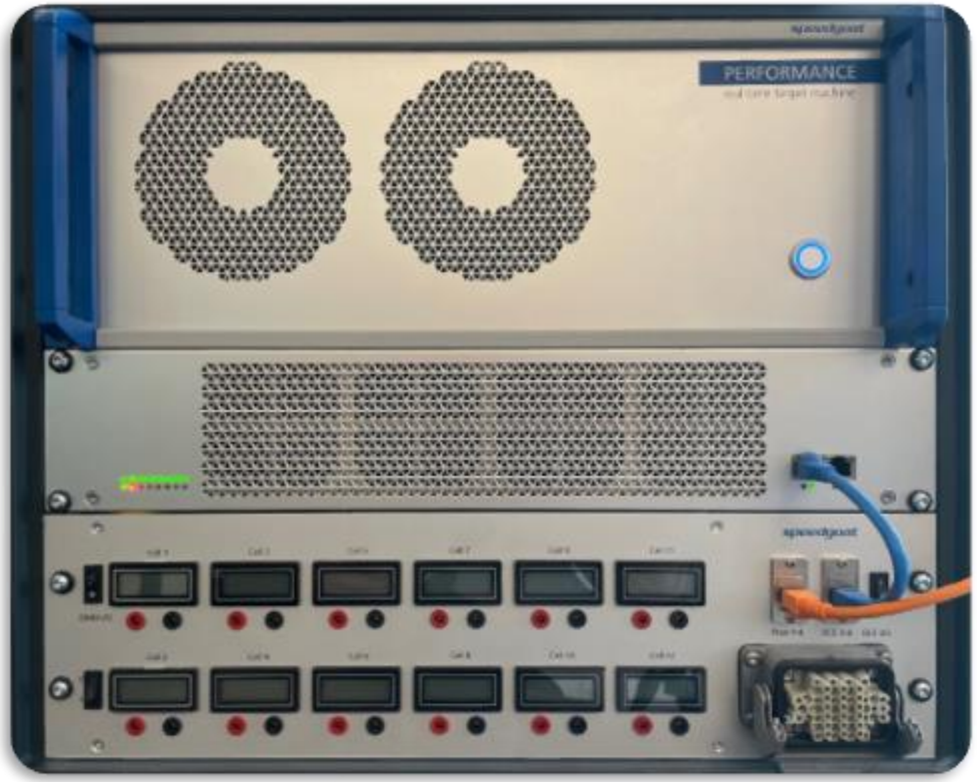
HIL Simulator

Performance real-time target machine

Cell Emulation
Battery Cell Emulator



BMS HIL System



HIL Simulator

Performance real-time target machine

Cell Emulation
Battery Cell Emulator

Measurement and Controller Interface

Junction Box

Cell Monitoring Unit

Battery Management Unit

BMS

Cell voltages

Battery pack current Battery pack voltage Cell temperatures

Success Story: Leclanché

Next Generation Li-Ion Battery Packs for Autonomous Vehicles

Challenge

- Unable to test and verify new BMS algorithms in realistic operating conditions before connecting to actual battery packs.
- Late bug discovery and no preliminary testing can damage batteries
- Poor development tool compatibility leading to manual testing

Solution

- Use Simulink and Speedgoat products for HIL testing of BMS
- Test platform with fault insertion, CAN communication, and Speedgoat battery cell emulators
- Use Simulink Test to thoroughly validate BMS and battery state estimation algorithms (SoC, SoH, etc.)

Results

- Reduced testing time with automated testing by 50%
- Increased test coverage for safety features by 40%
- Faster development with early bug detection

Leclanché
Energy Storage Solutions

"Speedgoat together with MathWorks products offer a very efficient workflow to design, test and validate algorithms for Battery Management Systems"

- Marc Lucea, Senior Application SW Engineer

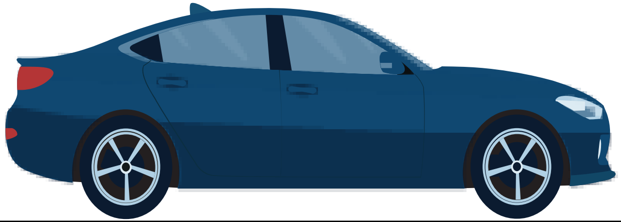
Unified Platform for Control Design & Testing

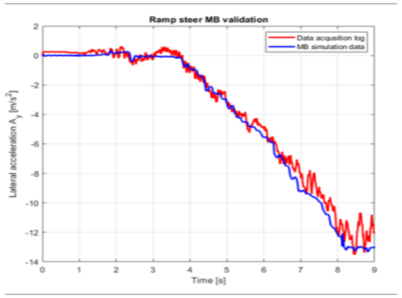
Power Electronics

Power Systems

Power Management

Key takeaways





System Level Modelling → **Validation & Testing** → **Large-Scale Studies**

Virtual Vehicle
Virtualization and Virtual Vehicles System-level models Powertrain Systems-Optimization

Model accurate System
Correlation with real world behavior ROM workflows

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India

November 19th , Pune

Tech Talk: Virtual Vehicle: Transforming Vehicle Engineering Through Simulation

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Transitioning from Desktop to Cloud

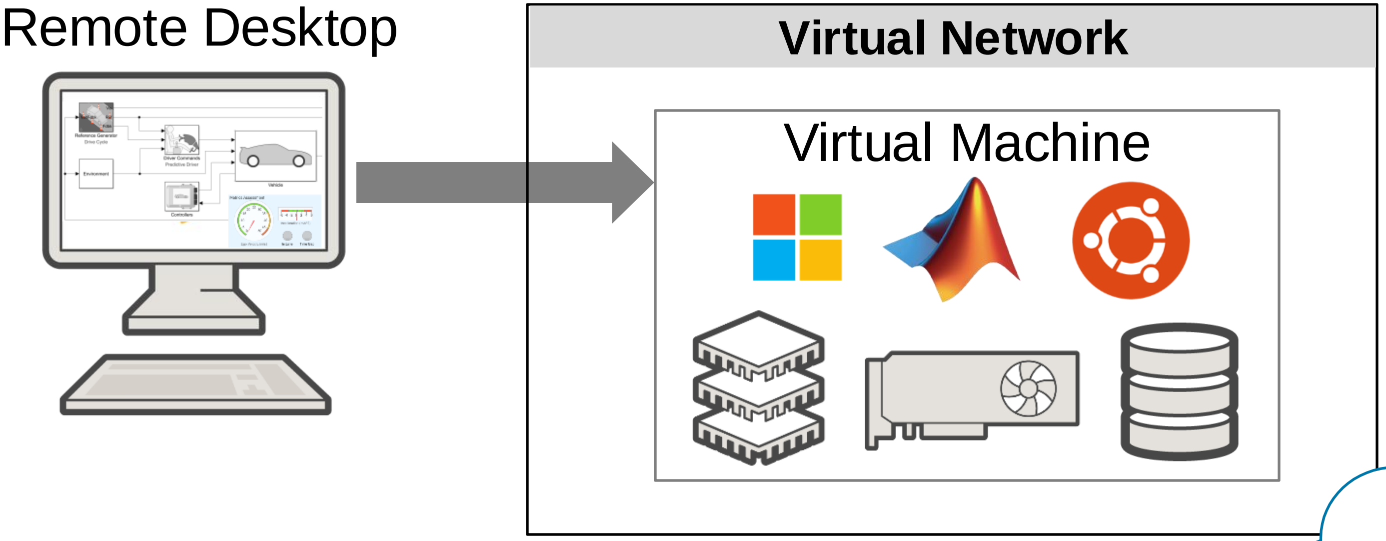
- Why would you want to use the cloud?
  - Offload computational load from your working machine
  - Scale up computing power (RAM, GPU, multi-core CPU, etc.)
  - On-demand access (“elastic computing”)
  - Proximity to cloud-based data repository
- It’s easy to port your code from desktop to cloud-based workflows
  - No need to rewrite your algorithm
  - Supports both Windows and Linux

Learn more:

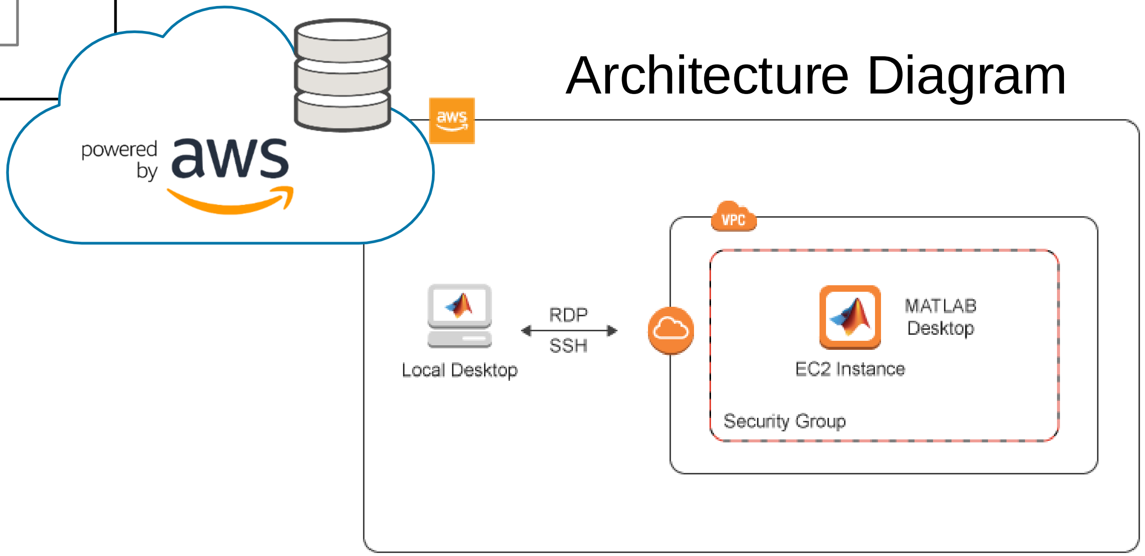
[Parallel Computing Toolbox](#)

[MATLAB Parallel Server](#)

Leveraging a Prebuilt Cloud Configuration via Reference Architecture



- MathWorks provides Reference Architectures for specific OS and software stacks on Virtual Machines (VM) in the cloud



- Select VM with desired hardware setup, then apply Reference Architecture

Learn more:

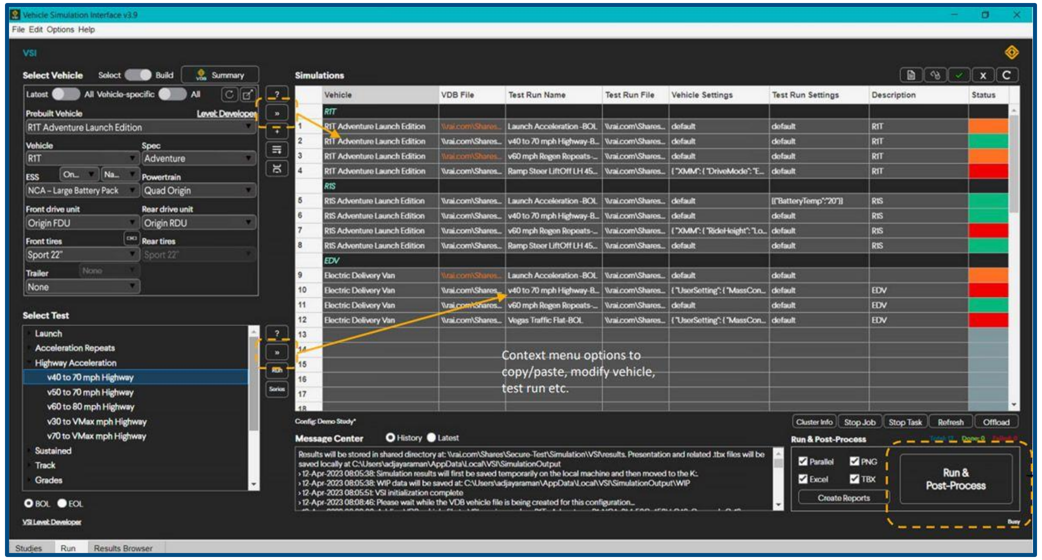
MATLAB on Amazon Web Services (AWS)

Rivian Scales Full-Vehicle Simulations with MATLAB and MATLAB Parallel Server

Rivian develops a scalable and easy-to-use platform to configure, run, and postprocess large numbers of full-vehicle simulations.

Key Outcomes/Results

- Reduced redundancy, increased reuse, and improved throughput for simulations using MATLAB and Simulink
- VSI platform built with App Designer eliminated bottlenecks caused by multiple simulation requests
- Democratized access to simulations for engineering teams across the company

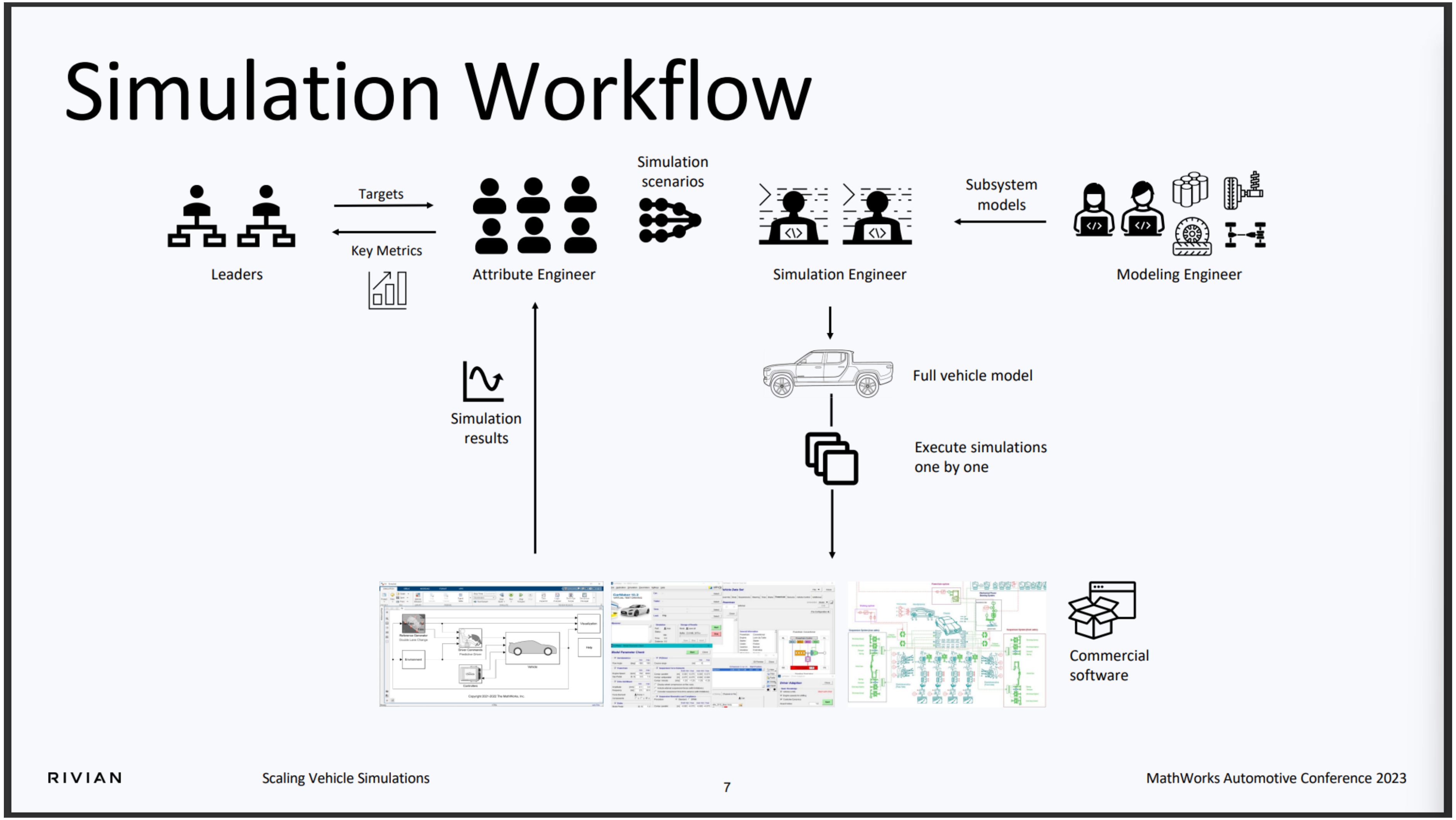


The VSI user interface.

Designing and building the Rivian Vehicle Simulation Interface platform with MATLAB and Simulink enabled us to achieve our key objectives. We created a single platform for engineers and nonengineers alike to run full-vehicle simulations, postprocess results, and create reports.

[Link to article](#)

Rivian Scales Full-Vehicle Simulations with MATLAB and MATLAB Parallel Server



[Link to article]

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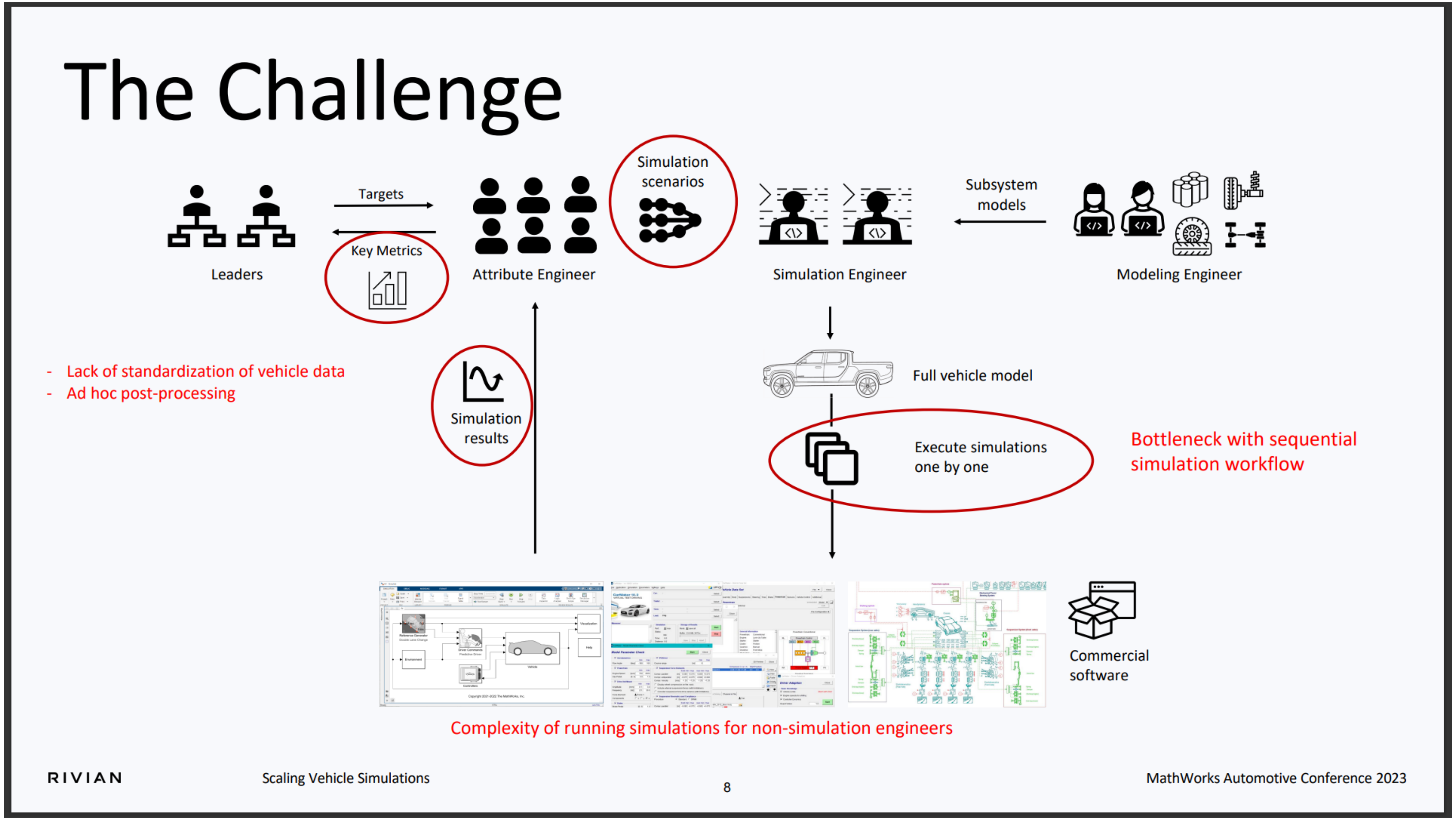

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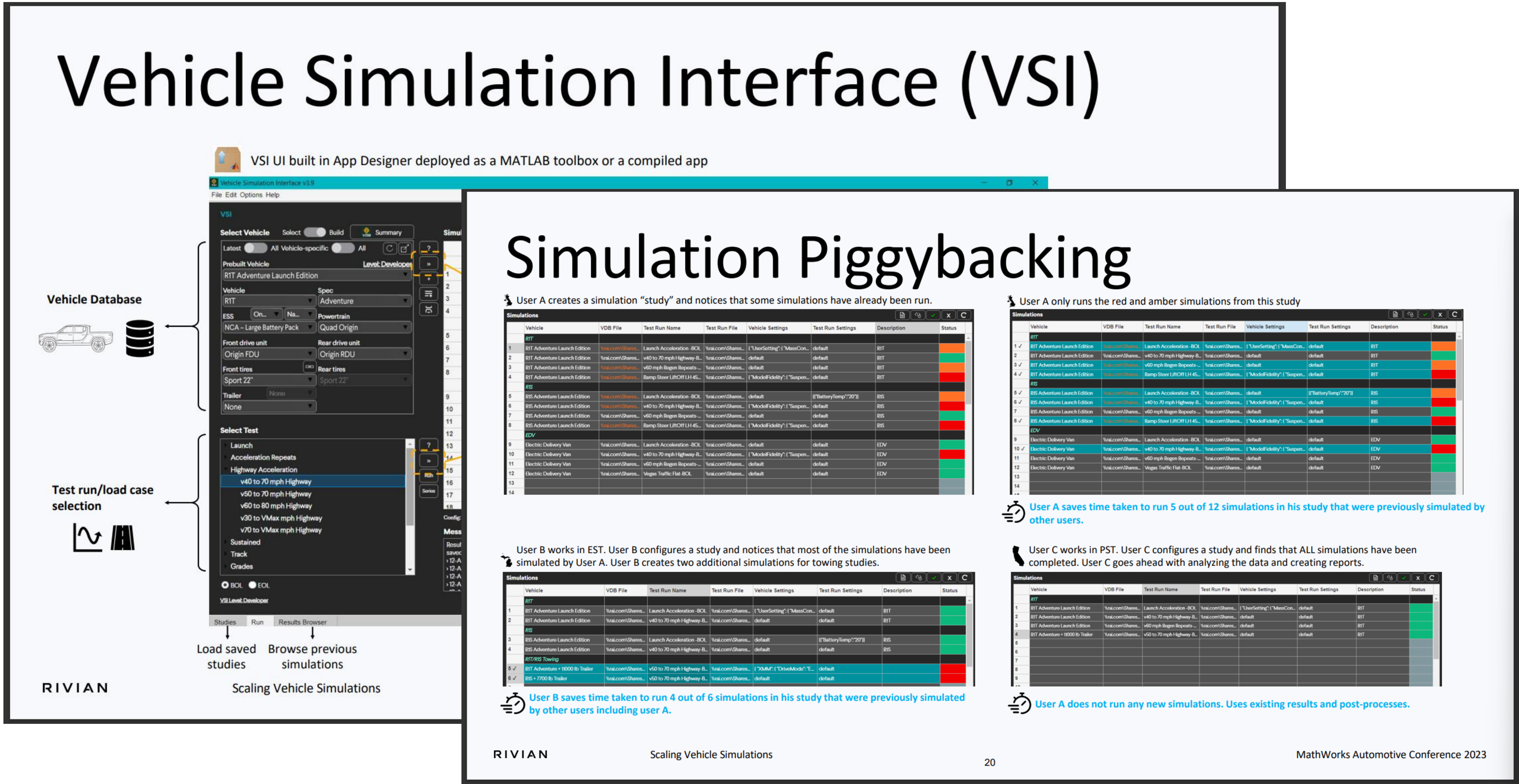

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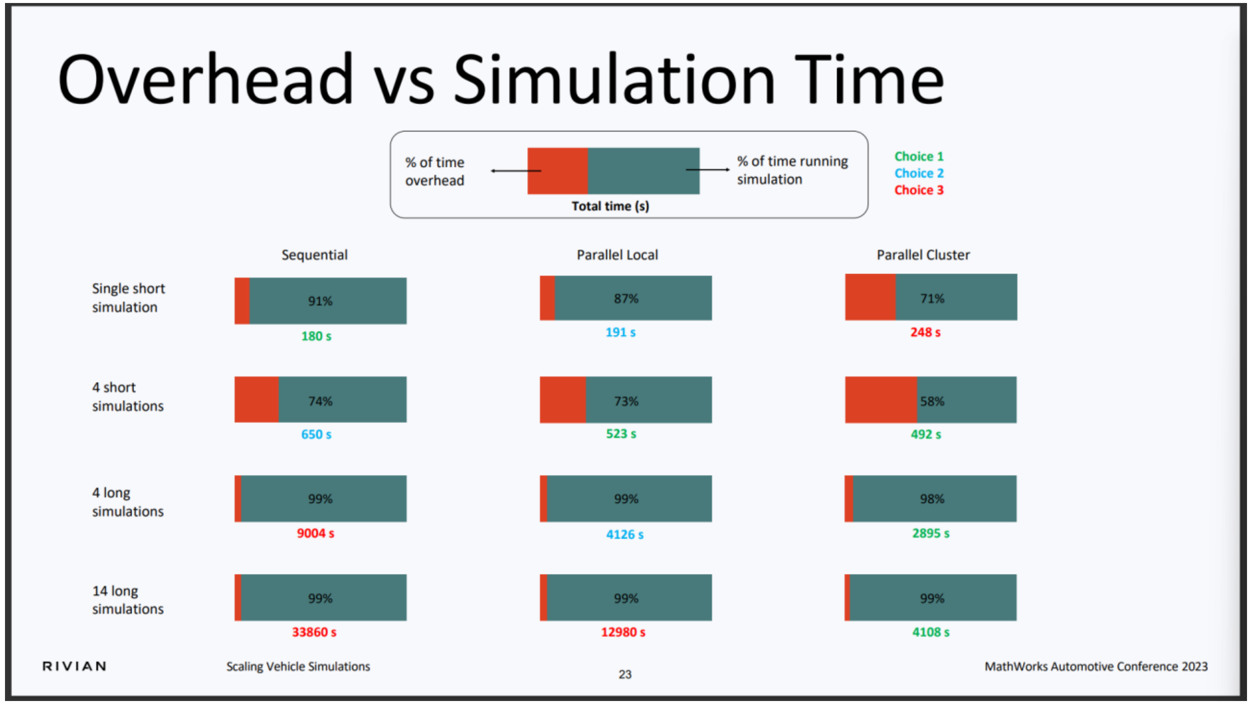

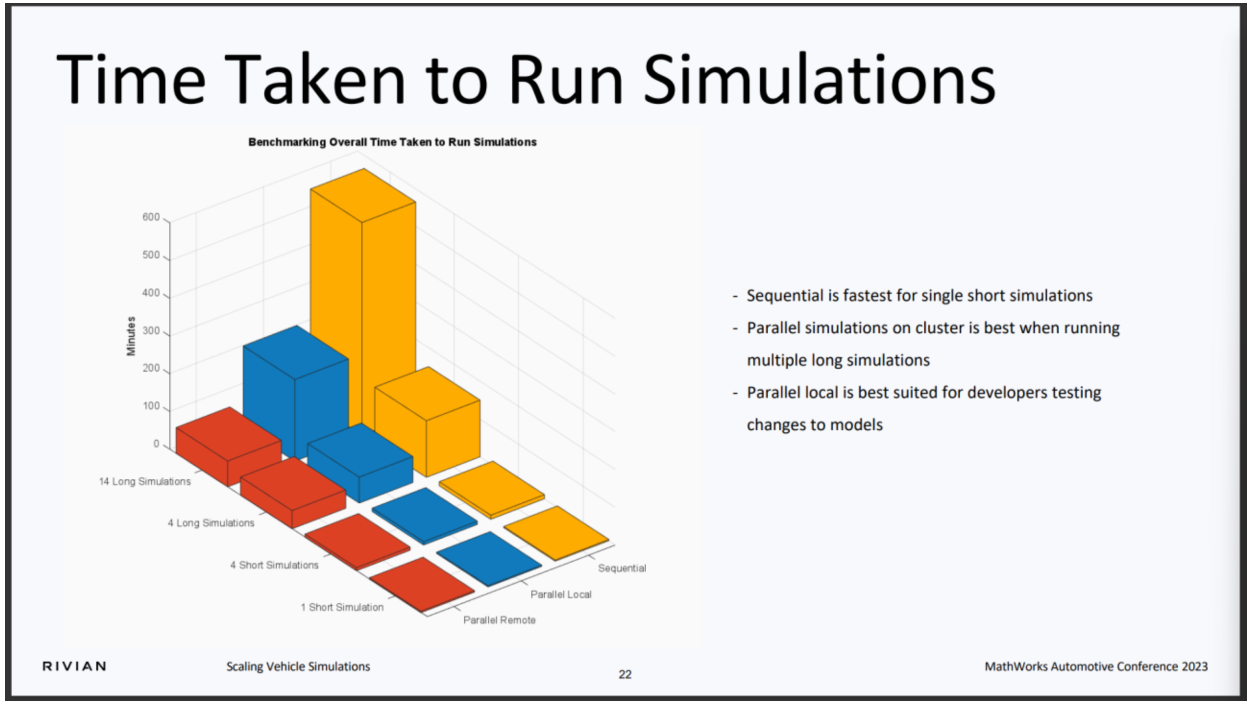

Link to article

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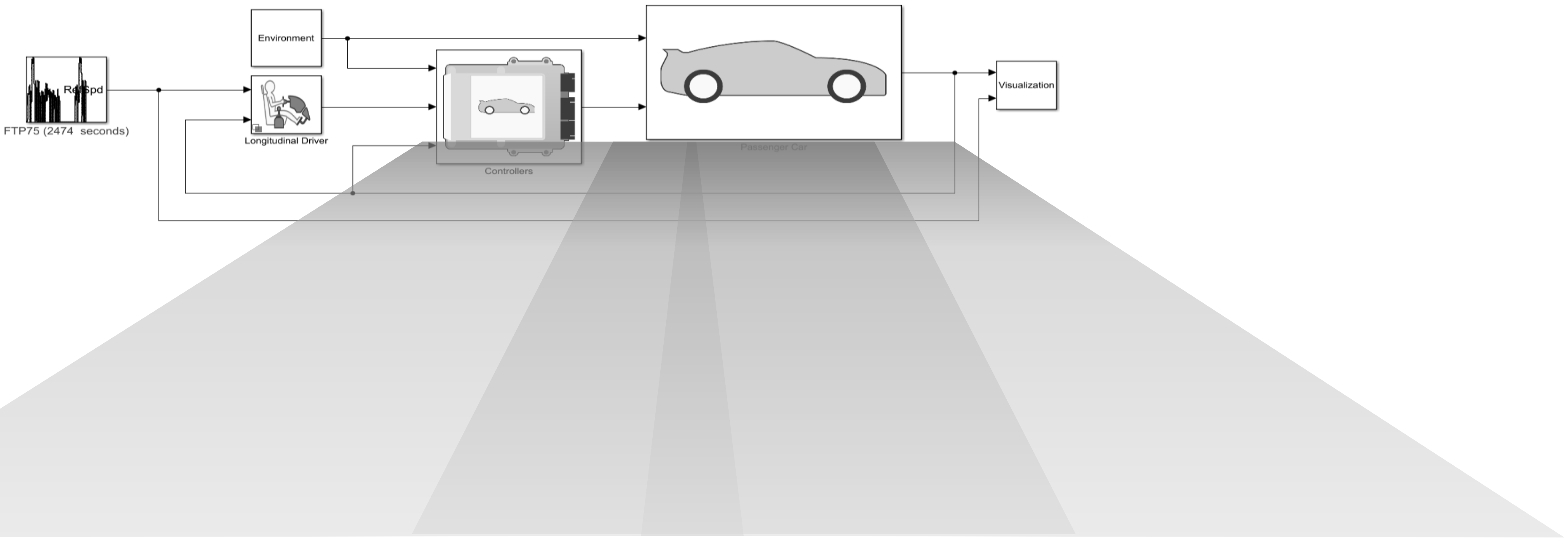
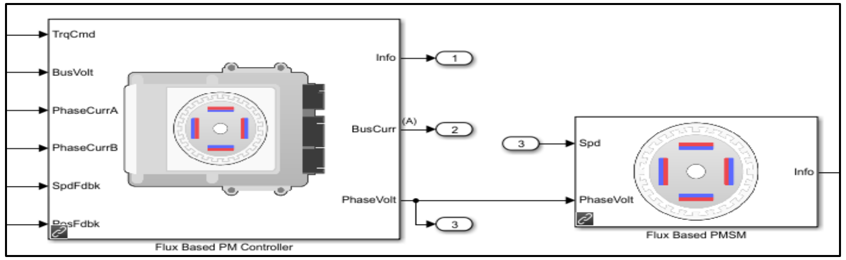
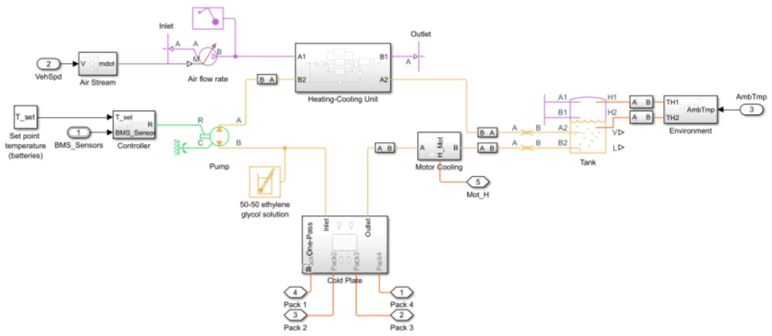
Integrating Components models with System Level Model

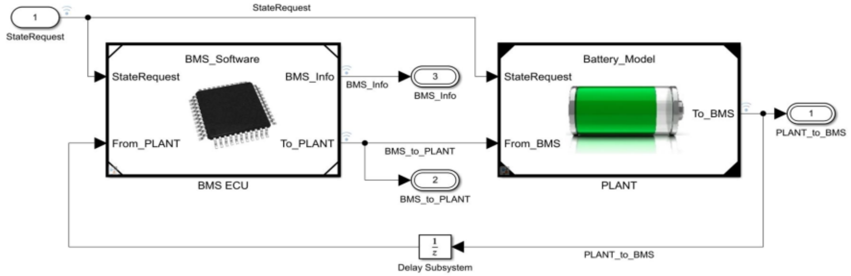




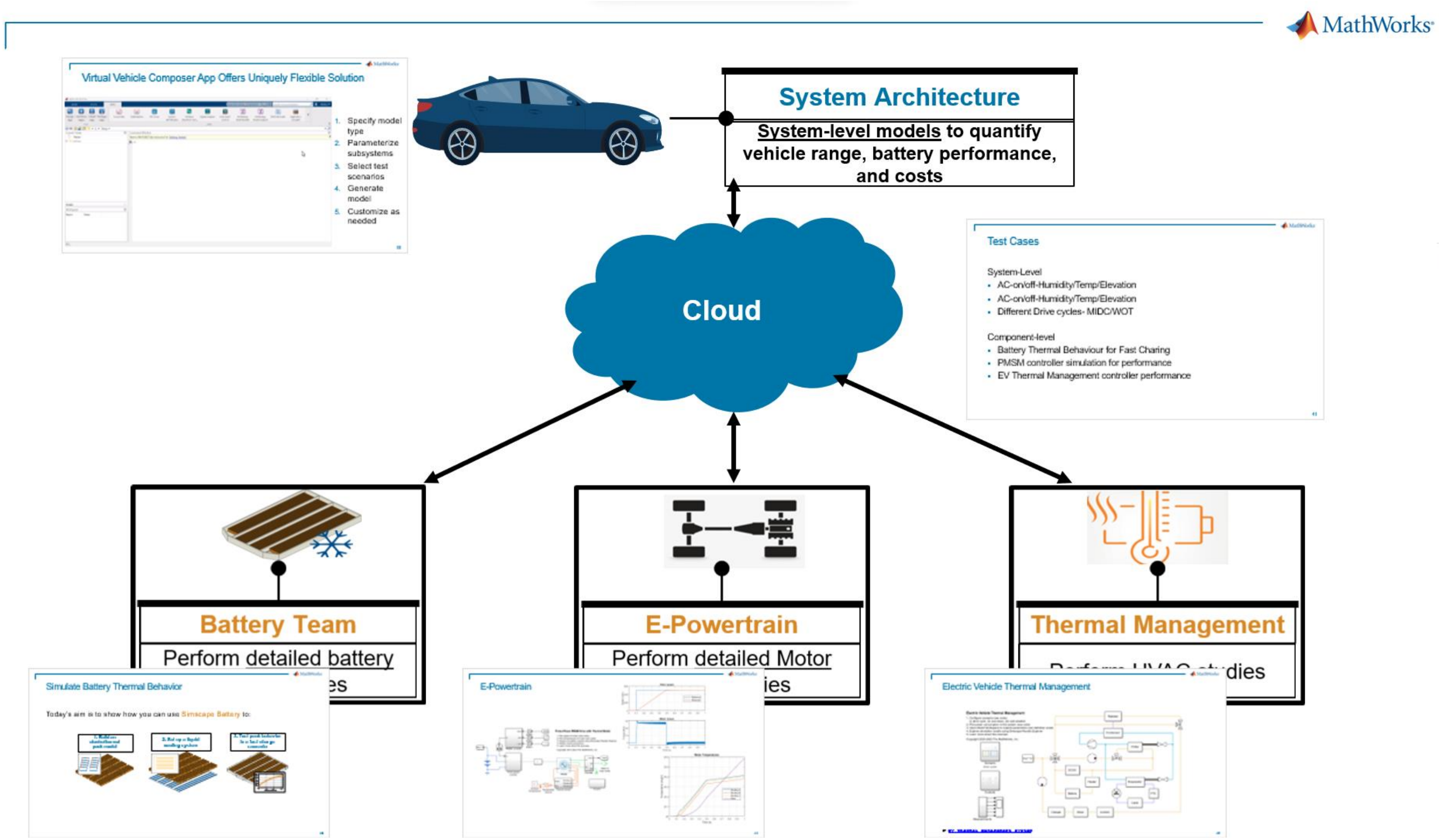
Motor and MCU



Thermal Management System



Battery and BMS



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Test Cases

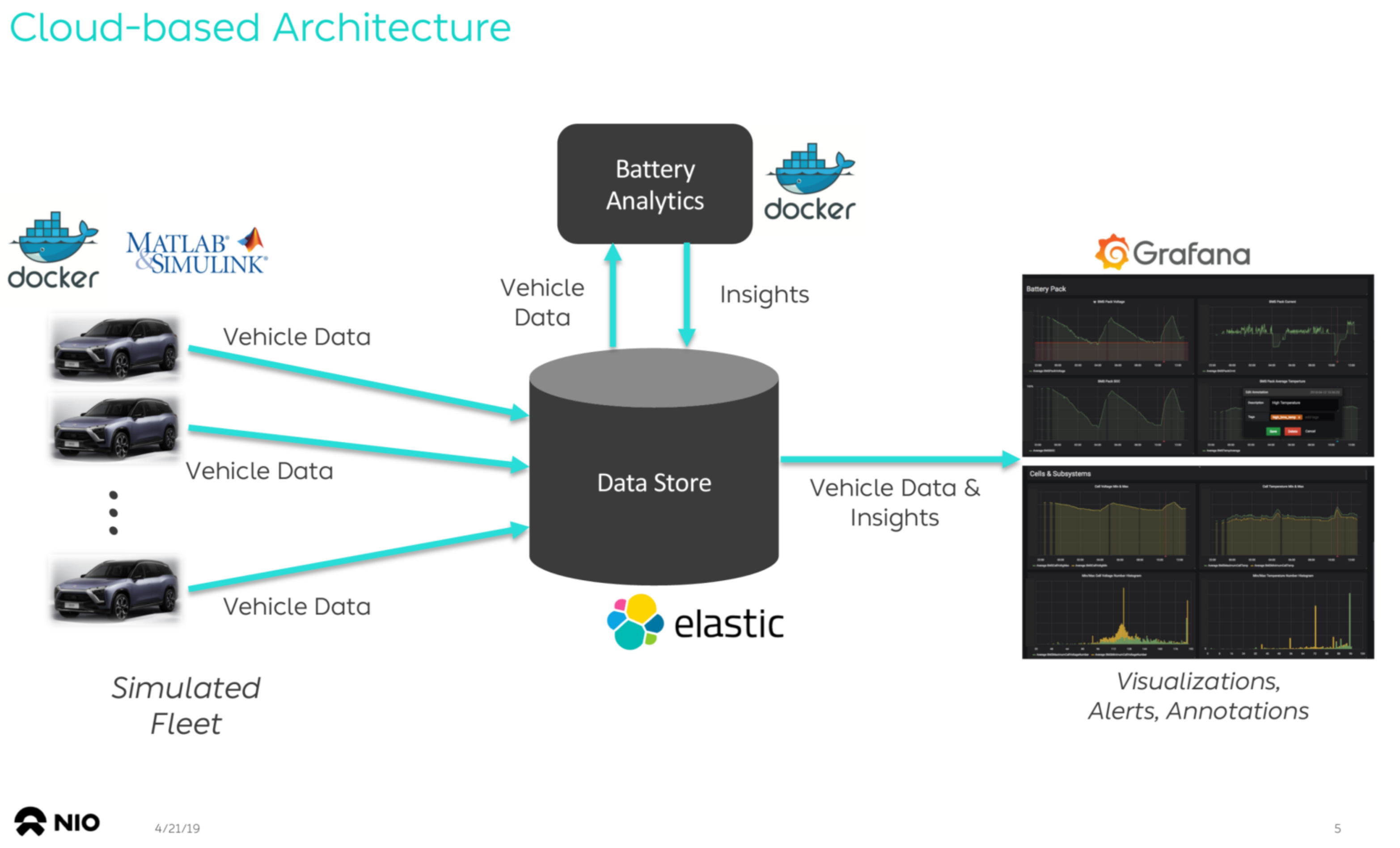
Component-level

- Battery Thermal Behaviour for Fast Charing
- PMSM controller simulation for performance
- EV Thermal Management controller performance

Interested to understand the performance of these subsystems when integrated with System Level Simulation!!

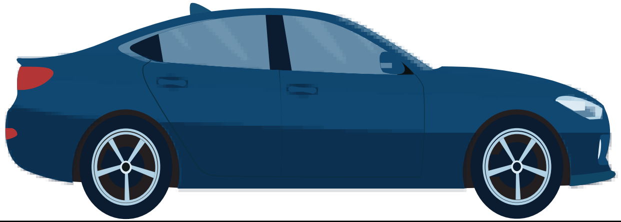
[Developing EV Components Using Virtualization and Scaling to the Cloud]

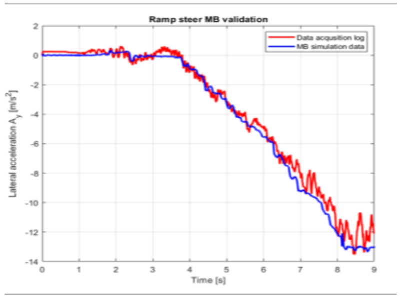
NIO Inc: Building Battery State-of-Health Estimation Pipelines for Electrified Vehicles



[Link to article]

Key takeaways





System Level Modelling	Validation & Testing	Large-Scale Studies
Virtual Vehicle	**Model accurate System**	**Desktop to Cloud**
Virtualization and Virtual Vehicles System-level models Powertrain Systems-Optimization	Correlation with real world behaviour ROM workflows	Large scale simulation Digital twins Synthetic Data Generation

Q&A

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Thank you

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