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India

*November 19<sup>th</sup> , 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)  $1.5 \text{ s} \leq t < 2 \text{ s}$

b)  $1 \text{ s} \leq t < 1.5 \text{ s}$

c)  $0.9 \text{ s} \leq t < 1 \text{ s}$

d)  $t < 0.9 \text{ s}$





## Panel Members



Moderator: Sree Varshini



Veer Alakshendra

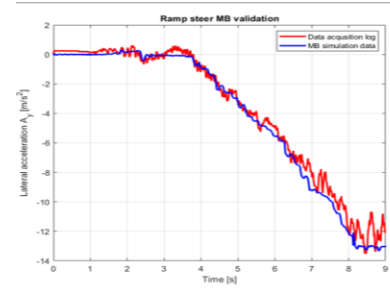
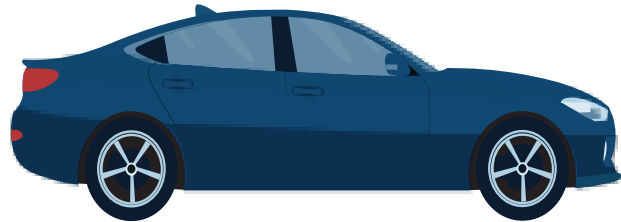


Abhisek Roy



Rahul Choudhary

# Key takeaways



System Level  
Modelling

Validation &  
Testing

Large-Scale  
Studies

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

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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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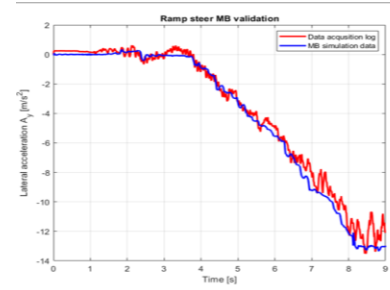
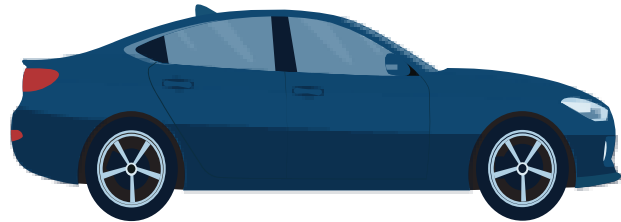
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# Key takeaways



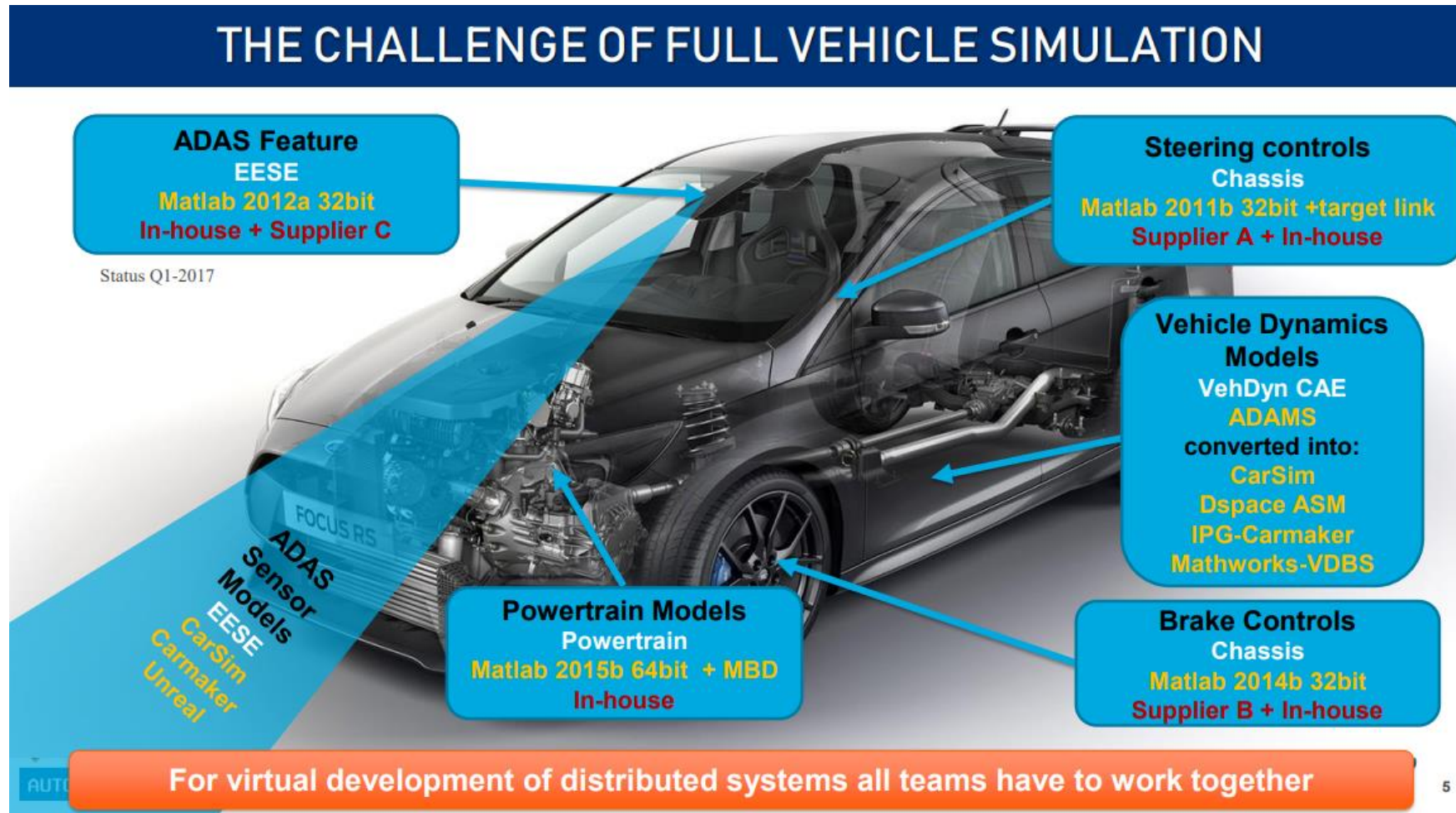
System Level  
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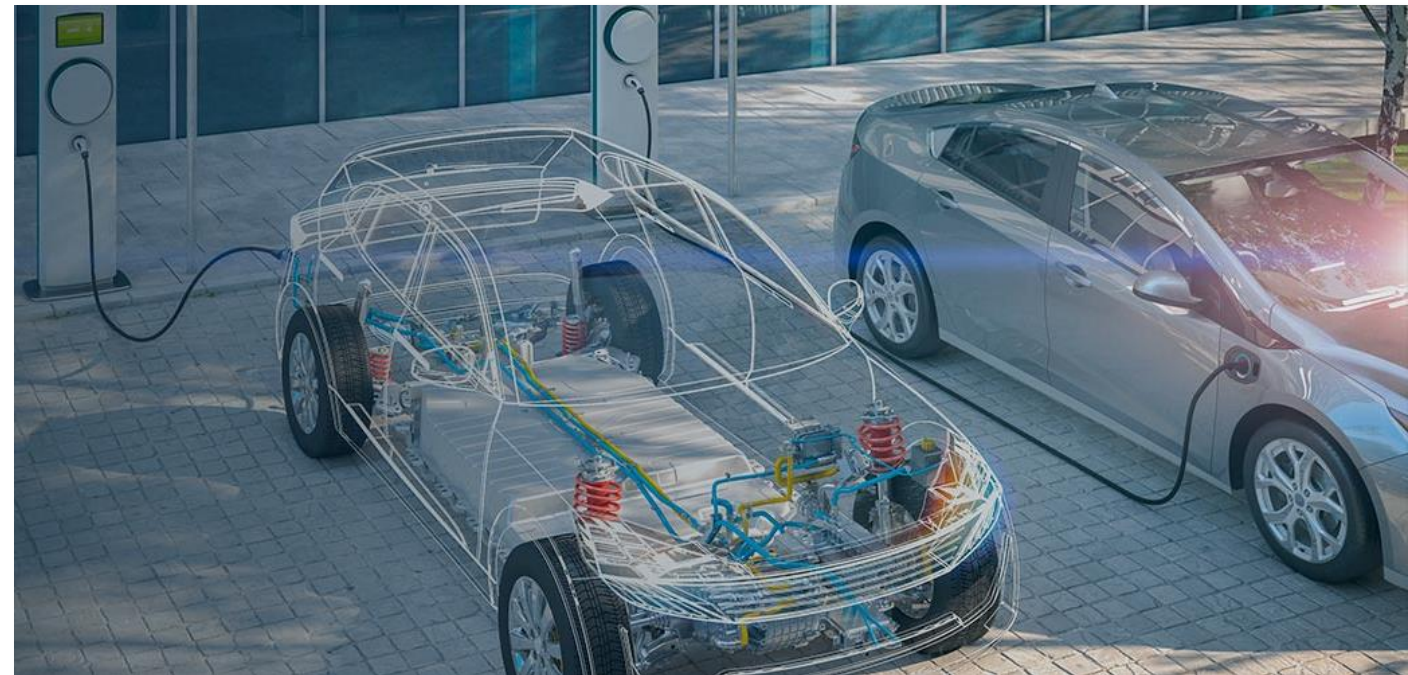
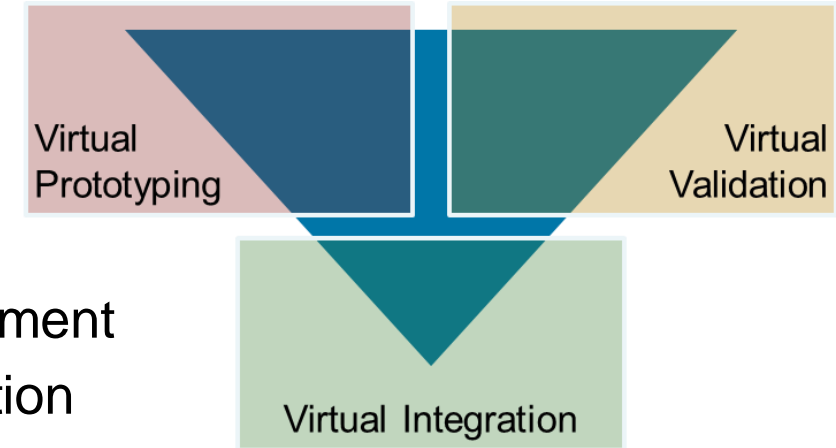


# Challenges: Ford: Model-Based Agility with FASST



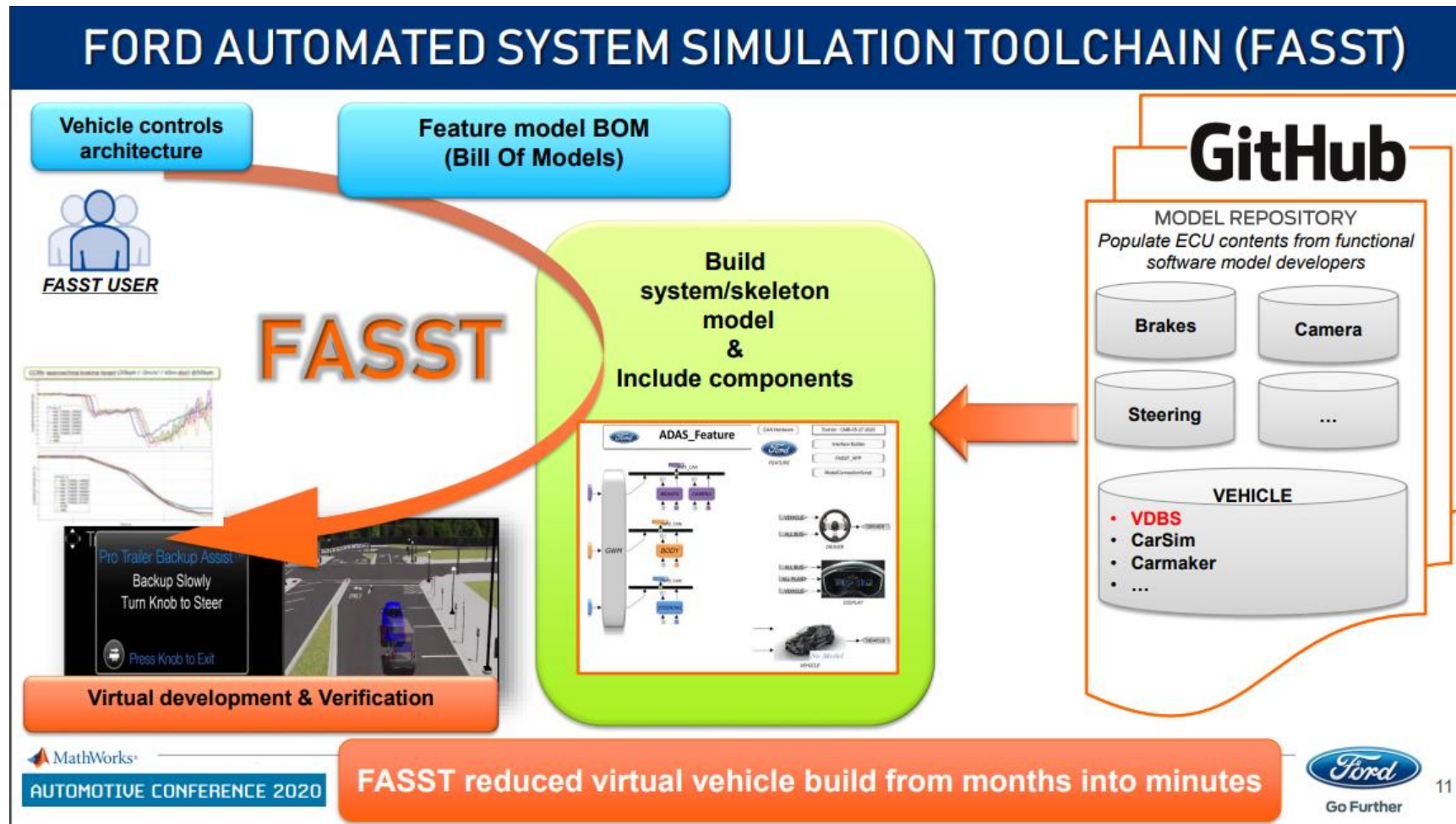
## Challenges: MathWorks observations

- 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**



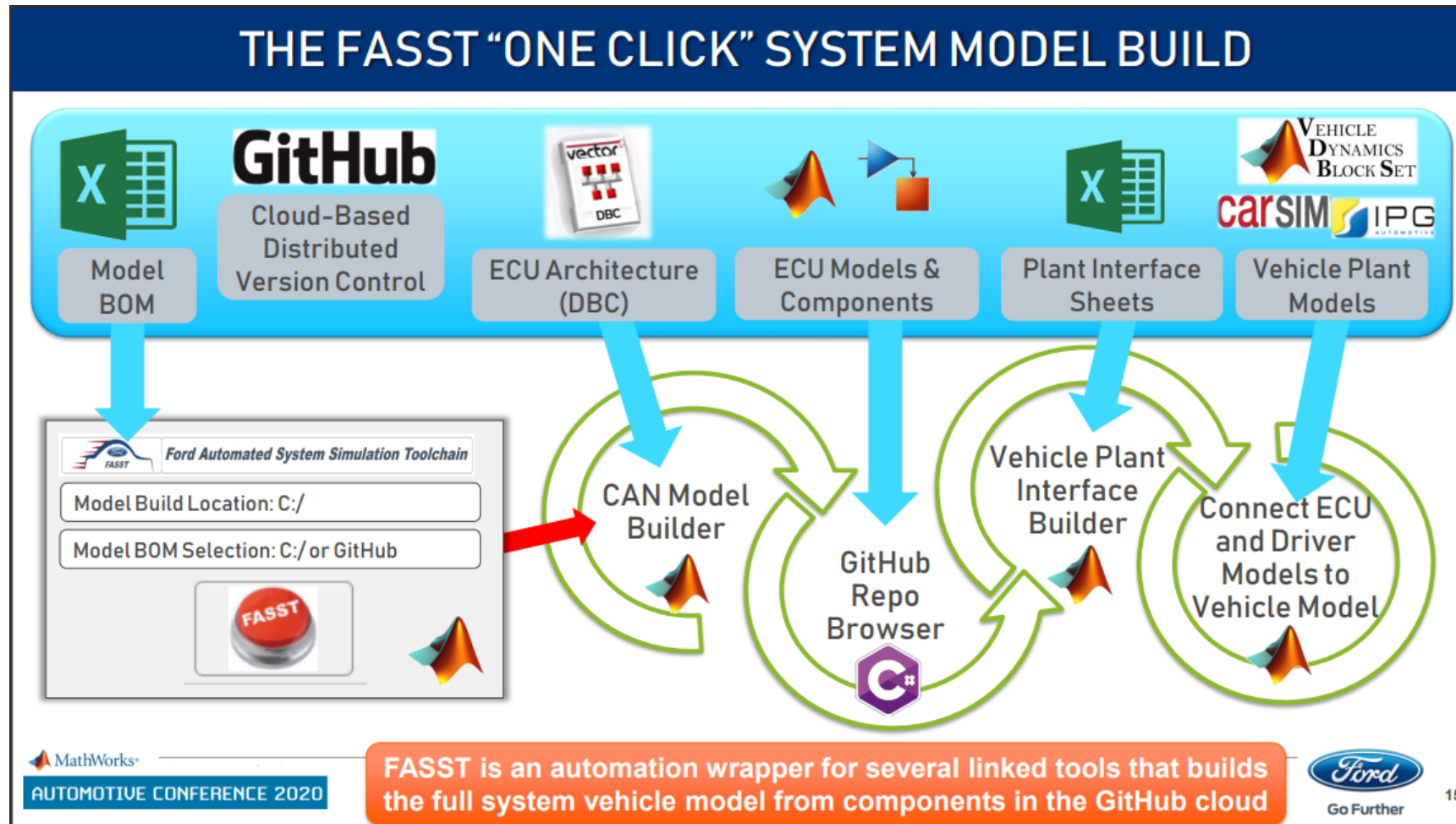


# Ford: Model-Based Agility with FASST



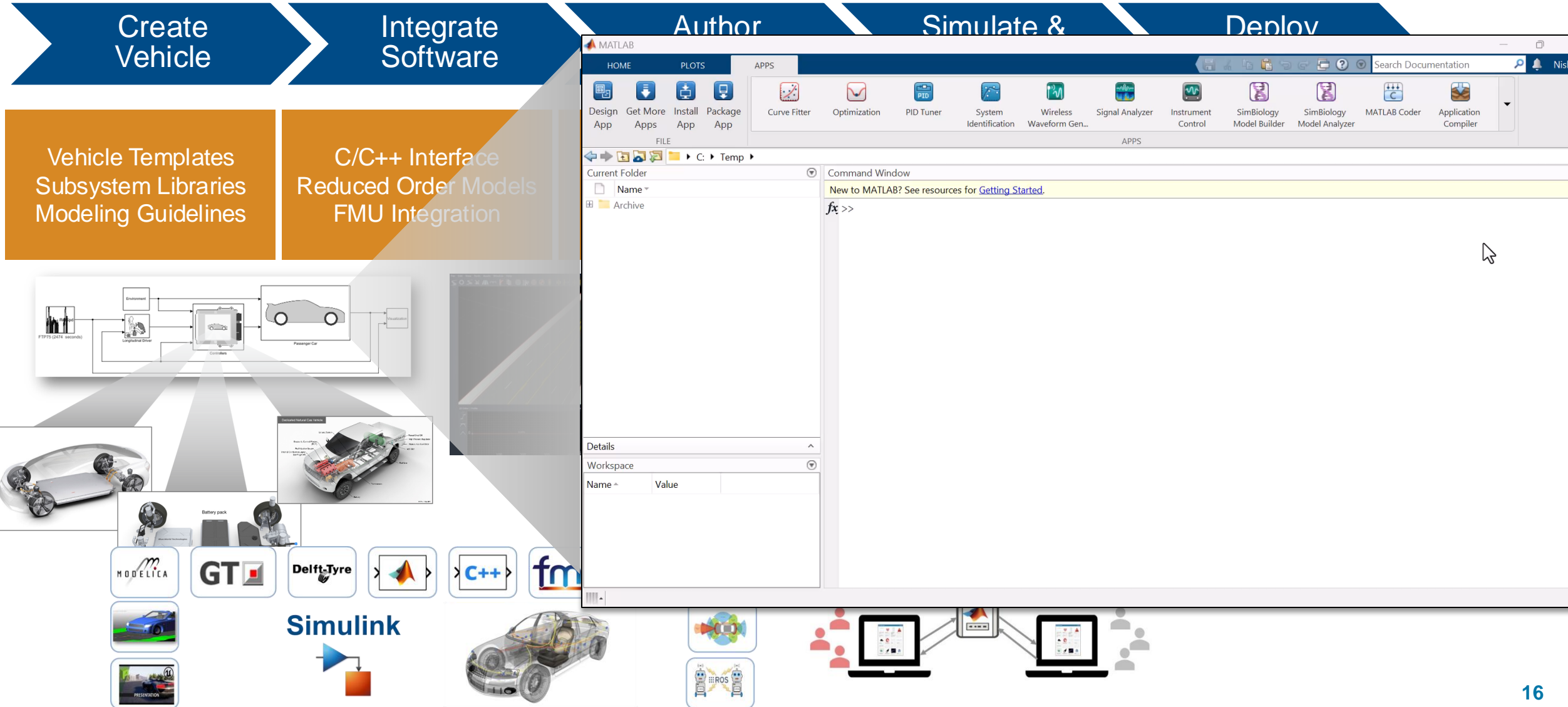


# Ford: Model-Based Agility with FASST



15

# Process to build Virtual Vehicle



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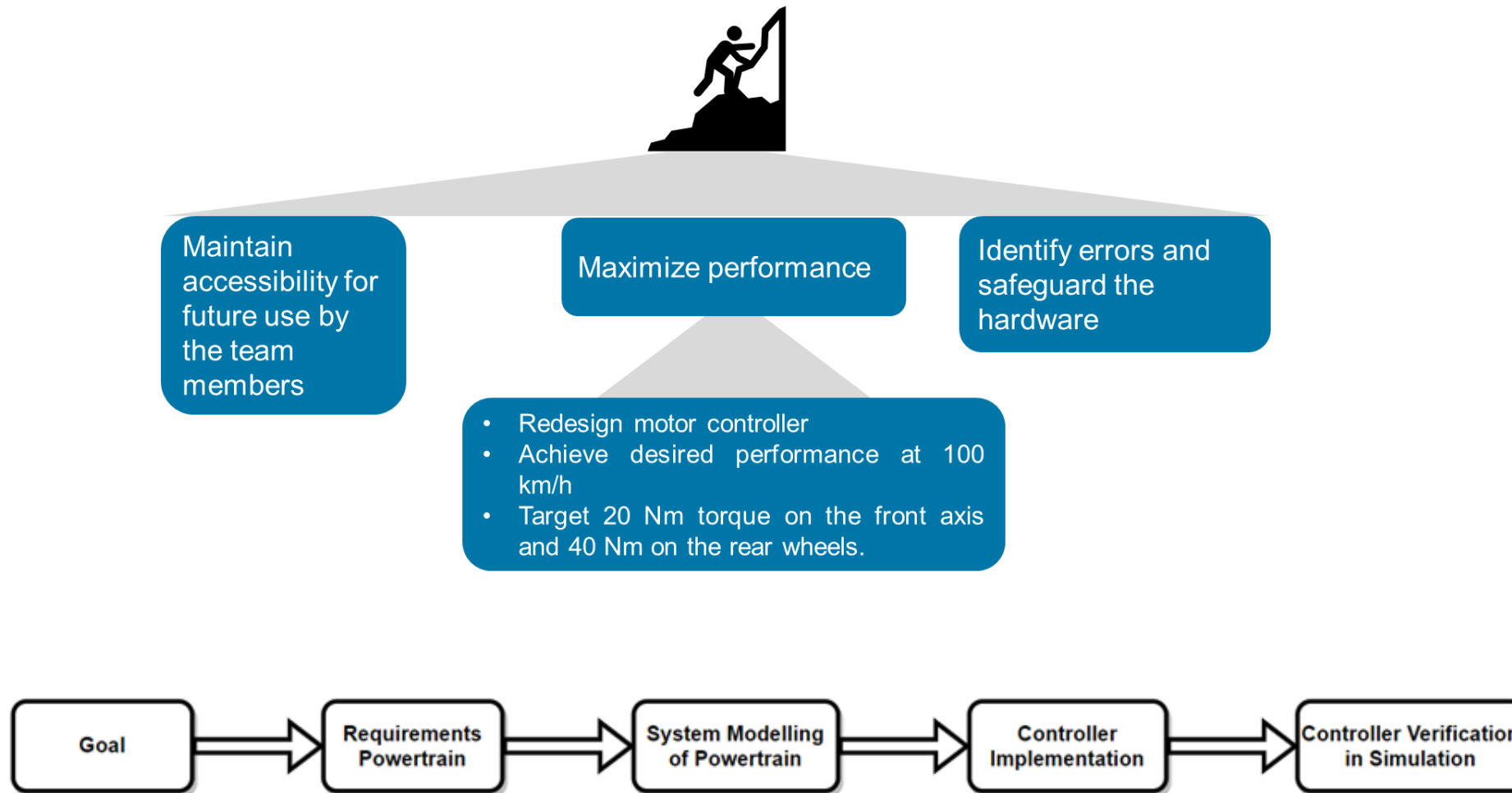
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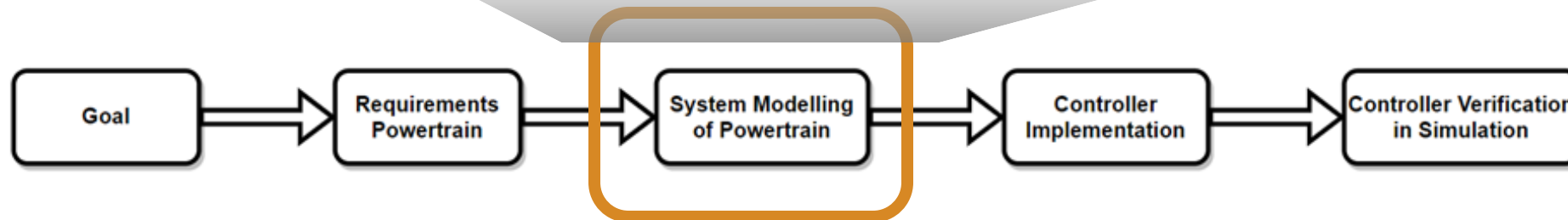
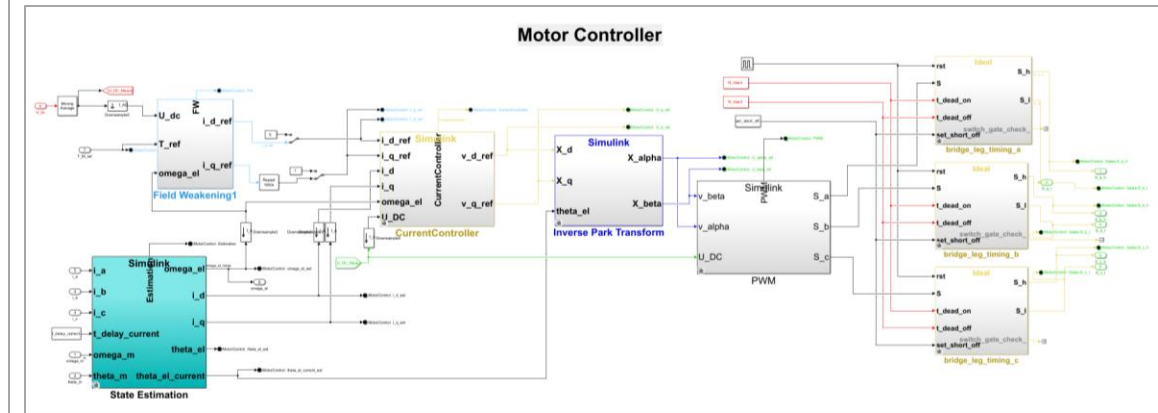
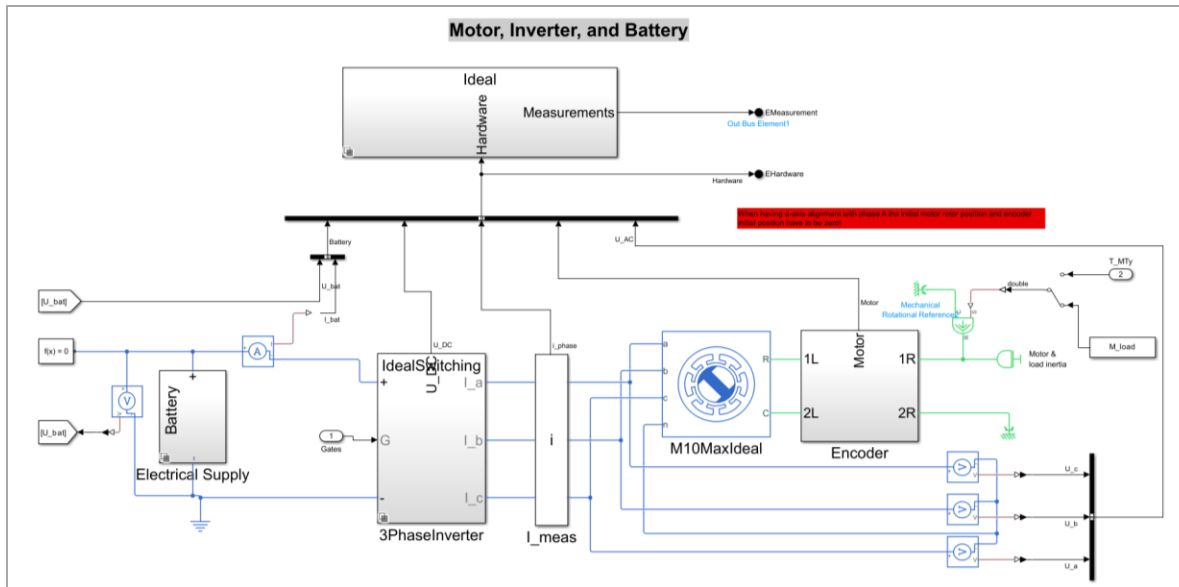
# Motivation and Methodology



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

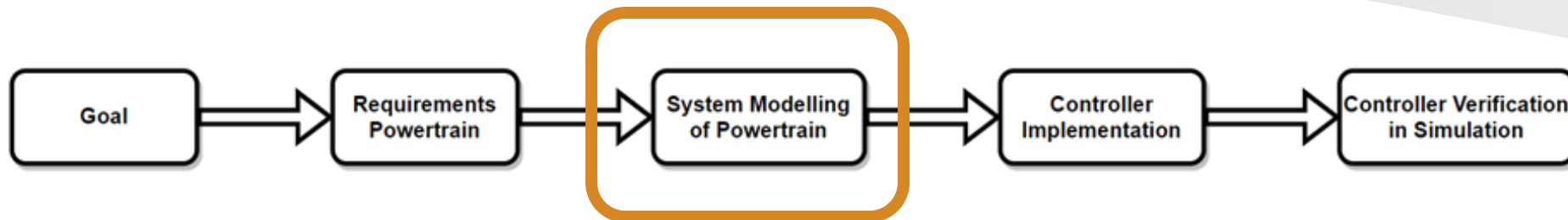
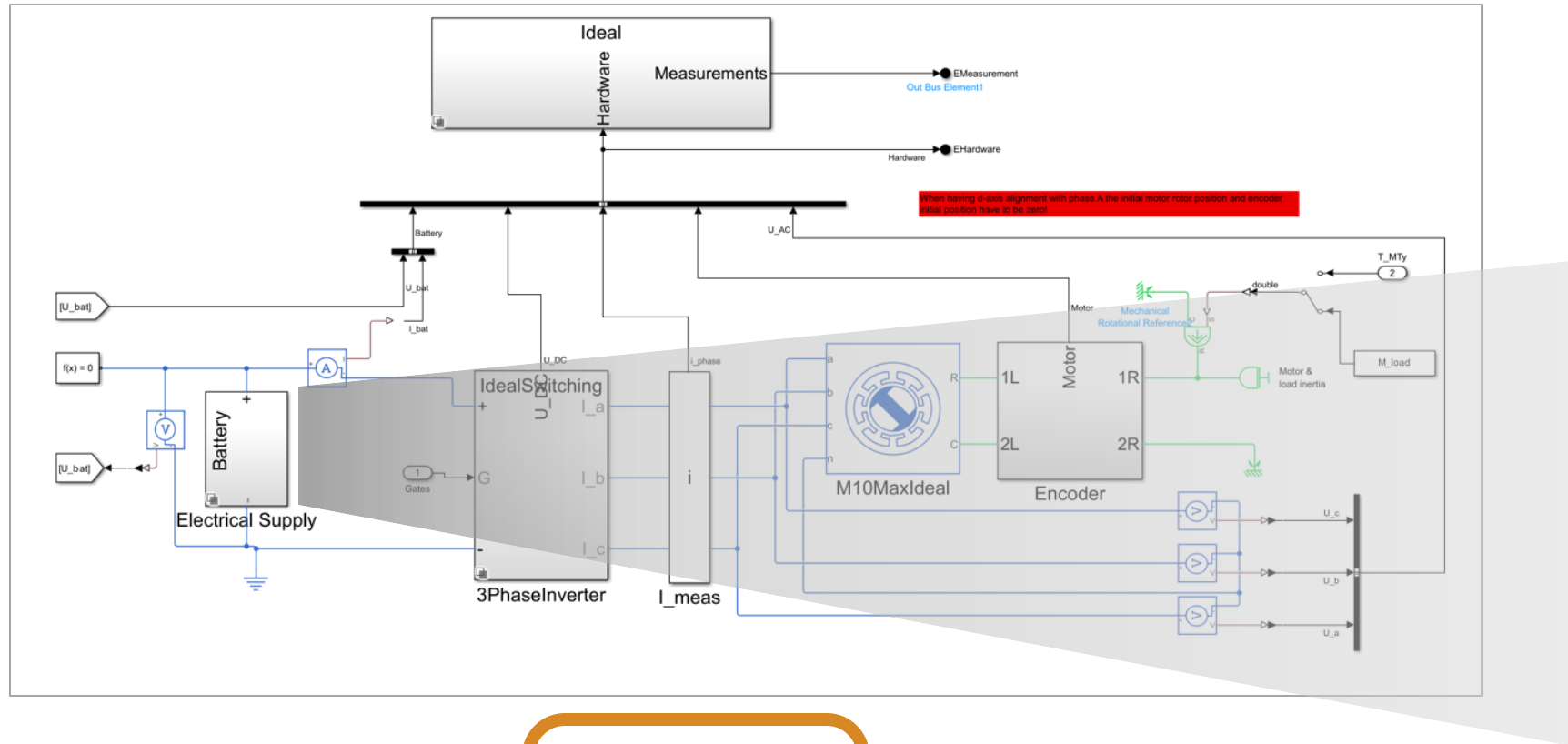
# System Modeling of Powertrain

## *Inverter, Battery, Motor, Motor Controller*

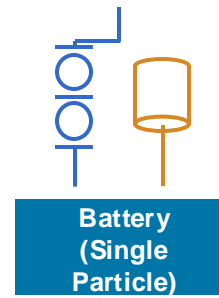
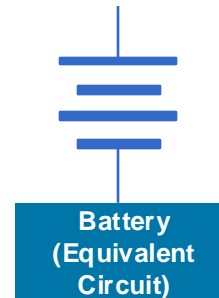
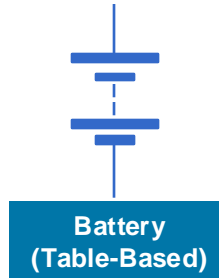


# System Modeling of Powertrain

## Battery, Motor, Inverter



### Different Model Fidelities





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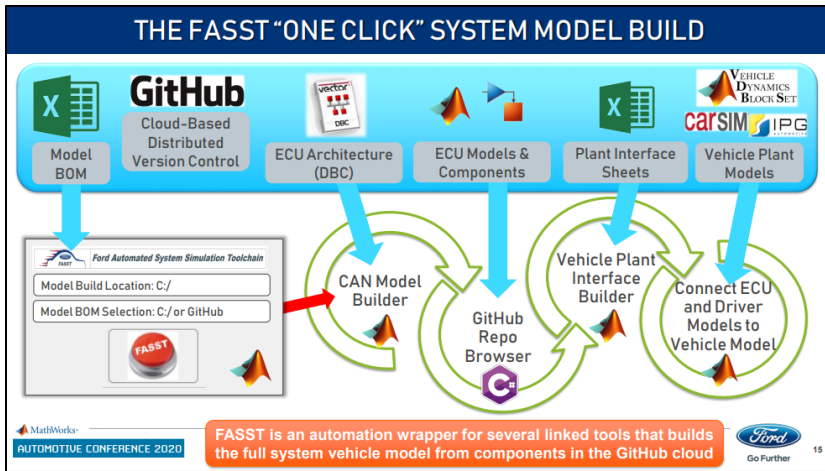
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# **Tech Talk: Virtual Vehicle: Transforming Vehicle Engineering Through Simulation**

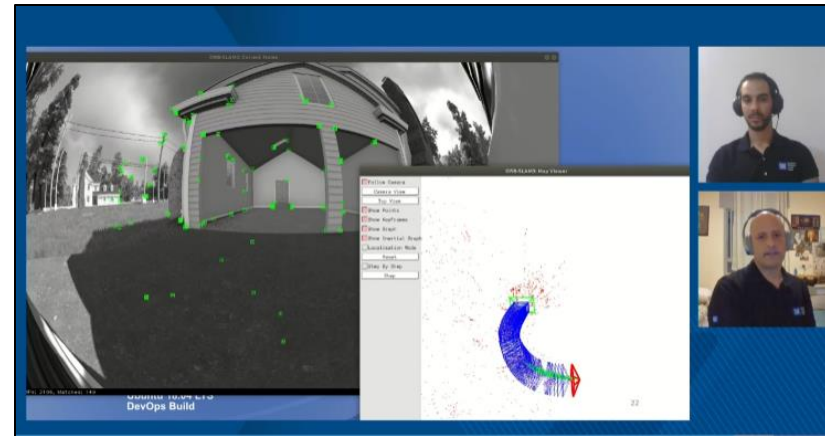


# How Are Companies Building Virtual Vehicles with MathWorks?

- 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

Simulation framework for highly autonomous trucks  
 Simulink as the simulation integration platform

|  |   |   |
|--|---|---|
| <p>Simulink offers a modular simulation framework with clear separation of vehicle from environment</p> <p><b>Modularity</b></p>   | <p>Many ego vehicles share the same environment making the framework scalable</p> <p><b>Scalability</b></p> | <p>Offers 3D scenario creation through RoadRunner and Unreal Engine</p> <p><b>Visualization</b></p> |
| <p>Planners, controllers and semi-trailer models readily available for fast framework prototyping</p> <p><b>Out of the box</b></p> | <p>Tool familiarity and ready-to-use reference examples</p> <p><b>Tooling</b></p>                           | <p>Ongoing collaboration with MathWorks and technical advisory</p> <p><b>Collaboration</b></p>      |

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Bosch: Autonomous truck development

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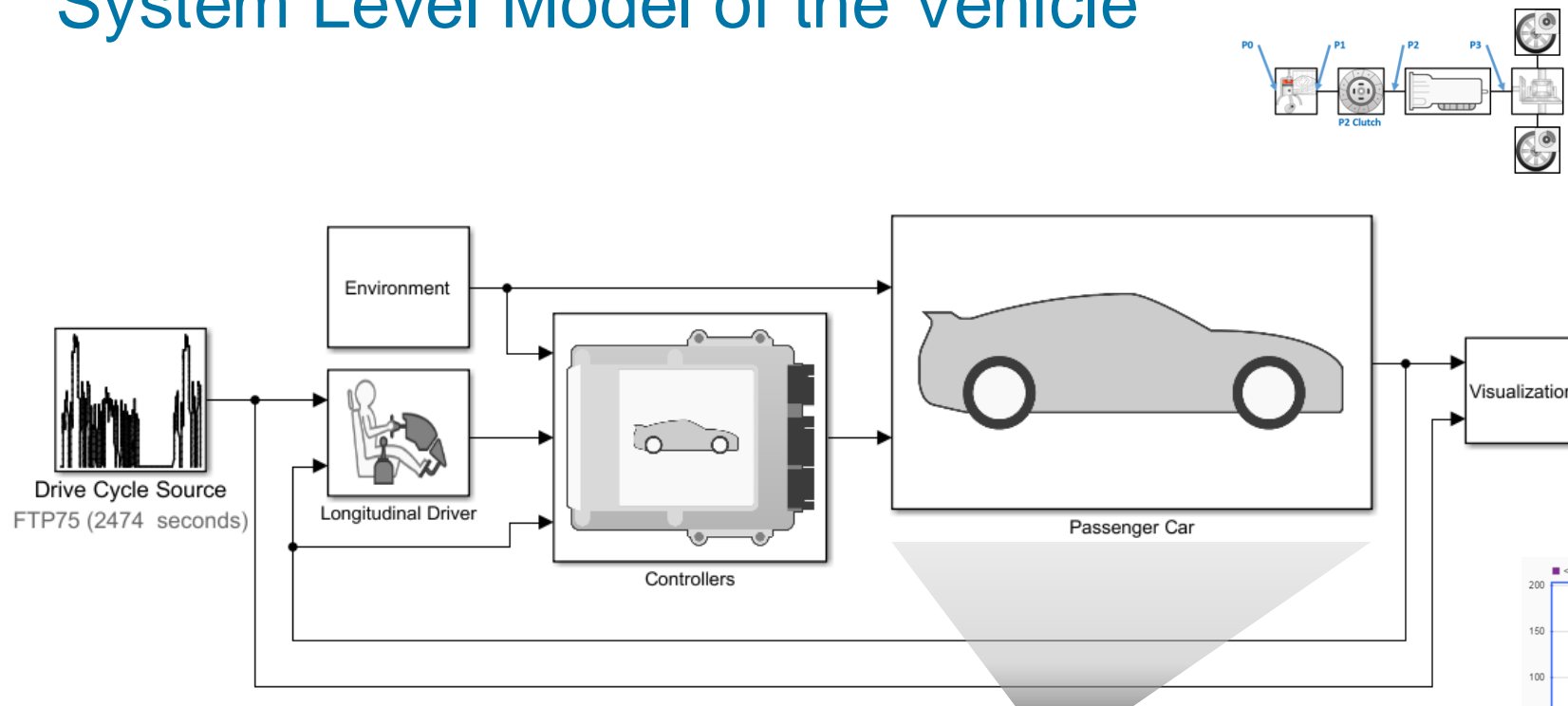
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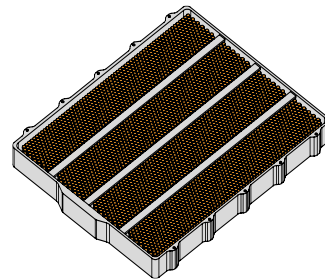




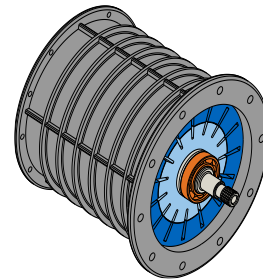
# System Level Model of the Vehicle



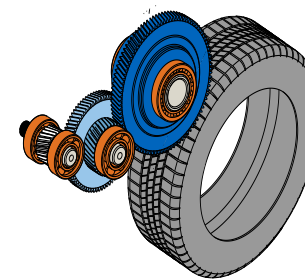
- Component Selection?
- Component Sizing?
- Trade-off Studies?
  
- Detailed Component Modeling and Control Design?



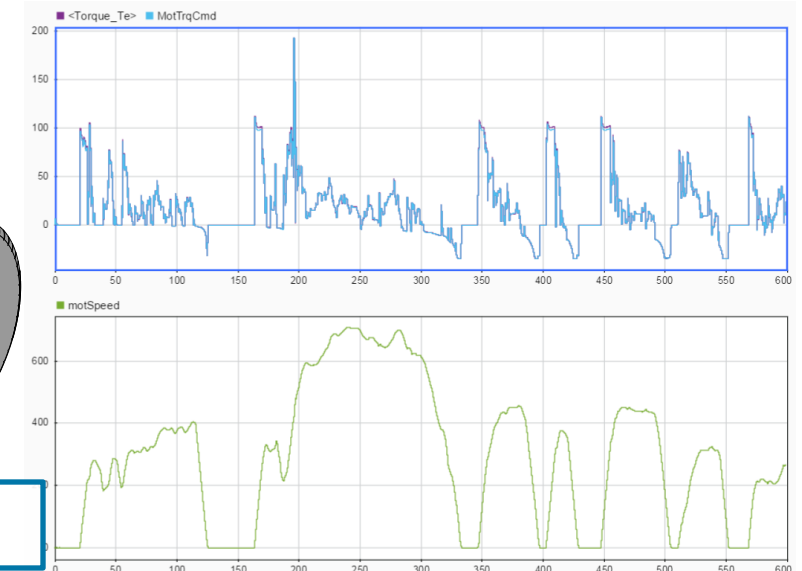
**Battery**



**Motor**

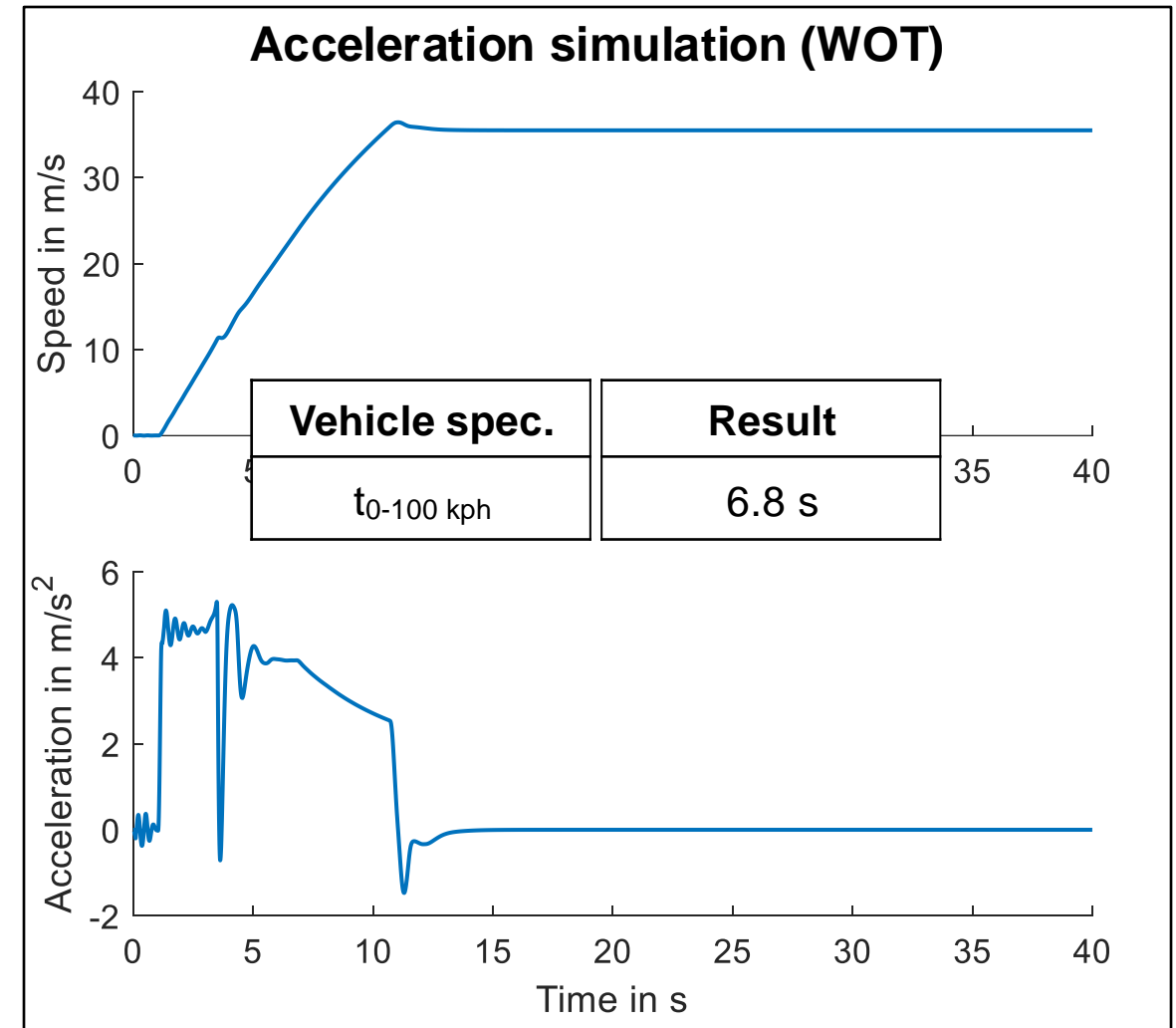
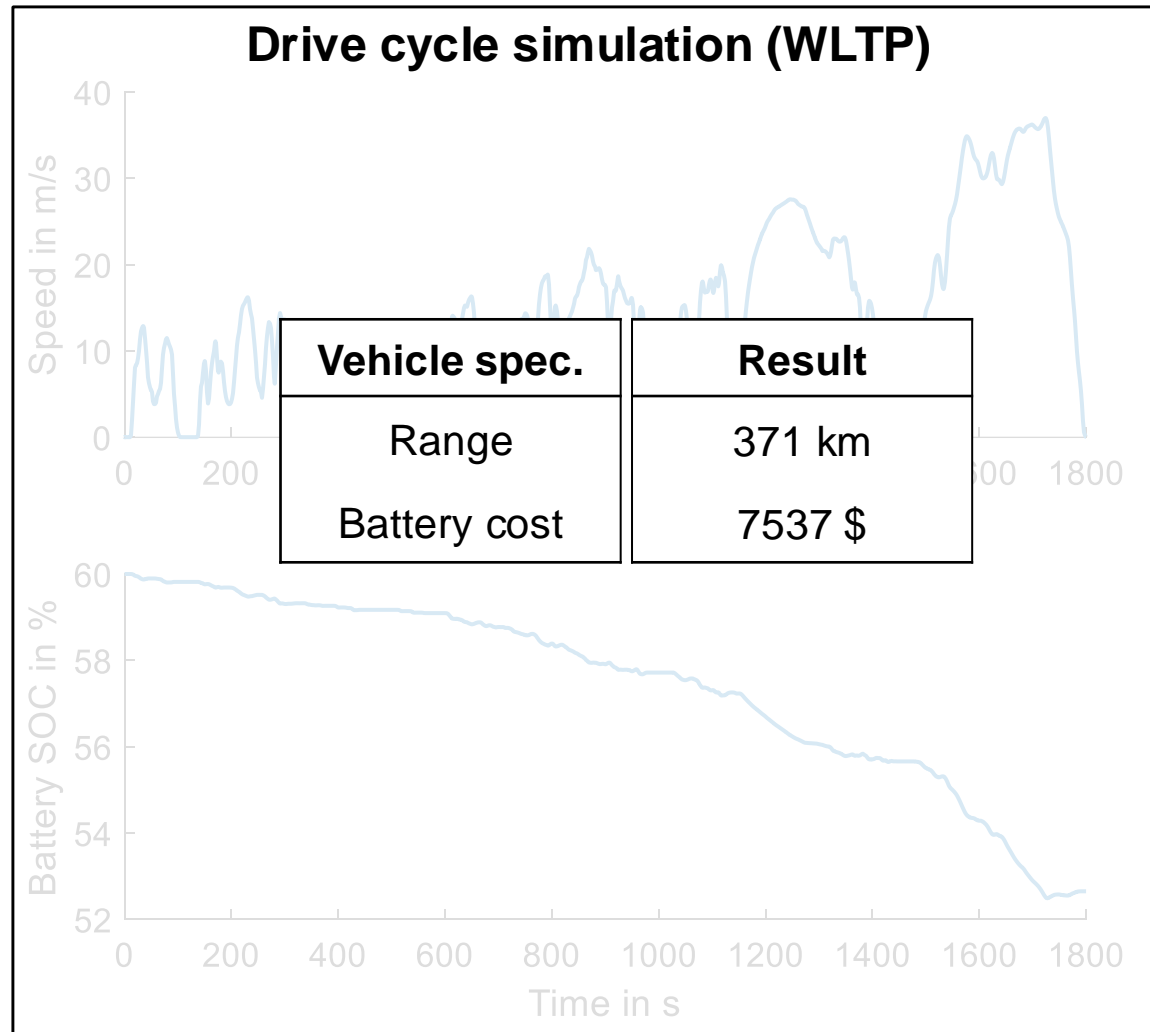


**Driveline**



# Overview vehicle model

Initial assessment, mid-size electric passenger car



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# Optimize Vehicle Performance

Given the vehicle model, define the optimization problem:

- Objective:

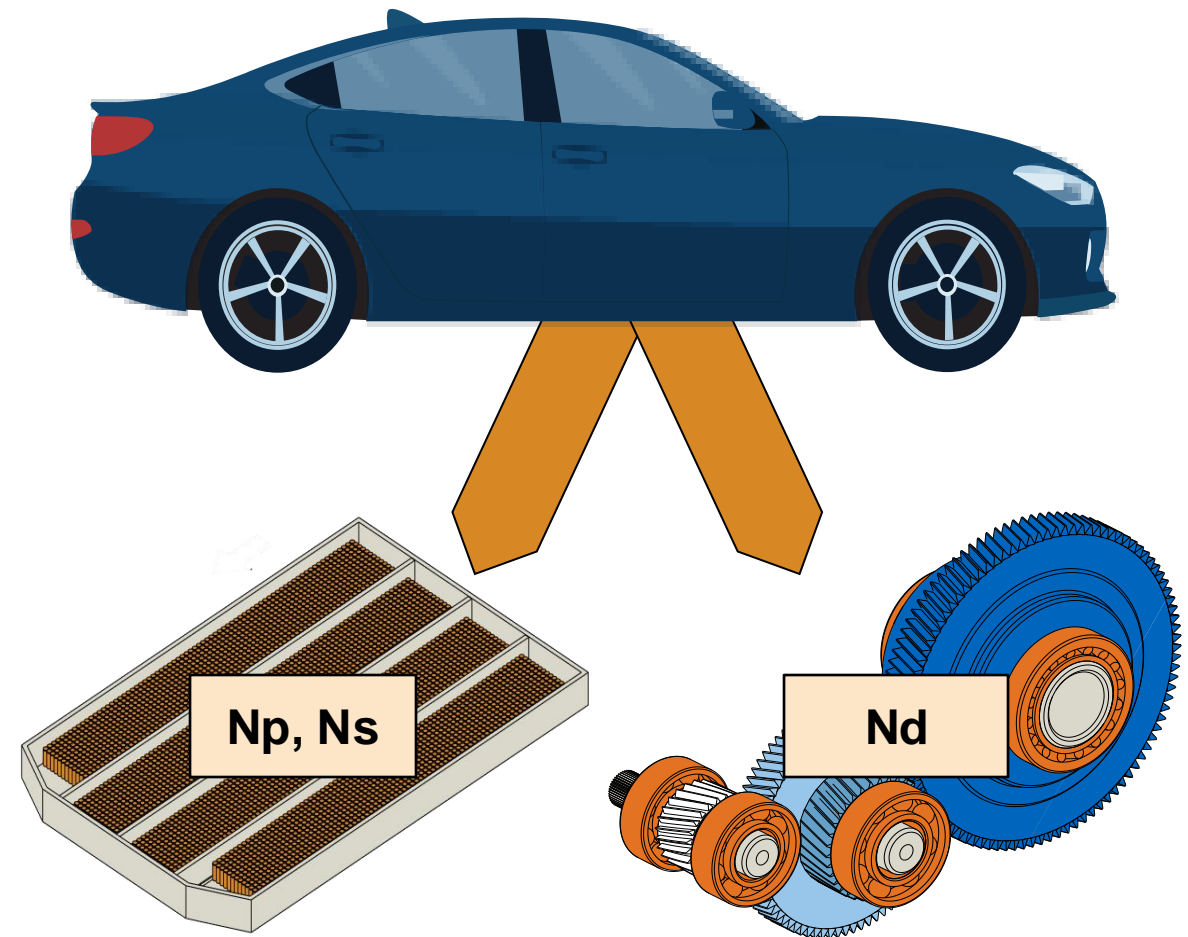
$$\text{minimize } f(x) = w_1 * \text{Cost} - w_2 * \text{Range}$$

- Constraints:

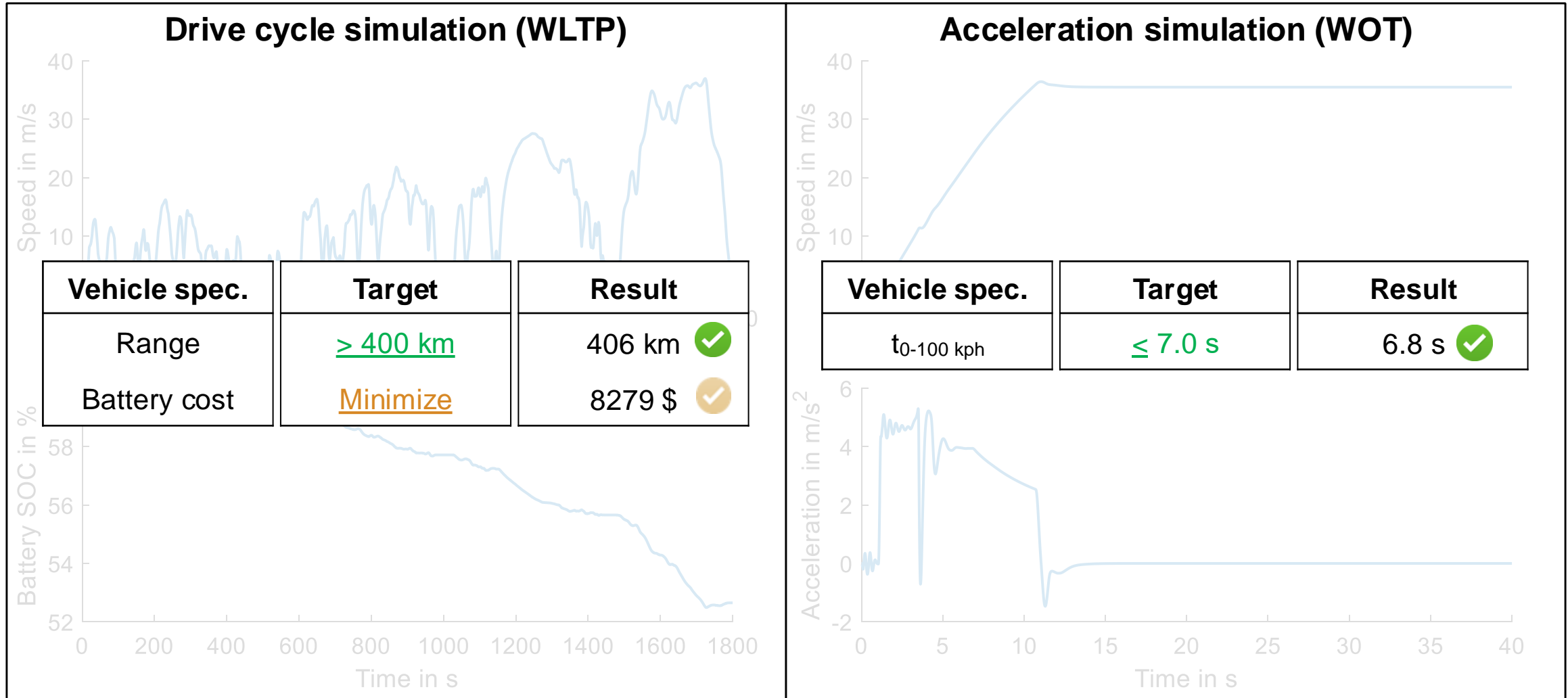
$$\begin{aligned} g_1: & \text{DriveCycleFault} \leq 0 \\ g_2: & \text{Range} \geq 400 \text{ km} \\ g_3: & t_{0-100 \text{ kph}} \leq 7 \text{ s} \end{aligned}$$

- Design variables

$$\begin{aligned} x_1: & 10 \leq N_p \leq 50 \text{ (Integer)} \\ x_2: & 80 \leq N_s \leq 140 \text{ (Integer)} \\ x_3: & 7 \leq N_d \leq 10 \text{ (Continuous)} \end{aligned}$$



# Optimization Results



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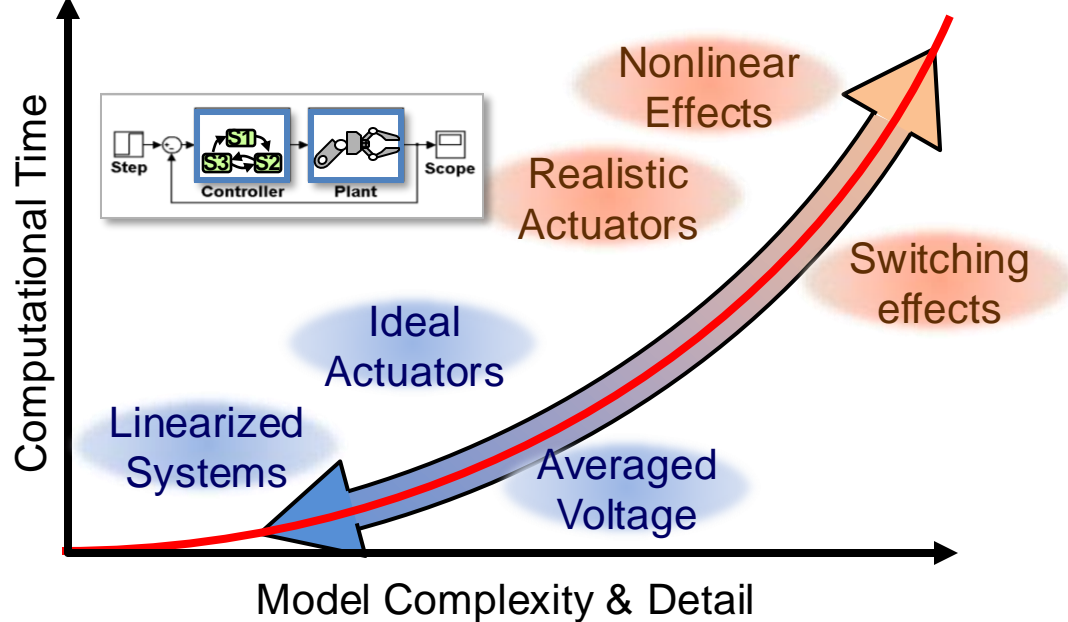
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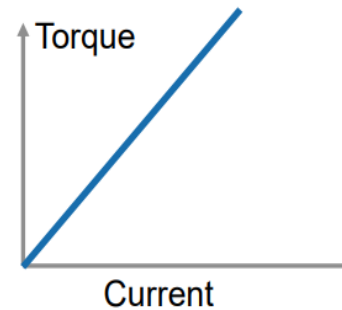
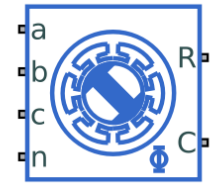
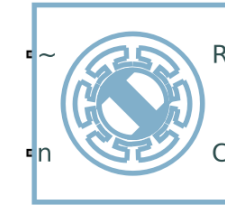
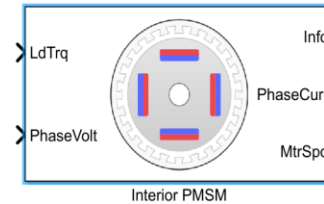


# Selecting Model Fidelity

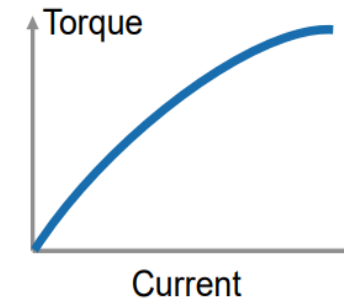
## Computational Time vs. Model Complexity



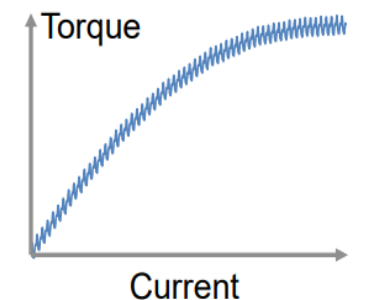
*Configure your model to balance simulation speed and model fidelity.*



Lumped Parameter



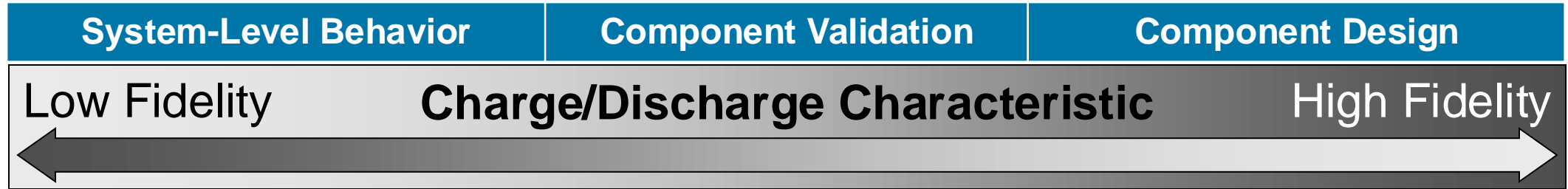
Saturation



Saturation + Spatial Harmonics



# Selecting Model Fidelity

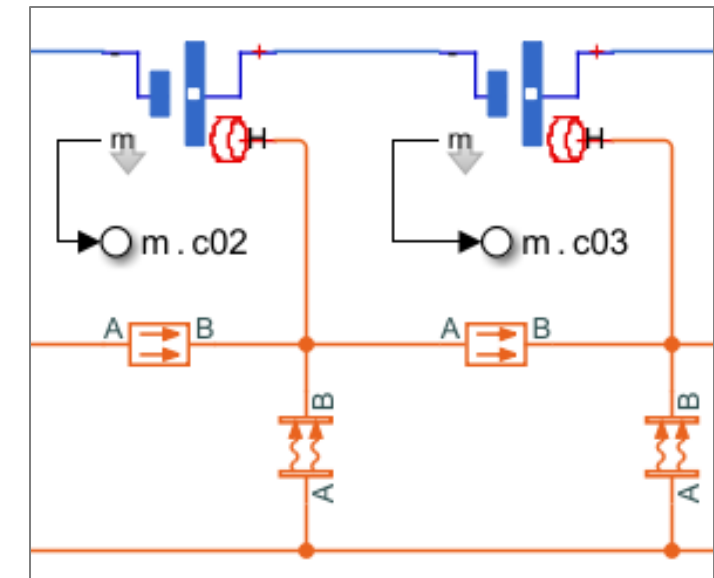
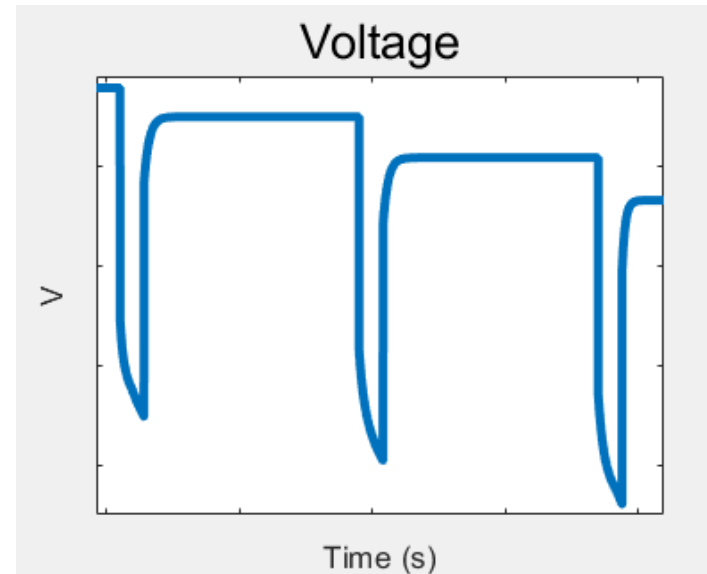
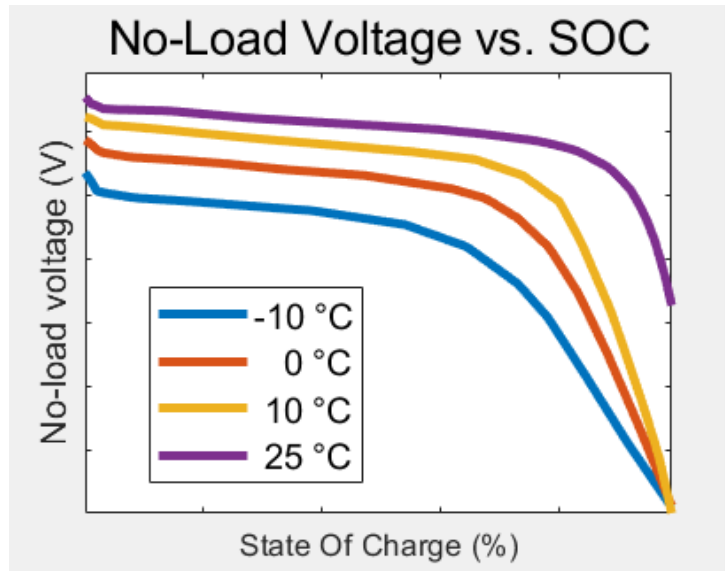


Infinite Charge

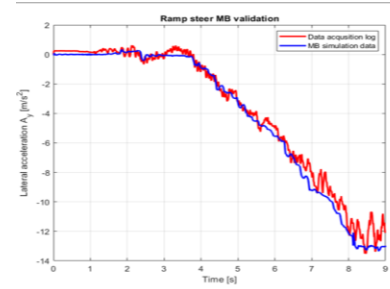
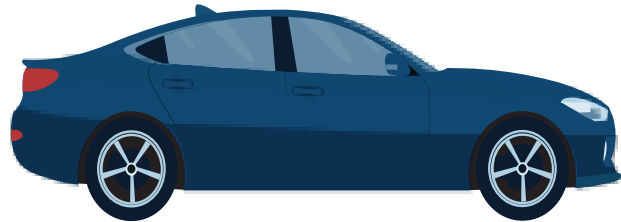
Finite Charge, Fade,  
Temperature Dependent

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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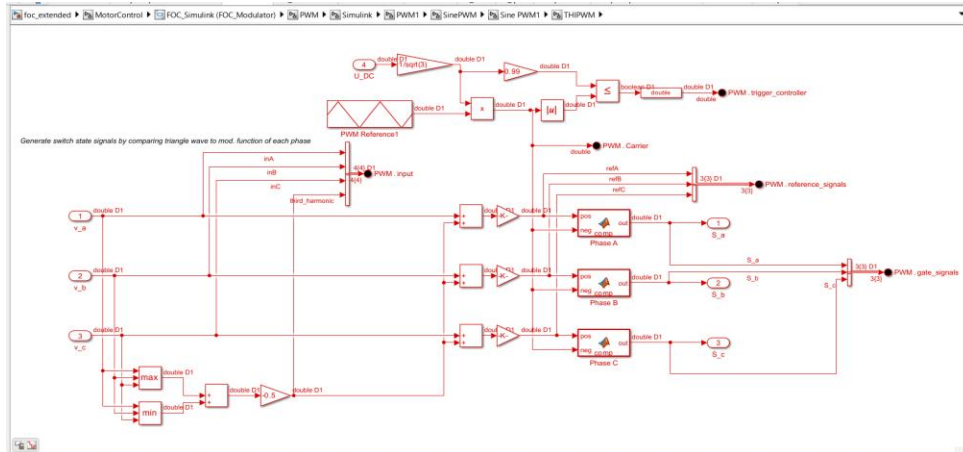
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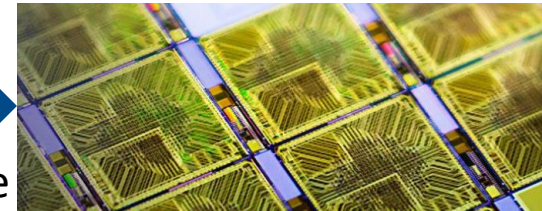
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# AMZ Racing Motor Control Deployment and Testing



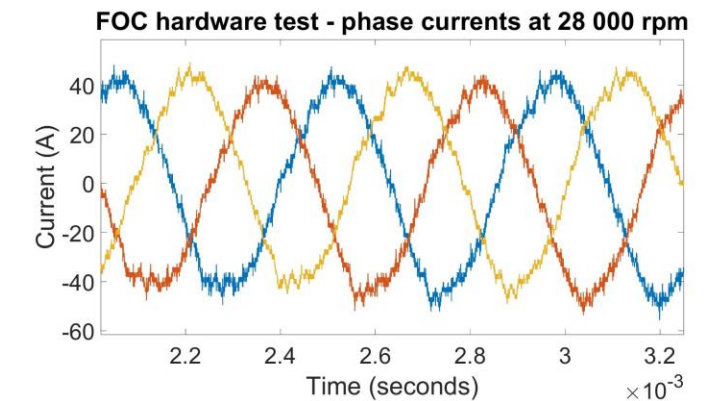
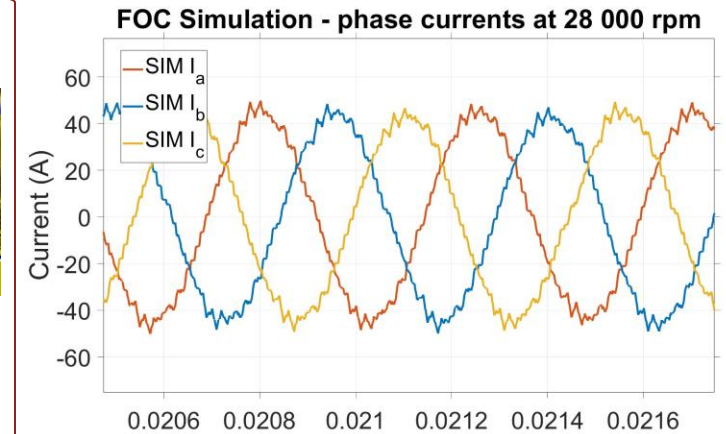
HDL Code



AMD FPGA

Simulink FOC Motor Controller Model

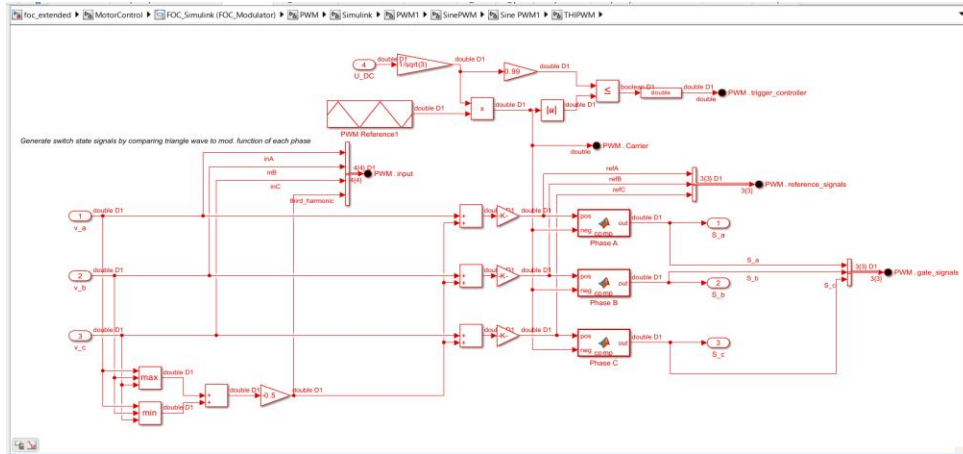
- Accuracy of the simulation model
- Realistic representation of the hardware
  - Controller gains



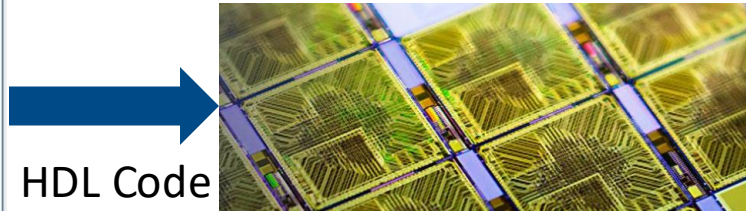
Comparison of FOC simulation and hardware test



# AMZ Racing Motor Control Deployment and Testing

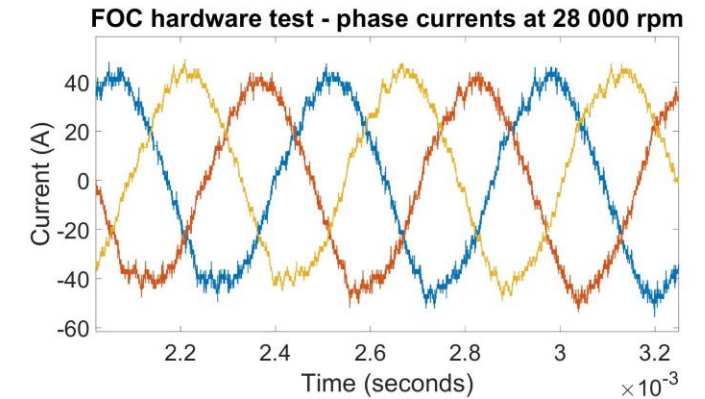
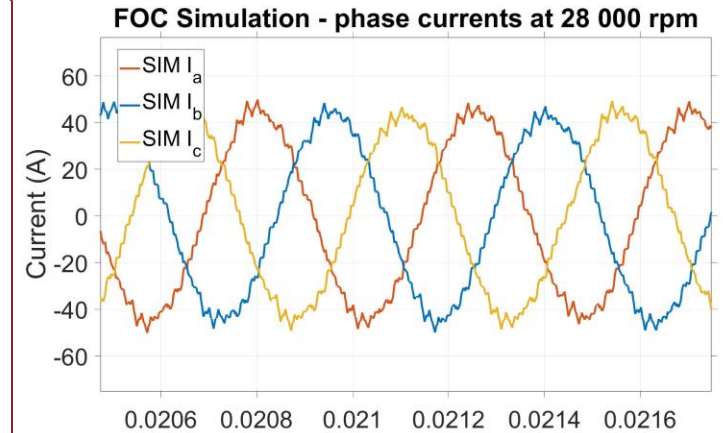


Simulink FOC Motor Controller Model

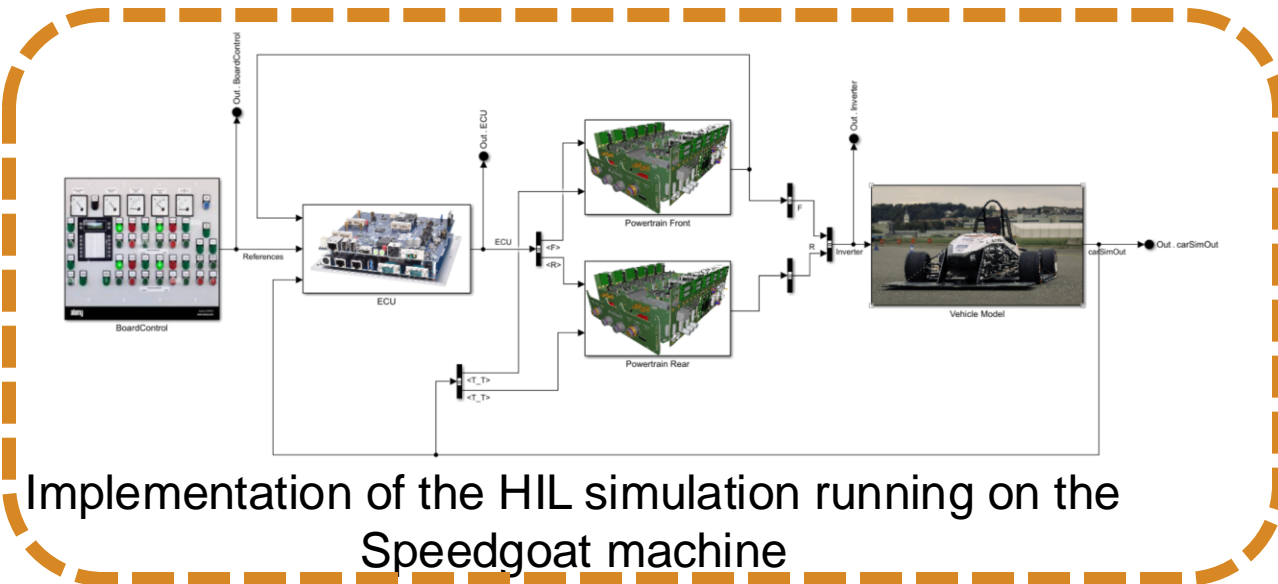


HDL Code

AMD FPGA



Comparison of FOC simulation and hardware test



Implementation of the HIL simulation running on the Speedgoat machine

# Validation and Testing

## Vehicle Dynamics

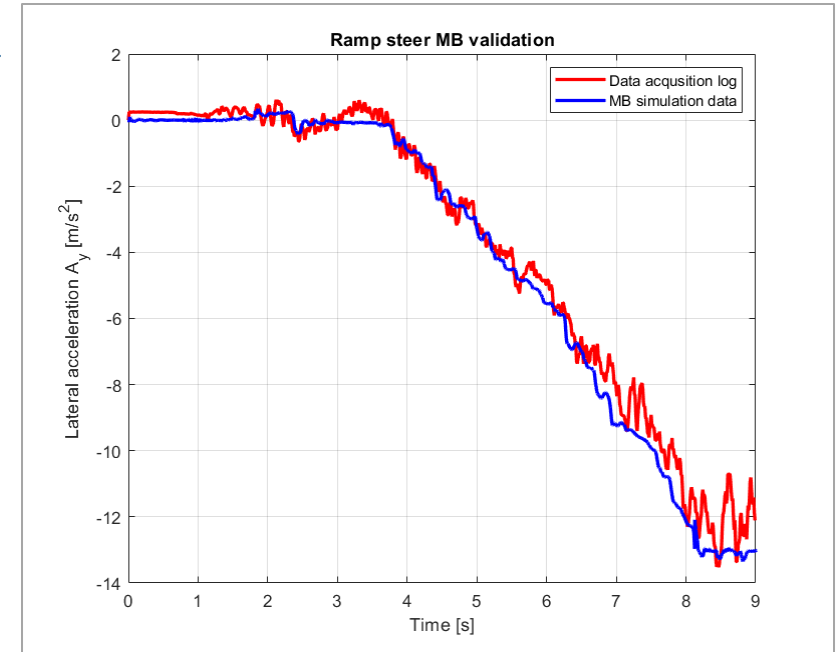
### Track Test



Simulation



Driver-in-the-Loop



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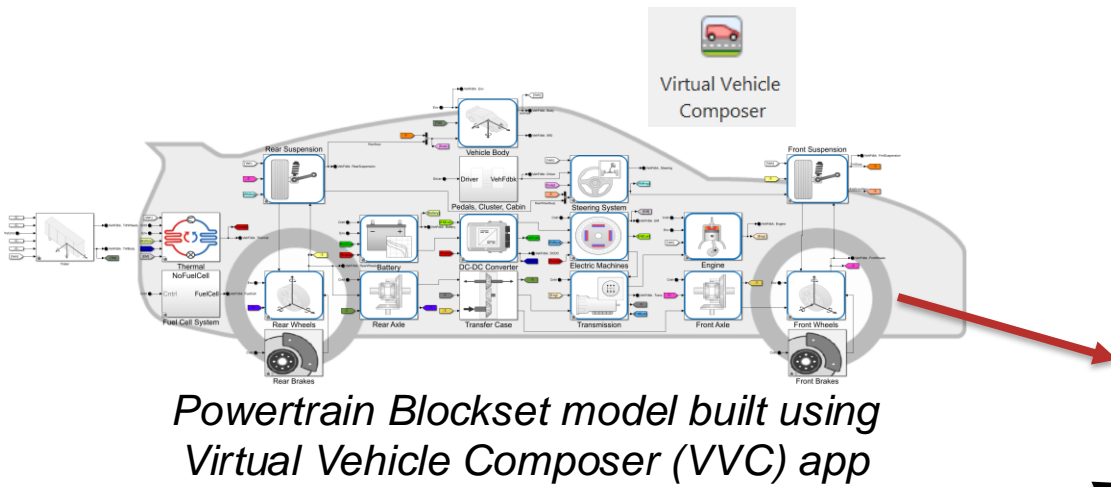
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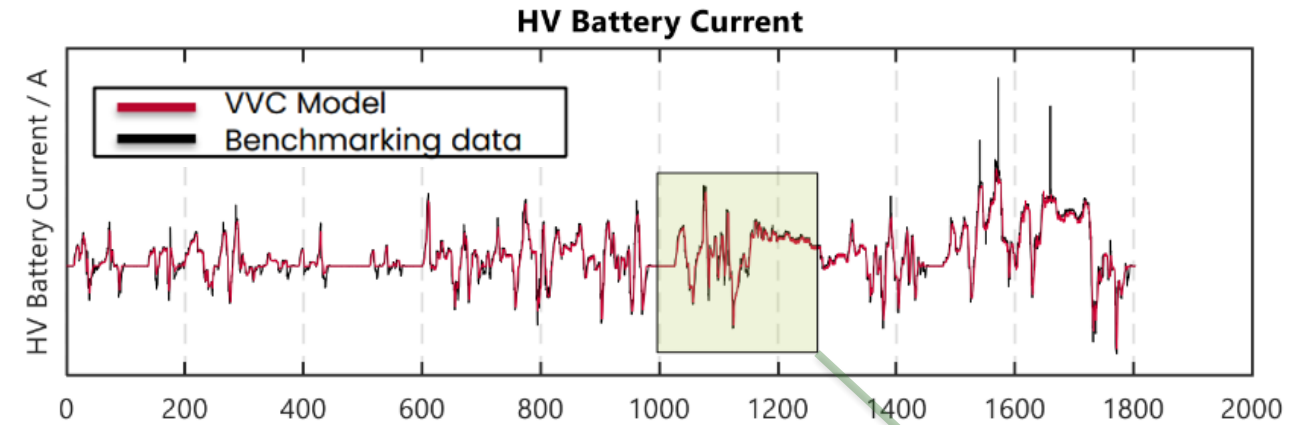


# FEV parameterizes and benchmarks VVC generated vehicle models



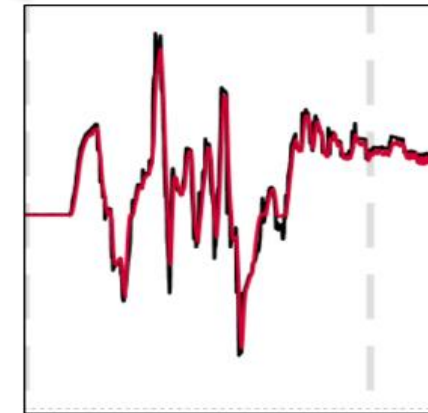
Benchmarking data

**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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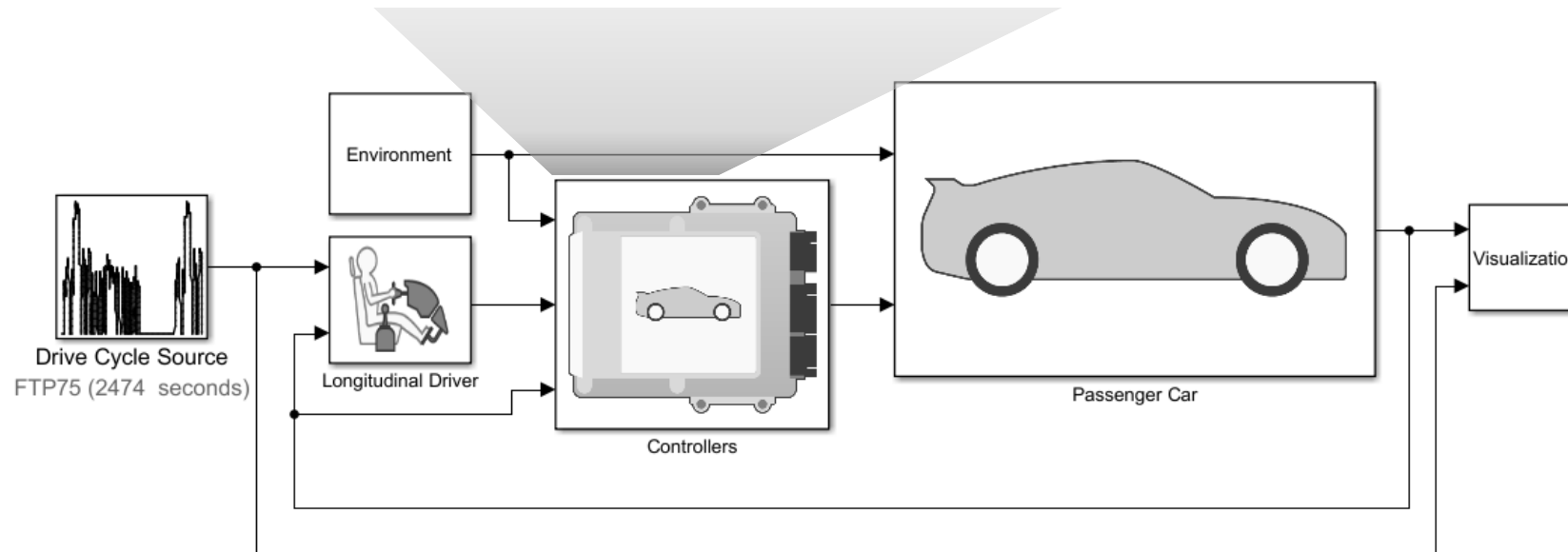
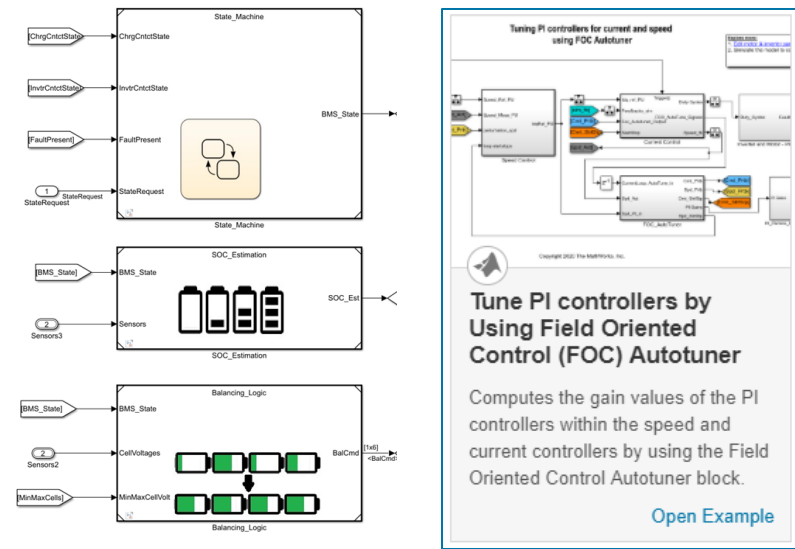
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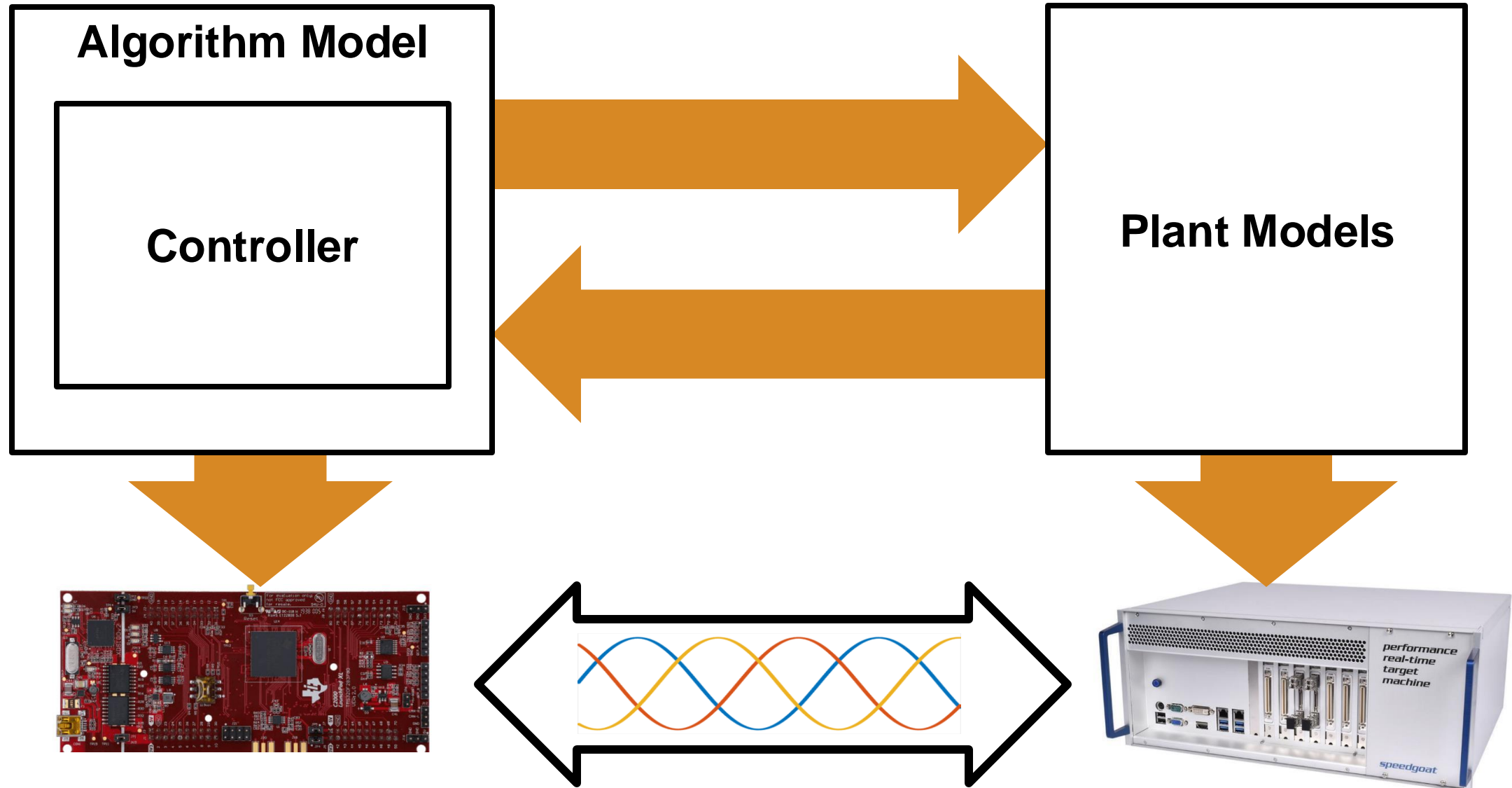
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# Validation Workflow

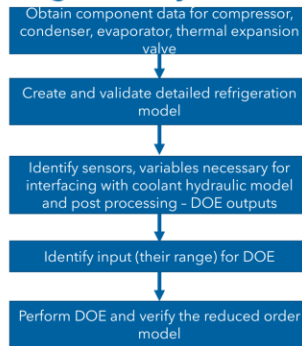


# Hardware-in-the-Loop Validation



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

## Procedure for refrigeration system modeling for HiL

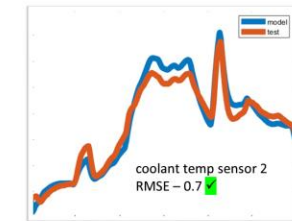
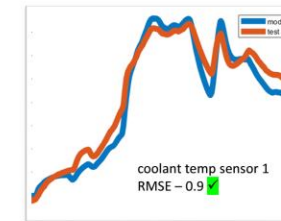


Generate data-driven Model of the chiller system



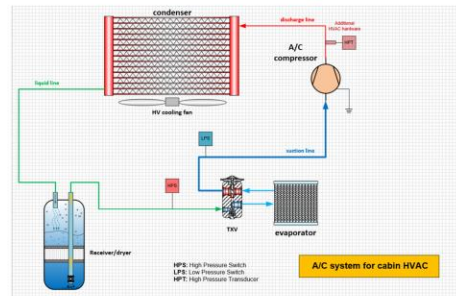
Simscape based thermal System model correlated well with the vehicle

## Vehicle Correlation

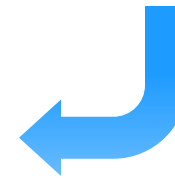


## Refrigeration model overview - Cabin Cooling

- The cabin is in thermal contact with refrigeration loop
- Refrigeration loop expels its heat to the environment
- The refrigeration loop contains four main components, an evaporator, a condenser, a compressor and an expansion valve
- Evaporator and condenser are both refrigerant to air heat exchanger

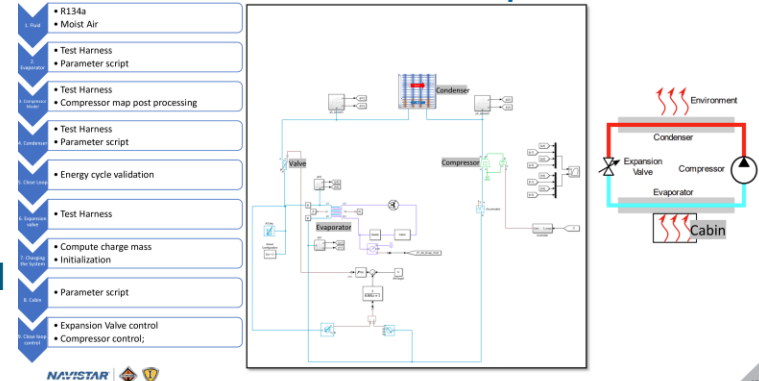


Workflow extended to The refrigeration system in cabin cooling



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

## Cabin HVAC Model Overview - Simscape v2022b

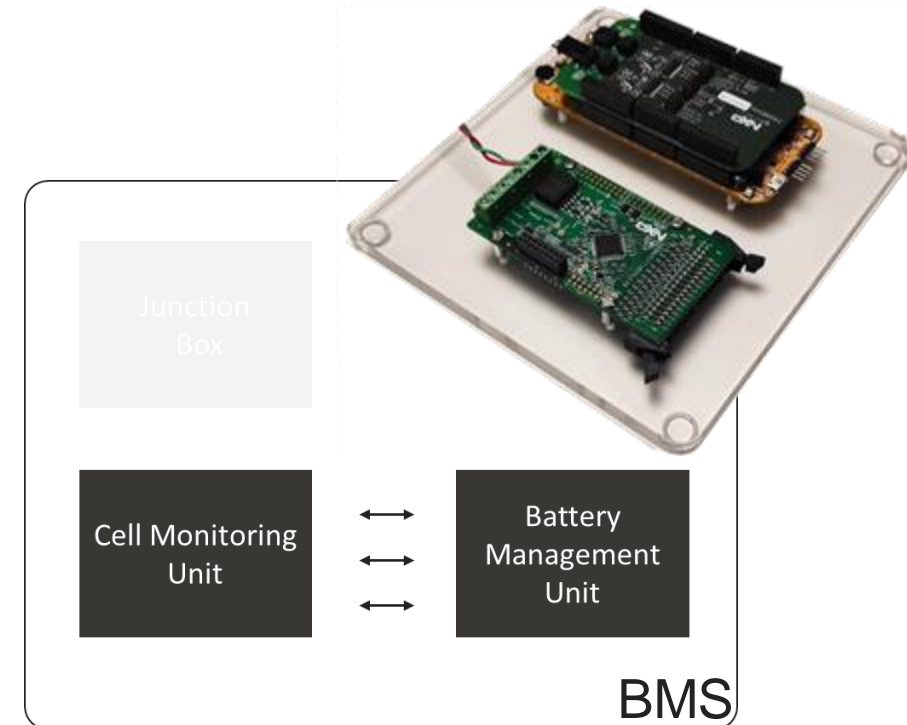


[Link to Article](#)



# HIL Testing of BMS hardware

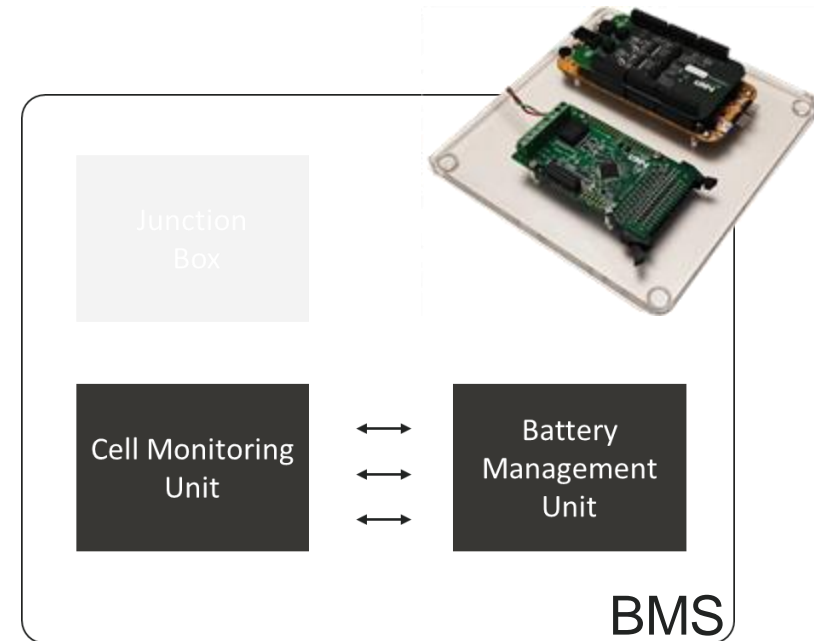
## BMS HIL System



## BMS HIL System



HIL Simulator  
Performance real-time target machine



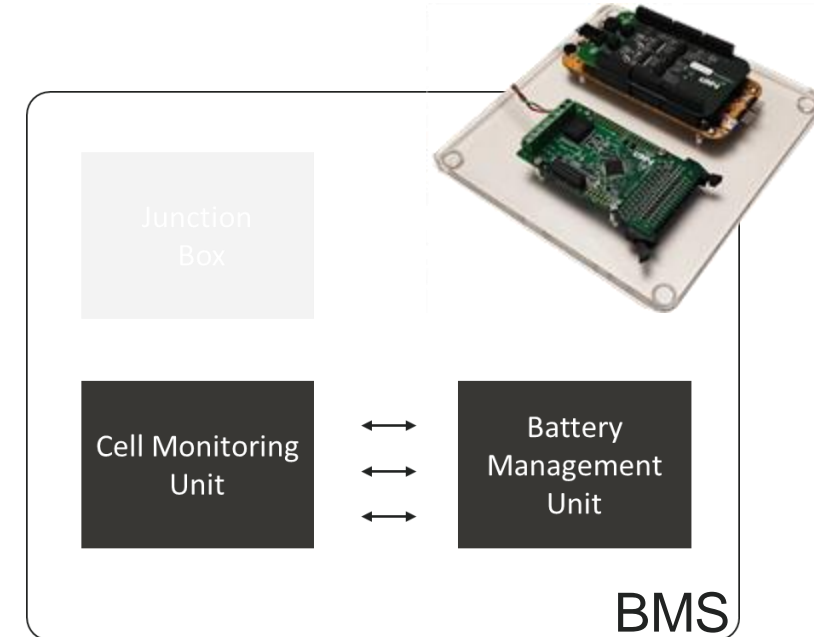
## BMS HIL System



HIL Simulator

Performance real-time target machine

Cell Emulation  
Battery Cell Emulator



## BMS HIL System

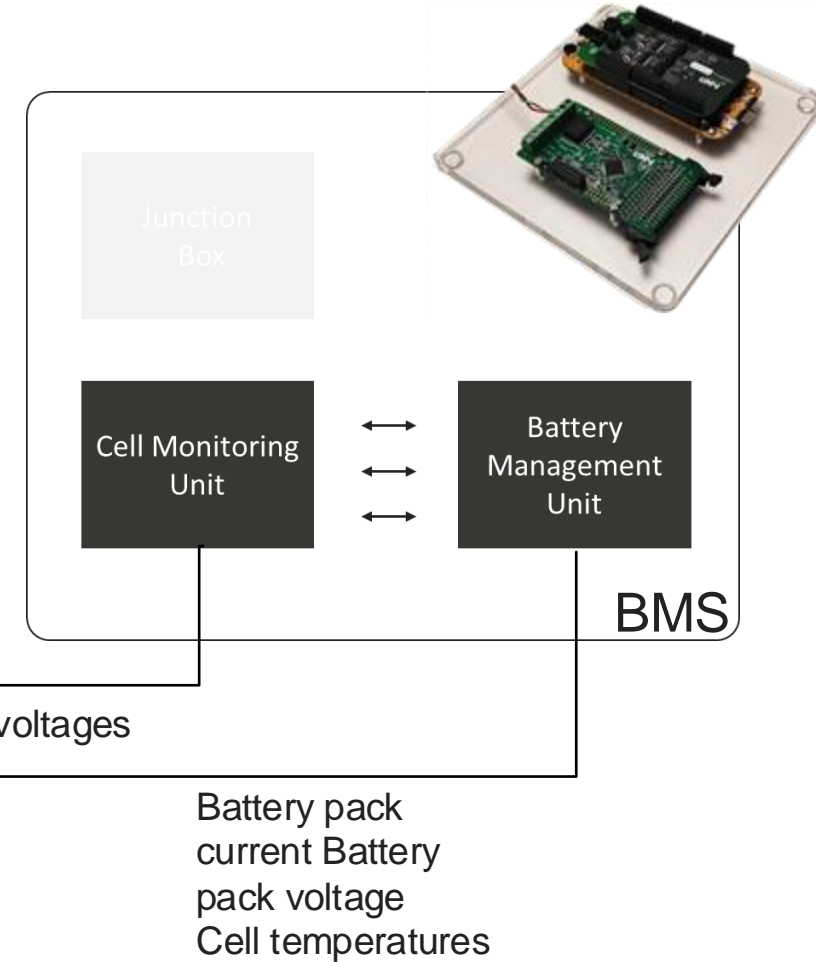


HIL Simulator

Performance real-time target machine

Cell Emulation  
Battery Cell Emulator

Measurement and  
Controller Interface



**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

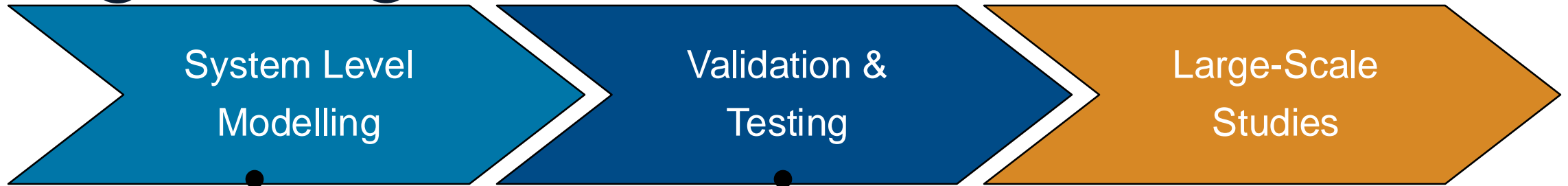
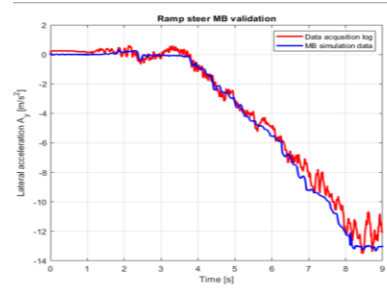
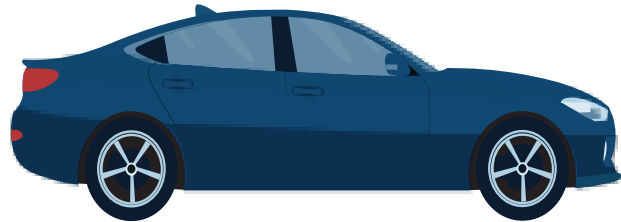


 **Leclanché**  
Energy Storage Solutions

*“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

# Key takeaways



## 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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*November 19<sup>th</sup> , 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



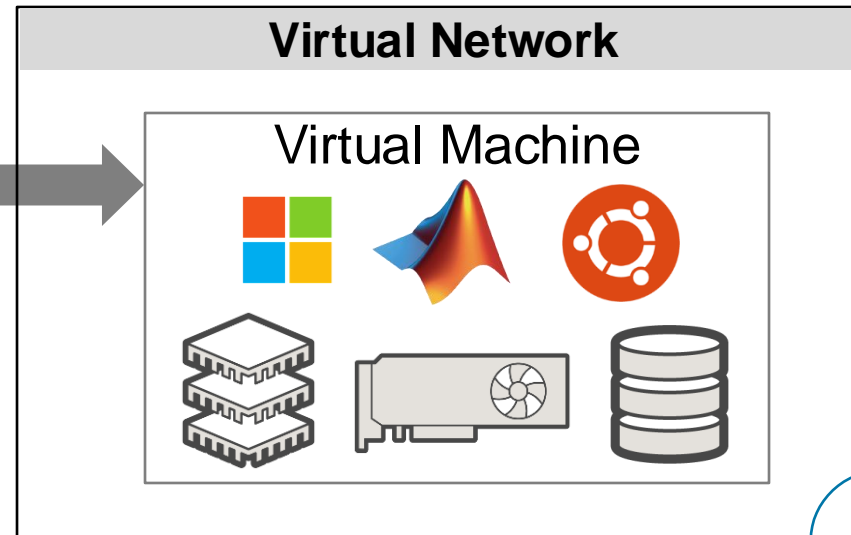
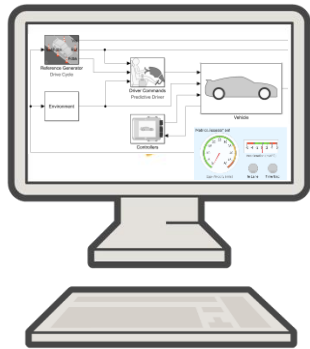
Learn more:

[Parallel Computing Toolbox](#)

[MATLAB Parallel Server](#)

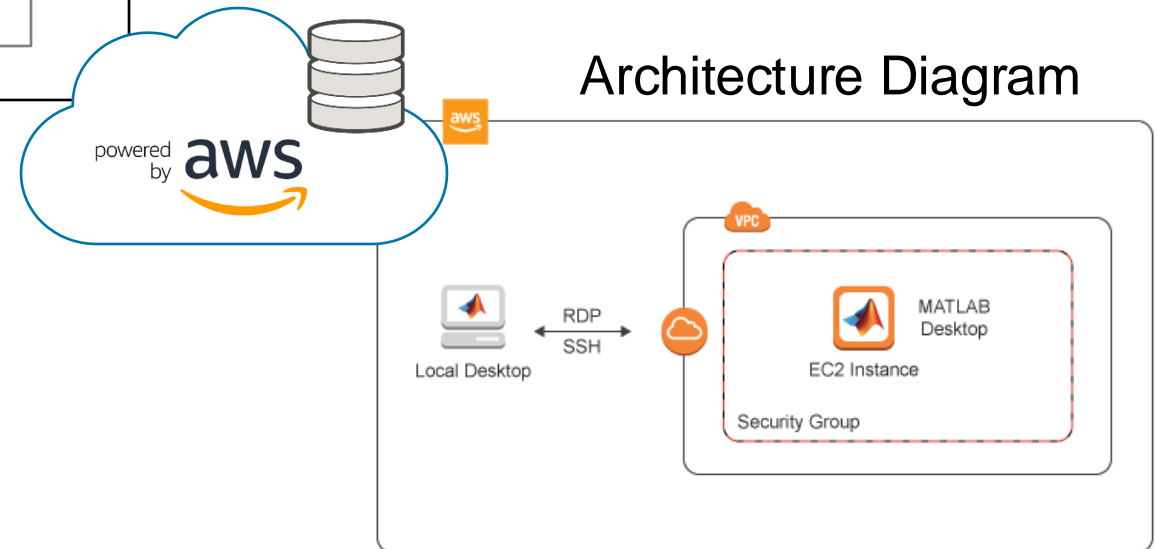
# Leveraging a Prebuilt Cloud Configuration via Reference Architecture

## Remote Desktop



- 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:

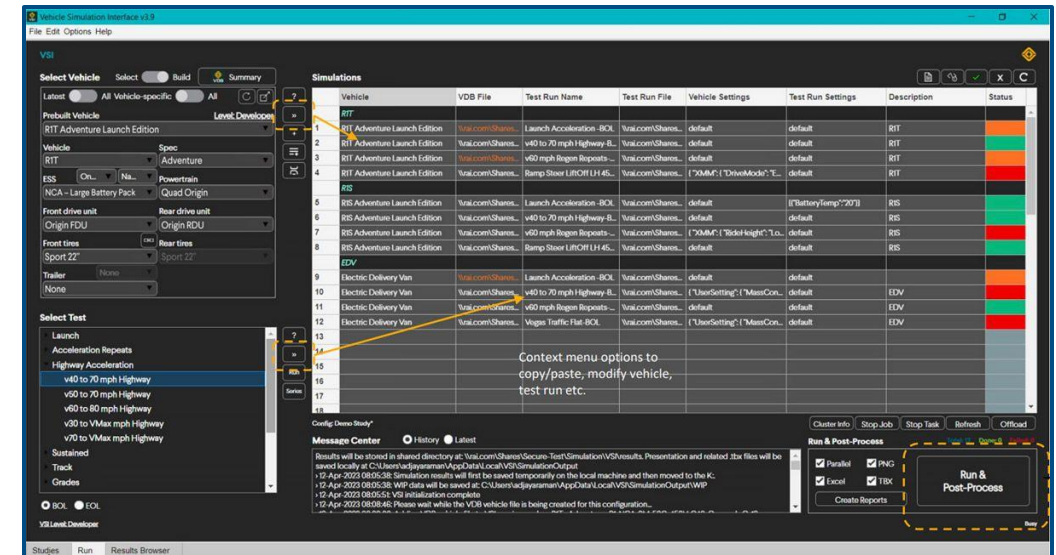
[MATLAB on Amazon Web Services \(AWS\)](#)

# 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

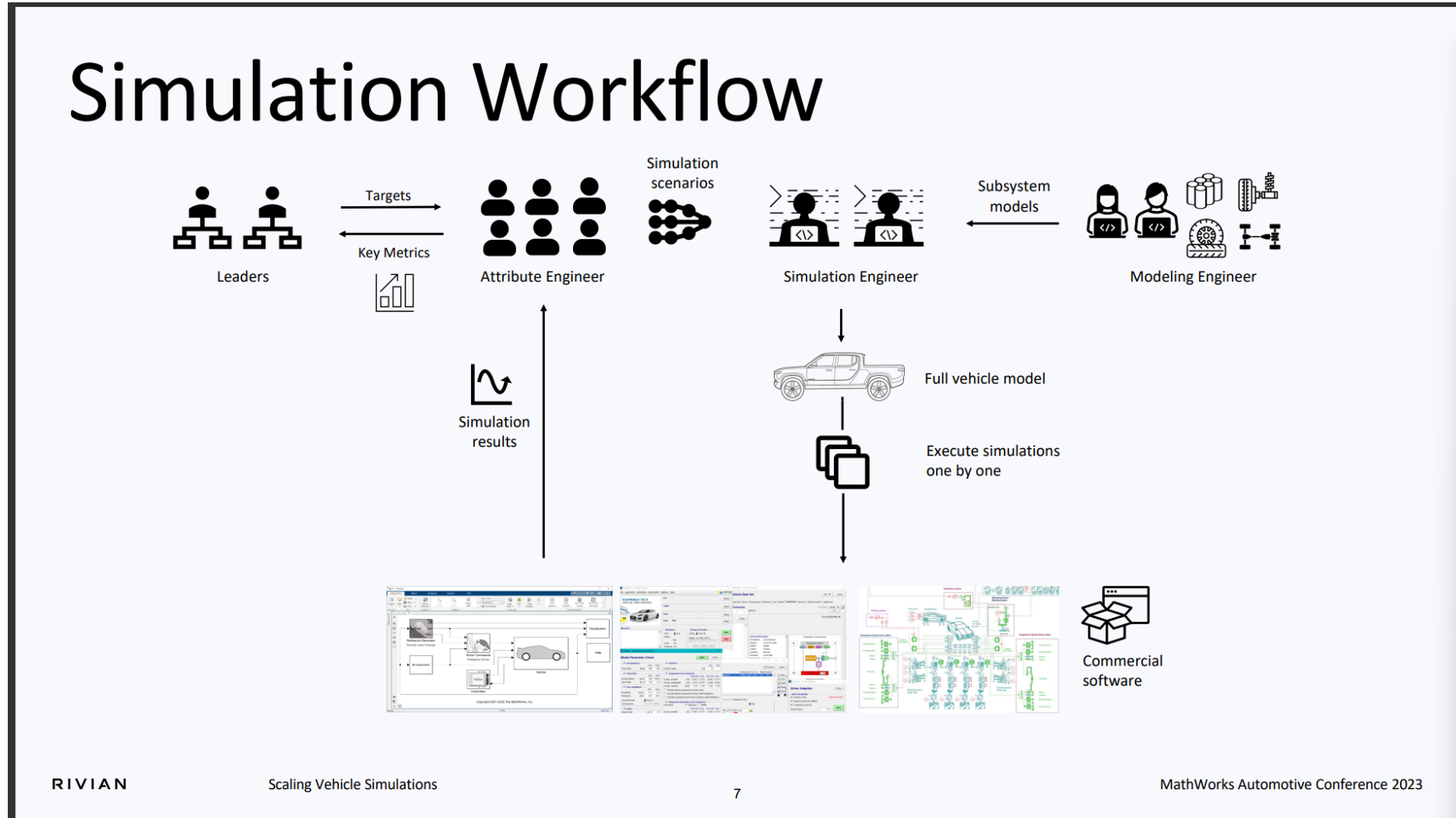
- Reduced redundancy, increased reuse, and improved throughput for simulations using MATLAB and Simulink
- VSI platform built with App Designer eliminated bottlenecks caused by multiple simulation requests
- Democratized access to simulations for engineering teams across the company



The VSI user interface.

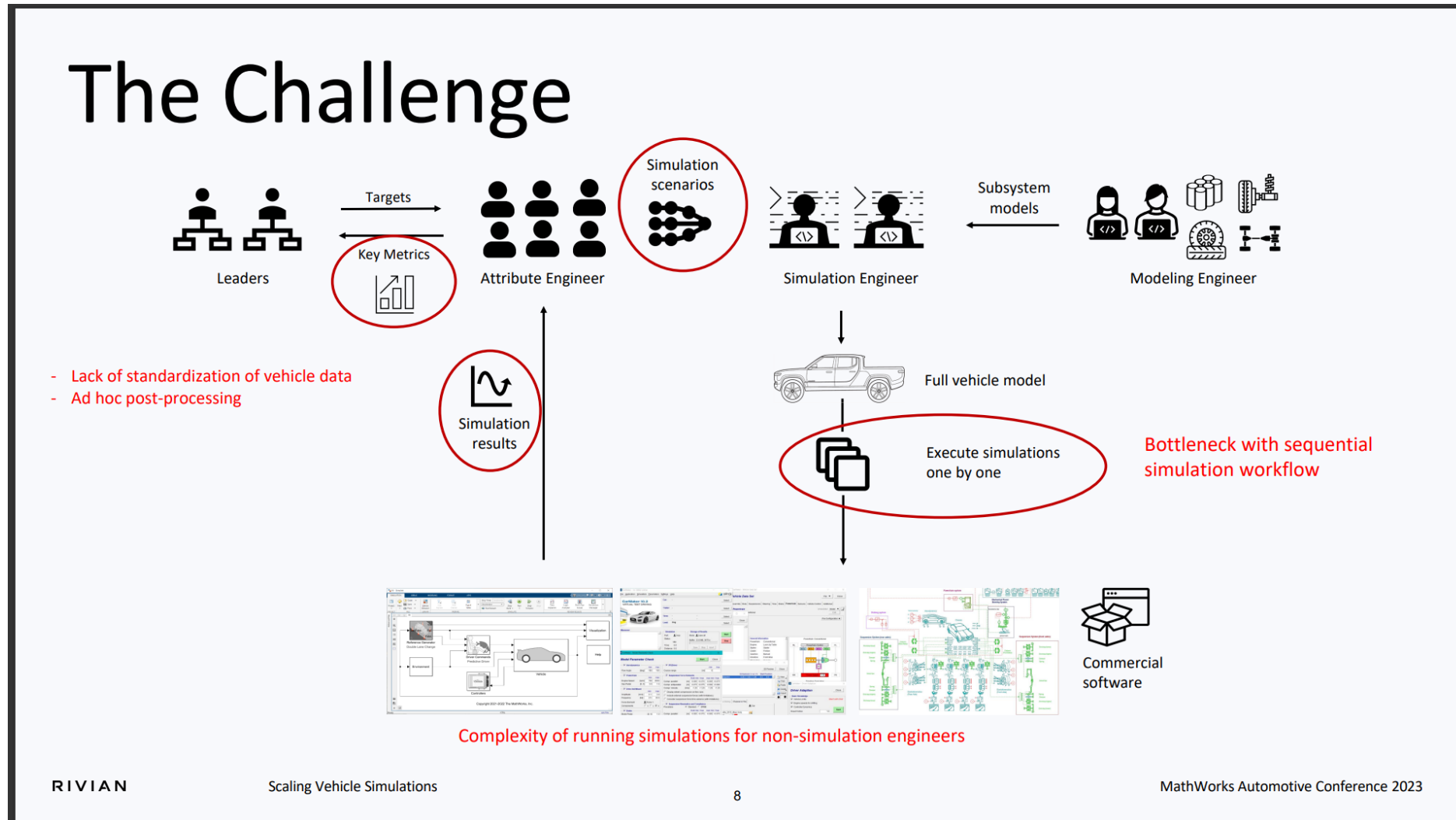
*Designing and building the Rivian Vehicle Simulation Interface platform with MATLAB and Simulink enabled us to achieve our key objectives. We created a single platform for engineers and nonengineers alike to run full-vehicle simulations, postprocess results, and create reports.*

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





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



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

## Vehicle Simulation Interface (VSI)

VSI UI built in App Designer deployed as a MATLAB toolbox or a compiled app

**Vehicle Database**

**Test run/load case selection**

**RIVIAN**

Load saved studies    Browse previous simulations

Scaling Vehicle Simulations

### Simulation Piggybacking

User A creates a simulation "study" and notices that some simulations have already been run.

| Vehicle | VDB File                     | Test Run Name              | Test Run File       | Vehicle Settings            | Test Run Settings    | Description | Status |
|---------|------------------------------|----------------------------|---------------------|-----------------------------|----------------------|-------------|--------|
| RIT     |                              |                            |                     |                             |                      |             |        |
| 1       | RIT Adventure Launch Edition | Launch Acceleration - BCL  | \\mat.com\Shares... | {UserSetting} \ "MassCon... | default              | RTT         | Green  |
| 2       | RIT Adventure Launch Edition | v40 to 70 mph Highway B... | \\mat.com\Shares... | default                     | default              | RTT         | Green  |
| 3       | RIT Adventure Launch Edition | v60 mph Region Repeats...  | \\mat.com\Shares... | default                     | default              | RTT         | Green  |
| 4       | RIT Adventure Launch Edition | Ramp Shore LIFTCH LH 45... | \\mat.com\Shares... | {ModelIdkity} \ "Susp...    | default              | RTT         | Green  |
| 5       | RIS Adventure Launch Edition | Launch Acceleration - BCL  | \\mat.com\Shares... | default                     | {BatteryTemp} \ "20" | RIS         | Red    |
| 6       | RIS Adventure Launch Edition | v40 to 70 mph Highway B... | \\mat.com\Shares... | {ModelIdkity} \ "Susp...    | default              | RIS         | Red    |
| 7       | RIS Adventure Launch Edition | v60 mph Region Repeats...  | \\mat.com\Shares... | default                     | default              | RIS         | Red    |
| 8       | RIS Adventure Launch Edition | Ramp Shore LIFTCH LH 45... | \\mat.com\Shares... | {ModelIdkity} \ "Susp...    | default              | RIS         | Red    |
| EDV     |                              |                            |                     |                             |                      |             |        |
| 9       | Electric Delivery Van        | Launch Acceleration - BCL  | \\mat.com\Shares... | default                     | default              | EDV         | Green  |
| 10      | Electric Delivery Van        | v40 to 70 mph Highway B... | \\mat.com\Shares... | {ModelIdkity} \ "Susp...    | default              | EDV         | Green  |
| 11      | Electric Delivery Van        | v60 mph Region Repeats...  | \\mat.com\Shares... | default                     | default              | EDV         | Green  |
| 12      | Electric Delivery Van        | Veget Traffic Flat - BCL   | \\mat.com\Shares... | default                     | default              | EDV         | Green  |
| 13      |                              |                            |                     |                             |                      |             |        |
| 14      |                              |                            |                     |                             |                      |             |        |

User A only runs the red and amber simulations from this study

| Vehicle | VDB File                     | Test Run Name              | Test Run File       | Vehicle Settings            | Test Run Settings    | Description | Status |
|---------|------------------------------|----------------------------|---------------------|-----------------------------|----------------------|-------------|--------|
| 1       | RIT Adventure Launch Edition | Launch Acceleration - BCL  | \\mat.com\Shares... | {UserSetting} \ "MassCon... | default              | RTT         | Green  |
| 2       | RIT Adventure Launch Edition | v40 to 70 mph Highway B... | \\mat.com\Shares... | default                     | default              | RTT         | Green  |
| 3       | RIT Adventure Launch Edition | v60 mph Region Repeats...  | \\mat.com\Shares... | default                     | default              | RTT         | Green  |
| 4       | RIT Adventure Launch Edition | Ramp Shore LIFTCH LH 45... | \\mat.com\Shares... | {ModelIdkity} \ "Susp...    | default              | RTT         | Green  |
| 5       | RIS Adventure Launch Edition | Launch Acceleration - BCL  | \\mat.com\Shares... | default                     | {BatteryTemp} \ "20" | RIS         | Red    |
| 6       | RIS Adventure Launch Edition | v40 to 70 mph Highway B... | \\mat.com\Shares... | {ModelIdkity} \ "Susp...    | default              | RIS         | Red    |
| 7       | RIS Adventure Launch Edition | v60 mph Region Repeats...  | \\mat.com\Shares... | default                     | default              | RIS         | Red    |
| 8       | RIS Adventure Launch Edition | Ramp Shore LIFTCH LH 45... | \\mat.com\Shares... | {ModelIdkity} \ "Susp...    | default              | RIS         | Red    |
| EDV     |                              |                            |                     |                             |                      |             |        |
| 9       | Electric Delivery Van        | Launch Acceleration - BCL  | \\mat.com\Shares... | default                     | default              | EDV         | Green  |
| 10      | Electric Delivery Van        | v40 to 70 mph Highway B... | \\mat.com\Shares... | {ModelIdkity} \ "Susp...    | default              | EDV         | Green  |
| 11      | Electric Delivery Van        | v60 mph Region Repeats...  | \\mat.com\Shares... | default                     | default              | EDV         | Green  |
| 12      | Electric Delivery Van        | Veget Traffic Flat - BCL   | \\mat.com\Shares... | default                     | default              | EDV         | Green  |
| 13      |                              |                            |                     |                             |                      |             |        |
| 14      |                              |                            |                     |                             |                      |             |        |

User A saves time taken to run 5 out of 12 simulations in his study that were previously simulated by other users.

User B works in EST. User B configures a study and notices that most of the simulations have been simulated by User A. User B creates two additional simulations for towing studies.

| Vehicle | VDB File                        | Test Run Name              | Test Run File       | Vehicle Settings            | Test Run Settings    | Description | Status |
|---------|---------------------------------|----------------------------|---------------------|-----------------------------|----------------------|-------------|--------|
| RIT     |                                 |                            |                     |                             |                      |             |        |
| 1       | RIT Adventure Launch Edition    | Launch Acceleration - BCL  | \\mat.com\Shares... | {UserSetting} \ "MassCon... | default              | RTT         | Green  |
| 2       | RIT Adventure Launch Edition    | v40 to 70 mph Highway B... | \\mat.com\Shares... | default                     | default              | RTT         | Green  |
| 3       | RIS Adventure Launch Edition    | Launch Acceleration - BCL  | \\mat.com\Shares... | default                     | {BatteryTemp} \ "20" | RIS         | Red    |
| 4       | RIS Adventure Launch Edition    | v40 to 70 mph Highway B... | \\mat.com\Shares... | default                     | default              | RIS         | Red    |
| 5       | RIT Adventure + 1000 lb Trailer | v50 to 70 mph Highway B... | \\mat.com\Shares... | {DMM} \ "DriveMode" \ "T... | default              | RTT         | Red    |
| 6       | RIS + 7000 lb Trailer           | v50 to 70 mph Highway B... | \\mat.com\Shares... | default                     | default              | RTT         | Red    |

User B saves time taken to run 4 out of 6 simulations in his study that were previously simulated by other users including user A.

User C works in PST. User C configures a study and finds that ALL simulations have been completed. User C goes ahead with analyzing the data and creating reports.

| Vehicle | VDB File                        | Test Run Name              | Test Run File       | Vehicle Settings            | Test Run Settings | Description | Status |
|---------|---------------------------------|----------------------------|---------------------|-----------------------------|-------------------|-------------|--------|
| RIT     |                                 |                            |                     |                             |                   |             |        |
| 1       | RIT Adventure Launch Edition    | Launch Acceleration - BCL  | \\mat.com\Shares... | {UserSetting} \ "MassCon... | default           | RTT         | Green  |
| 2       | RIT Adventure Launch Edition    | v40 to 70 mph Highway B... | \\mat.com\Shares... | default                     | default           | RTT         | Green  |
| 3       | RIT Adventure Launch Edition    | v60 mph Region Repeats...  | \\mat.com\Shares... | default                     | default           | RTT         | Green  |
| 4       | RIT Adventure + 1000 lb Trailer | v50 to 70 mph Highway B... | \\mat.com\Shares... | default                     | default           | RTT         | Green  |
| 5       |                                 |                            |                     |                             |                   |             |        |
| 6       |                                 |                            |                     |                             |                   |             |        |
| 7       |                                 |                            |                     |                             |                   |             |        |
| 8       |                                 |                            |                     |                             |                   |             |        |
| 9       |                                 |                            |                     |                             |                   |             |        |
| 10      |                                 |                            |                     |                             |                   |             |        |
| 11      |                                 |                            |                     |                             |                   |             |        |
| 12      |                                 |                            |                     |                             |                   |             |        |
| 13      |                                 |                            |                     |                             |                   |             |        |
| 14      |                                 |                            |                     |                             |                   |             |        |

User A does not run any new simulations. Uses existing results and post-processes.

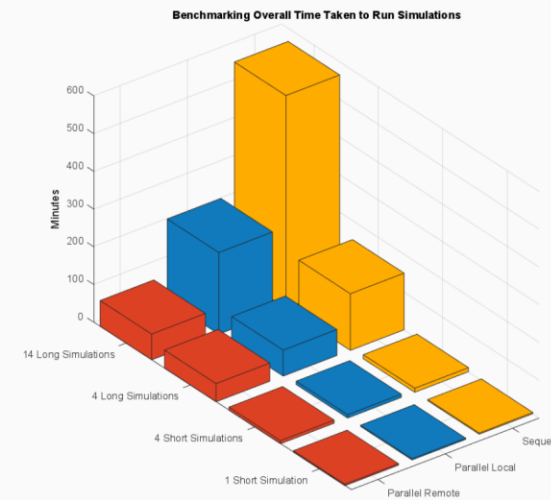
[Link to article](#)

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

## Overhead vs Simulation Time



## Time Taken to Run Simulations



- Sequential is fastest for single short simulations
- Parallel simulations on cluster is best when running multiple long simulations
- Parallel local is best suited for developers testing changes to models

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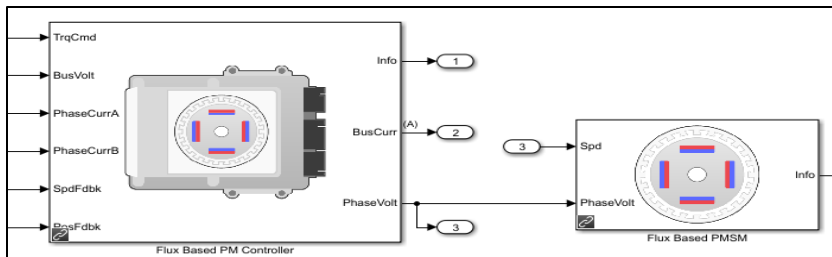
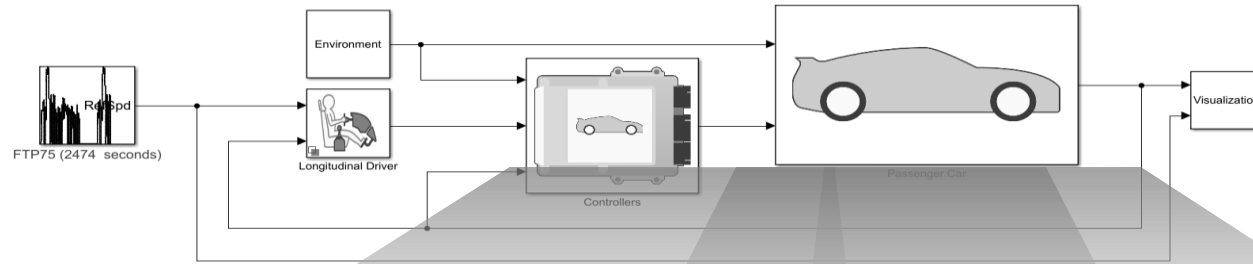
*November 19<sup>th</sup> , Pune*

# **Tech Talk: Virtual Vehicle: Transforming Vehicle Engineering Through Simulation**

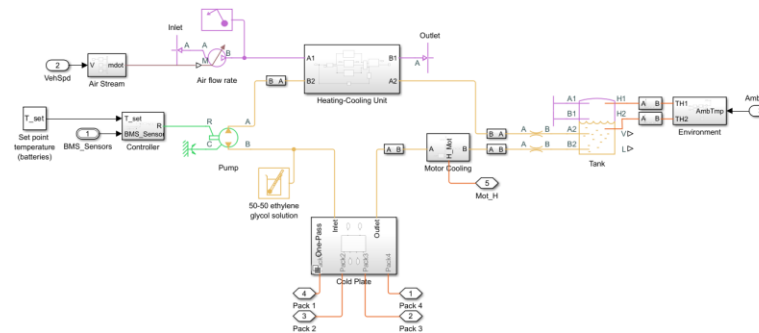




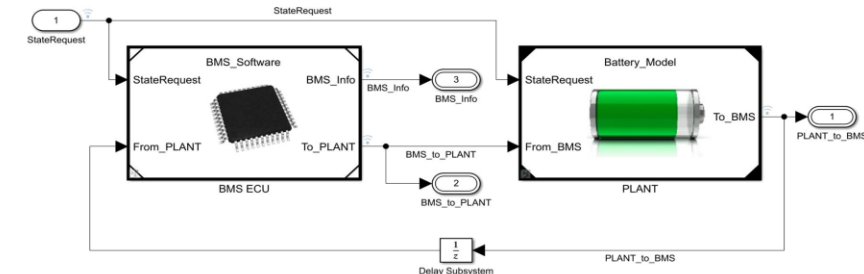
# Integrating Components models with System Level Model



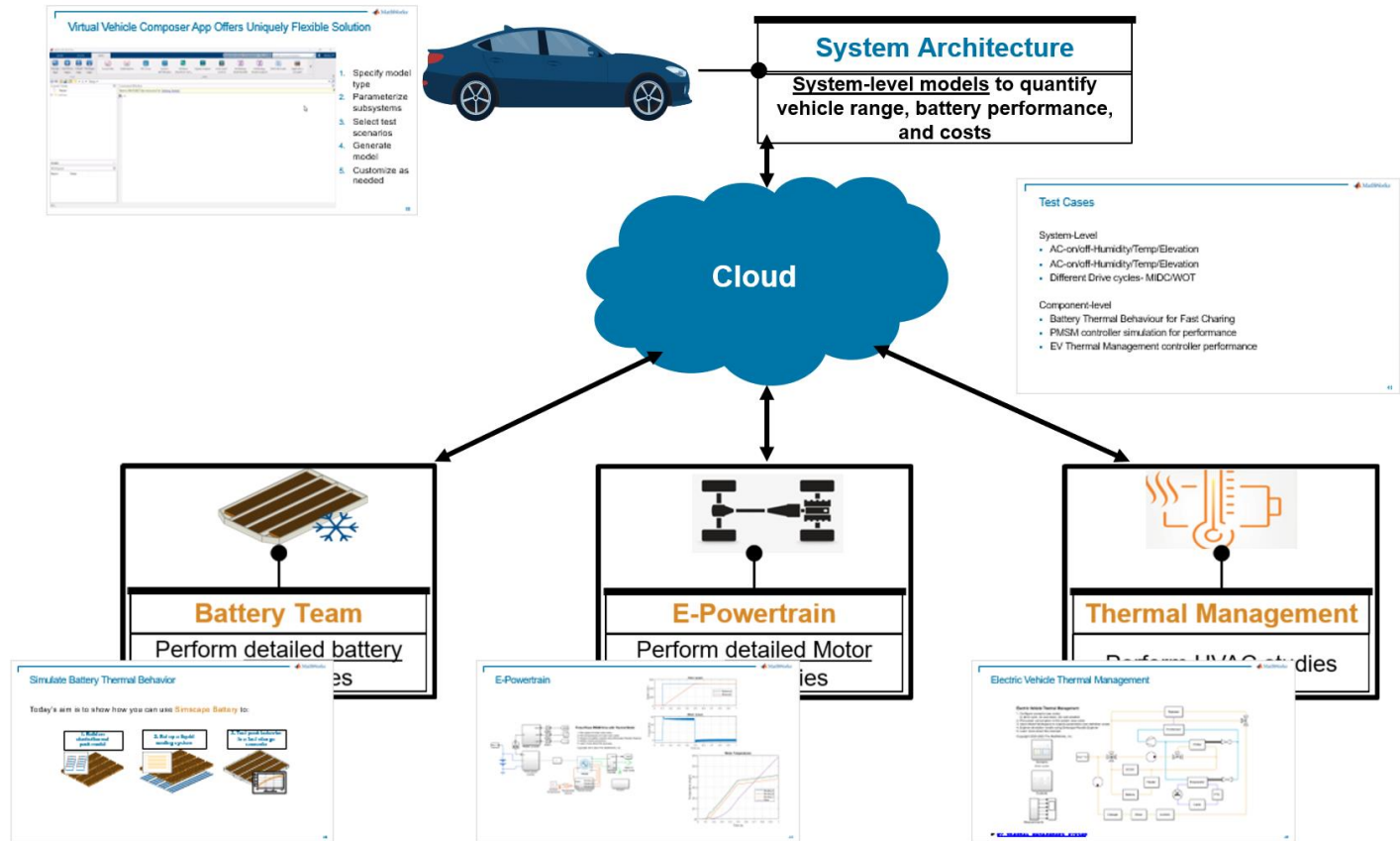
Motor and MCU



Thermal Management System



Battery and BMS



**Test Cases**

Component-level

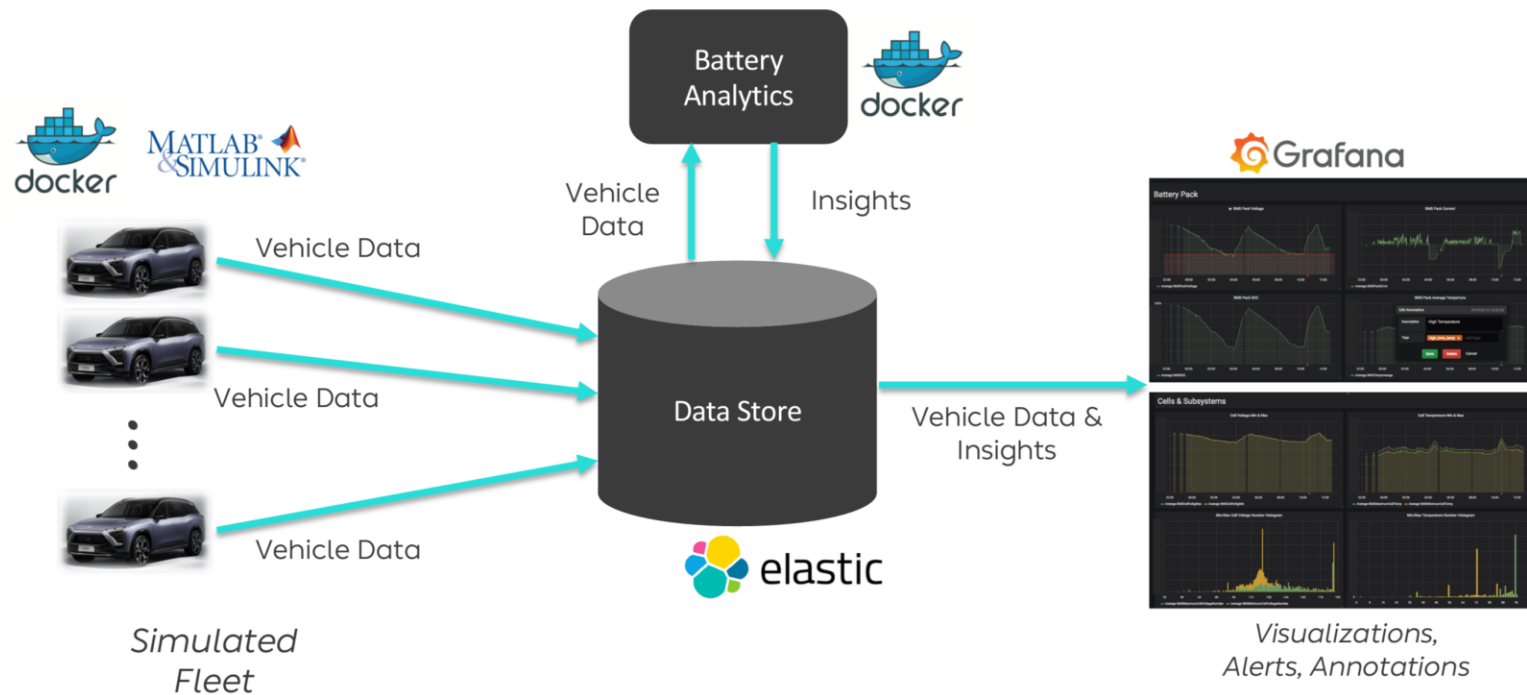
- Battery Thermal Behaviour for Fast Charging
- PMSM controller simulation for performance
- EV Thermal Management controller performance

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

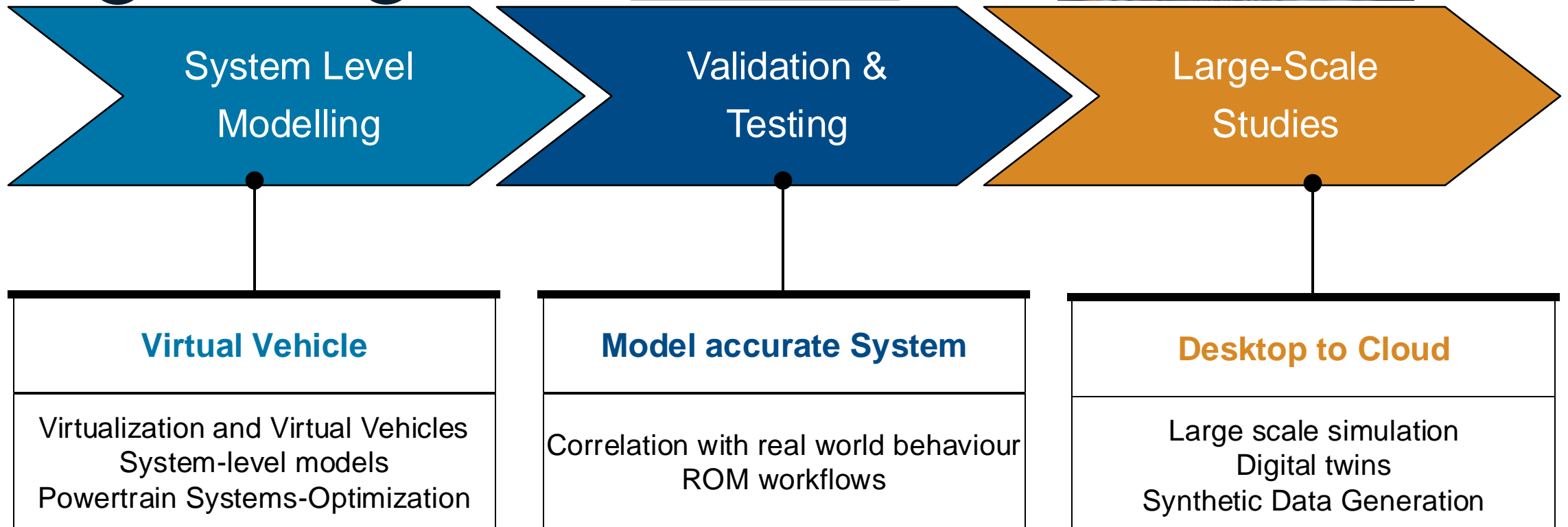
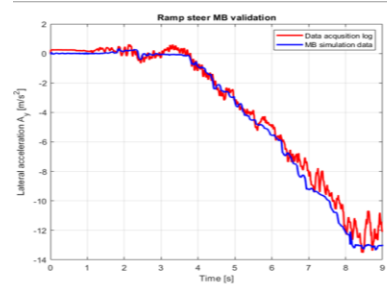
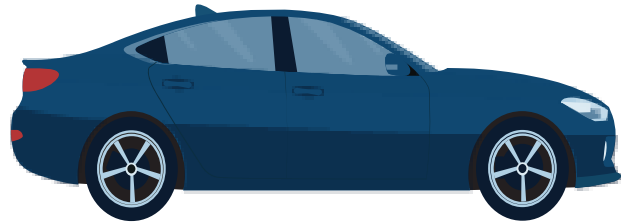
Developing EV Components Using Virtualization and Scaling to the Cloud

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

## Cloud-based Architecture



# Key takeaways





# Q&A

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**Thank you**



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