MathWorks
AUTOMOTIVE CONFERENCE 2024
North America

Electric Vehicle Chassis Modeling and Control Applications

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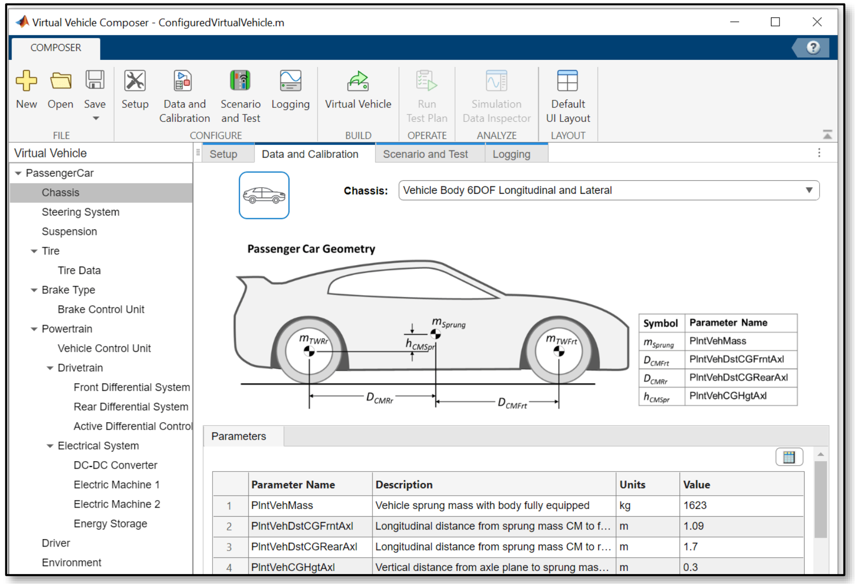
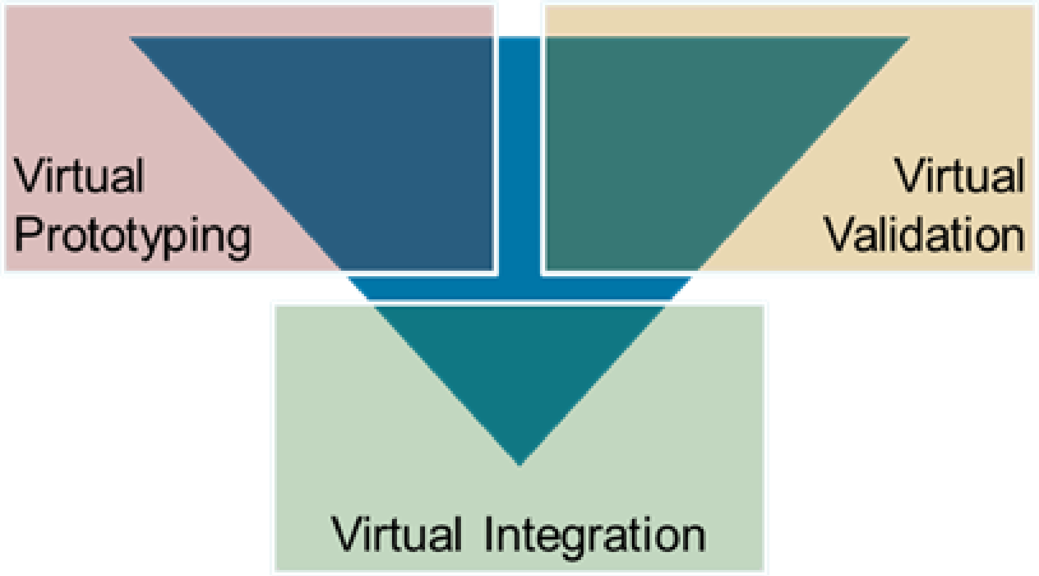
Key Take Aways

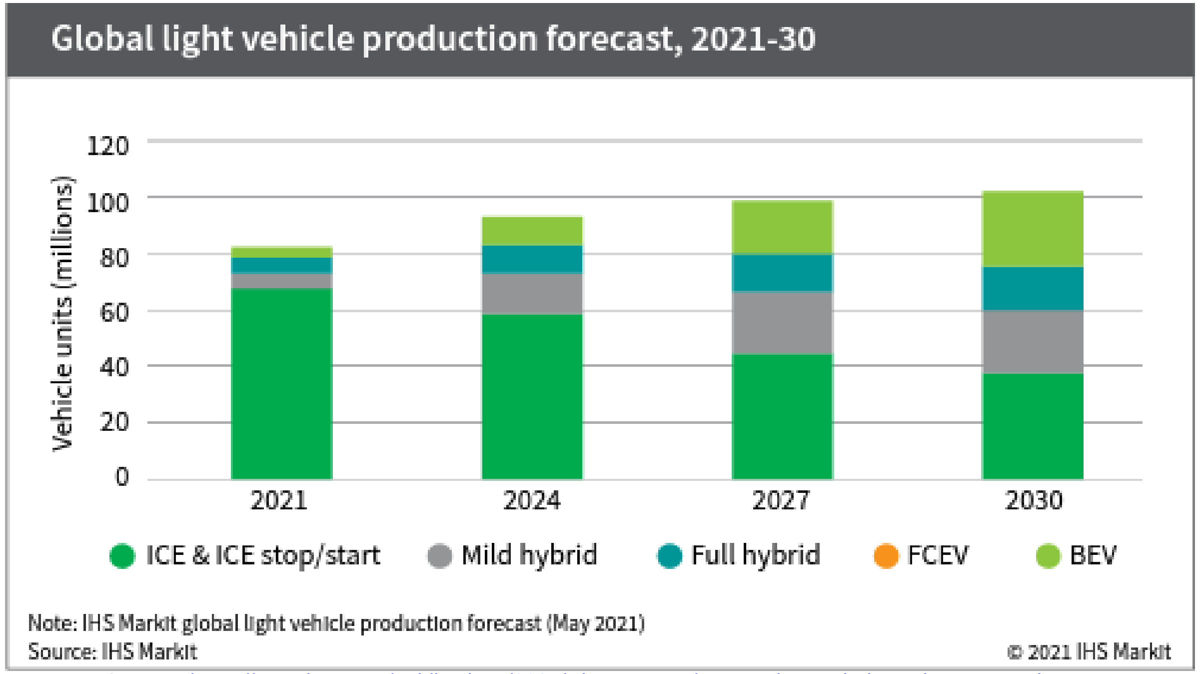
- **MathWorks tools** can be used for *chassis control development* through the whole *development cycle*
- **Virtual Vehicle Composer App** provides the framework *for flexible vehicle modeling and control development*
- **Integrated Chassis Control** can be used to coordinate multiple chassis actuators for *improved vehicle performance, safety and comfort*





EV Trends in Automotive

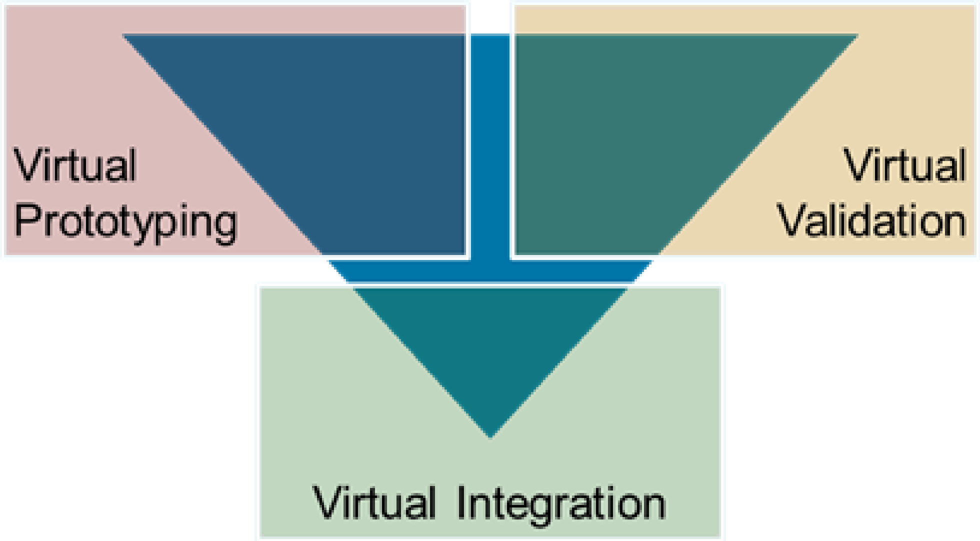
- As EV market grows, new technologies are becoming commonplace
  - Elector-hydraulic/electro-mechanical brakes
  - Active and semi-active suspension
  - Multi-wheel independent steering
  - Multiple electric motors
- Areas of focus for EV vehicle performance
  - Longitudinal dynamics
    - Energy optimization of multiple motors
  - Lateral dynamics
    - Stability control
    - Torque vectoring



Source : https://www.bcg.com/publications/2021/why-evs-need-to-accelerate-their-market-penetration

Early Virtual Vehicle Development

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



- Common challenges

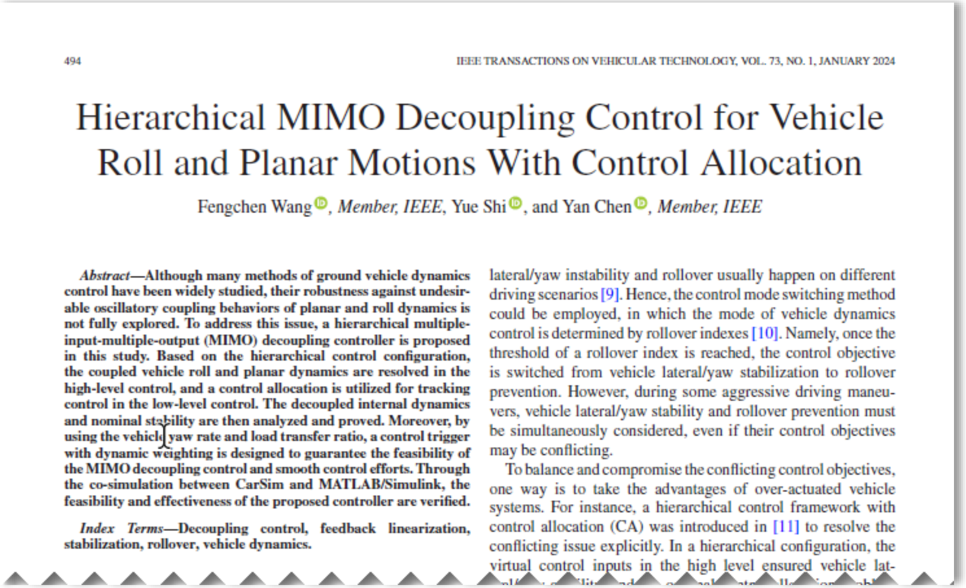
Access to "right level" **fidelity** models across organization

Integration of both **physics** and **software** models

Deploying models to users who **aren't tool experts**

Case Study: Integrated Chassis Control

- Case Study: Intelligent integrated chassis control (ICC)
  - Coordinates multiple chassis actuators to improve *roll stability* and *vehicle performance*
    - Front and rear steering
    - Multiple electric motors
  - *Multi-objective* control
    - Roll
    - Lateral Velocity
    - Yaw rate
  - Multiple ways to meet targets
    - How to dictate between actuators?



494 IEEE TRANSACTIONS ON VEHICULAR TECHNOLOGY, VOL. 73, NO. 1, JANUARY 2024

Hierarchical MIMO Decoupling Control for Vehicle Roll and Planar Motions With Control Allocation

Fengchen Wang, *Member, IEEE*, Yue Shi, and Yan Chen, *Member, IEEE*

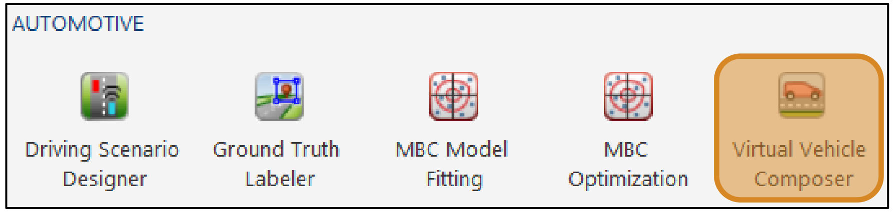
***Abstract*—Although many methods of ground vehicle dynamics control have been widely studied, their robustness against undesirable oscillatory coupling behaviors of planar and roll dynamics is not fully explored. To address this issue, a hierarchical multiple-input-multiple-output (MIMO) decoupling controller is proposed in this study. Based on the hierarchical control configuration, the coupled vehicle roll and planar dynamics are resolved in the high-level control, and a control allocation is utilized for tracking control in the low-level control. The decoupled internal dynamics and nominal stability are then analyzed and proved. Moreover, by using the vehicle yaw rate and load transfer ratio, a control trigger with dynamic weighting is designed to guarantee the feasibility of the MIMO decoupling control and smooth control efforts. Through the co-simulation between CarSim and MATLAB/Simulink, the feasibility and effectiveness of the proposed controller are verified.**

***Index Terms*—Decoupling control, feedback linearization, stabilization, rollover, vehicle dynamics.**

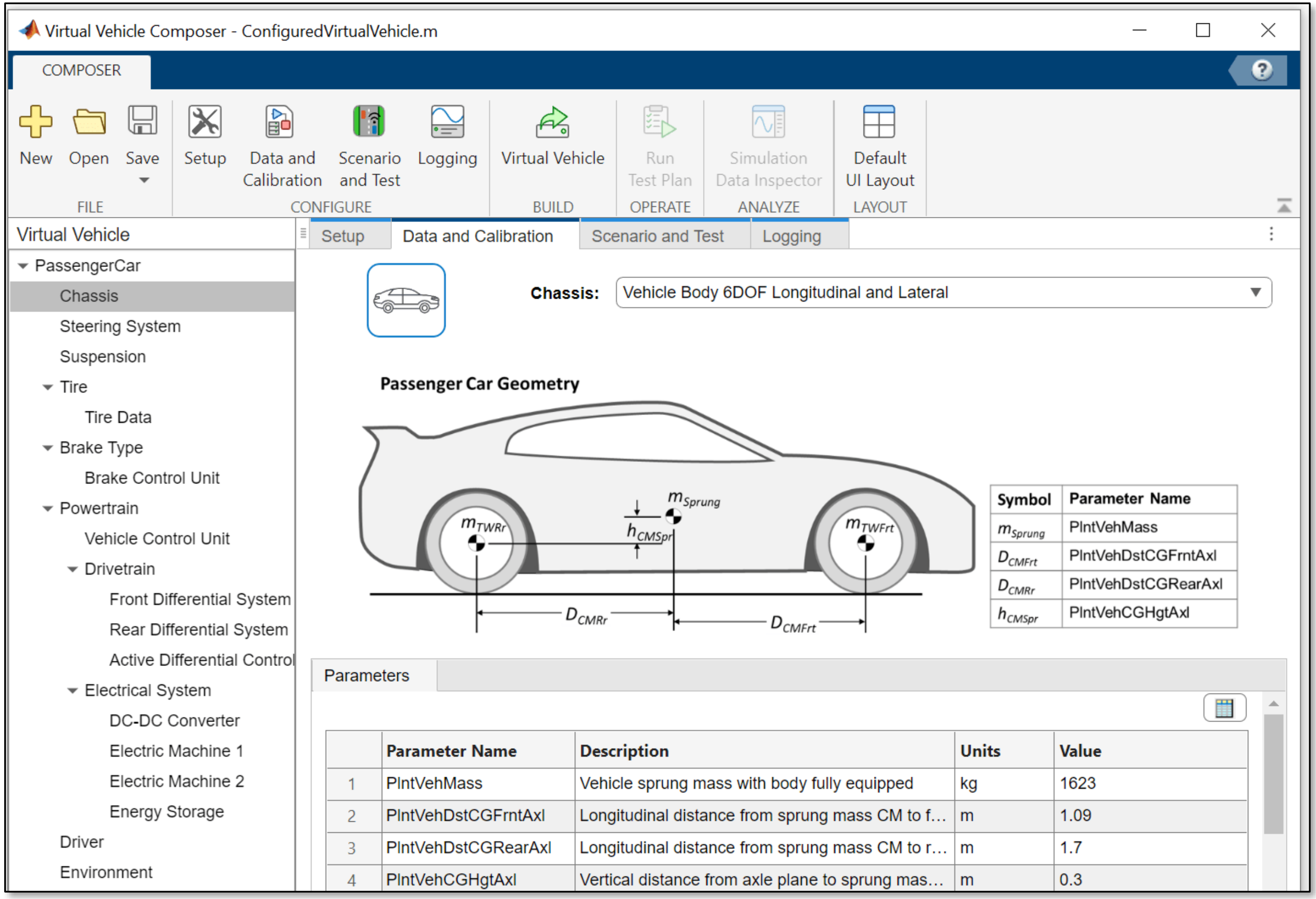
lateral/yaw instability and rollover usually happen on different driving scenarios [9]. Hence, the control mode switching method could be employed, in which the mode of vehicle dynamics control is determined by rollover indexes [10]. Namely, once the threshold of a rollover index is reached, the control objective is switched from vehicle lateral/yaw stabilization to rollover prevention. However, during some aggressive driving maneuvers, vehicle lateral/yaw stability and rollover prevention must be simultaneously considered, even if their control objectives may be conflicting.

To balance and compromise the conflicting control objectives, one way is to take the advantages of over-actuated vehicle systems. For instance, a hierarchical control framework with control allocation (CA) was introduced in [11] to resolve the conflicting issue explicitly. In a hierarchical configuration, the virtual control inputs in the high level ensured vehicle lat-

Virtual Vehicle Composer App

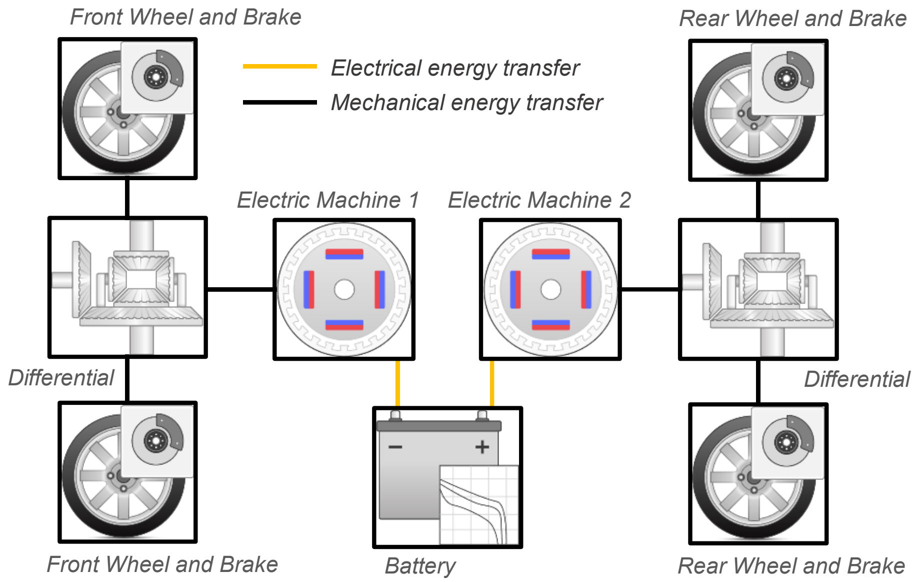


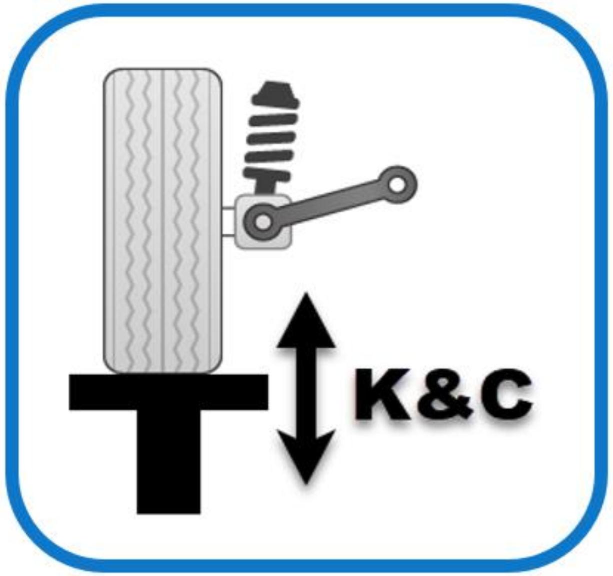
- Unified interface to help you quickly configure and run a virtual vehicle model
- Includes choices for powertrain, vehicle dynamics, and closed-loop controls
- Includes both Simulink and Simscape-based plant models
- Available with:
  - Powertrain Blockset
  - Vehicle Dynamics Blockset

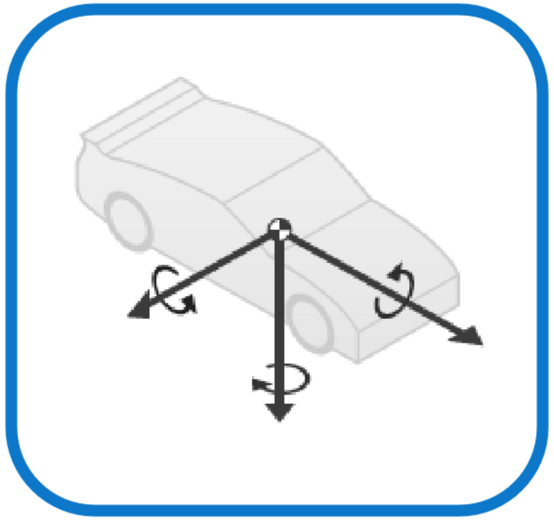


Plant Specifics/Modifications

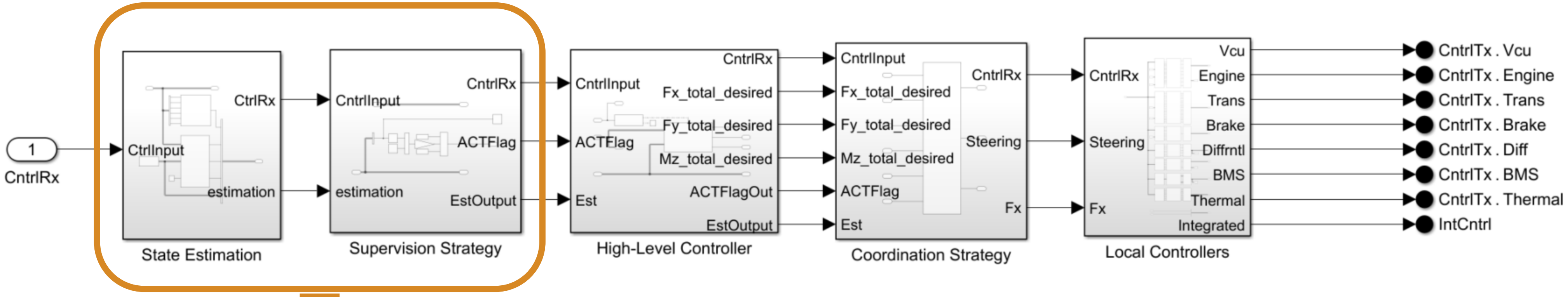
- Powertrain
  - 2x 200kW Motor BEV
  - 55kWh Battery
- Steering
  - Front axle: Steering wheel input with control correction
  - Rear Axle: Enabled by control only
- Vehicle Dynamics
  - 14 Degrees of Freedom (DOF)
  - Magic Formula tires: 2 DOF
  - Mass: 1600kg







Controller: Supervision

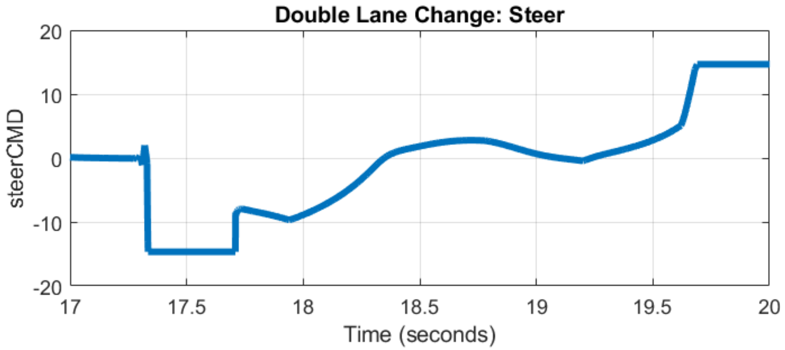


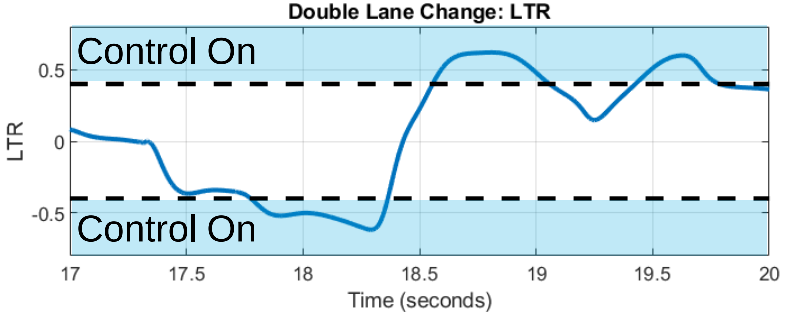
Supervision Strategy

- Uses Lateral Load Transfer Ratio (LTR) to determine if control is activated
- LTR represents the load transfer between the left and right wheels and is an indicator of vehicle rollover

$$LTR = \frac{2m_\phi h_\phi}{Mt_w}\left[\frac{(\dot{v}_y + rv_x)cos\phi}{g} + sin\phi\right]$$

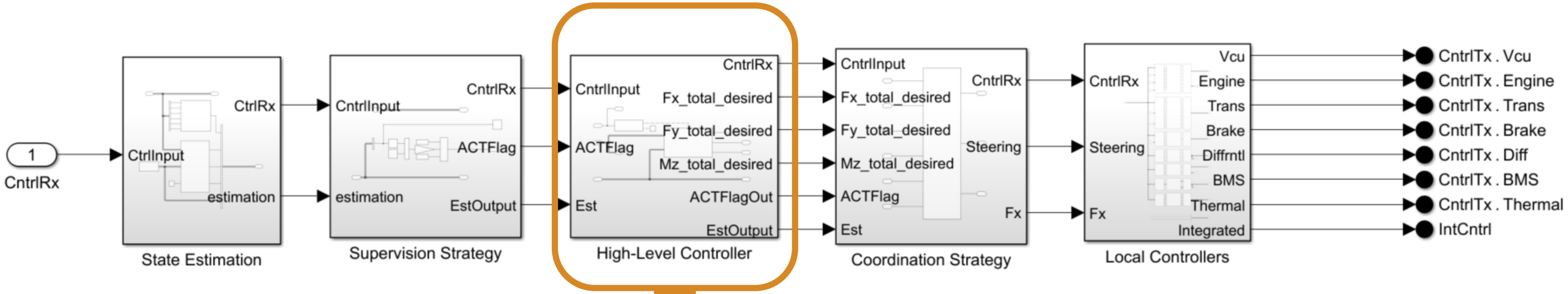
- State estimation of tire forces





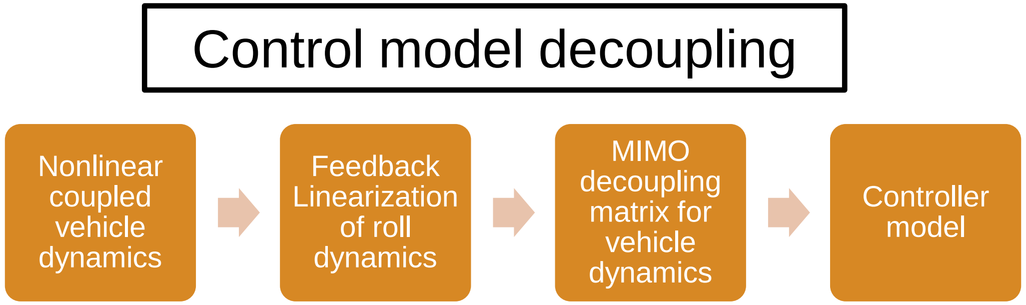
F. Wang, Y. Shi and Y. Chen, "Hierarchical MIMO Decoupling Control for Vehicle Roll and Planar Motions With Control Allocation," in *IEEE Transactions on Vehicular Technology*, vol. 73, no. 1, pp. 494-503, Jan. 2024, doi: 10.1109/TVT.2023.3308577

Controller: High-Level Controller



High Level Controller

- MIMO decoupling controller
  - Feedback decoupling on roll dynamics
    - Yaw rate and lateral velocity
  - Decoupling matrix for rest of vehicle dynamics
- Outputs *yaw moment, lateral and longitudinal forces* targets



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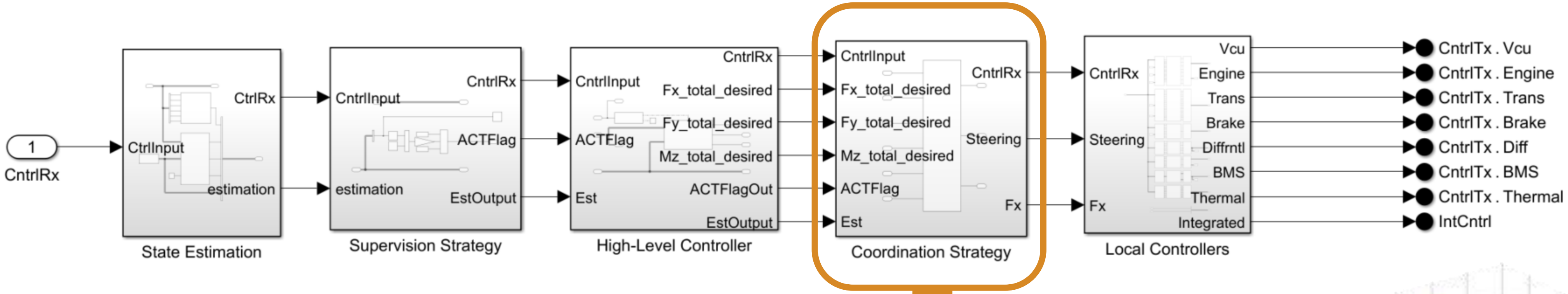
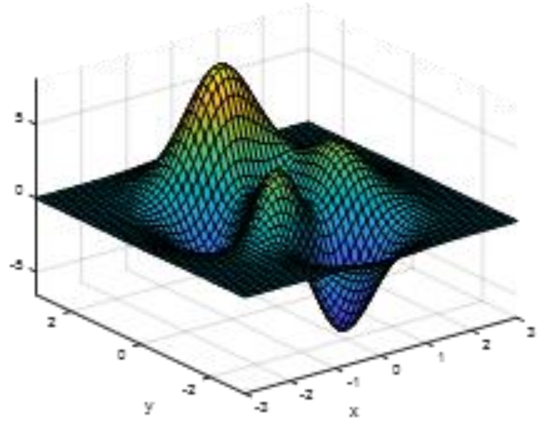
Controller: Control Allocation



Control Allocation

- Distributes the high-level control command to the lower-level actuators
  - Additional body longitudinal force (+/-)
  - Front steer correction
  - Rear steer
- Uses *optimization* algorithm to solve for best way to distribute commands
  - Subject to actuator limits
  - Provides *flexibility* for multiple control scenarios and vehicle architectures



$$\min_{u} w_1|u| + w_2|T - f(u)|$$

u = Lower-Level Control
T = High-Level Control Targets
$f(u)$= Mapping from Forces/Moments to Actuators

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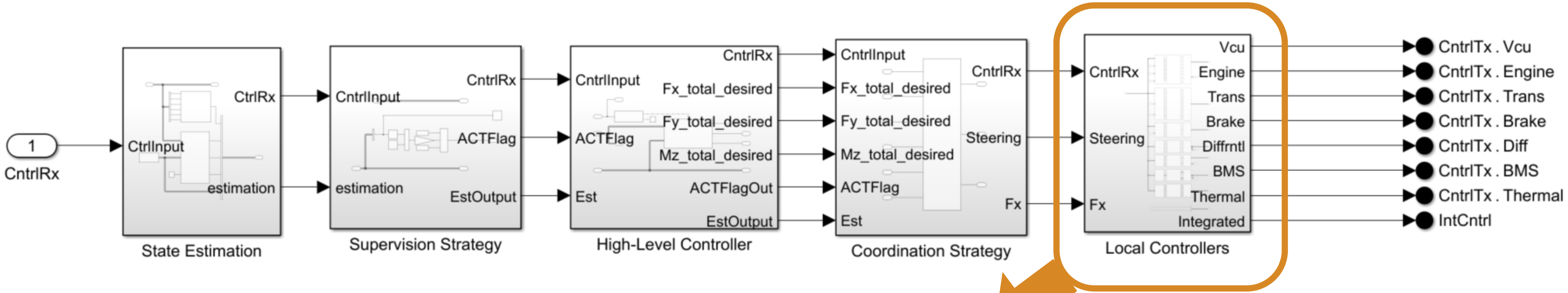
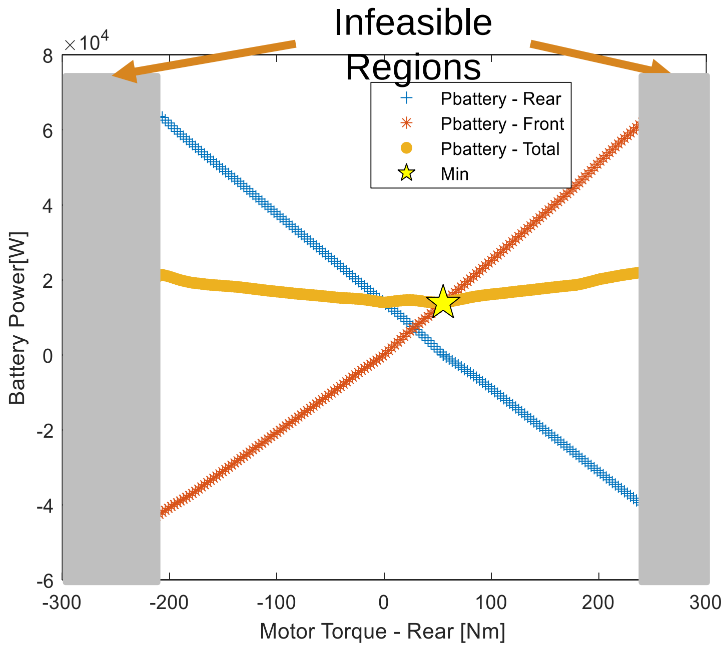
Controller: Local Controllers



Local Controllers

- Default controllers provided with Virtual Vehicle Composer model
- Battery Management System
  - Manages battery health
- Vehicle Control Unit
  - Front/Rear motor torques determined by energy optimization
  - Series braking



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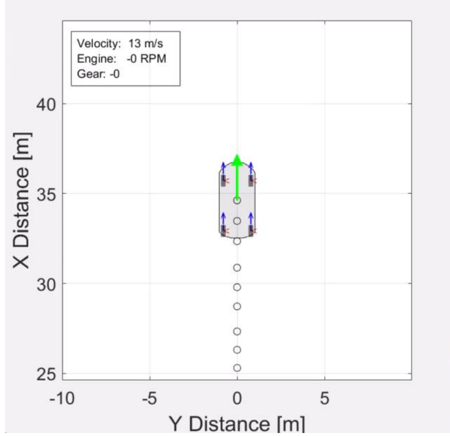
Testing Scenarios

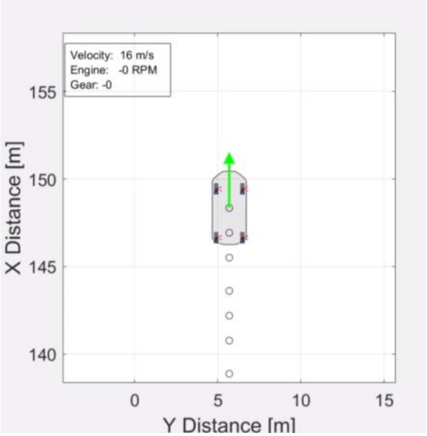
Increasing Steer

- Based on SAEJ266
- Vehicle accelerates to target velocity (50 MPH) and held
- Steering wheel is linearly increased until a max angle is reach



Double Lane Change

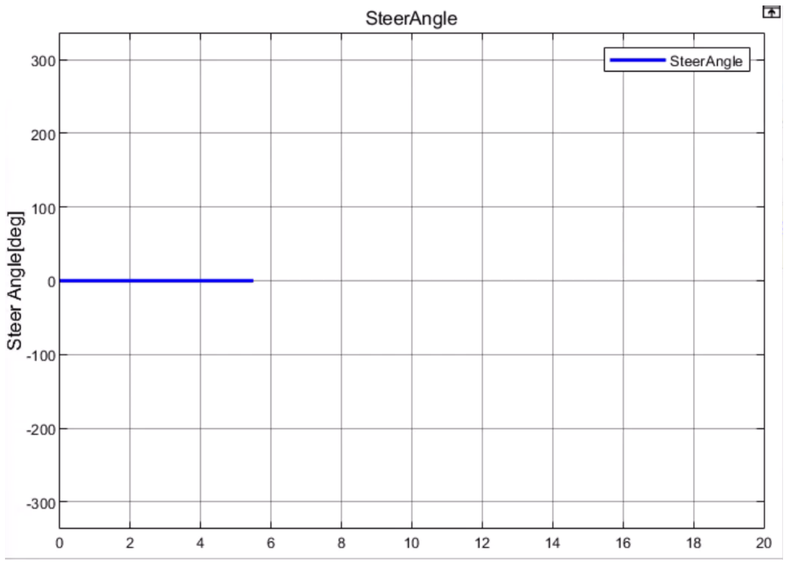
- Based on ISO 3888
- Vehicle accelerates to target velocity (35 MPH)
- Accelerator pedal is held
- Steering wheel is actuated to turn into left then right lane

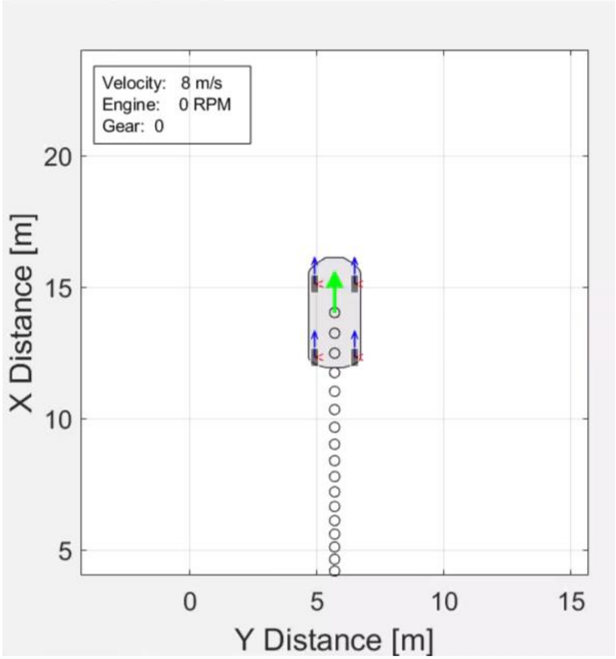


Testing Scenarios

Fishhook

- Accelerates until it hits a target velocity (50MPH).
- Maintains the target velocity.
- Responds to initial rapid steering input.
- Responds to steering overcorrection.



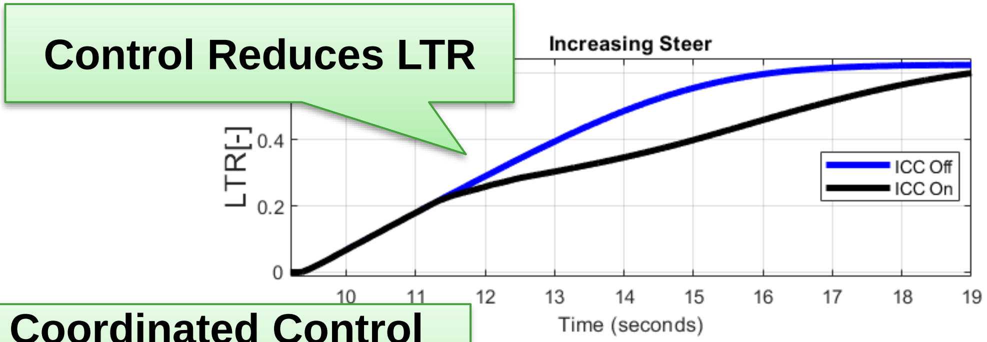


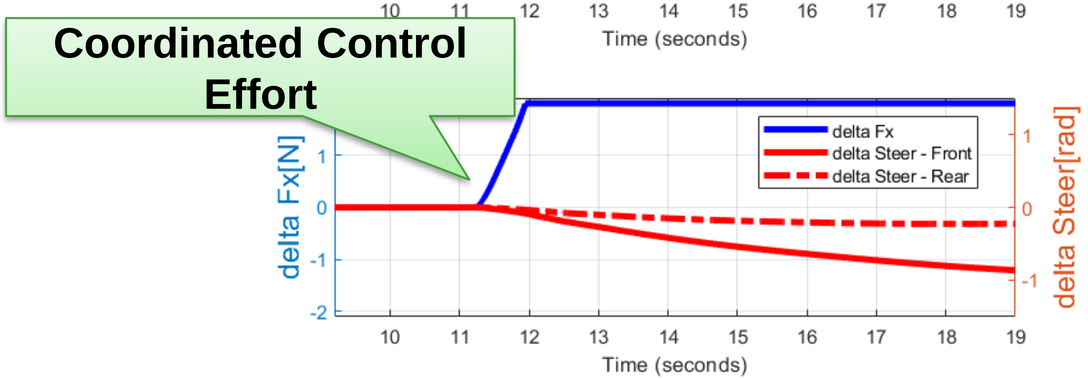
Results

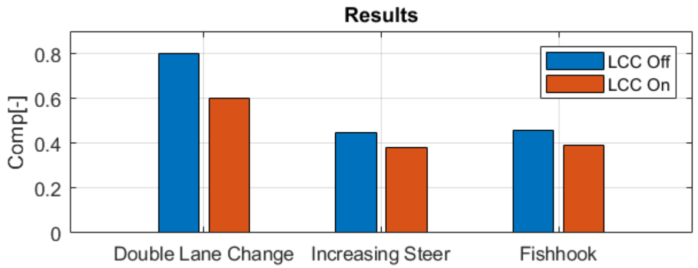
- Coordinated control shows an improvement for vehicle stability
  - Front and rear steer work cohesively to improve roll stability
- Comprehensive index to evaluate performance
  - Measures the effect on LTR reduction and error tracking

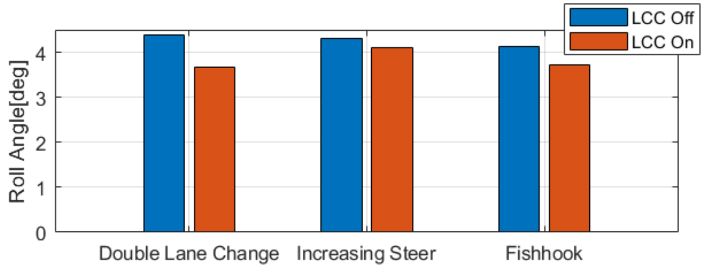
$$Comp = \frac{1}{3}\left(\frac{|LTR|}{\max(|LTR|)} + \sum_{m=1}^{2} \frac{|e_m|}{\max(|e_m|)}\right)$$

- Roll angle and Comprehensive index shows improvement for all tested scenarios





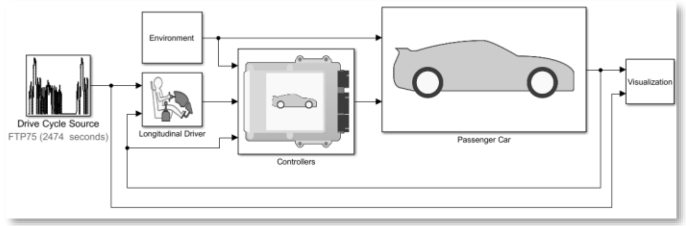


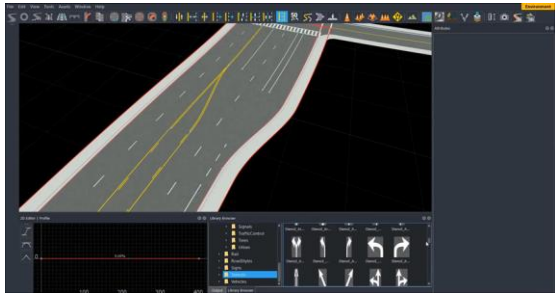


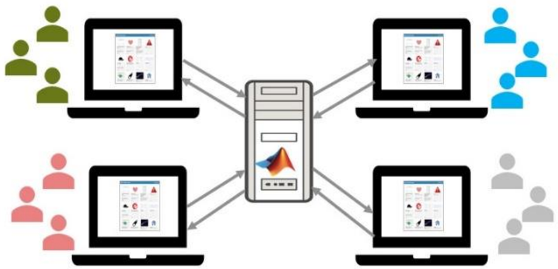
MathWorks Virtual Vehicle Offering Spans Development Process

Application Expertise + Engineering Tools for your needs

Create Vehicle	Integrate Software	Author Scenarios	Simulate & Analyze	Deploy Simulation
Vehicle Templates Subsystem Libraries Modeling Guidelines	C/C++ Interface Reduced Order Models FMU Integration	Scene & Scenarios Open Standards Drive Cycles	Visualization Data Analysis Report Generation	Cloud Integration Datalake Integration HIL Deployment







Value proposition:

- Proven tools for modeling of physics and software
- Reference applications for reduced time-to-simulation
- Common platform for model reuse
- Solutions for large-scale modeling and simulation
- Flexible platform for growth / new use cases

Key Take Aways

- **MathWorks tools** can be used for *chassis control development* through the whole *development cycle*
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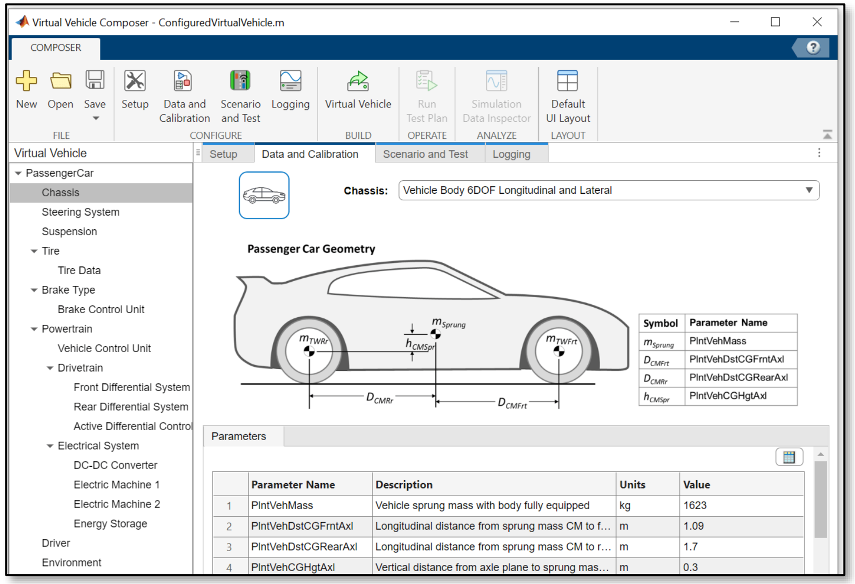

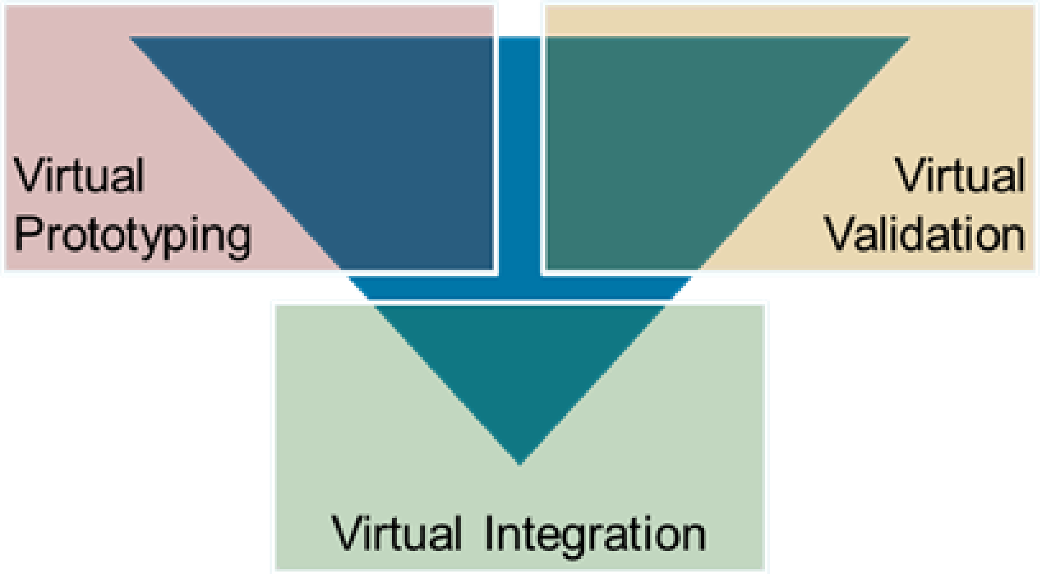

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