



Development of an Enhanced Heavy Duty Truck Autonomous Driving Simulation Environment

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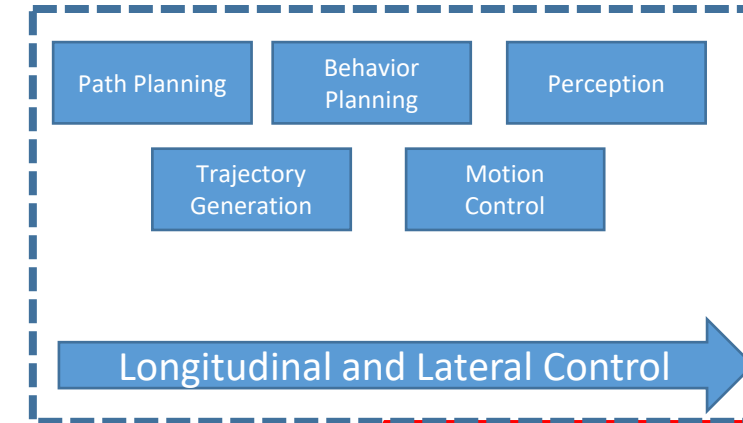
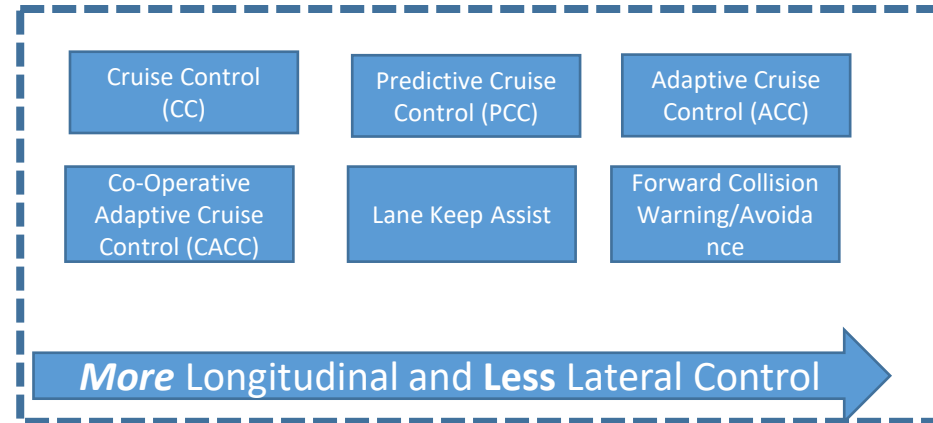
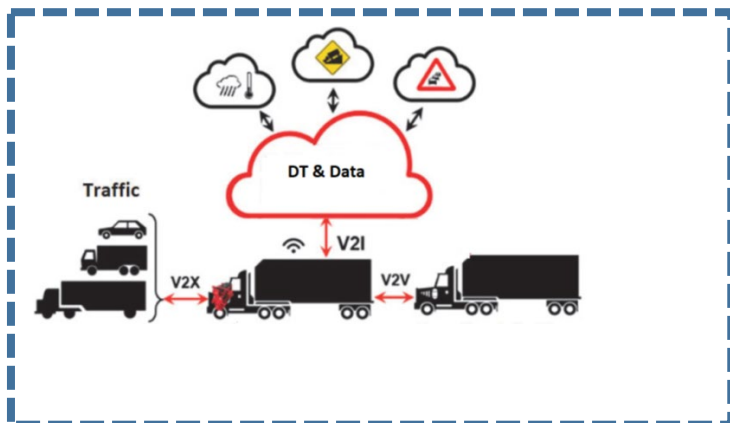
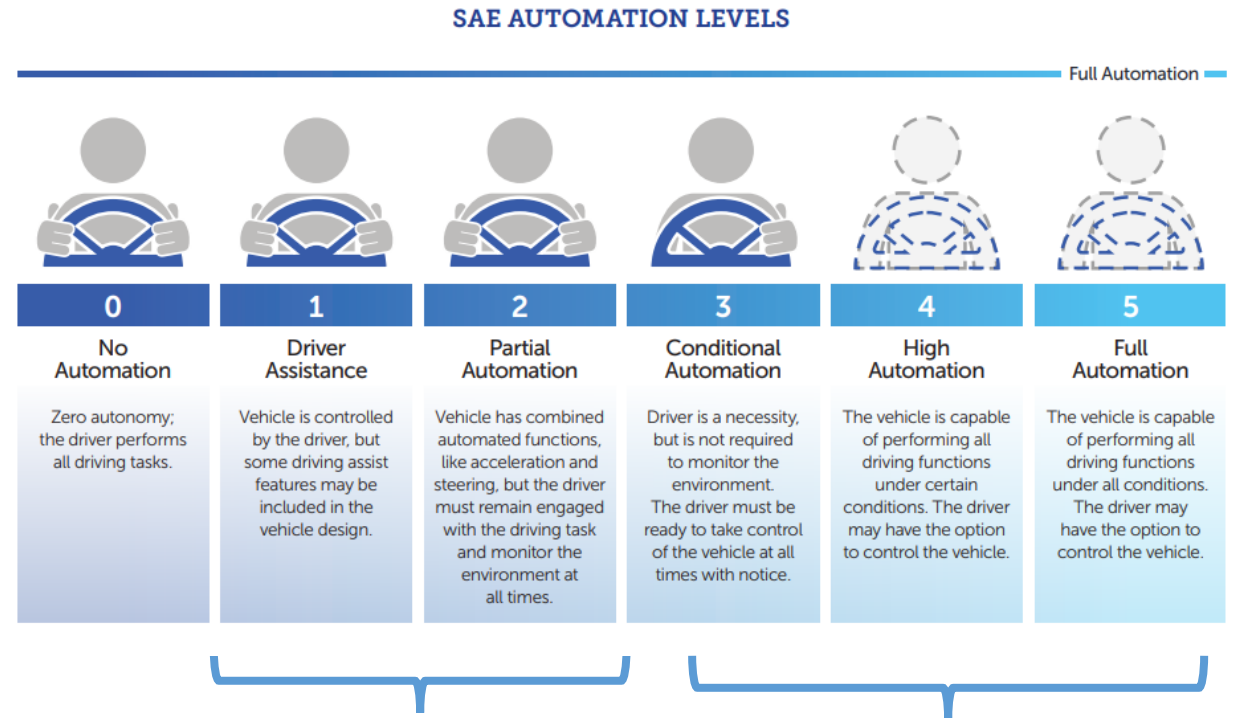
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Outline

- Motivation: Connectivity and Advanced Driver Assist Systems (ADAS) and Automated Driving Systems (ADS) for Transportation
- Interaction of ADAS and ADS with the Powertrain Systems
- Need for Simulation Framework
- Simulation Framework Overview
 - Collaboration with MathWorks and integration of Mathworks Automated Driving Toolbox Motion Planning and Motion Control Features
- Identify Improvement Opportunities and Simulate Advanced Solutions on Different Scenarios

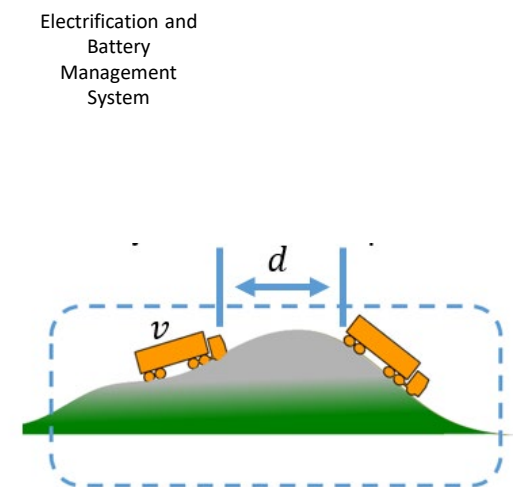
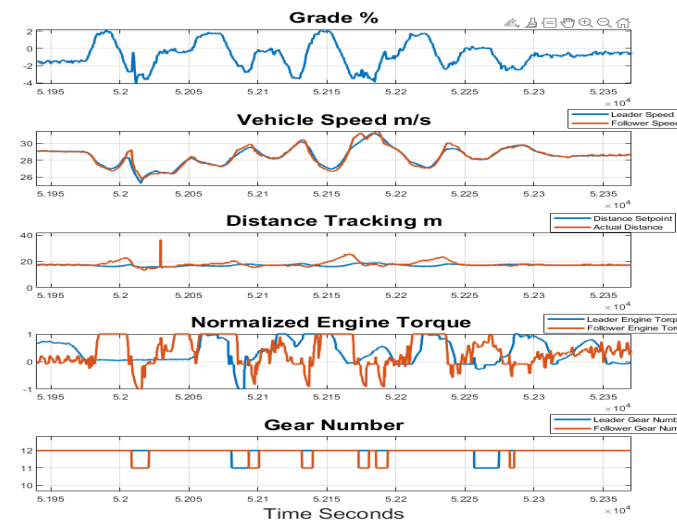
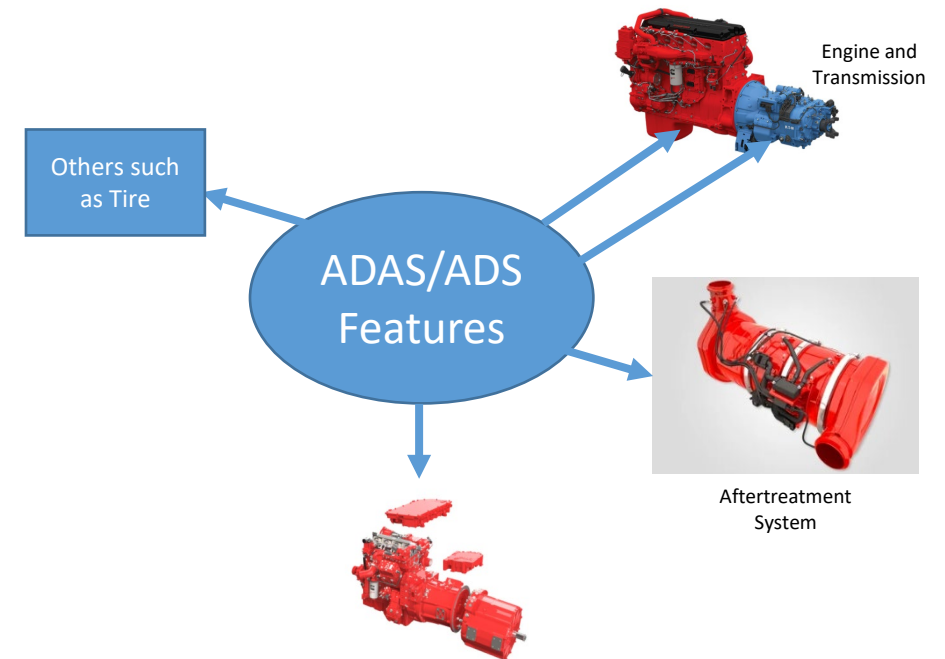
Motivation: Connectivity and ADAS/ADS for Transportation

- Only limited research/solutions available combining autonomous driving with Fuel/Energy Efficiency
- Extend our core competency and expertise in Powertrain controls development to help in system integration and automation
- Goal is to provide interface for ADAS/ADS solutions considering Powertrain Efficiency and Fuel/Energy Optimization
- Deep integration requirements between our powertrain, ADAS and ADS Suppliers and OEM



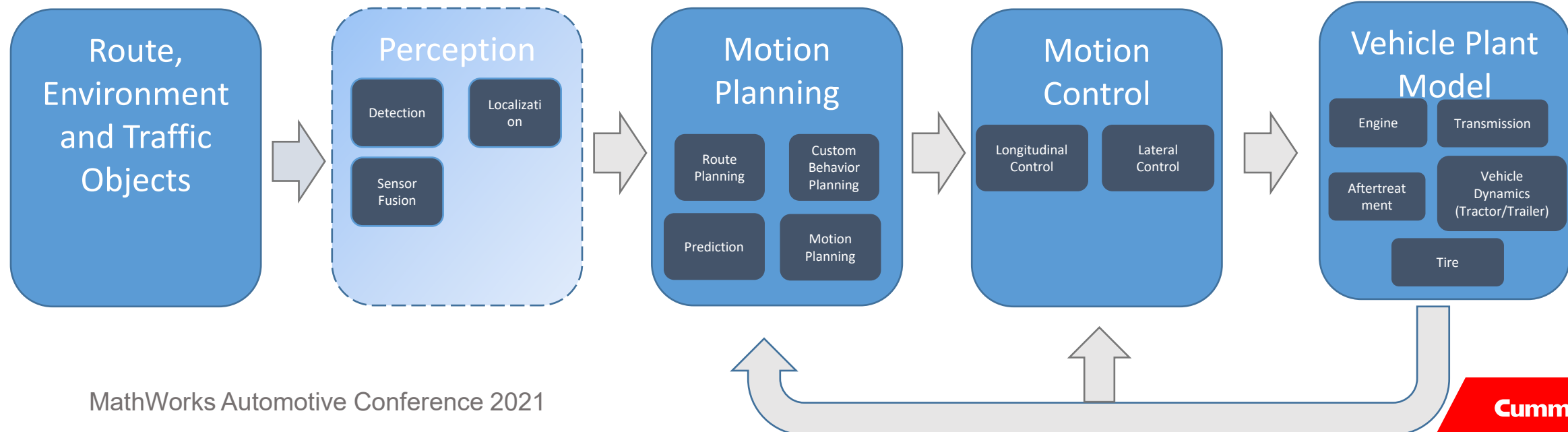
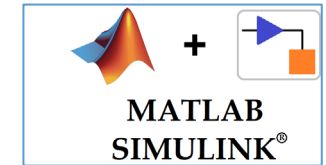
Interaction of ADAS and ADS with the Powertrain Systems

- Important to understand the interaction between the components and features: CACC Example
- Typically path planning/motion planning does not consider optimizing energy utilization of the powertrain system
 - Mostly considers start/end locations and trip time for global path planning
- Global path/speed profile can be optimized considering powertrain, road grade profiles, traffic etc.
- Local optimization during short horizon trajectory generation for
 - Lane change decisions
 - Opportunistic platooning



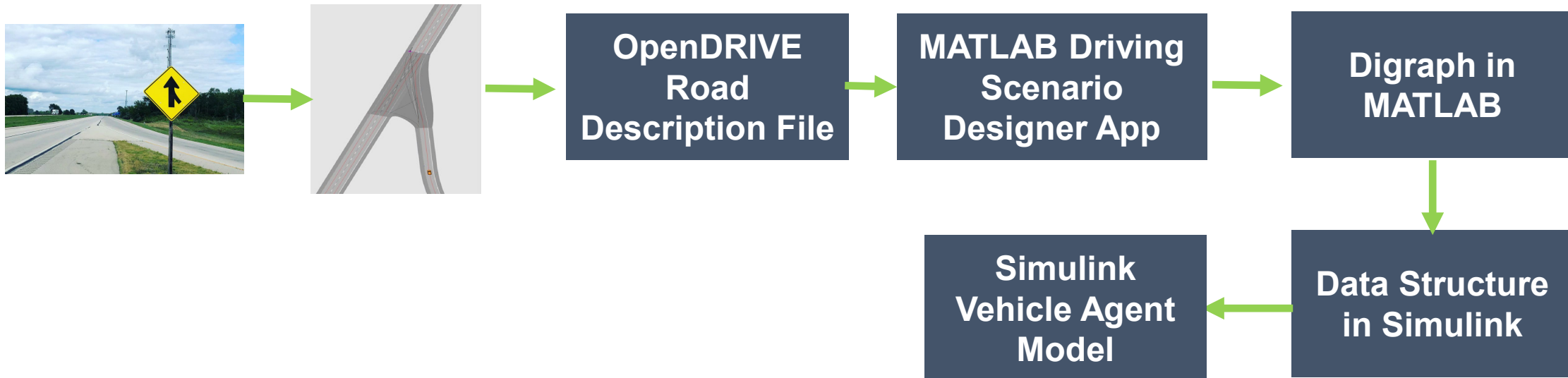
Need for Simulation Framework

- Plug and play interface for components and ADAS options for longitudinal and lateral control
- Assess existing and new controls
- Simulink as integration platform
 - Engine, Transmission, Aftertreatment
 - Different levels of fidelity of components
- Motion Planner and Motion Controller from Mathworks Automated Driving Toolbox
- IPG Truckmaker
 - Longitudinal and lateral vehicle dynamics
 - Tractor/Trailer/Tire models
 - Visualization

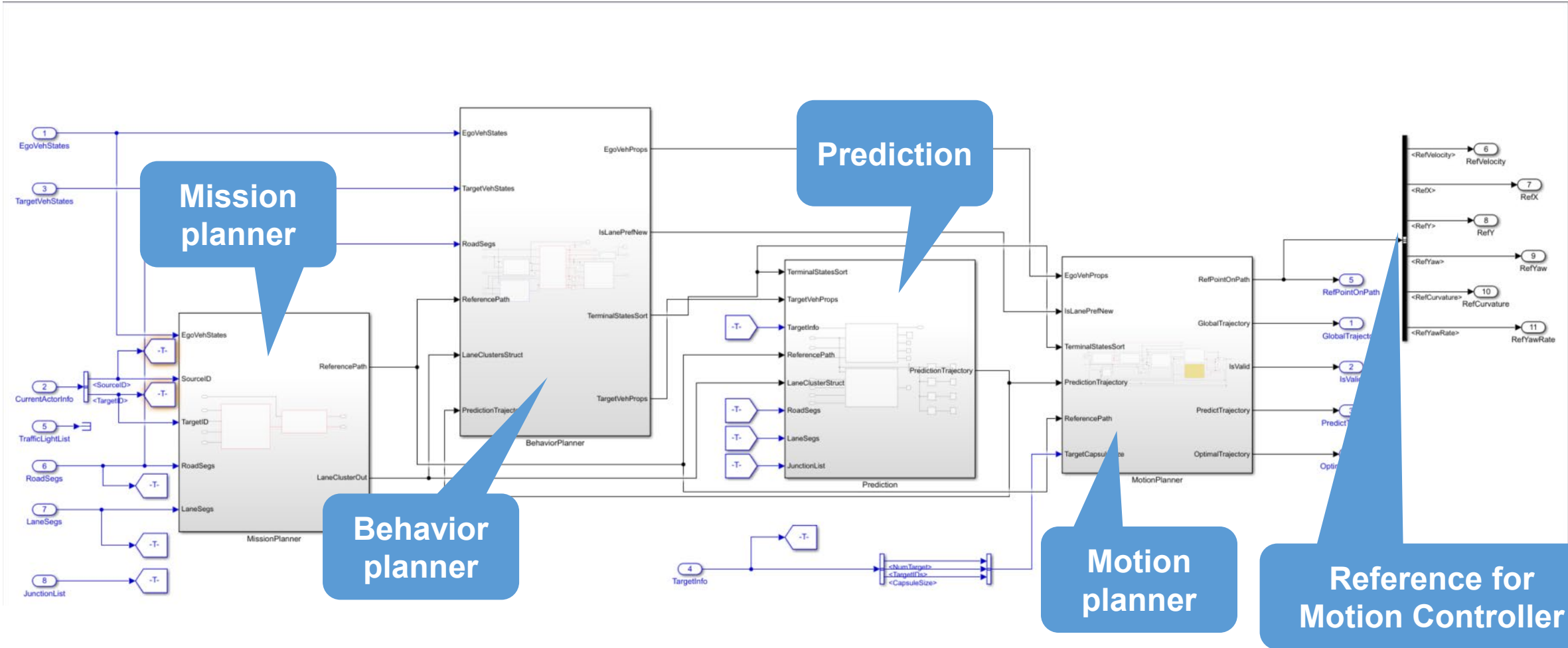


Importing Real World Routes/Scenarios

- Import real world road networks into the simulation framework using the OpenDrive file support
 - Elevation and Speed limit required
- OpenDrive is a standard open format specification for describing road networks

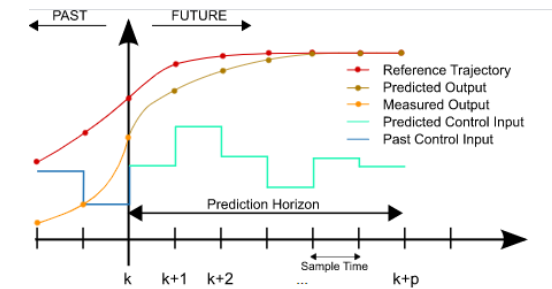
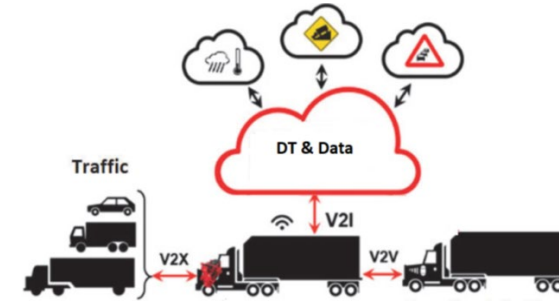


Motion Planning from Automated Driving Toolbox (Customized)



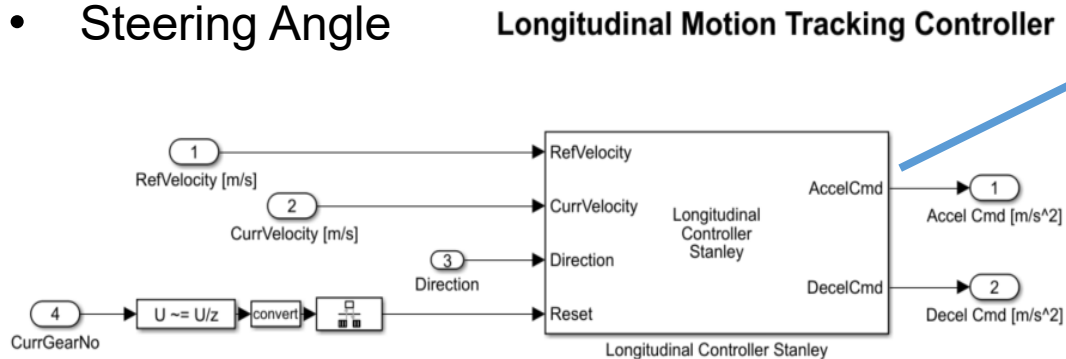
Custom Behavior Layer

- Customizable behavior layer for
 - Optimal speed target, preferred lane, target gaps to the front and rear vehicles
 - For example inhibit lane change under certain conditions
- Can interface advanced control methodologies to utilize connectivity, and look ahead information
 - Model Predictive Control (Online)
 - Dynamic Programming for global optimization (Offline + Cloud connectivity)



Motion Tracking Controllers from Automated Driving Toolbox

- Longitudinal and Lateral Stanley controllers from Automated Driving System toolbox
- Tunable controller parameters makes it easy to adapt these controllers for different class of vehicles
 - Gains
 - Acceleration/Deceleration Limits
 - Mass
 - Steering Angle



Block Parameters: Longitudinal Controller Stanley

Longitudinal Controller Stanley

Compute acceleration and deceleration commands that control the velocity of a vehicle given the reference velocity, the current velocity, and the current driving direction.

The controller is implemented as a discrete Proportional-Integral (PI) controller with integral anti-windup. To reset the integral of velocity error to zero, pass a nonzero value to the Reset port.

The Direction port accepts a scalar representing the driving direction with two possible values: 1 for forward motion and -1 for reverse motion. The outputs AccelCmd and DecelCmd are saturated by the maximum longitudinal acceleration and the maximum longitudinal deceleration parameters.

Controller Settings

Proportional gain, Kp:

Integral gain, Ki:

Sample time (s):

Vehicle Parameters

Maximum longitudinal acceleration (m/s²):

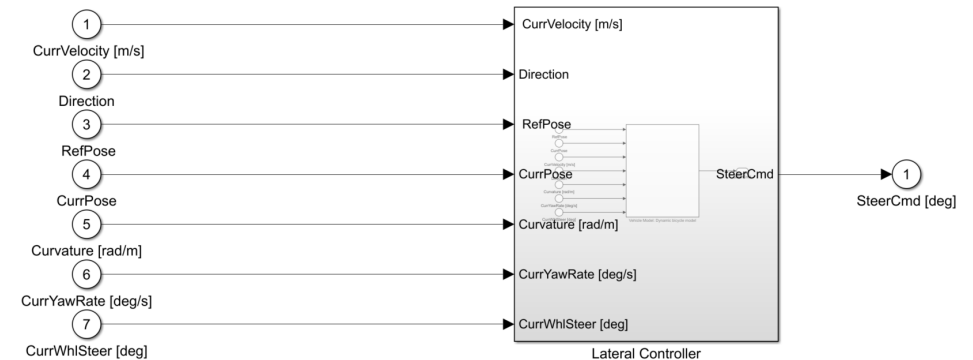
Maximum longitudinal deceleration (m/s²):

OK Cancel Help Apply

Motion Tracking Controllers from Automated Driving Toolbox

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Lateral Motion Tracking Controller



Block Parameters: Lateral Controller Stanley

Compute the steering angle command in degrees that controls the current pose of the vehicle with respect to the desired reference pose, using the Stanley method.

The RefPose port accepts a 1-by-3 vector [x, y, theta] as the position of the reference point on the path and the orientation of the path at the point in degrees. In forward motion, the reference point is the nearest point on the path to the center of the front axle of the vehicle. In reverse motion, the reference point is the nearest point on the path to the center of the rear axle. The CurrPose port accepts a 1-by-3 vector [x, y, theta] as the position of the center of the rear axle and the heading angle of the vehicle in degrees. The CurrVelocity port accepts a scalar as the current longitudinal velocity of the vehicle in meters/second. The Direction port accepts a scalar representing the driving direction: 1 for forward motion and -1 for reverse motion.

Setting the Vehicle model parameter to Dynamic bicycle model enables additional input ports. The Curvature port accepts a scalar representing the curvature of the path at the reference point. The CurrYawRate port accepts a scalar as the current yaw rate in degrees/second. The CurrSteer port accepts a scalar representing the current steering angle in degrees.

Controller Settings

Vehicle model:

Position gain of forward motion:

Position gain of reverse motion:

Yaw rate feedback gain:

Steering angle feedback gain:

Vehicle Parameters

Vehicle mass (kg):

Longitudinal distance from center of mass to front axle (m):

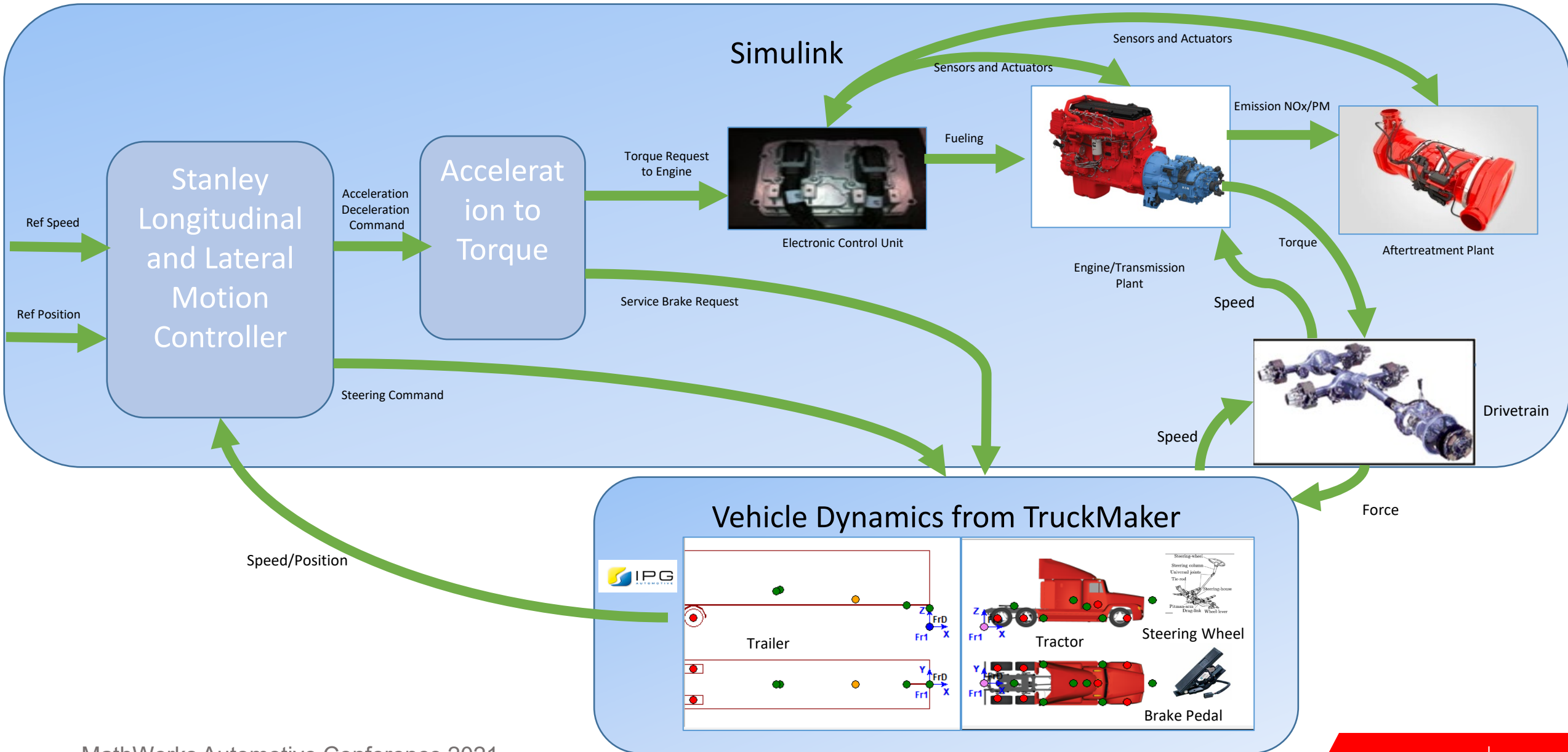
Longitudinal distance from center of mass to rear axle (m):

Front tire corner stiffness (N/rad):

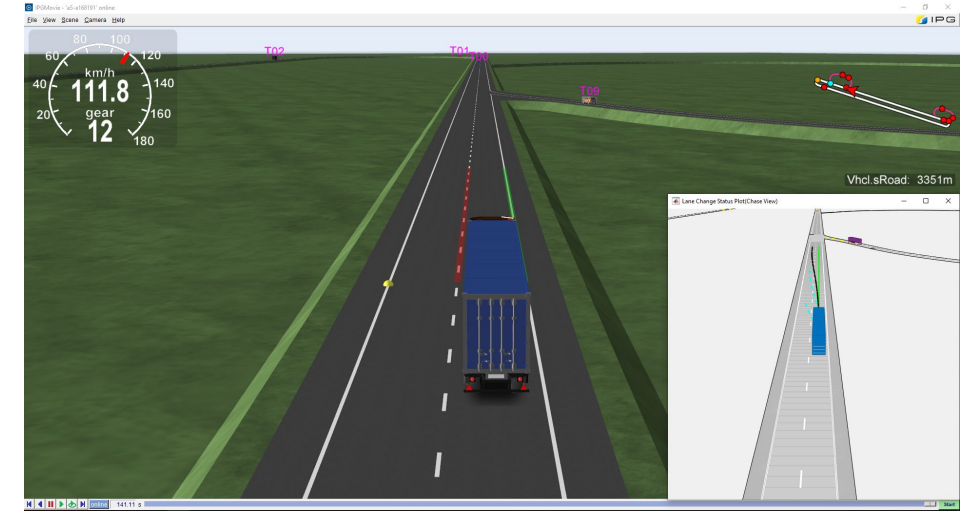
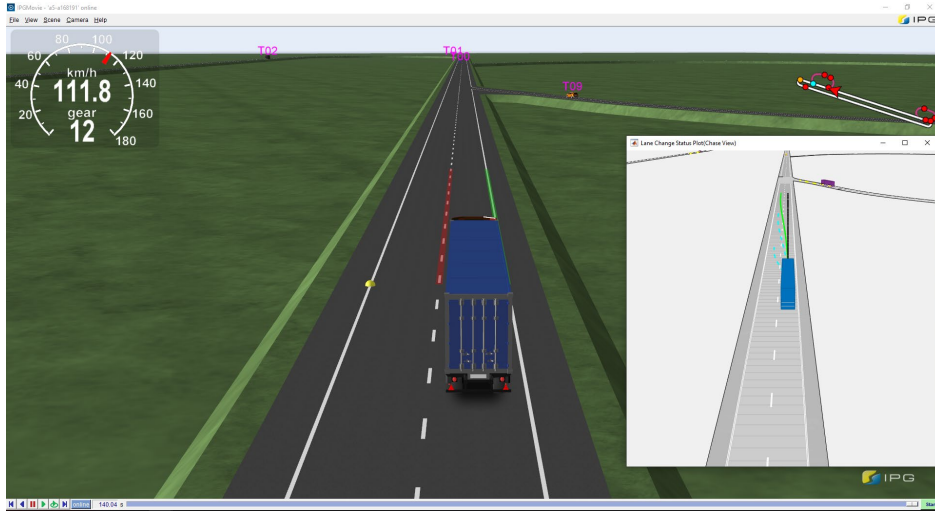
Maximum steering angle (deg):

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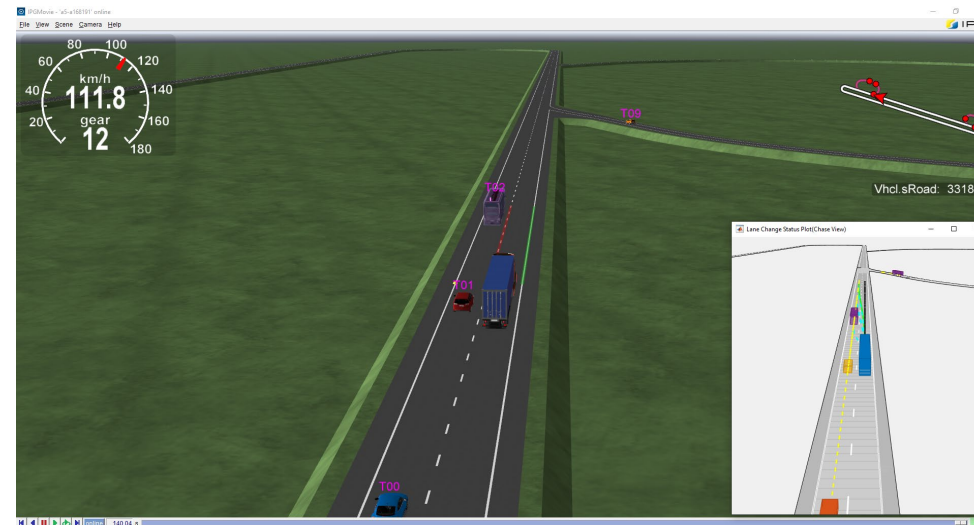
Motion Controller and Vehicle Dynamics



Scenario 1.1: Highway Passenger Car Merging

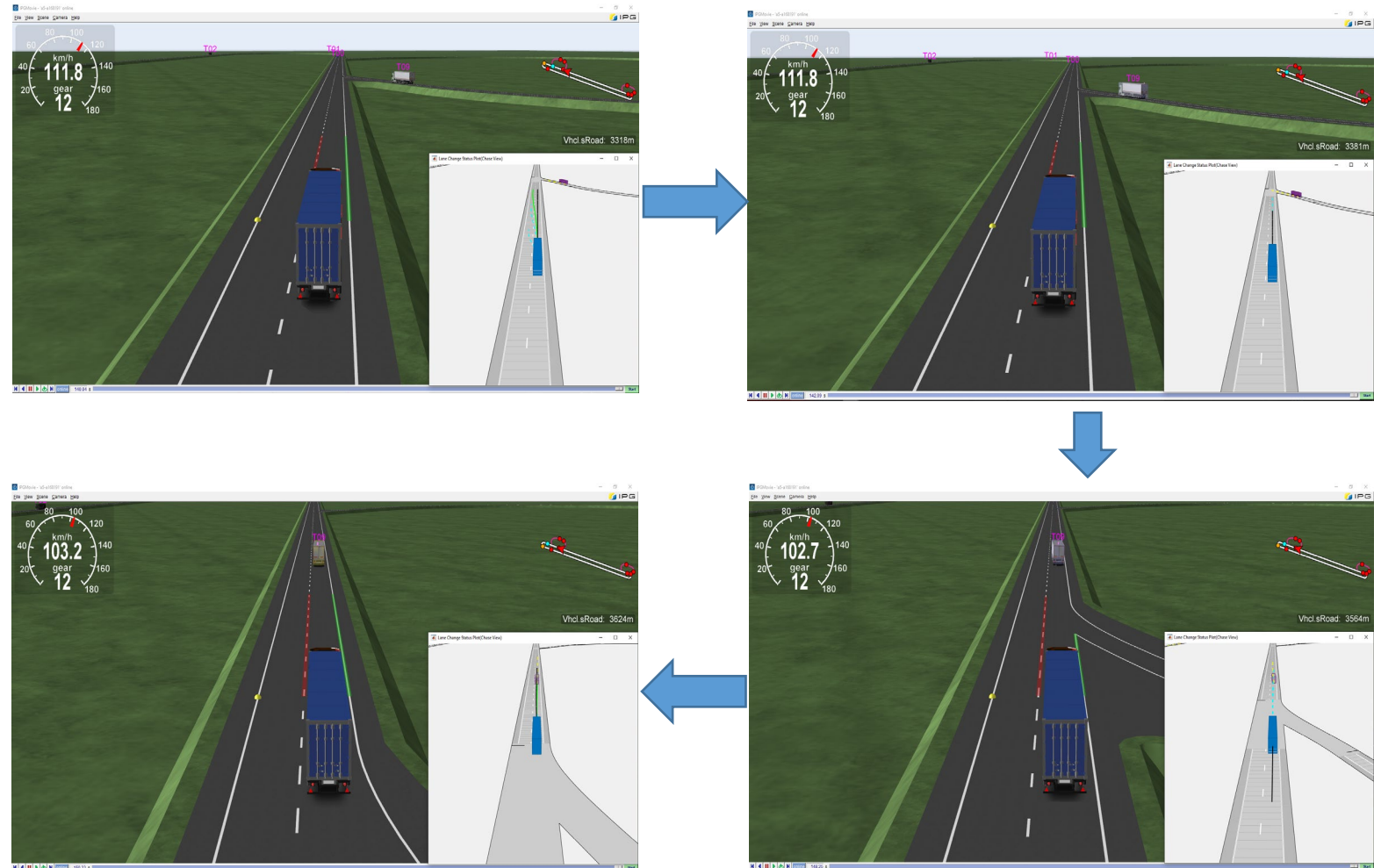


- Merging scenario with left lane occupied
 - Option 1: Go with the target speed and at the merge apply deceleration or brake => Energy Loss
 - Option 2: Coast down to the merge (Zero Fueling) , and then change to left lane => Energy Efficient



Scenario 1.2: Highway Truck Merging Opportunity for Platooning

- If the truck which is merging is equipped with V2V / DSRC communication and exchange information such as the destinations, planned paths, trip times, their weights etc. and decide to form platoon instead of changing lane and trying to overtake
- Drag reduction benefits



Concluding remarks

- Used MATLAB, Simulink as a plug and play simulation integration platform for evaluating existing and new control strategies for ADAS features
- With MathWorks collaboration and support, blocks and algorithms from Automated Driving Toolbox are used for Motion Planning and Motion Control, with customized behavior planner
- Integrated with IPG Truckmaker for detailed vehicle dynamics, visualization, and Traffic objects interaction
- Developed plug and play interface ready to be used with Motion planning/control features from different ADAS suppliers



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