MATLAB EXPO 2019

Develop and Test Vehicle Controllers for ADAS/Automated Driving Applications through System Simulation

Abhisek Roy

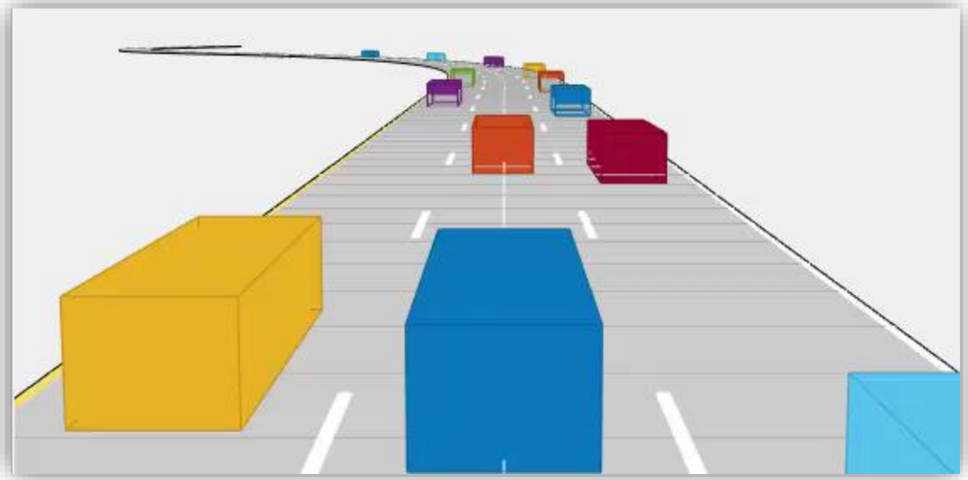
Highway Traffic Jam Assist

- It helps drivers to follow the preceding vehicle automatically with a predefined time interval in a dense traffic condition

… while controlling steering for keeping current lane.

Longitudinal control with ACC with stop & go

Lateral control with lane following



- Partial/conditional automation at level 2/3
  - Speed limit < 60~65 km/h
  - Dense traffic condition in highway

Challenges

- Wide variety of scenarios and difficult to gather real data
- Complex interplay between multiple sensors
- Incorporate models of right fidelity for various system components
- Costly and hazardous in-vehicle testing

Agenda

- Design model-predictive control-based vehicle controllers
- Run close-loop simulation with synthetic scenarios and test sensor fusion and control algorithms at a model level
- Improve simulation fidelity by incorporating detailed vehicle models and integrating with Unreal gaming engine

Performance Requirements: Longitudinal Control

ISO 15622

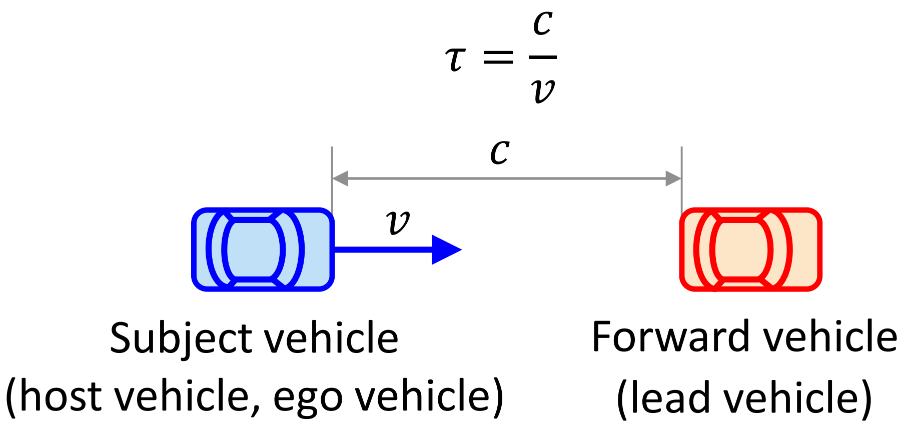
- **Ego velocity control** : $v \leq v_{set}$

  where, v : ego velocity, v_{set} : set velocity

- **Time gap control**: $\tau \geq \tau_{min}$

  where, $\tau = \frac{c}{v}$: time gap = 1.5 .. 2.2 sec

  τ_{min} : min time gap = 0.8 sec

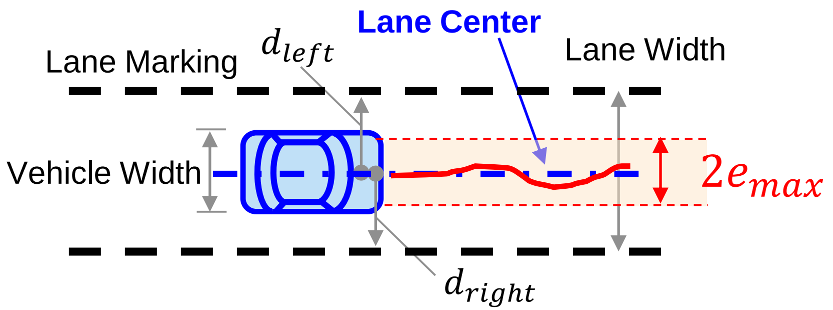


- Operation limits
  - Minimum operational speed, v_{min} = 5m/s
  - Average automatic deceleration ≤ 3.5 m/s^2 (average over 2s)
  - Average automatic acceleration ≤ 2.0 m/s^2

Performance Requirements: Lateral Control

- Vehicle should follow the lane center with allowable lateral deviation.

$$\left|(d_{left} + d_{right})/2\right| \leq \ e_{max}$$



where,

d_{left} : lateral offset of left lane w.r.t. ego car

d_{right} : lateral offset of right lane w.r.t. ego car

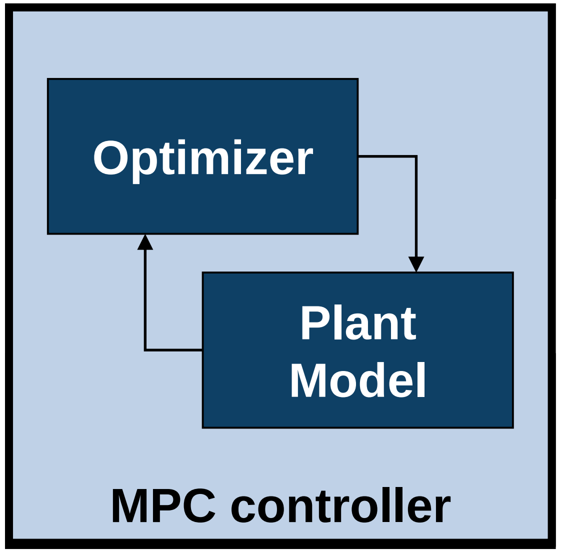
e_{max} : allowable lateral deviation

For example, $e_{max} = (LaneWidth - VehicleWidth)/2$ = (3.6-1.8)/2 = 0.9 m

What is model predictive control (MPC)?

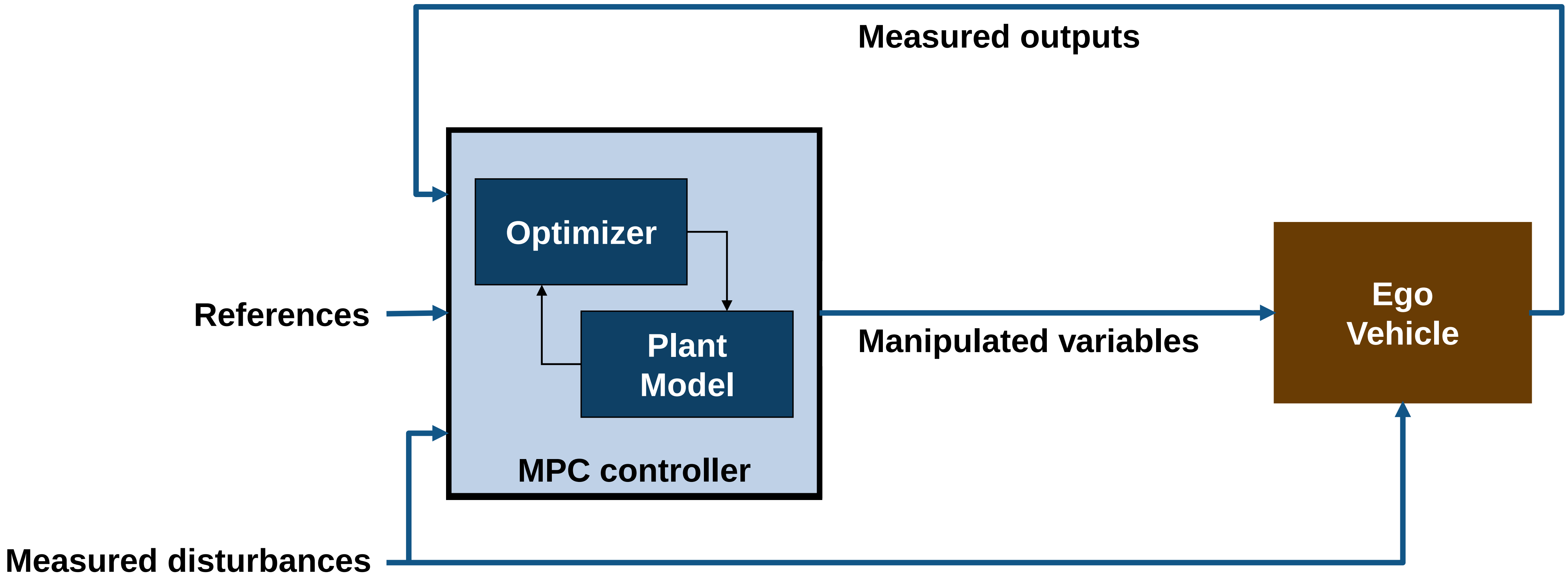
- **Multi-variable control** strategy leveraging an internal model to predict plant behavior in the near future

- **Optimizes** for the current timeslot while keeping future timeslots in account



- **Suitable** for our problem statement
  - Handles MIMO systems with coupling
  - Handles constraints
  - Has preview capabilities

How can MPC be applied to Highway Traffic Jam Assist?



How can MPC be applied to Highway Traffic Jam Assist?

minimize:

$$w_1|V_{ego} - V_{set}|^2 + w_2|E_{lateral}|^2$$

References
- Ego velocity set point (V_{set})
- Target lateral deviation (=0)

Measured disturbances
- MIO velocity (V_{mio})
- Previewed road curvature (ρ)

subject to:

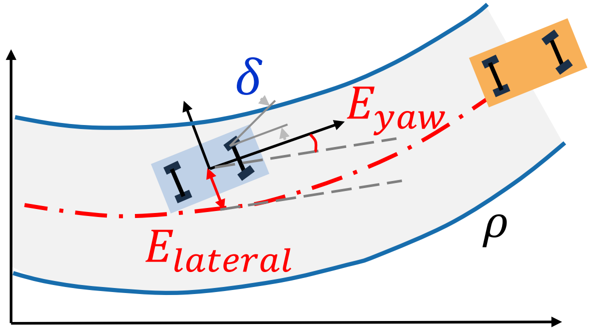
$$D_{relative} \geq D_{safe}$$
$$a_{min} \leq a \leq a_{max}$$
$$\delta_{min} \leq \delta \leq \delta_{max}$$

MPC controller
- Optimizer
- Ego Vehicle Model

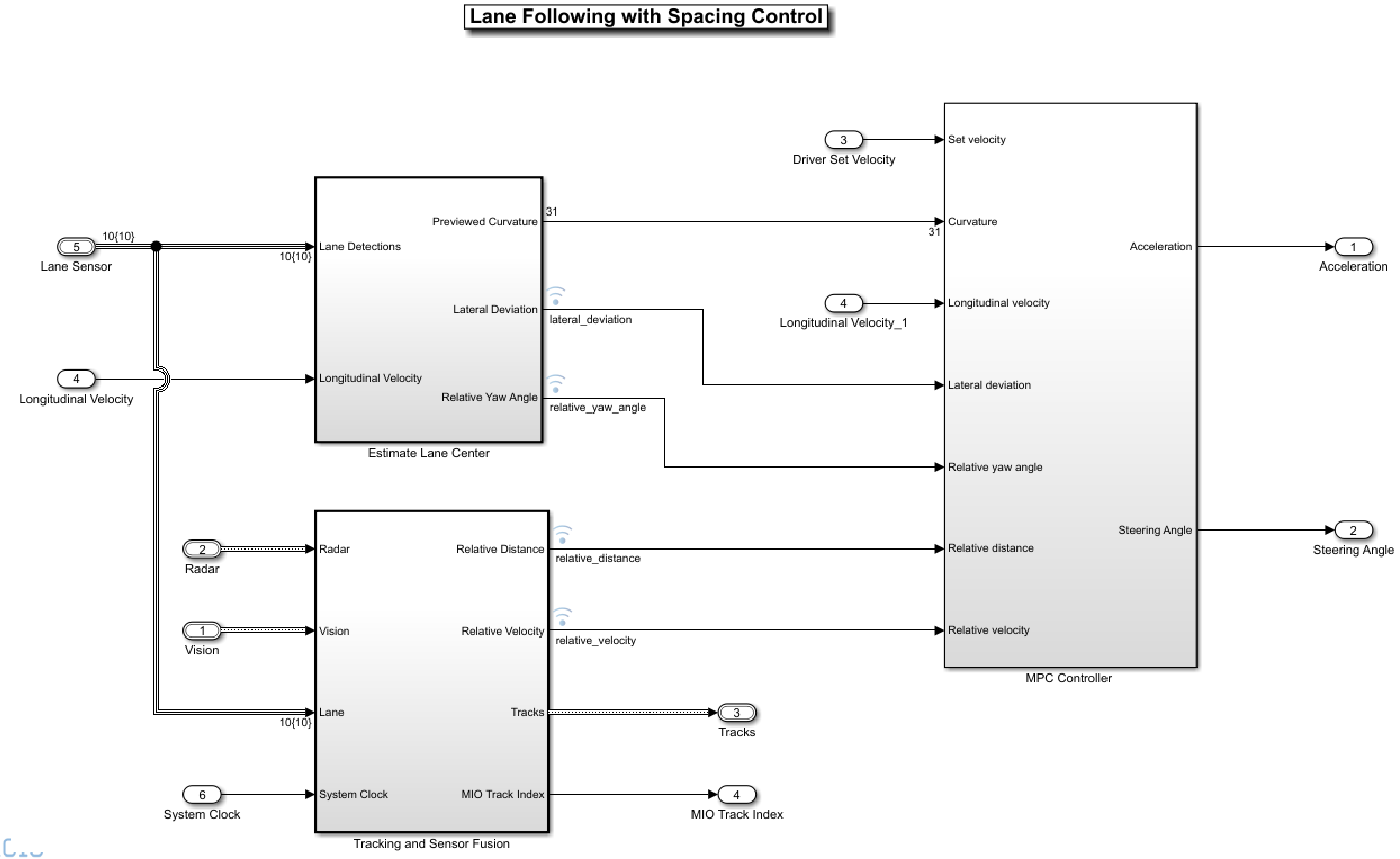
Measured outputs
- Relative distance ($D_{relative}$)
- Ego velocity (V_{ego})
- Lateral deviation ($E_{lateral}$)
- Relative yaw angle (E_{yaw})

Manipulated variables
- Acceleration (a)
- Steering angle (δ)

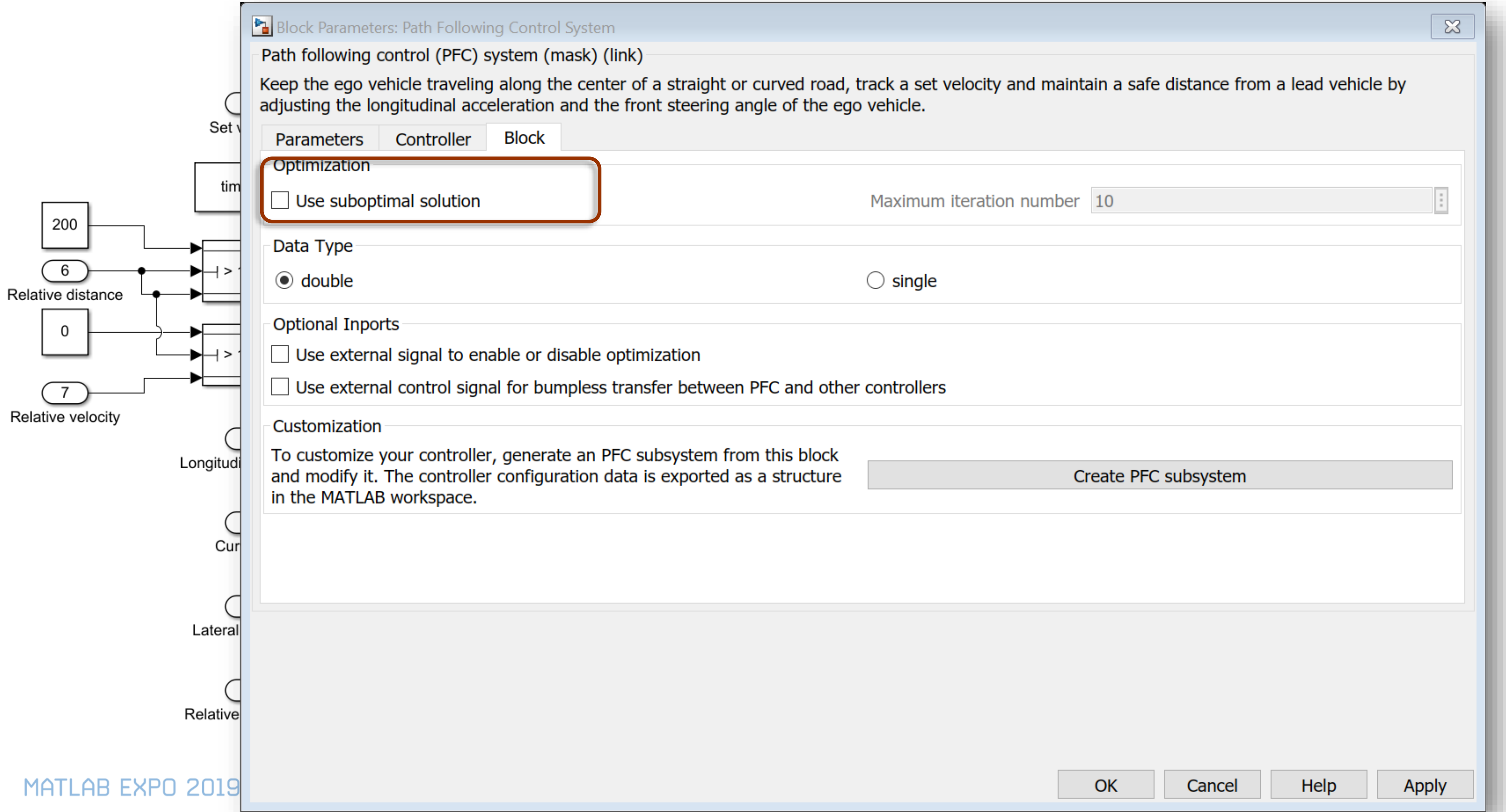
Ego Vehicle



Control Algorithm



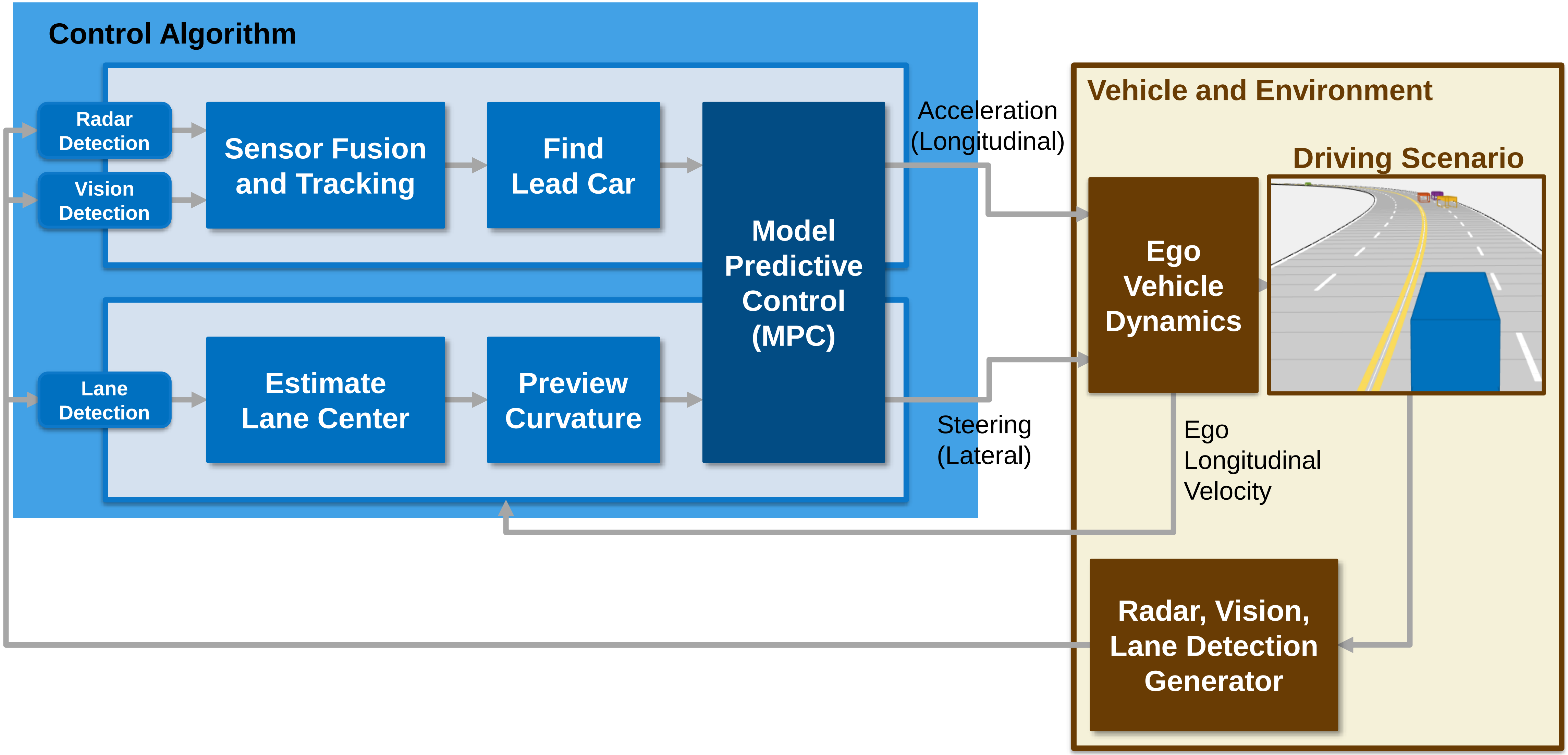
Control Algorithm



Agenda

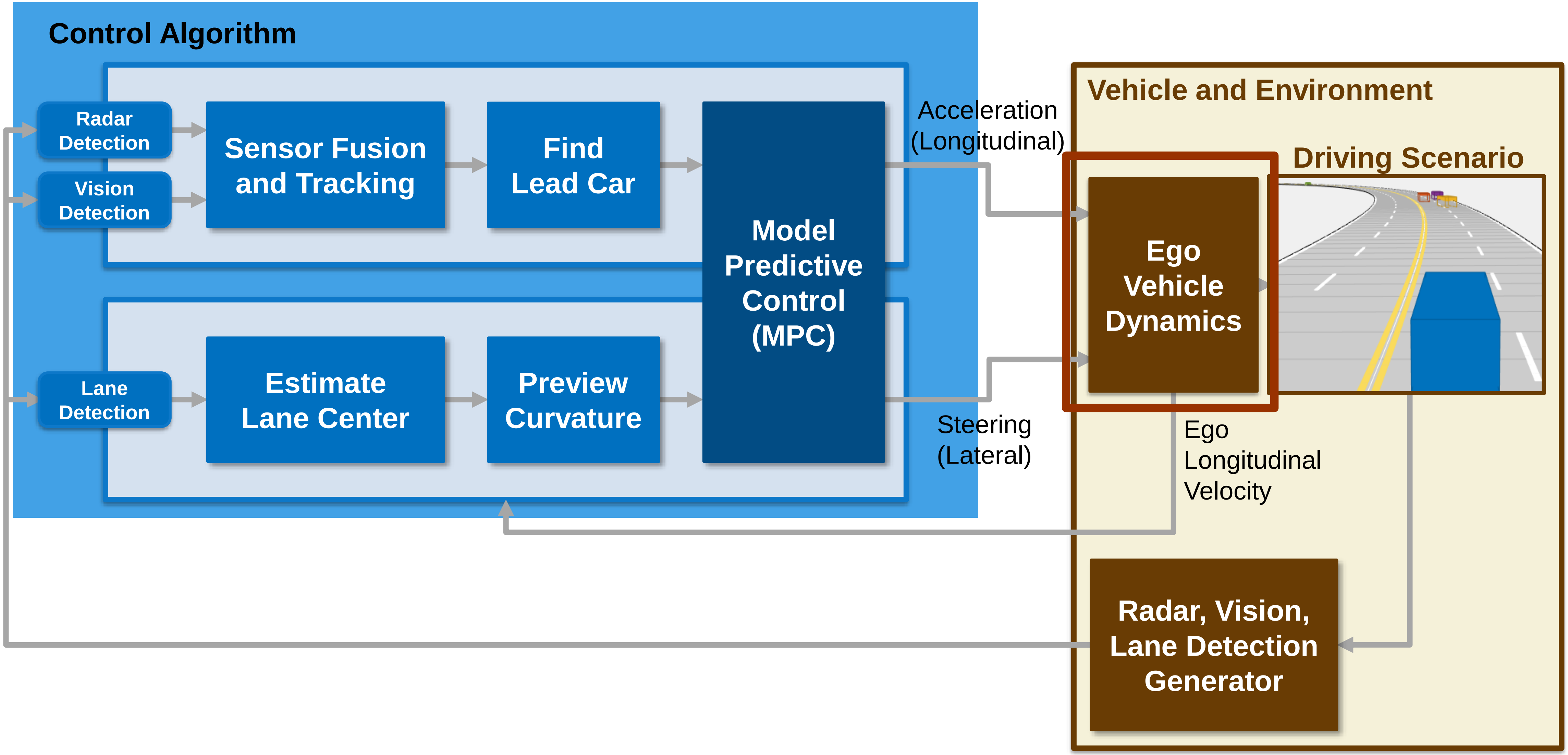
- Design model-predictive control-based vehicle controllers
- Run close-loop simulation with synthetic scenarios and test sensor fusion and control algorithms at a model level
- Improve simulation fidelity with gaming engine integration, vehicle dynamics modelling, and automated scenario creation from recorded data

Architecture for Traffic Jam Assist Controller

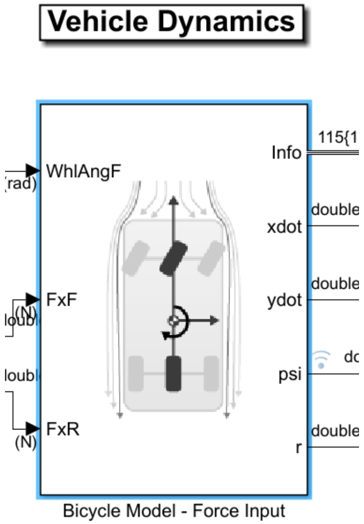


Develop and Test Vehicle Controller

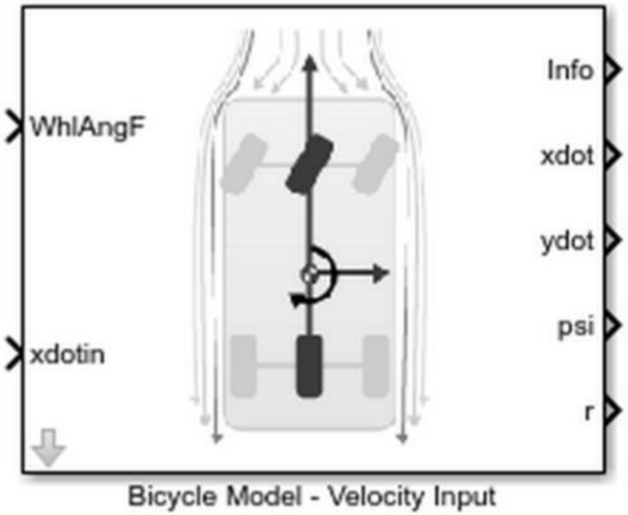
Traffic Jam Assist



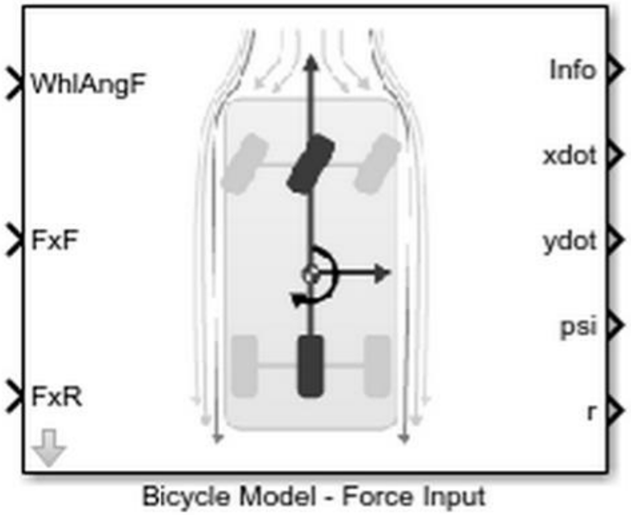
Incorporate Ego Vehicle Dynamics



Bicycle Model - Velocity Input



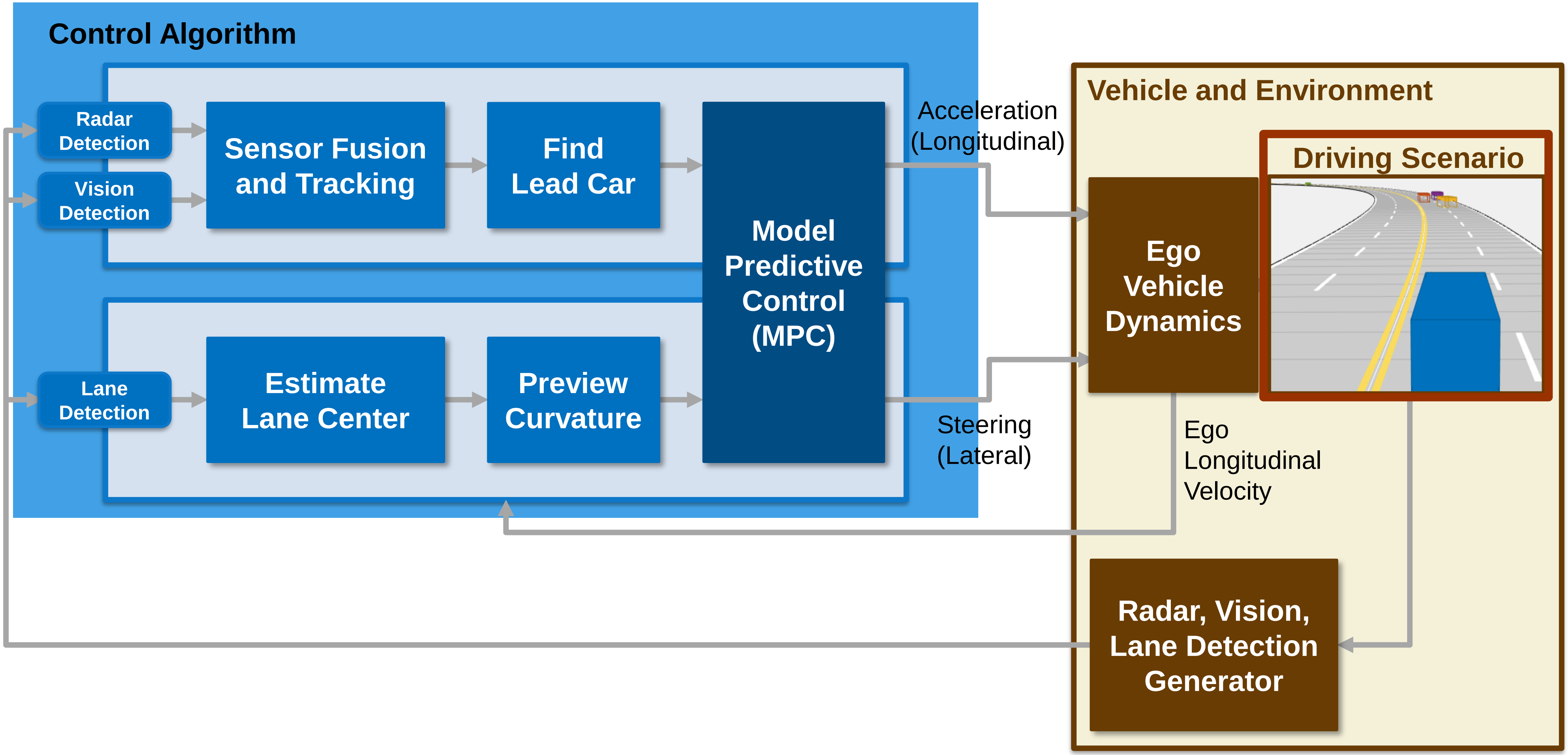
Bicycle Model - Force Input



- Implement a single track 3DOF rigid vehicle body to calculate longitudinal, lateral, and yaw motion
- Block calculates only lateral forces using the tire slip angles and linear cornering stiffness.

Develop and Test Vehicle Controller

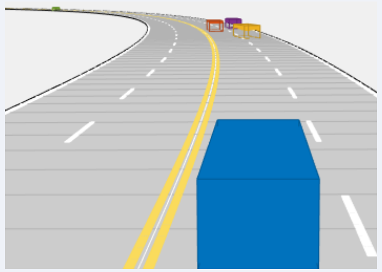
Traffic Jam Assist

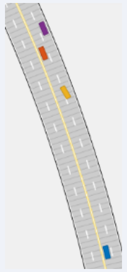


Create Test Scenario using Driving Scenario Designer

Test Description

Lead car cut in and out in curved highway (curvature of road = 1/500 m)





Host car

initial velocity = 20.6m/s
HWT(Headway Time) to lead car = 4sec
HW(Headway) to lead car = ~80m
v_set(set velocity for ego car) = 21.5m/s

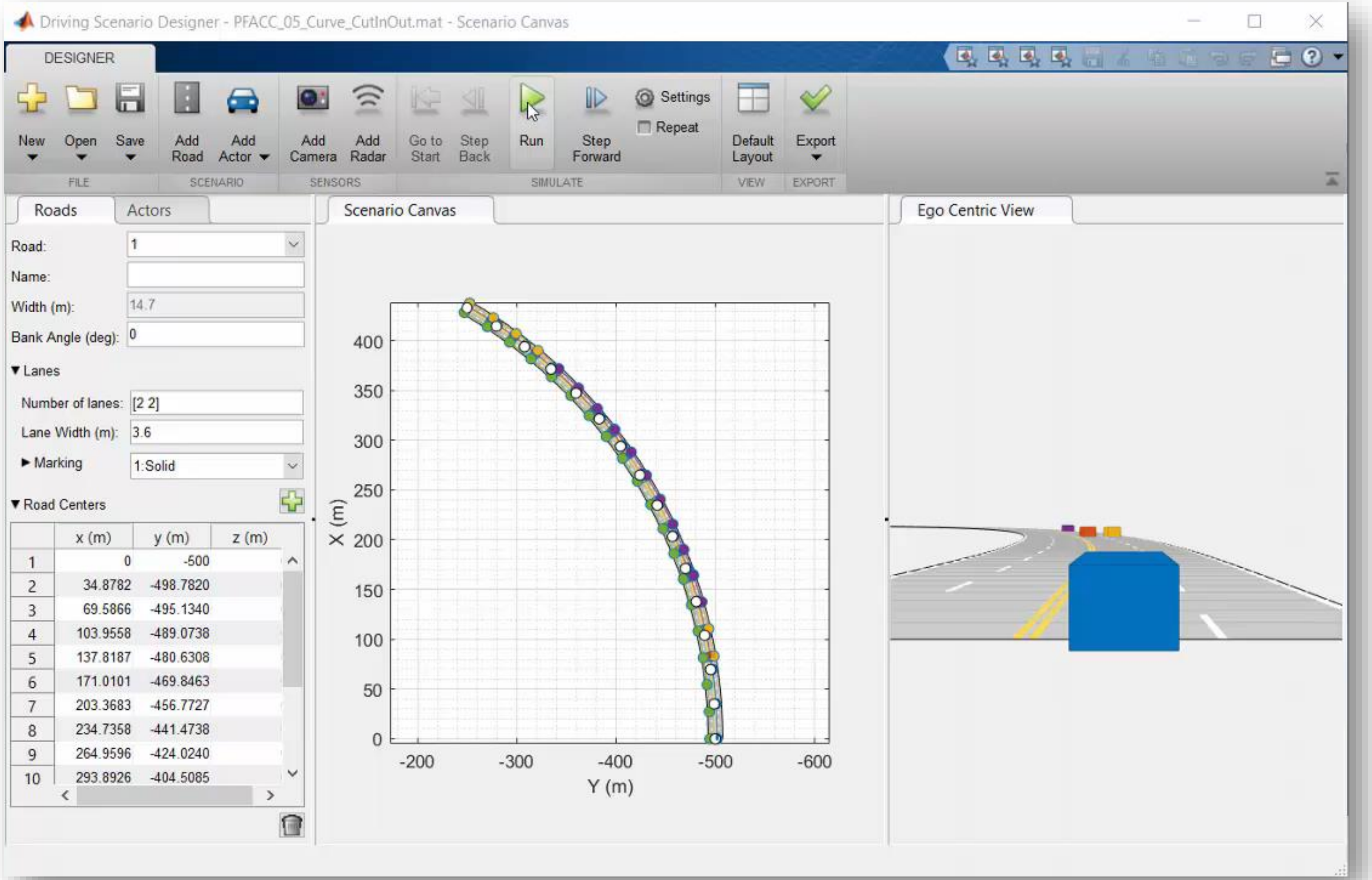
Lead Car

Initially, fast moving car (orange) at 19.4m/s

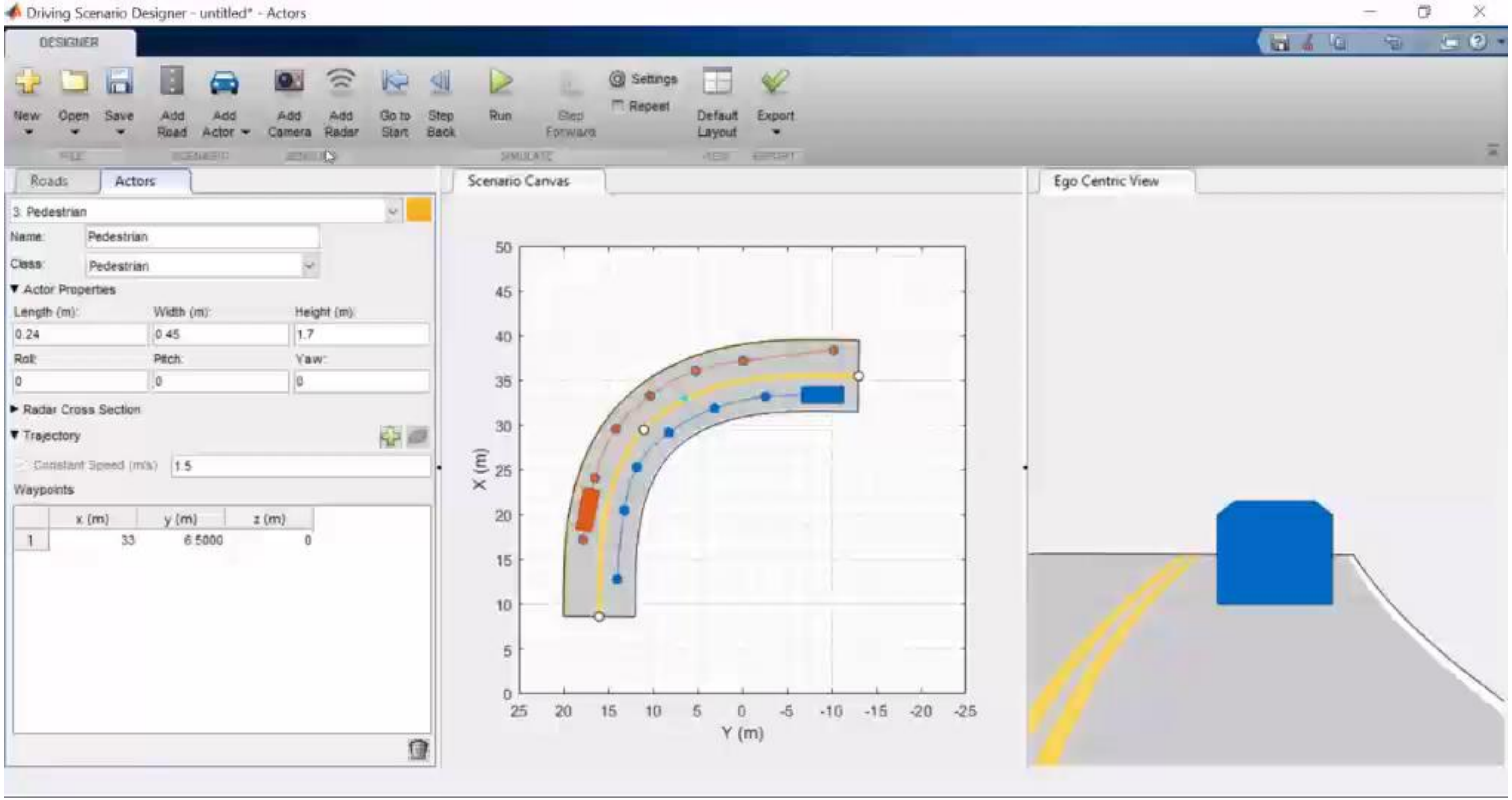
Passing car (yellow) at 19.6m/s cut in the ego path with HWT=2.3s, then cut out

Third Car

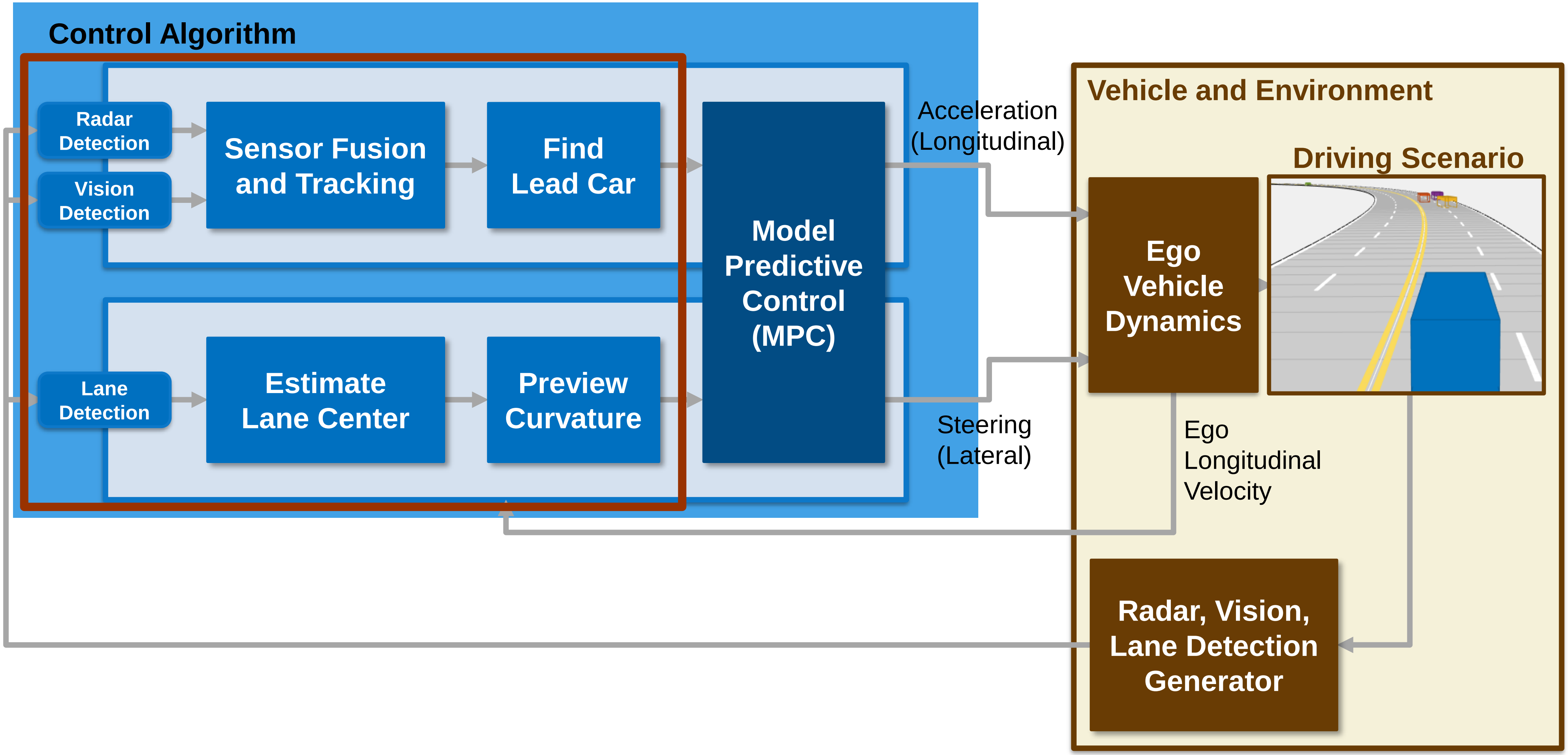
Slow moving car (purple) at 11.1m/s in the 2nd lane



Add sensors to test scenario



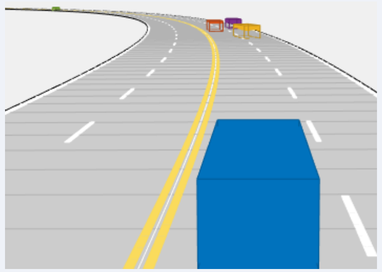
Develop and Test Vehicle Controller
Traffic Jam Assist

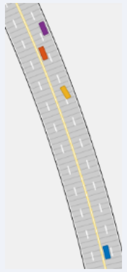


Simulation with Simulink Model for Traffic Jam Assist

Test Description

Lead car cut in and out in curved highway (curvature of road = 1/500 m)





Host car

initial velocity = 20.6m/s
HWT(Headway Time) to lead car = 4sec
HW(Headway) to lead car = ~80m
v_set(set velocity for ego car) = 21.5m/s

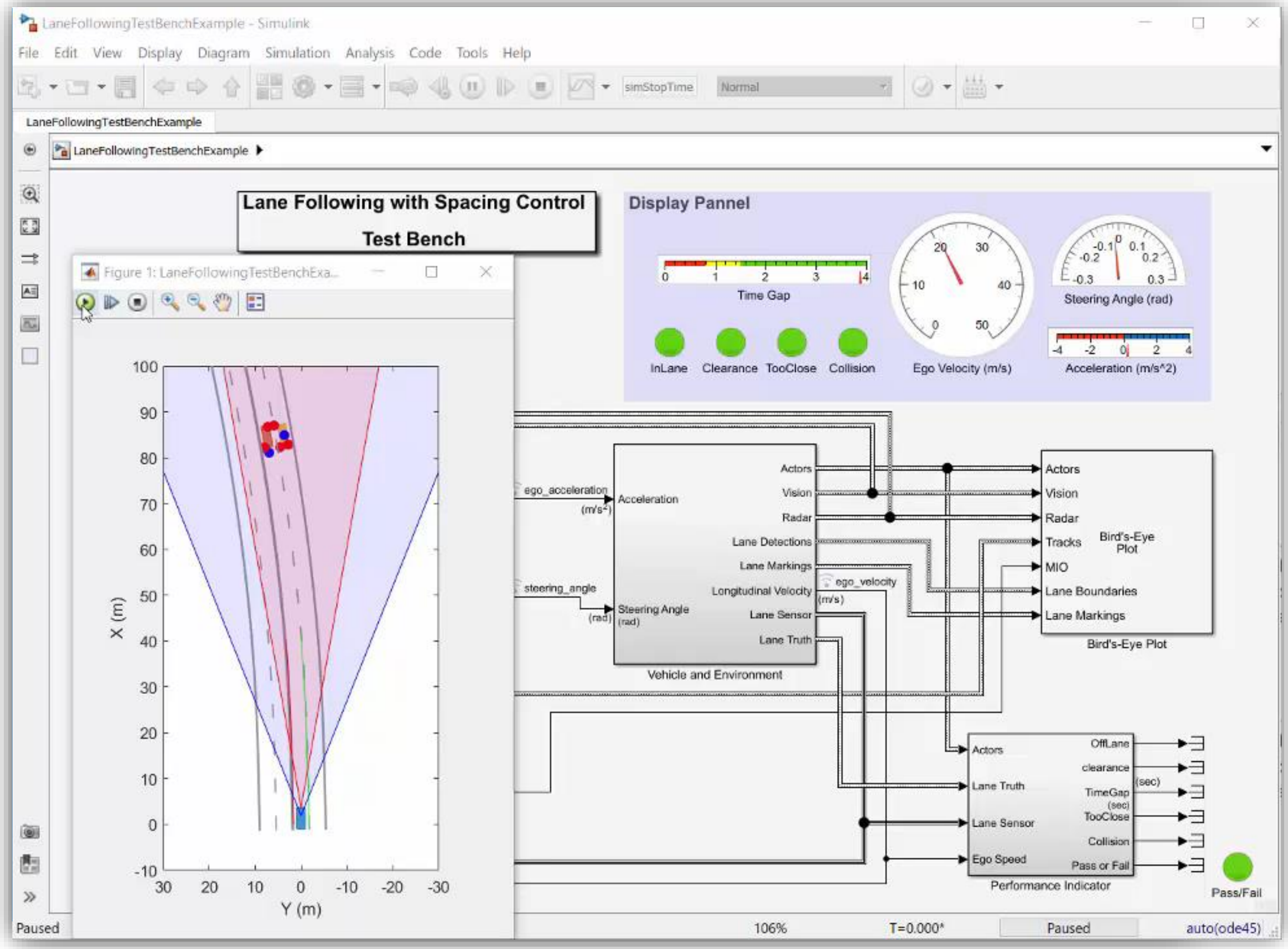
Lead Car

Initially, fast moving car (orange) at 19.4m/s

Passing car (yellow) at 19.6m/s cut in the ego path with HWT=2.3s, then cut out

Third Car

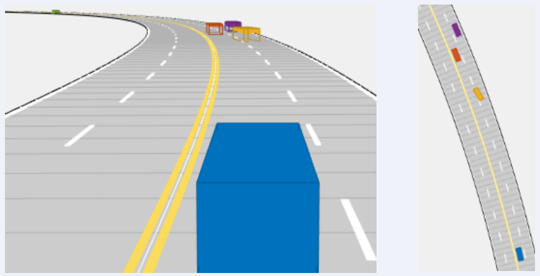
Slow moving car (purple) at 11.1m/s in the 2nd lane



Simulation with Simulink Model for Traffic Jam Assist

Test Description

Lead car cut in and out in curved highway (curvature of road = 1/500 m)



Host car

initial velocity = 20.6m/s
HWT(Headway Time) to lead car = 4sec
HW(Headway) to lead car = ~80m
v_set(set velocity for ego car) = 21.5m/s

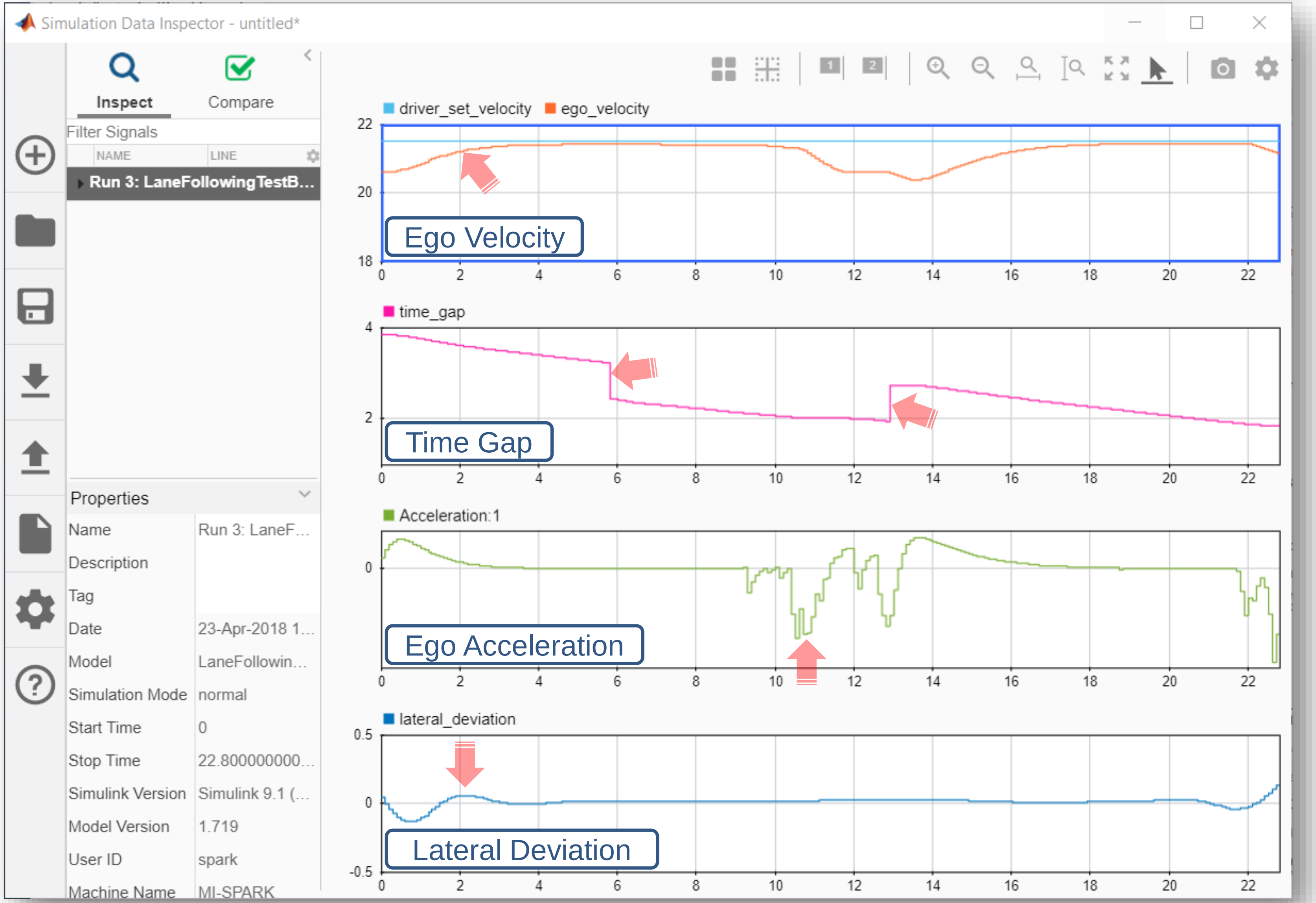
Lead Car

Initially, fast moving car (orange) at 19.4m/s

Passing car (yellow) at 19.6m/s cut in the ego path with HWT=2.3s, then cut out

Third Car

Slow moving car (purple) at 11.1m/s in the 2nd lane

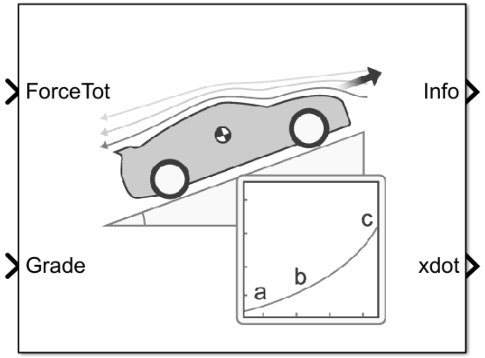


Agenda

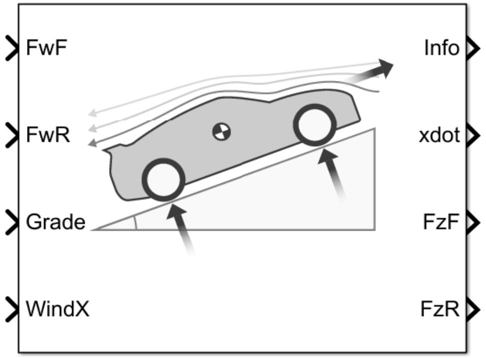
- Design model-predictive control-based vehicle controllers
- Run close-loop simulation with synthetic scenarios and test sensor fusion and control algorithms at a model level
- Improve simulation fidelity with gaming engine integration, vehicle dynamics modelling, and automated scenario creation from recorded data

Improve simulation fidelity: Include detailed vehicle dynamics

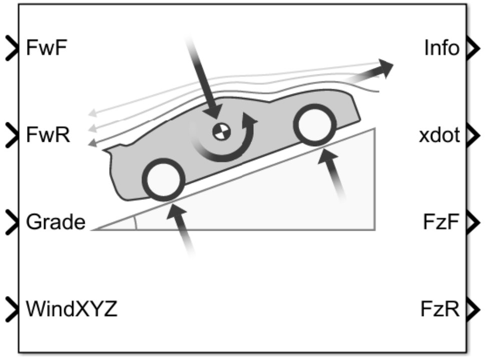
Vehicle Dynamics Blockset



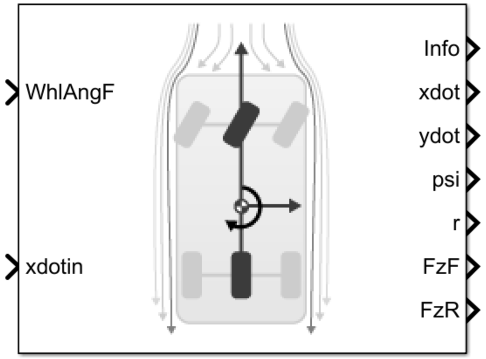
Vehicle Body Total Road Load



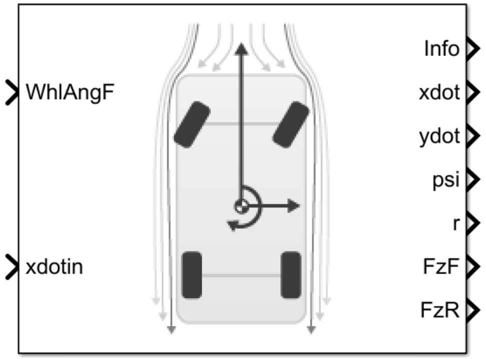
Vehicle Body 1DOF Longitudinal



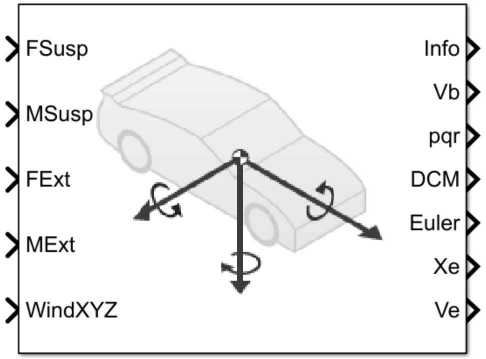
Vehicle Body 3DOF Longitudinal



Vehicle Body 3DOF Single Track



Vehicle Body 3DOF Dual Track

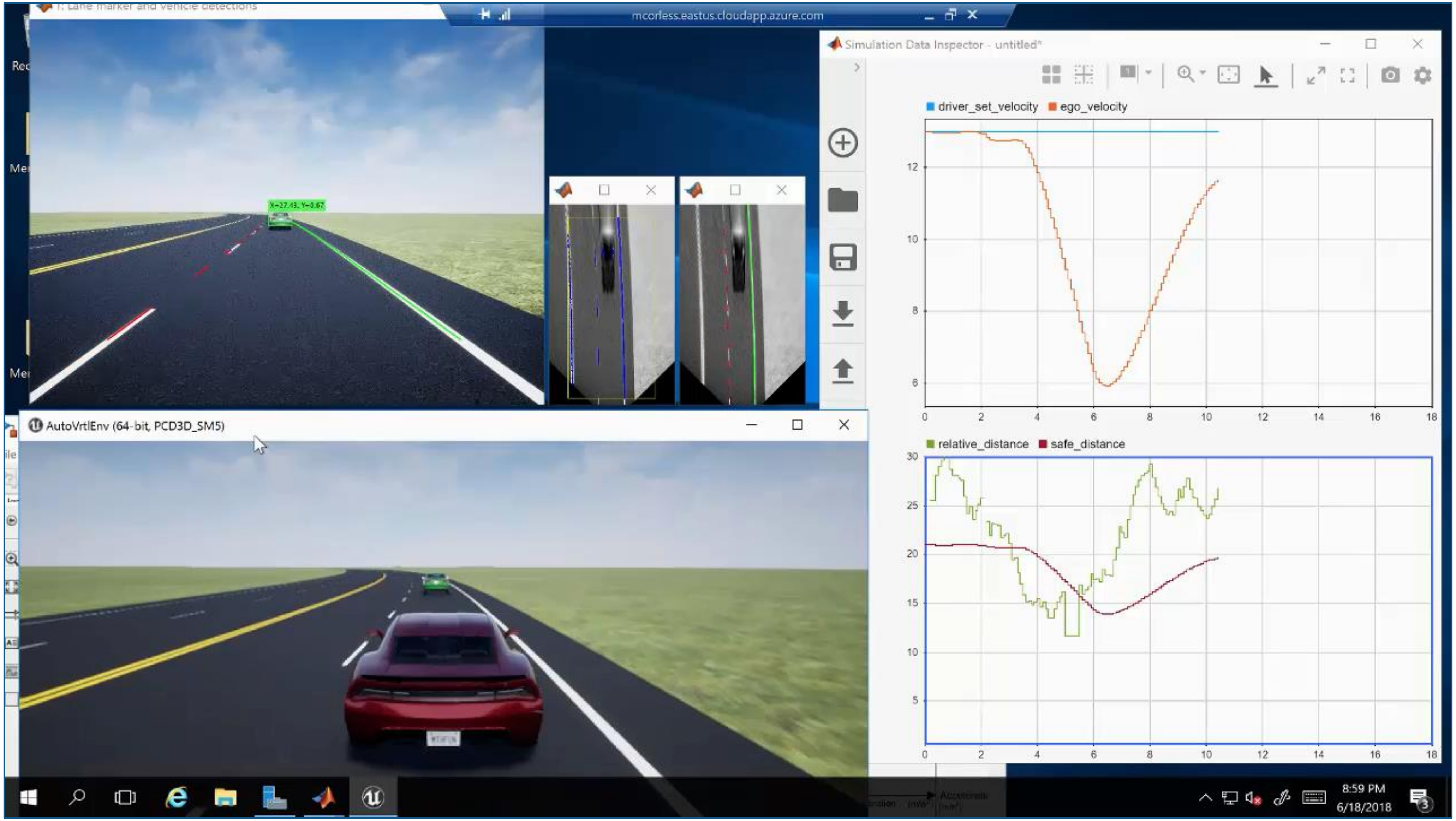


Vehicle Body 6DOF

Improve simulation fidelity:
Include detailed vehicle dynamics

<table>
<tr><th>Vehicle Model</th><th>Description</th><th>Vehicle Body Degrees-of-Freedom (DOFs)</th><th>Wheel DOFs</th></tr>
<tr><td>Passenger 14DOF Vehicle</td><td>Vehicle with four wheels
Available as model variant in the maneuver reference applications</td><td>Six<table><tr><th>Translational</th><th></th><th>Rotational</th><th></th></tr><tr><td>Longitudinal</td><td>✓</td><td>Pitch</td><td>✓</td></tr><tr><td>Lateral</td><td>✓</td><td>Yaw</td><td>✓</td></tr><tr><td>Vertical</td><td>✓</td><td>Roll</td><td>✓</td></tr></table></td><td>Two per wheel - eight total<table><tr><th>Translational</th><th></th><th>Rotational</th><th></th></tr><tr><td>Vertical</td><td>✓</td><td>Rolling</td><td>✓</td></tr></table></td></tr>
<tr><td>Passenger 7DOF Vehicle</td><td>Vehicle with four wheels
Available as model variant in the maneuver reference applications</td><td>Three<table><tr><th>Translational</th><th></th><th>Rotational</th><th></th></tr><tr><td>Longitudinal</td><td>✓</td><td>Pitch</td><td></td></tr><tr><td>Lateral</td><td>✓</td><td>Yaw</td><td>✓</td></tr><tr><td>Vertical</td><td></td><td>Roll</td><td></td></tr></table></td><td>One per wheel - four total<table><tr><th>Rotational</th><th></th></tr><tr><td>Rolling</td><td>✓</td></tr></table></td></tr>
<tr><td>Passenger 3DOF Vehicle</td><td>Vehicle with ideal tire</td><td>Three<table><tr><th>Translational</th><th></th><th>Rotational</th><th></th></tr><tr><td>Longitudinal</td><td>✓</td><td>Pitch</td><td></td></tr><tr><td>Lateral</td><td>✓</td><td>Yaw</td><td>✓</td></tr><tr><td>Vertical</td><td></td><td>Roll</td><td></td></tr></table></td><td>None</td></tr>
</table>

Improve simulation fidelity: Co-simulate with Unreal Engine



Game Engine Co-Simulation

Simulink

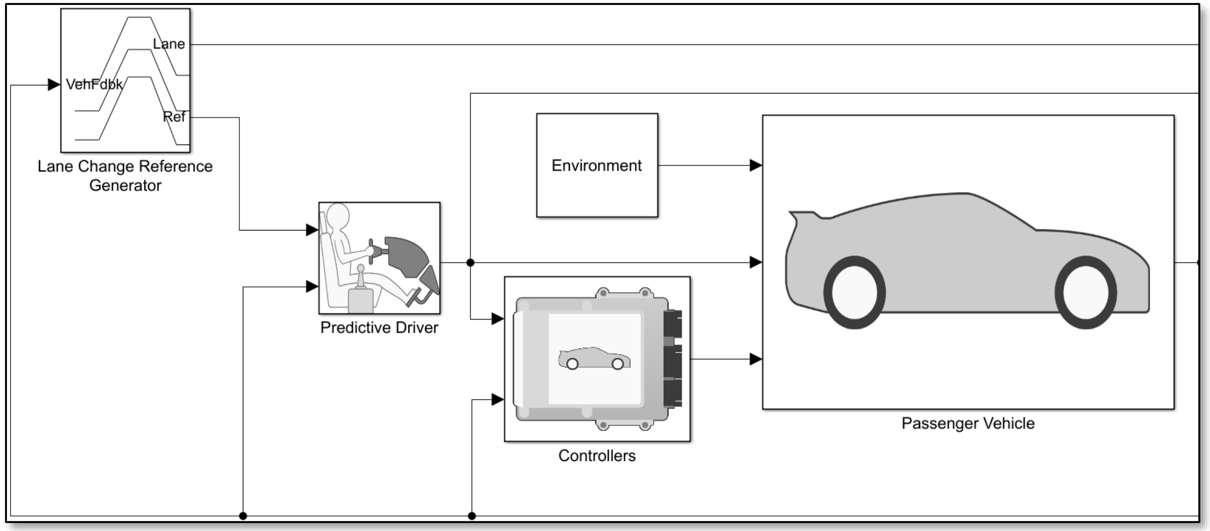
- Physics of vehicle
- Initialization of game engine camera

vehicle / camera location

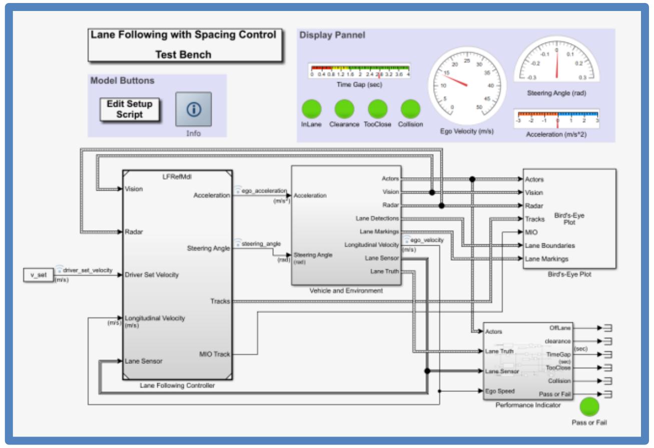
camera image, ground height, …

Unreal Engine

- Rendering / lighting
- Physics of non-Simulink objects
- Collision detection



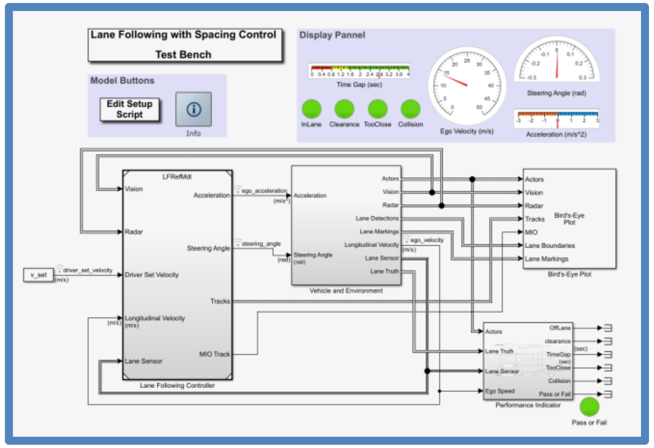
Develop and Test Vehicle Controller
Traffic Jam Assist: Key takeways



Design Traffic Jam Assist Controller

- Create driving scenario
- Synthesize sensor detection
- Include Vehicle Dynamics
- Design sensor fusion algorithm
- Design controller using MPC

Develop and Test Vehicle Controller
Traffic Jam Assist: Next Steps



Design Traffic Jam Assist Controller

- Create driving scenario
- Synthesize sensor detection
- Include Vehicle Dynamics
- Design sensor fusion algorithm
- Design controller using MPC

Reference examples to get started:

1. Lane Following Using Nonlinear Model Predictive Control

2. Lane Following Control with Sensor Fusion and Lane Detection

3. Testing a Lane-Following Controller with Simulink Test

Hitachi develops model-predictive controller for adaptive cruise control in traffic jam

FAST-zero '17

Model Predictive Control Approach to Design
Practical Adaptive Cruise Control for Traffic Jam

Taku TAKAHAMA [1] Daisuke AKASAKA [2]

1) Hitachi Automotive Systems, Ltd.
4-7-1 Onna, Atsugi, Kanagawa, 243-8510, Japan (E-mail: taku.takahama.tz@hitachi-automotive.co.jp)
2) The MathWorks GK
4-15-1 Akasaka, Minato-ku, Tokyo, 107-0052, Japan

The MPC controller was implemented in an embedded microprocessor (Renesas SH-4A, 32-bit processor), we confirmed the processing time of the MPC. The measurement result is shown in Fig. 5, the average time of the ACC function was 1.1ms. The C-code is automatically generated from a Simulink model using Embedded Coder®.

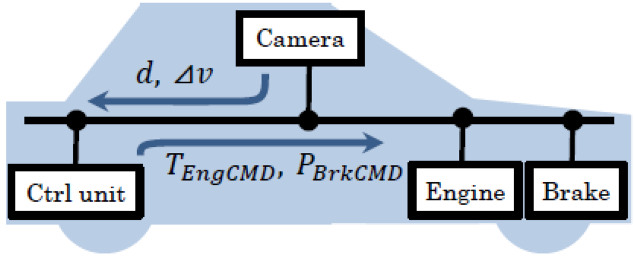


Fig. 4 System configuration of the experimental vehicle

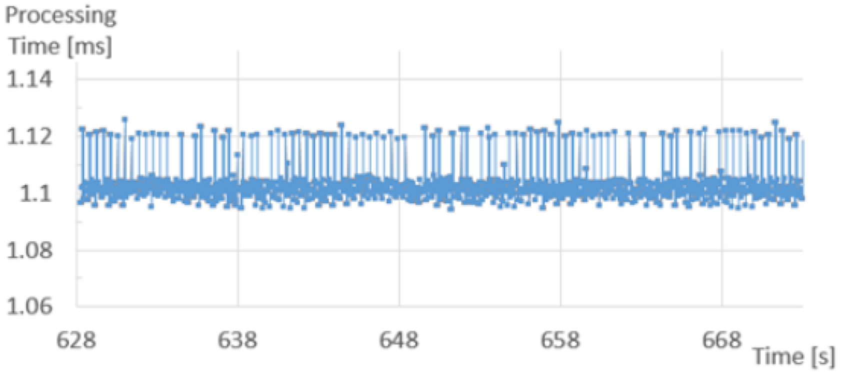


Fig. 5 The processing time of the proposed MPC

Hitachi paper published with SAE, Japan 2017
Hitachi also presented at 2017 MathWorks Expo, Japan

Call to action

- Visit the booth!

- Attend the session:
  - Simplifying Requirements-Based Verification with Model-Based Design

- MATLAB Tech Talk:
  - Understanding Model Predictive Control