MathWorks
AUTOMOTIVE CONFERENCE 2023
North America

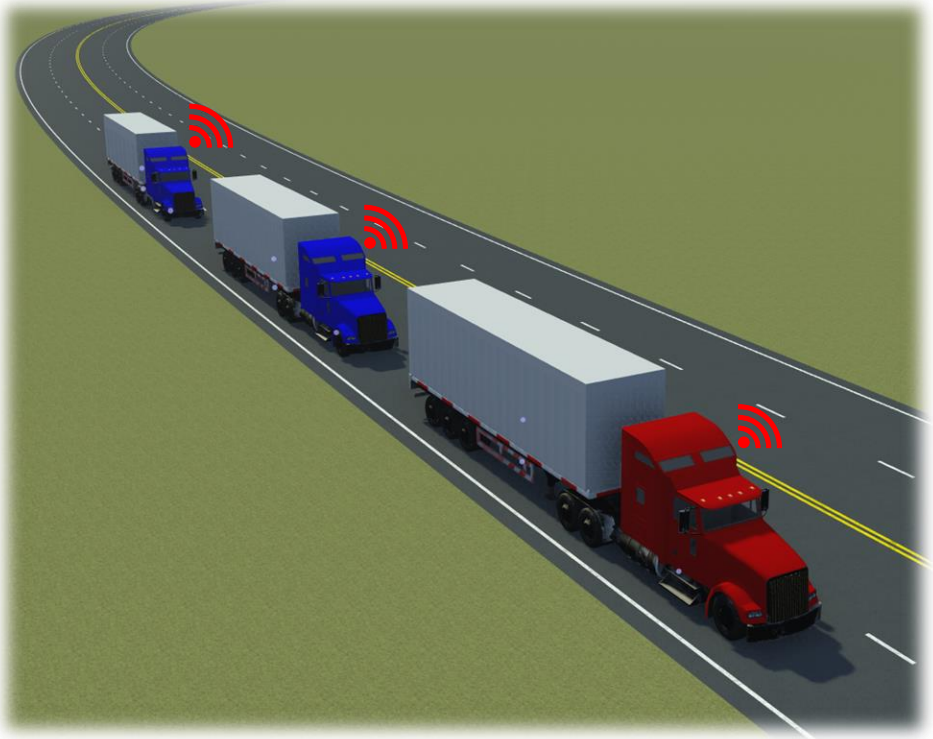
Lateral Control of Truck Platooning With RoadRunner Scenario

Seo-Wook Park, MathWorks

MathWorks®

Why “Truck Platooning”?

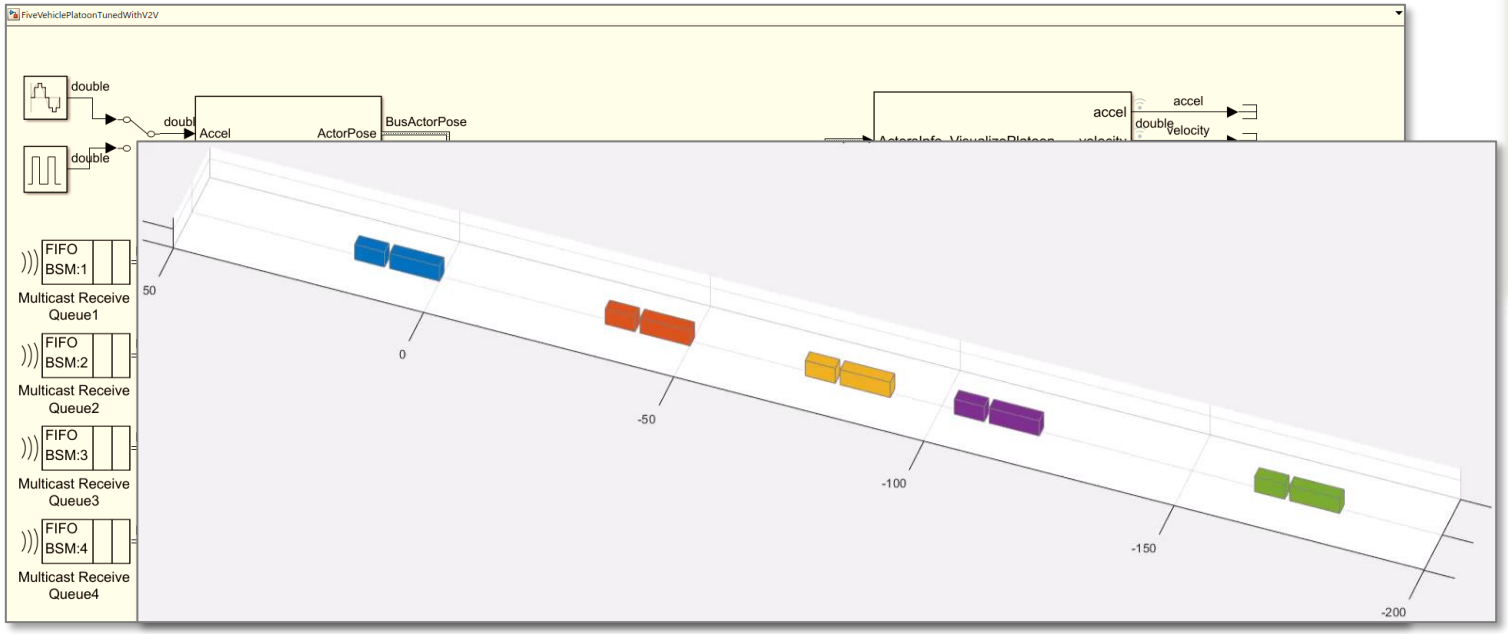
- Truck platooning allows trucks to follow each other closely, thereby **reducing air drag** and **improving fuel economy**.
- Platooning also has the potential to **increase vehicle capacity** on highways.
- **V2V** allows the truck platooning to form an **electronically “coupled”** two or more trucks.

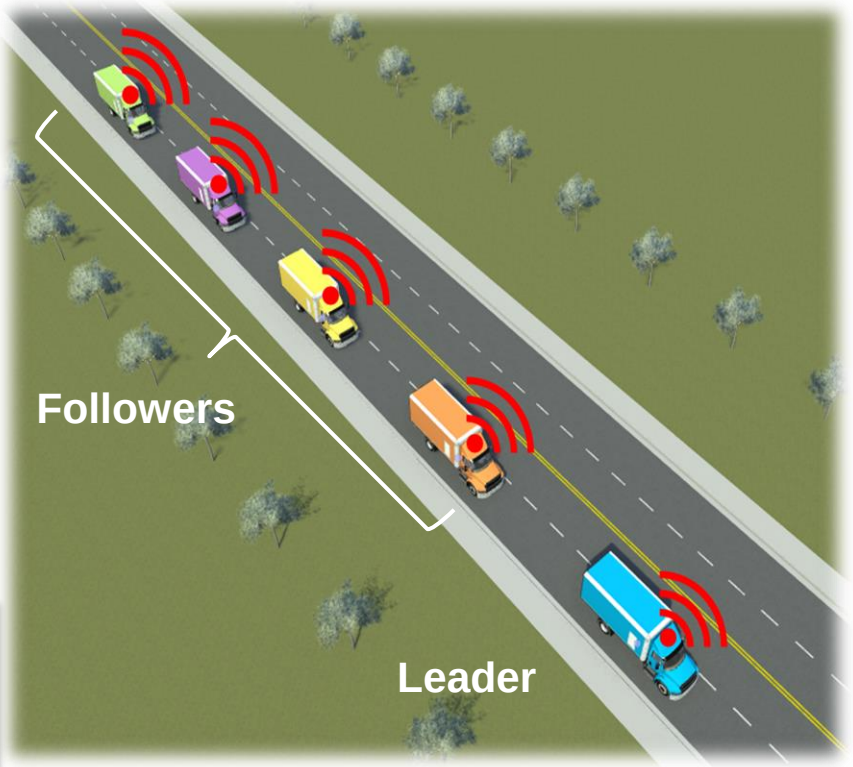


Reference: US DoT FHWA

Design of vehicle platooning controller with V2V communication

- Platooning longitudinal control
- Truck-trailer kinematic model
- V2V communication
- A simple cuboid visualization





Truck platooning reference examples

R2022b

Truck Platooning Using Vehicle-to-Vehicle Communication

Simulate truck platooning application using V2V communication in Unreal Engine simulation environment.

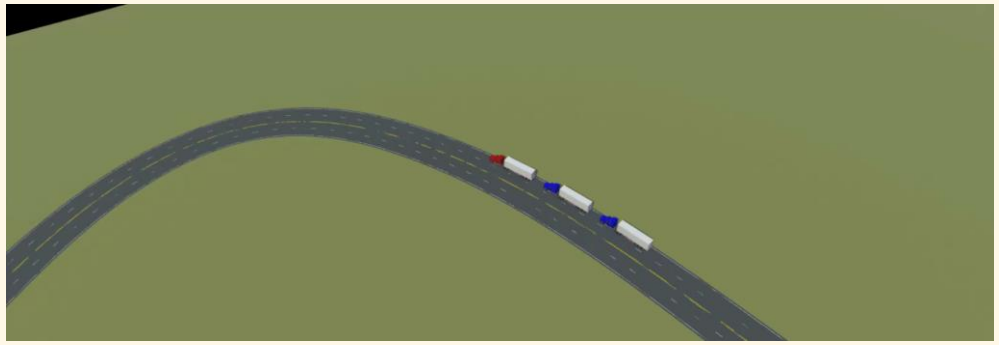
Vehicle Dynamics Blockset
Automated Driving Toolbox

+ Lateral Control
RoadRunner Scenario

- Platooning **longitudinal** control
- 3D visualization using the **Unreal Engine**
- **High fidelity** Three-Axle Tractor Towing Three-Axle Trailer
- V2V communication

R2023a

Truck Platooning with RoadRunner Scenario



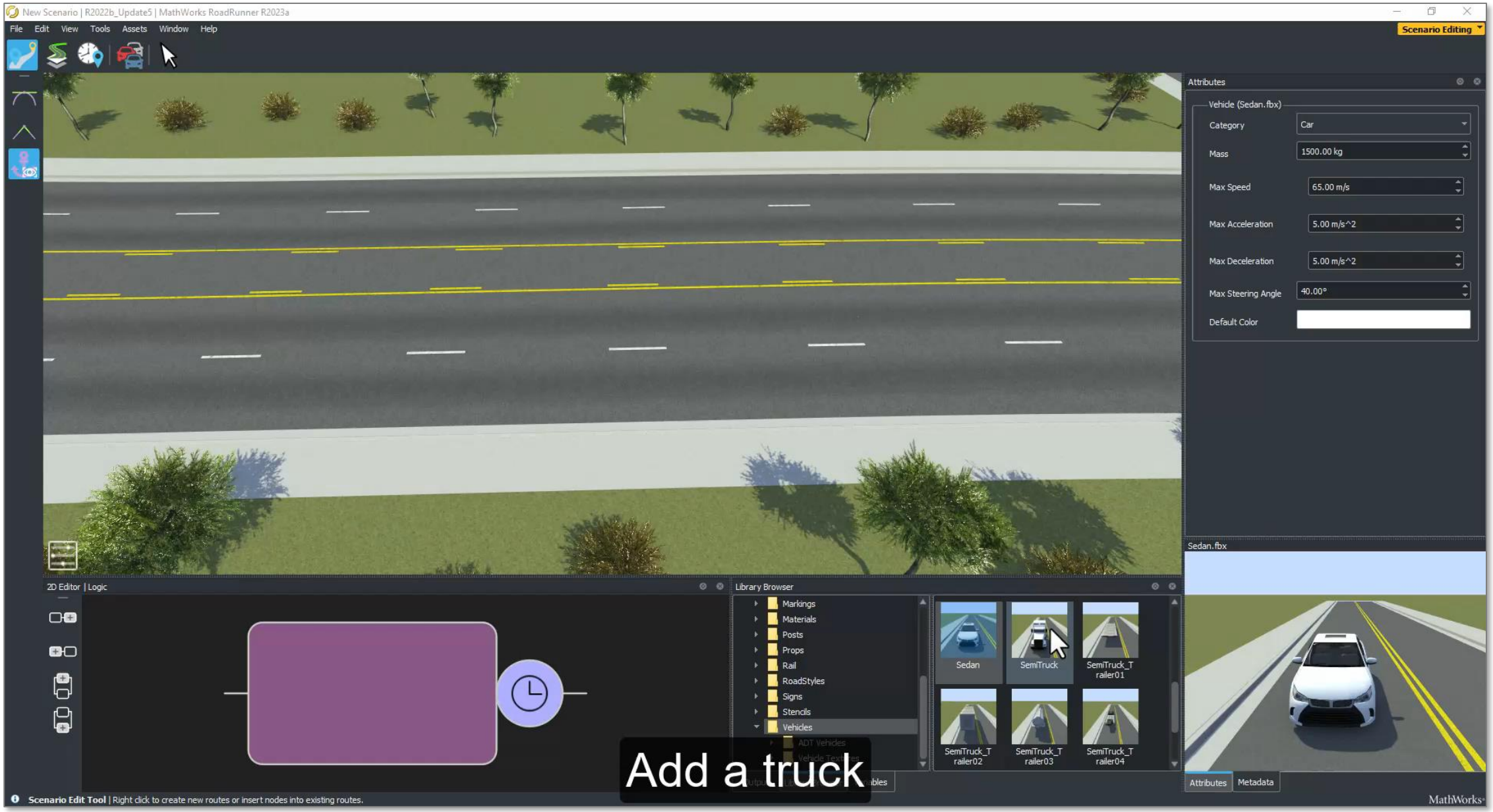
- Platooning longitudinal and **lateral** control
- Lateral control by **LKA MPC** controller and **linearized truck-trailer lateral dynamics**
- Simulate the Simulink test bench with **RoadRunner Scenario**
- High-fidelity Three-Axle Tractor Towing Three-Axle Trailer
- V2V communication

Model Predictive Control Toolbox
RoadRunner Scenario

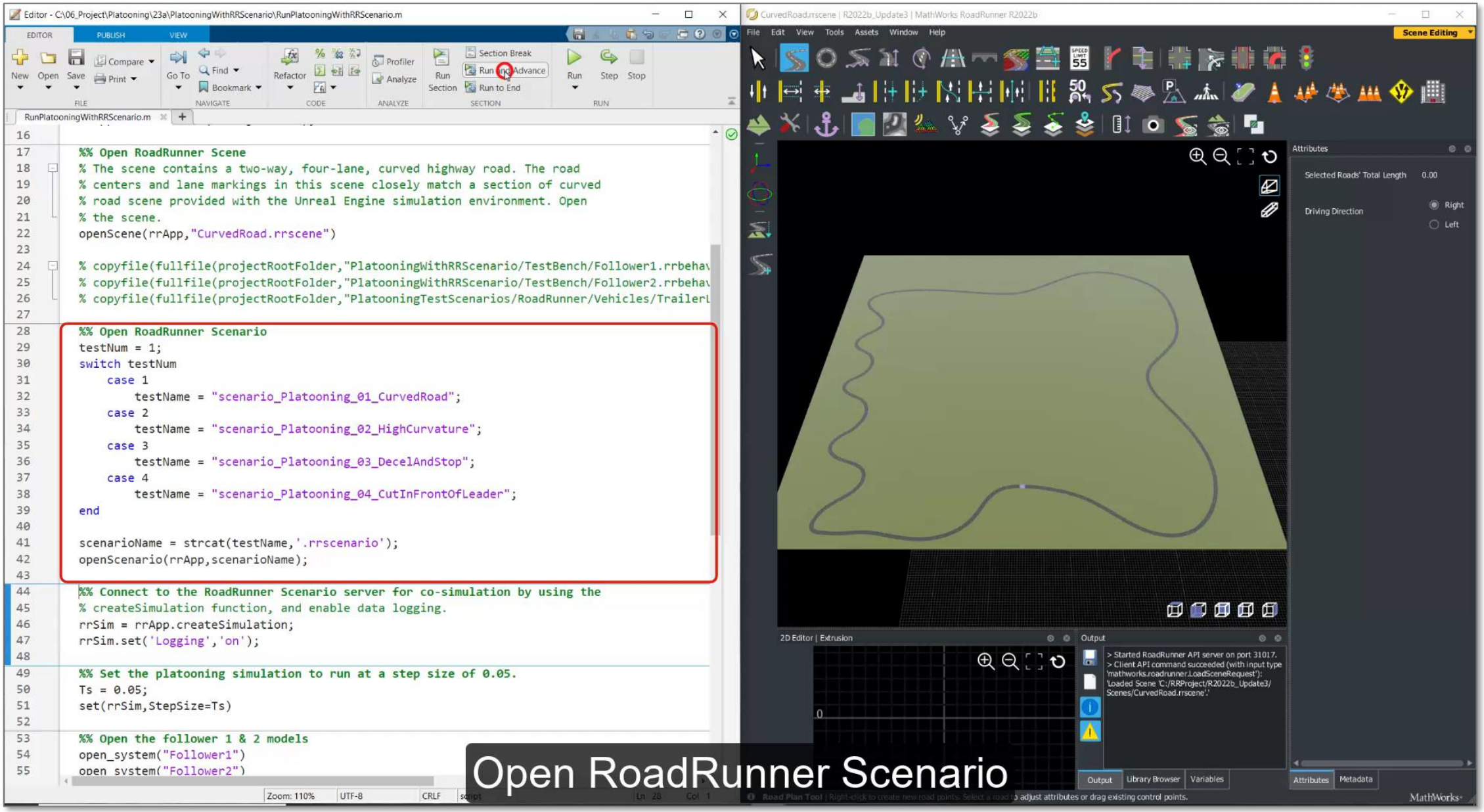
https://www.mathworks.com/help/releases/R2023a/roadrunner-scenario/ug/design-vehicle-with-trailer-scenario.html

Add Truck with Trailer to Scenario

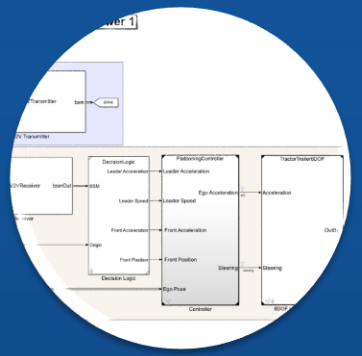
R2022b *RoadRunner Scenario*



Lateral Control of Truck platooning with RoadRunner Scenario

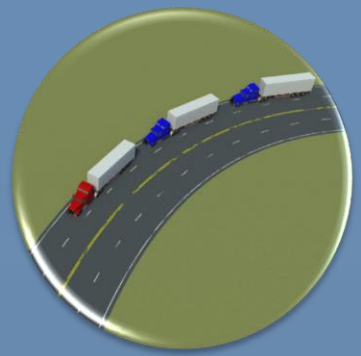


Workflow



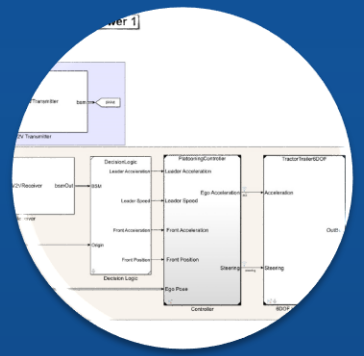
Platooning Test Bench

Scenario Authoring



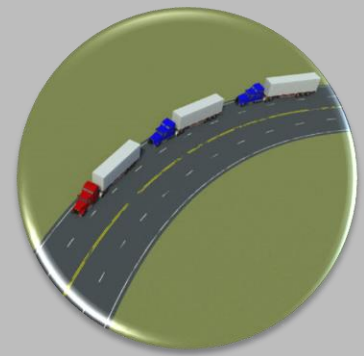
Scenario Simulation

Workflow



Platooning Test Bench

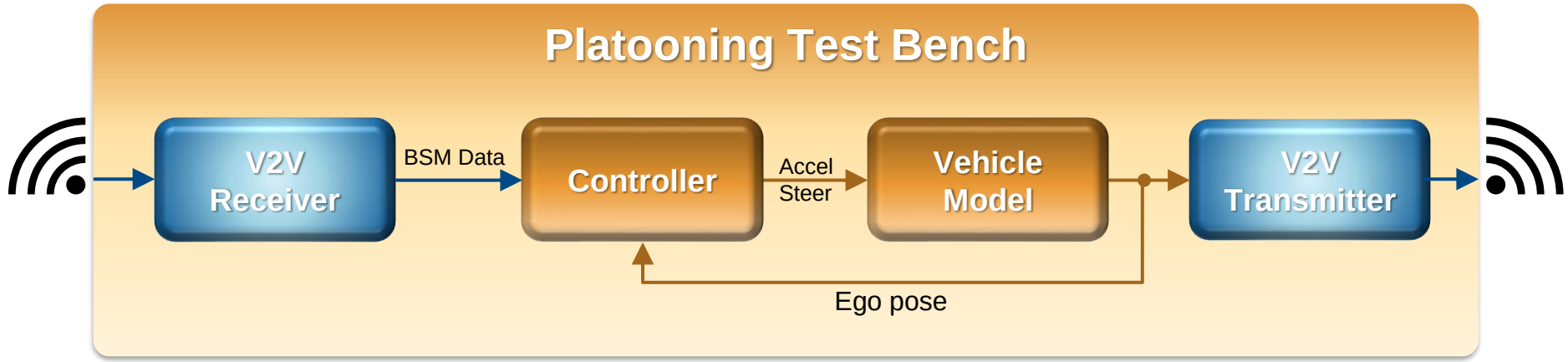
Scenario Authoring



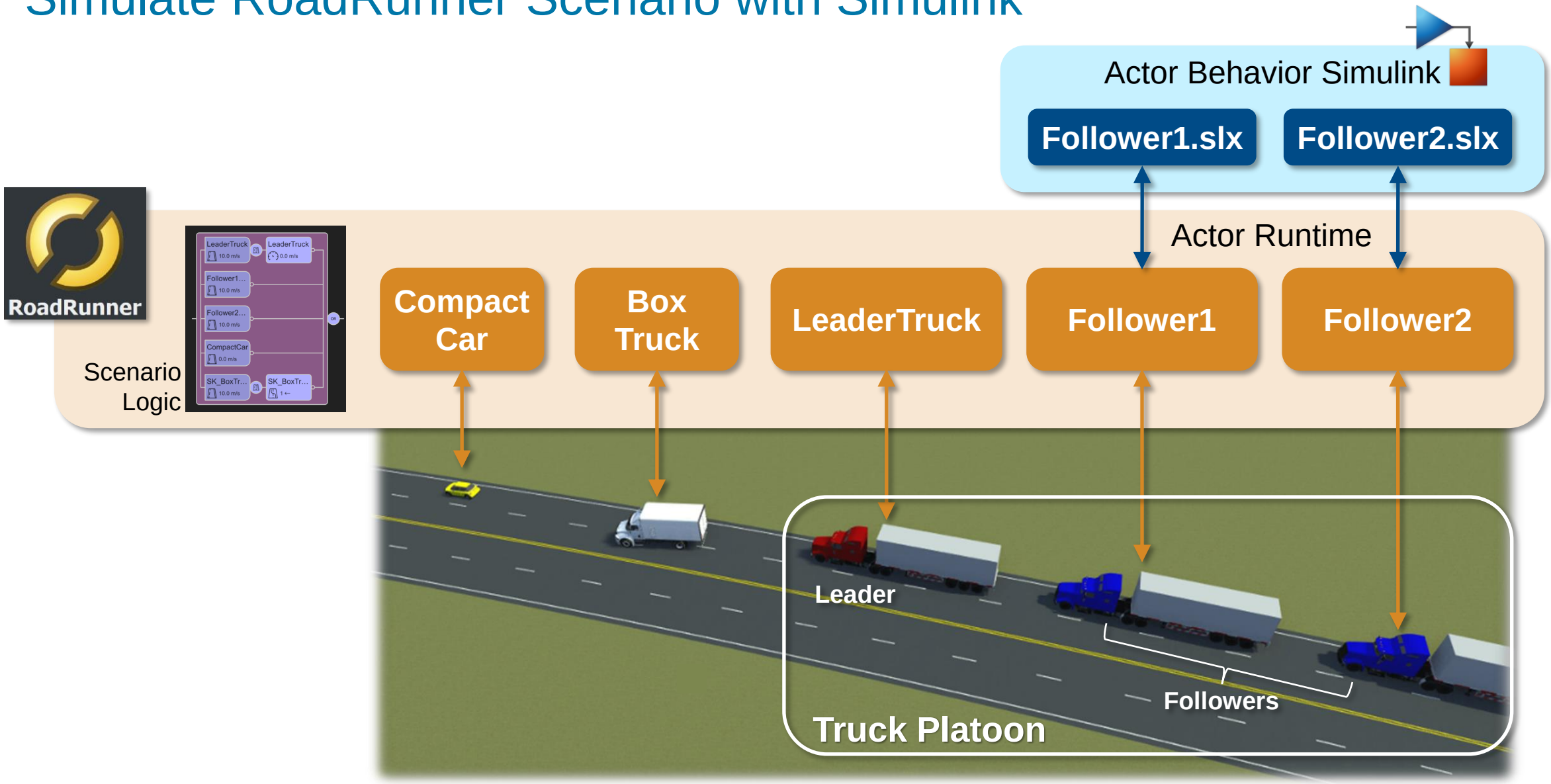
Scenario Simulation

Platooning Test Bench

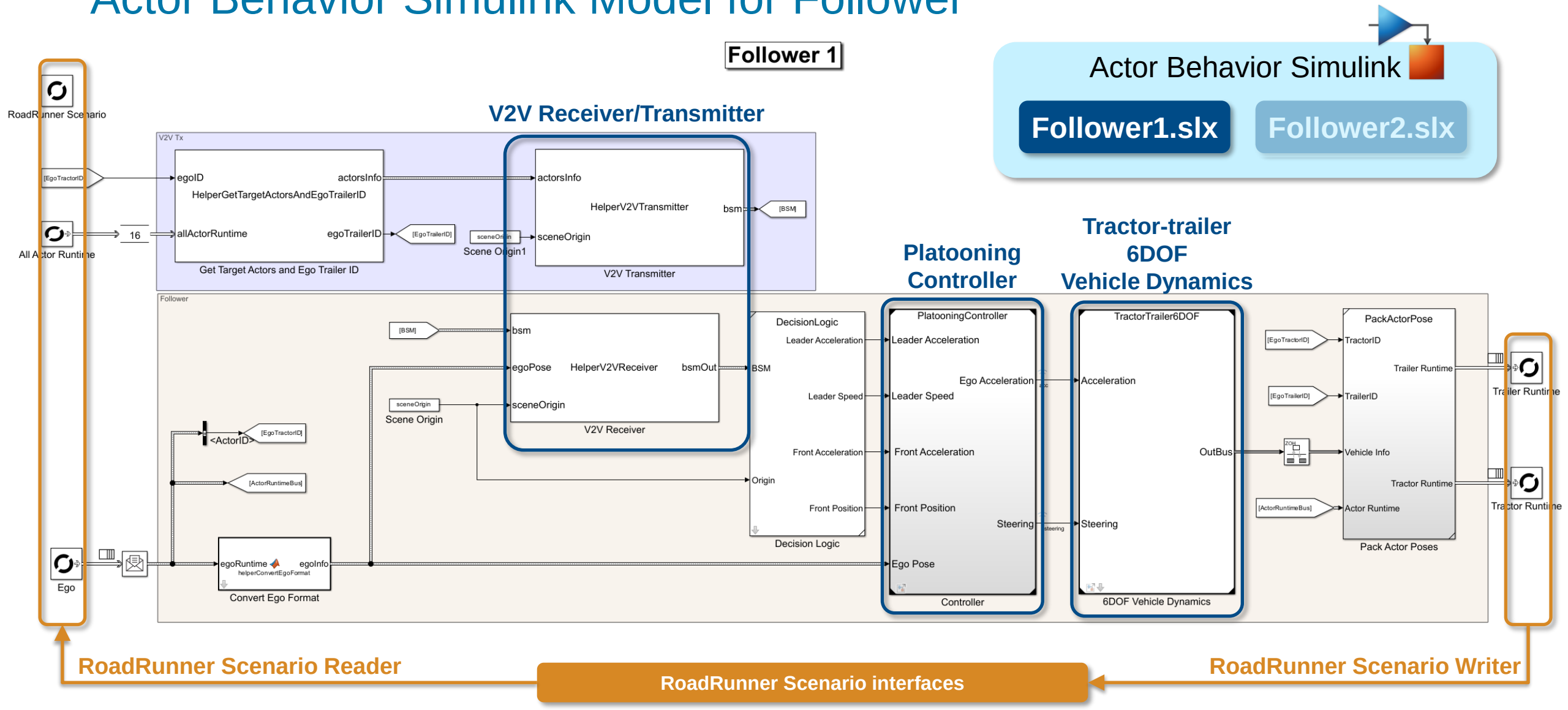
- V2V Receiver/Transmitter
  - Receive the position and movement information of the other vehicles in the platoon
  - Transmit ego pose to the platoon
- Platooning controller
  - Longitudinal & Lateral Control
- Vehicle model
  - High-fidelity Tractor-Trailer Dynamics



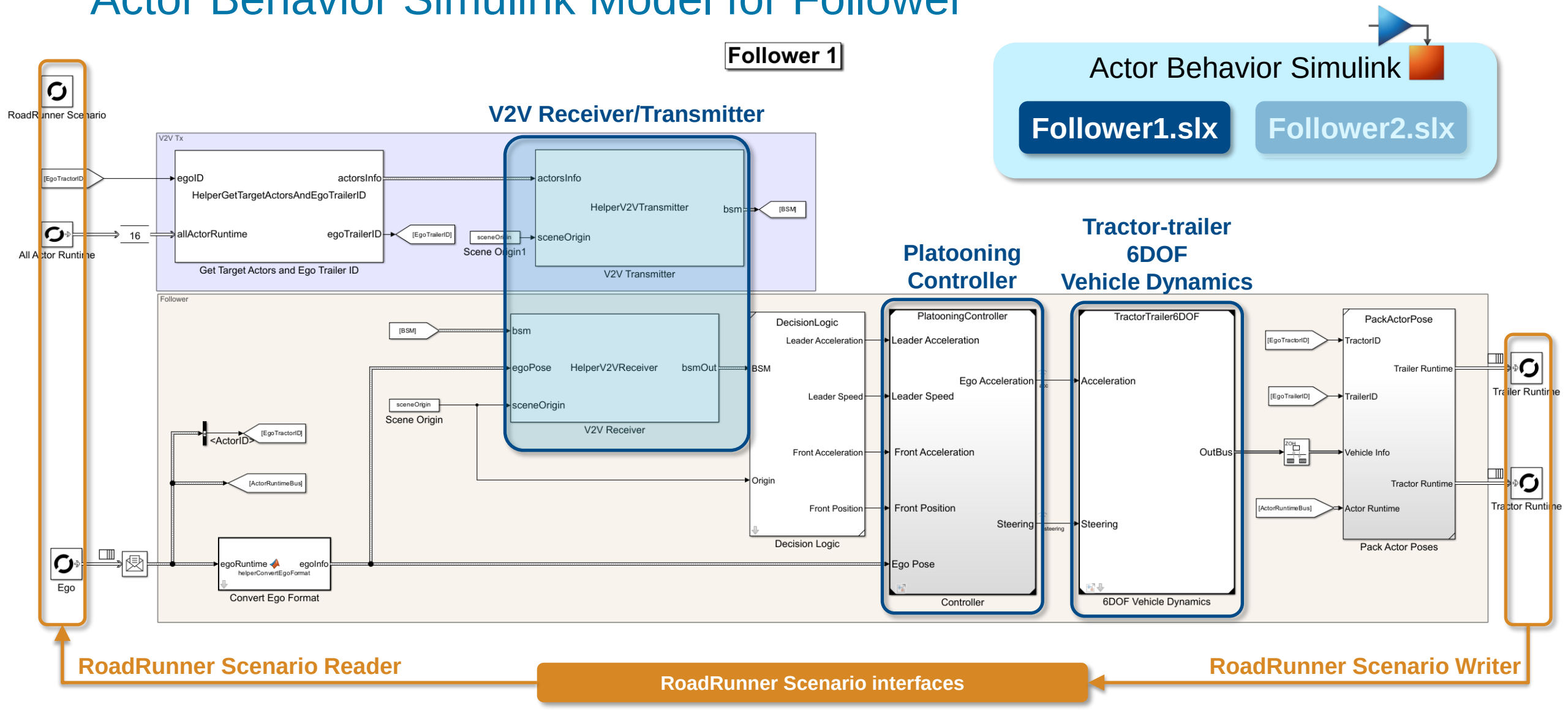
Simulate RoadRunner Scenario with Simulink



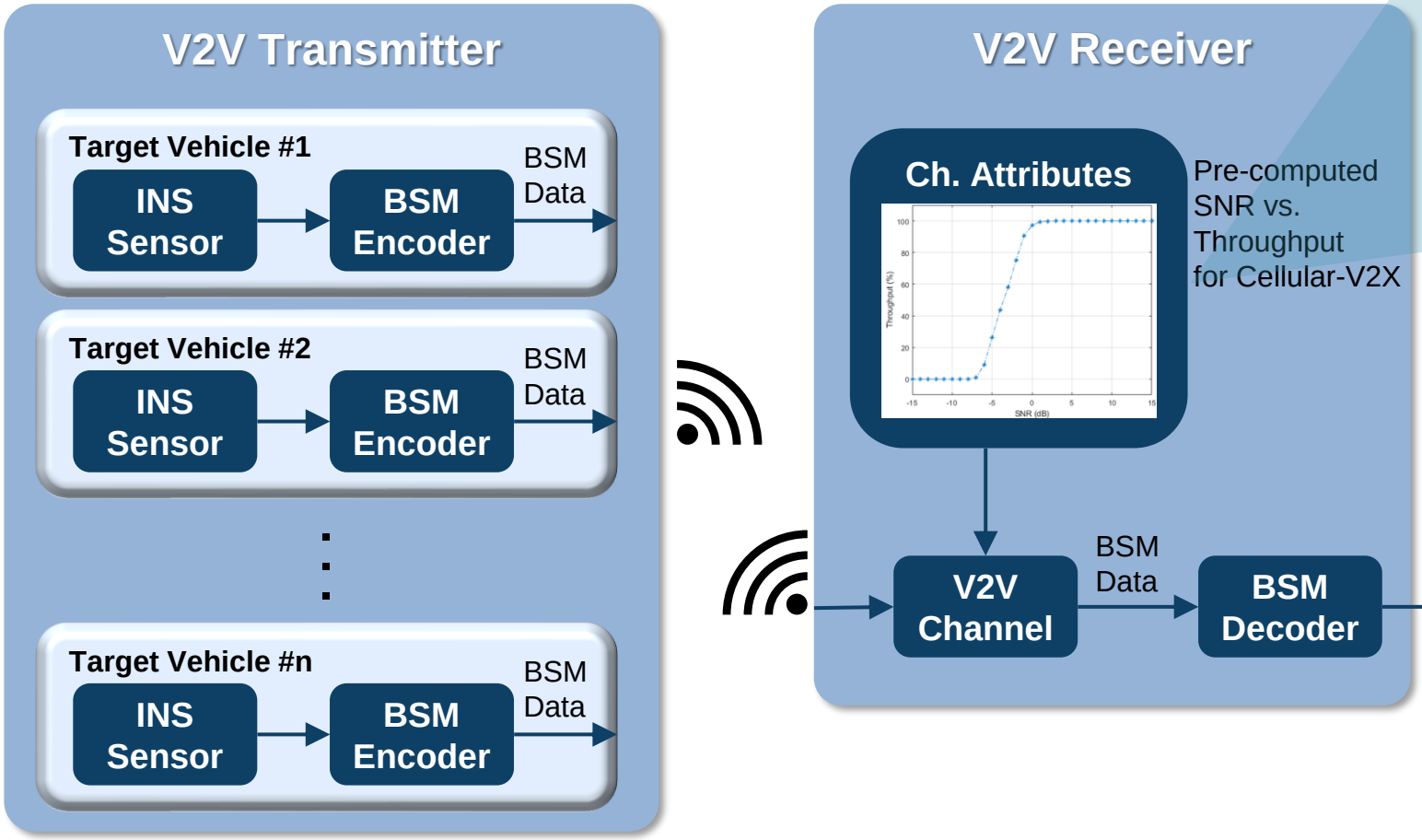
Actor Behavior Simulink Model for Follower

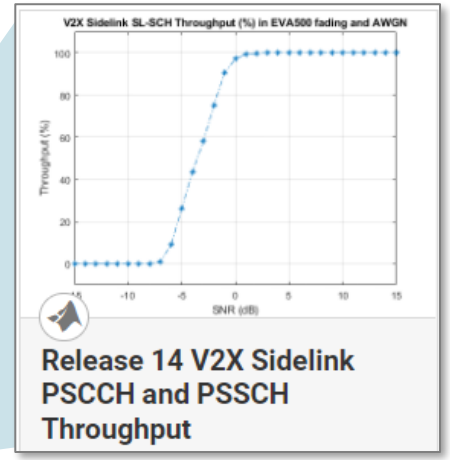


Actor Behavior Simulink Model for Follower

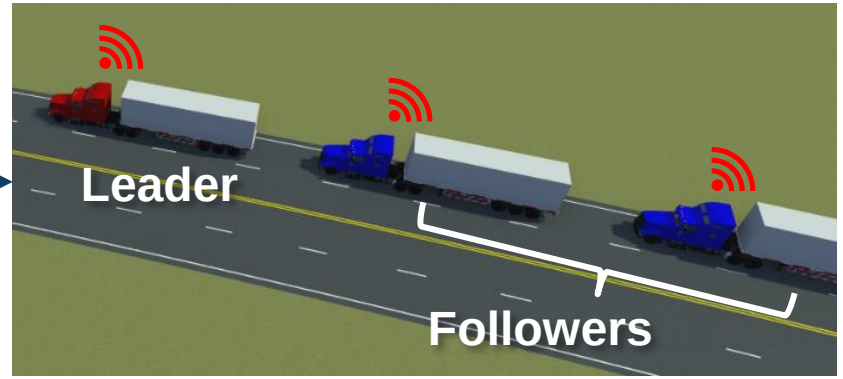


V2V Transmitter and Receiver





LTE Toolbox™



Platooning with V2V

BSM (Basic Safety Message) by SAE J2735

Automated Driving Toolbox

Basic Safety Message (BSM) by SAE J2735

- SAE J2735 – Data and message set dictionary

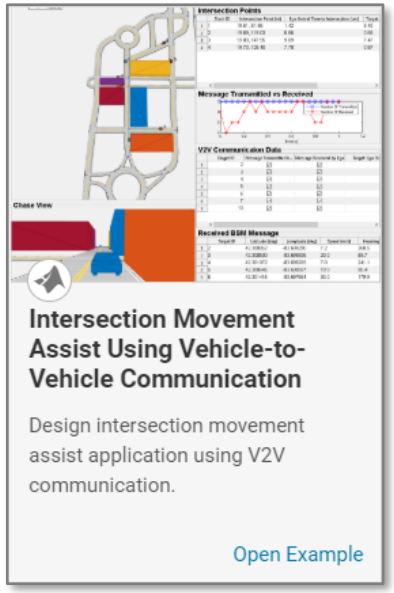
- Defines the **Basic Safety Message (BSM)**
  - Latitude, longitude, Elev
  - Speed
  - Heading angle
  - Steering wheel angle
  - Lat, long acceleration
  - Vehicle length, width

SAE INTERNATIONAL

SURFACE VEHICLE STANDARD	J2735®	JUL2020
	Issued 2006-12 Revised 2020-07 Superseding J2735 MAR2016	
(R) V2X Communications Message Set Dictionary		

```
BSMcoreData ::= SEQUENCE {
  msgCnt          MsgCount,
  id              TemporaryID,
  secMark         DSecond,
  lat             Latitude,
  long            Longitude,
  elev            Elevation,
  accuracy        PositionalAccuracy,
  transmission    TransmissionState,
  speed           Speed,
  heading         Heading,
  angle           SteeringWheelAngle,
  accelSet        AccelerationSet4Way,
  brakes          BrakeSystemStatus,
  size            VehicleSize
  }
```

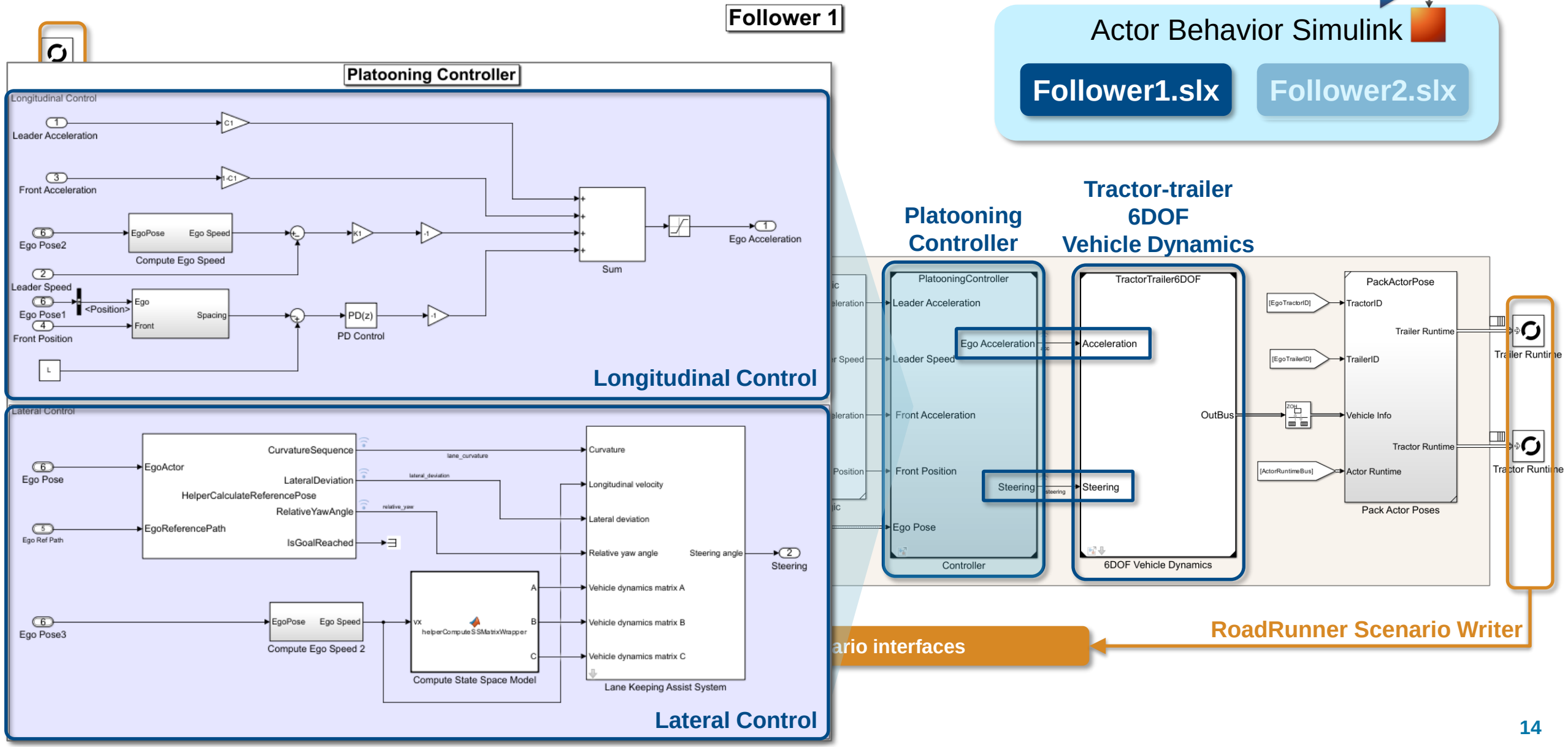
For more details



Automated Driving Toolbox™

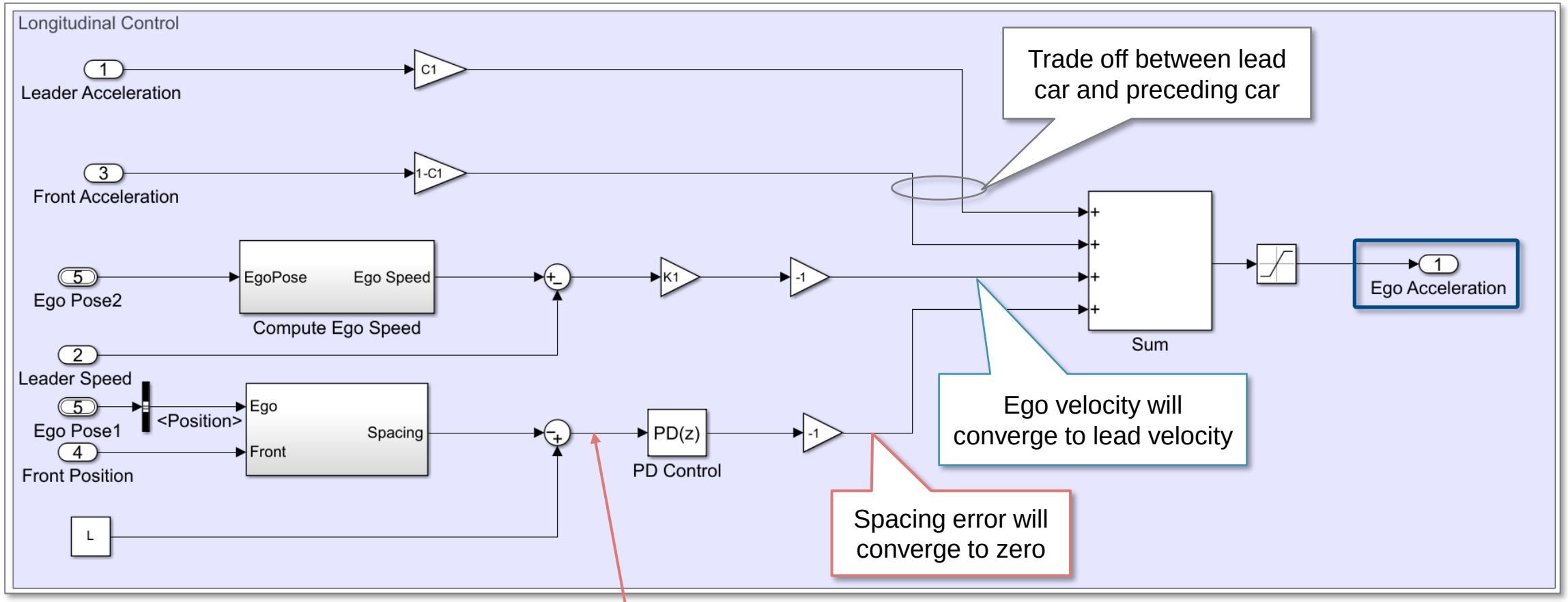
R2022a

Actor Behavior Simulink Model for Follower



Longitudinal control

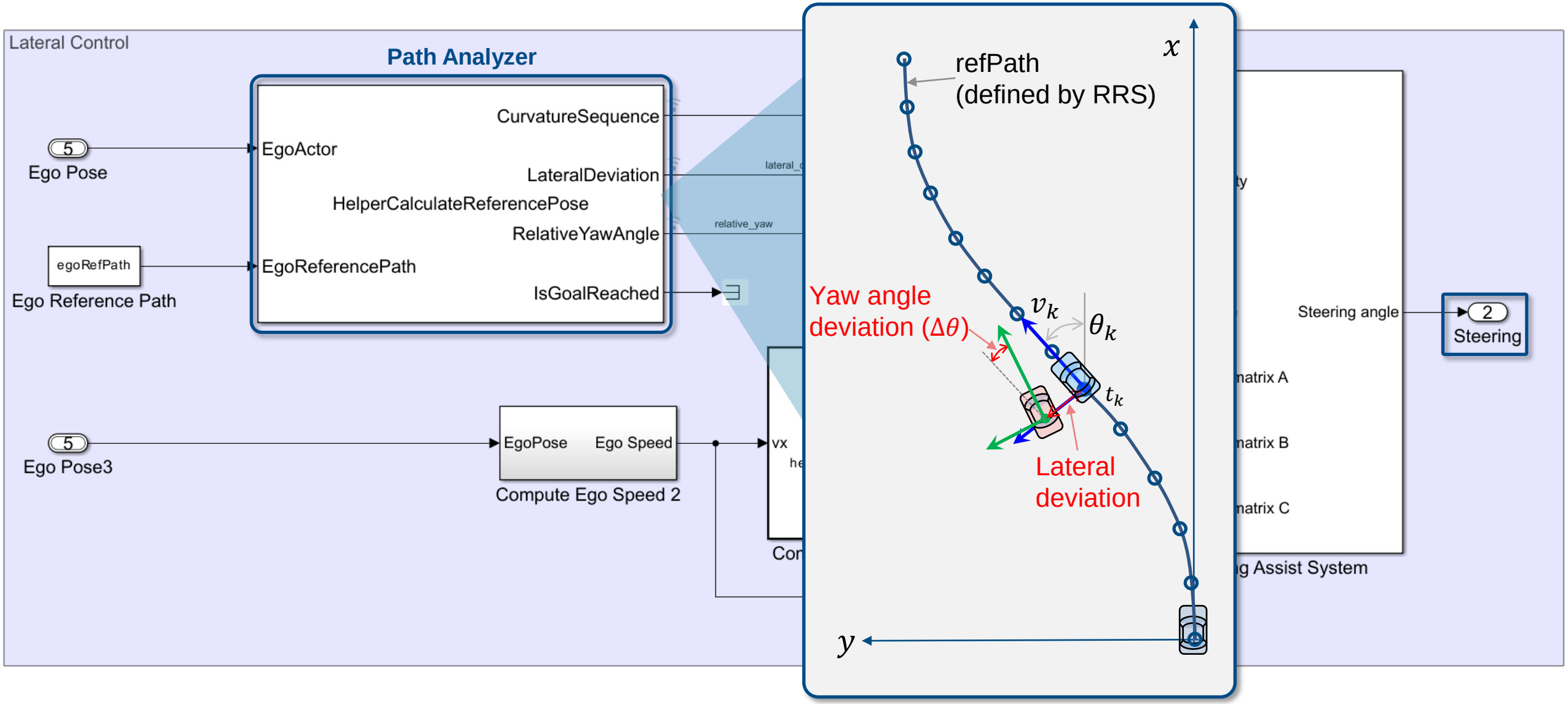
$$a_{ego} = C_1 a_{lead} + (1 - C_1) a_{front} - K_1 (v_{ego} - v_{lead}) - K_2 \left(L - \sqrt{(x_{ego} - x_{front})^2 + (y_{ego} - y_{front})^2} \right)$$



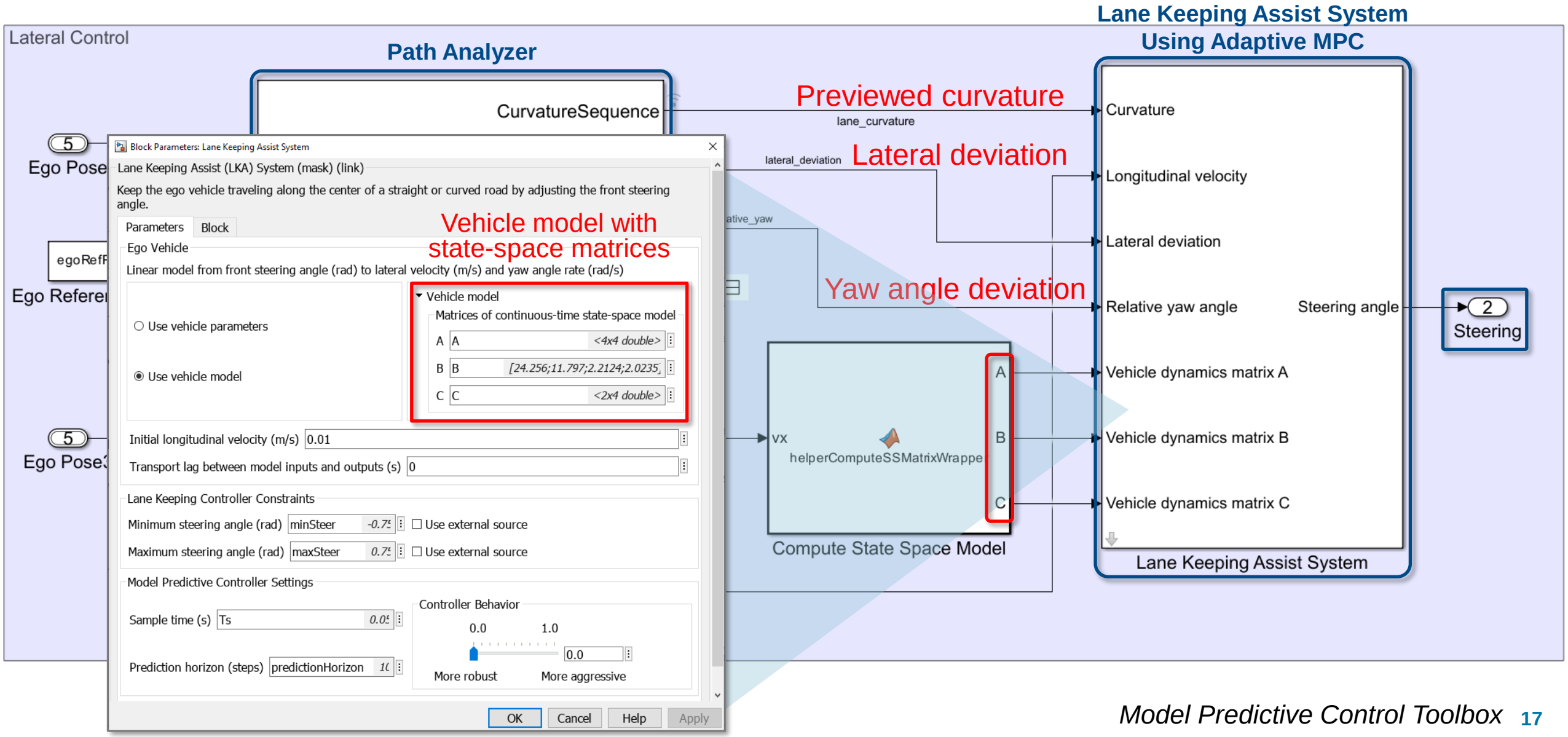
$$\varepsilon_i = L - \sqrt{(x_{ego} - x_{front})^2 + (y_{ego} - y_{front})^2}$$

Spacing error = ego - preceding car position

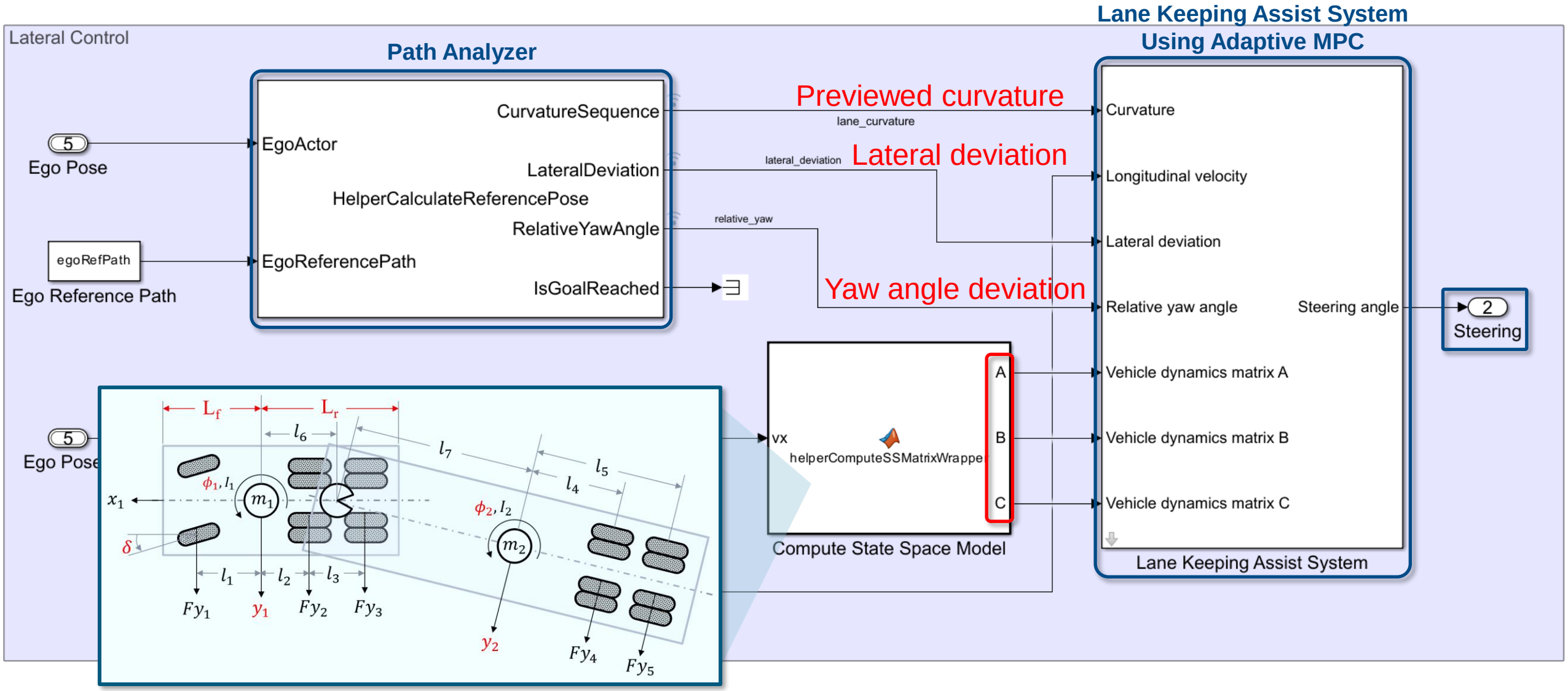
Lateral control



Lateral control



Lateral control



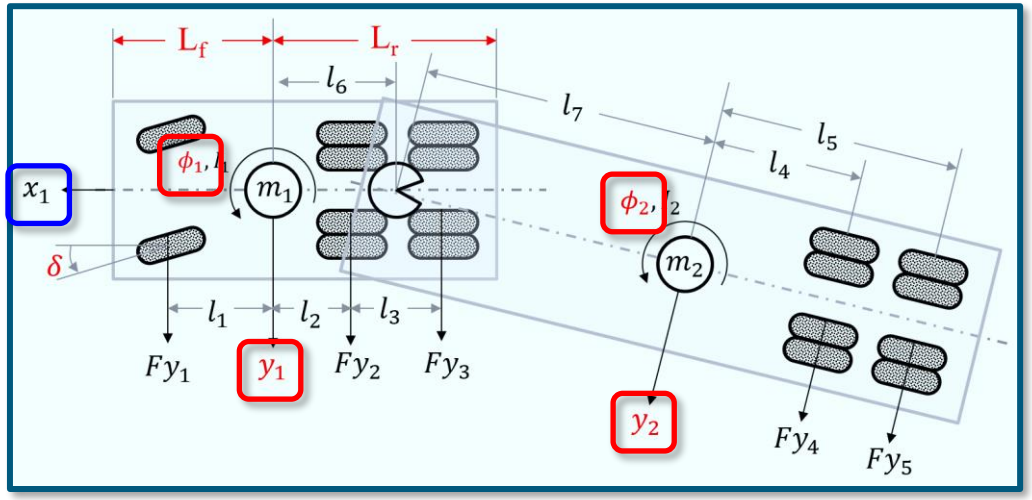
Plant Model - Truck-trailer lateral dynamics

$$M\dot{x} = Ax + Bu$$
$$z = Cx$$

$$M = \begin{bmatrix} m_1 & 0 & m_2 & 0 \\ 0 & I_1 & -l_6 m_2 & 0 \\ 0 & 0 & -l_7 m_2 & I_2 \\ 1 & -l_6 & -1 & -l_6 \end{bmatrix} \quad x = \begin{bmatrix} \dot{y}_1 \\ \dot{\phi}_1 \\ \dot{y}_2 \\ \dot{\phi}_2 \end{bmatrix} \quad u = [\delta]$$

$$A = \begin{bmatrix} \frac{-C_1 - C_2 - C_3}{\dot{x}_1} & \frac{-C_1 l_1 + C_2 l_2 + C_3 l_3}{\dot{x}_1} - m_1 \dot{x}_1 & \frac{-C_4 - C_5}{\dot{x}_1} & \frac{C_4 l_4 + C_5 l_5}{\dot{x}_1} - m_2 \dot{x}_1 \\ \frac{-C_1 l_1 + C_2 l_2 + C_3 l_3}{\dot{x}_1} & \frac{-C_1 l_1^2 - C_2 l_2^2 - C_3 l_3^2}{\dot{x}_1} & \frac{-C_4 l_6 - C_5 l_6}{\dot{x}_1} & l_6\left(\frac{-C_4 l_4 - C_5 l_5}{\dot{x}_1} + m_2 \dot{x}_1\right) \\ 0 & 0 & \frac{C_4 l_7 + C_5 l_7 + C_4 l_4 + C_5 l_5}{\dot{x}_1} & \frac{-C_4 l_4 l_7 - C_5 l_5 l_7 - C_4 l_4^2 - C_5 l_5^2}{\dot{x}_1} + l_7 m_2 \dot{x}_1 \\ 0 & -\dot{x}_1 & 0 & \dot{x}_1 \end{bmatrix}$$

$$B = \begin{bmatrix} C_1 \\ C_1 l_1 \\ 0 \\ 0 \end{bmatrix} \quad C = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

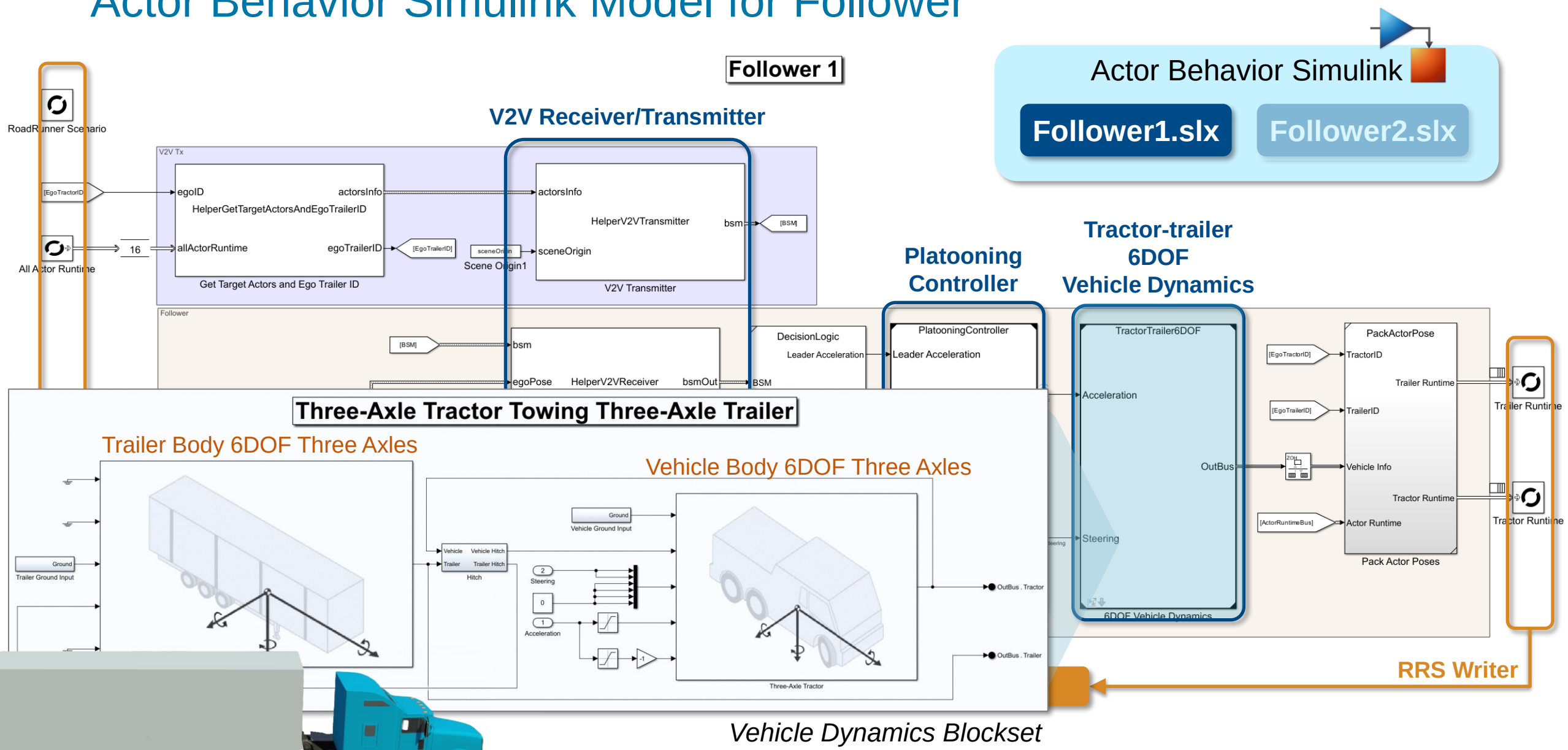


Linearized truck-trailer lateral dynamics

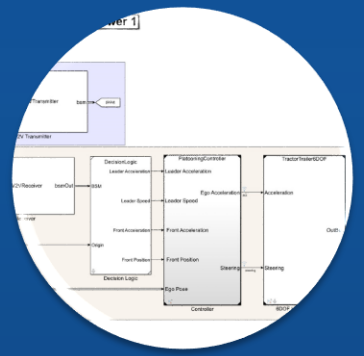
$\dot{x}_1$: forward velocity of tractor is not included in the state vector to make the system linear.

Reference paper

Actor Behavior Simulink Model for Follower

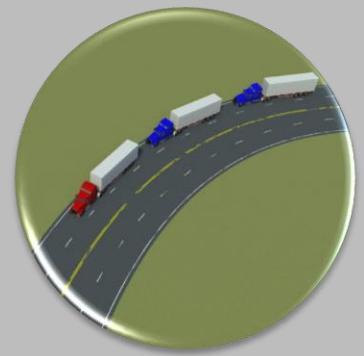


Workflow



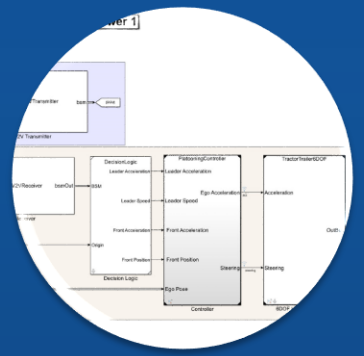
Platooning Test Bench

Scenario Authoring



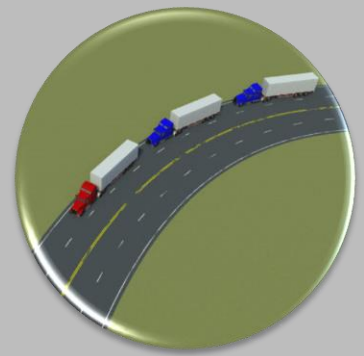
Scenario Simulation

Workflow



Platooning Test Bench

Scenario Authoring



Scenario Simulation

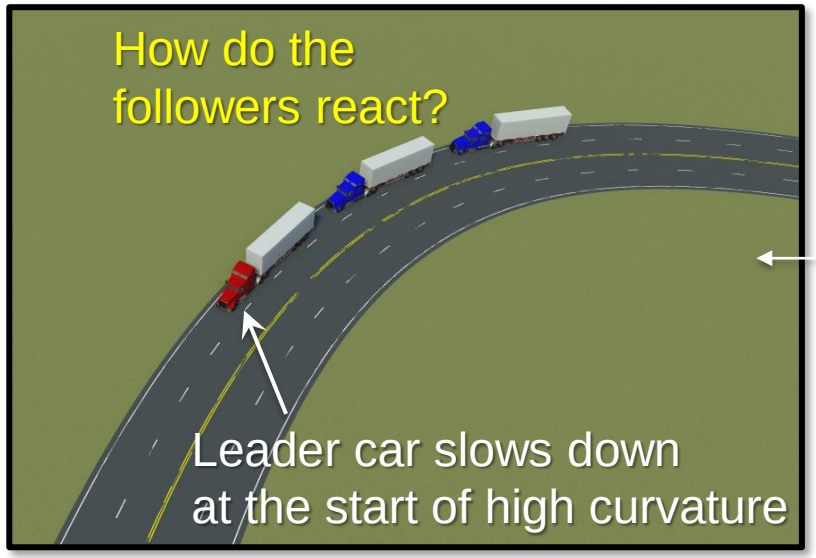
RoadRunner Scene & Scenarios

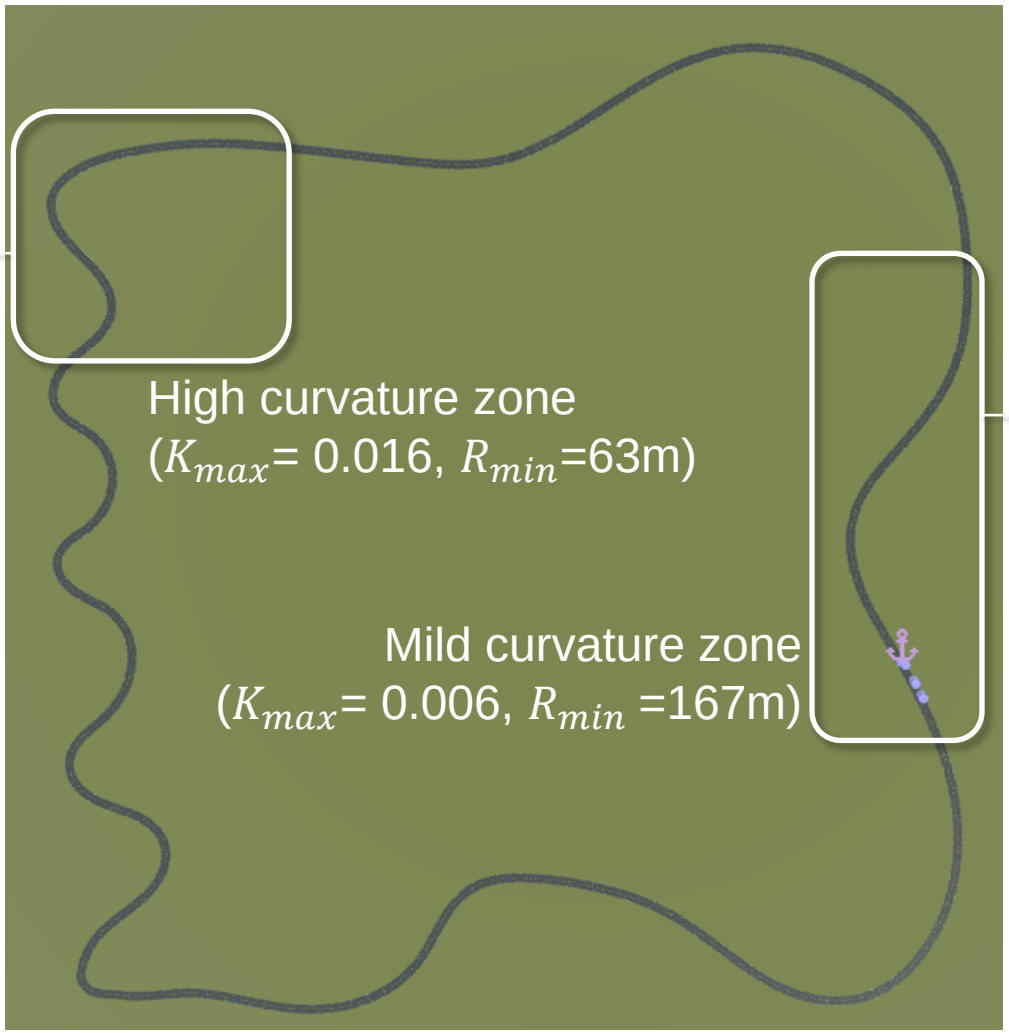
Lateral control

***Control objective**: The truck follows a lane center of a curved road while maintaining a predefined space between vehicles in a platoon.*

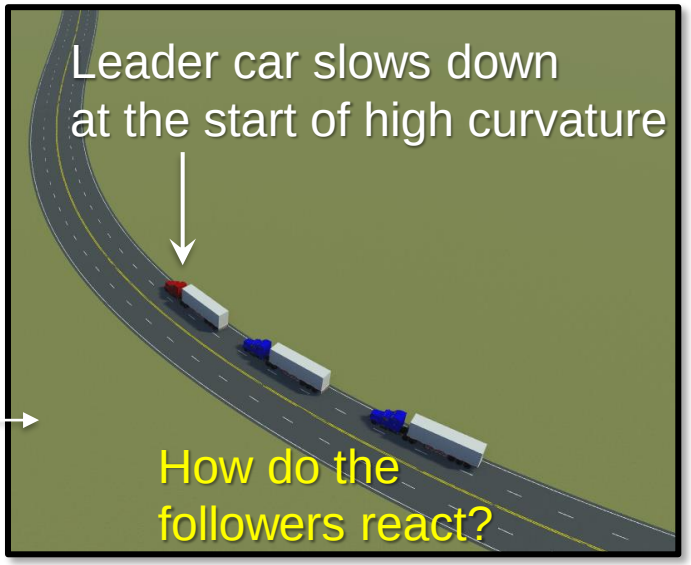
Longitudinal control

scenario_Platooning_02_HighCurvature





scenario_Platooning_01_CurvedRoad

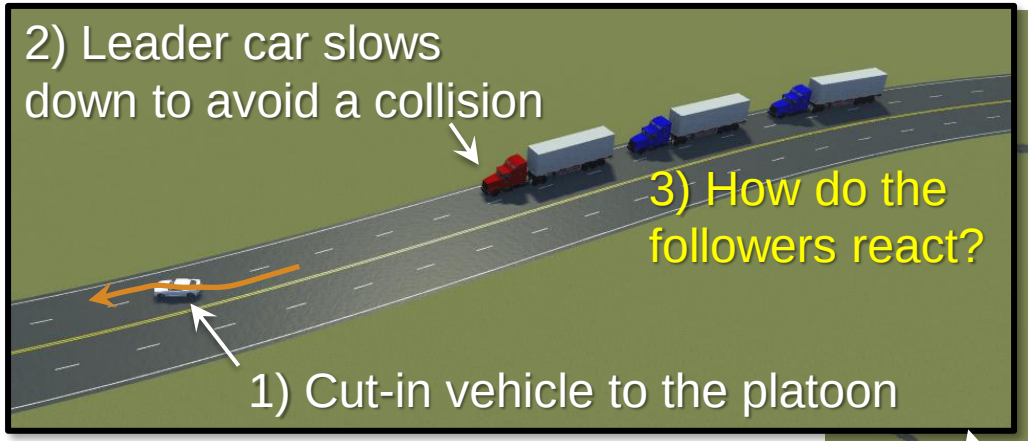


RoadRunner scene equivalent to [Unreal default scene – Curved Road]

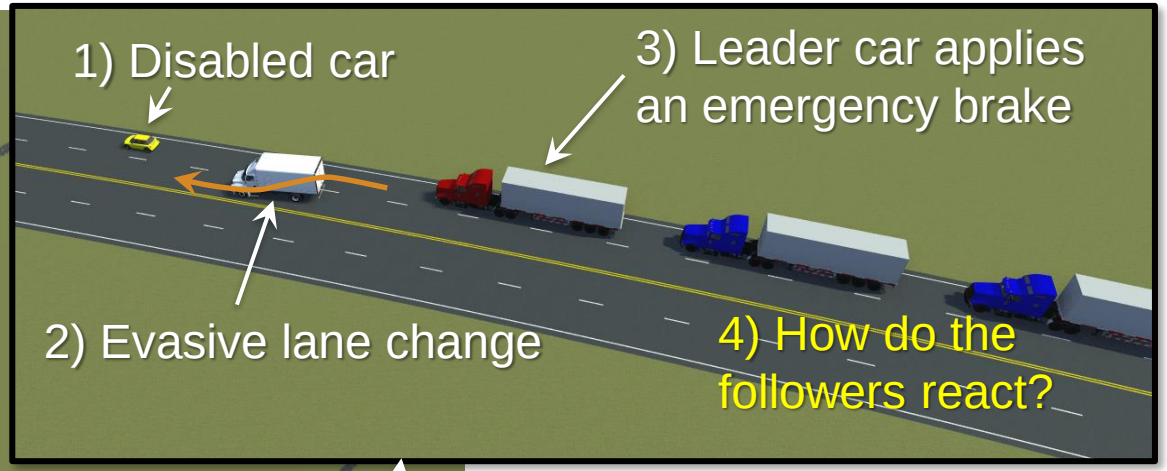
RoadRunner Scene & Scenarios

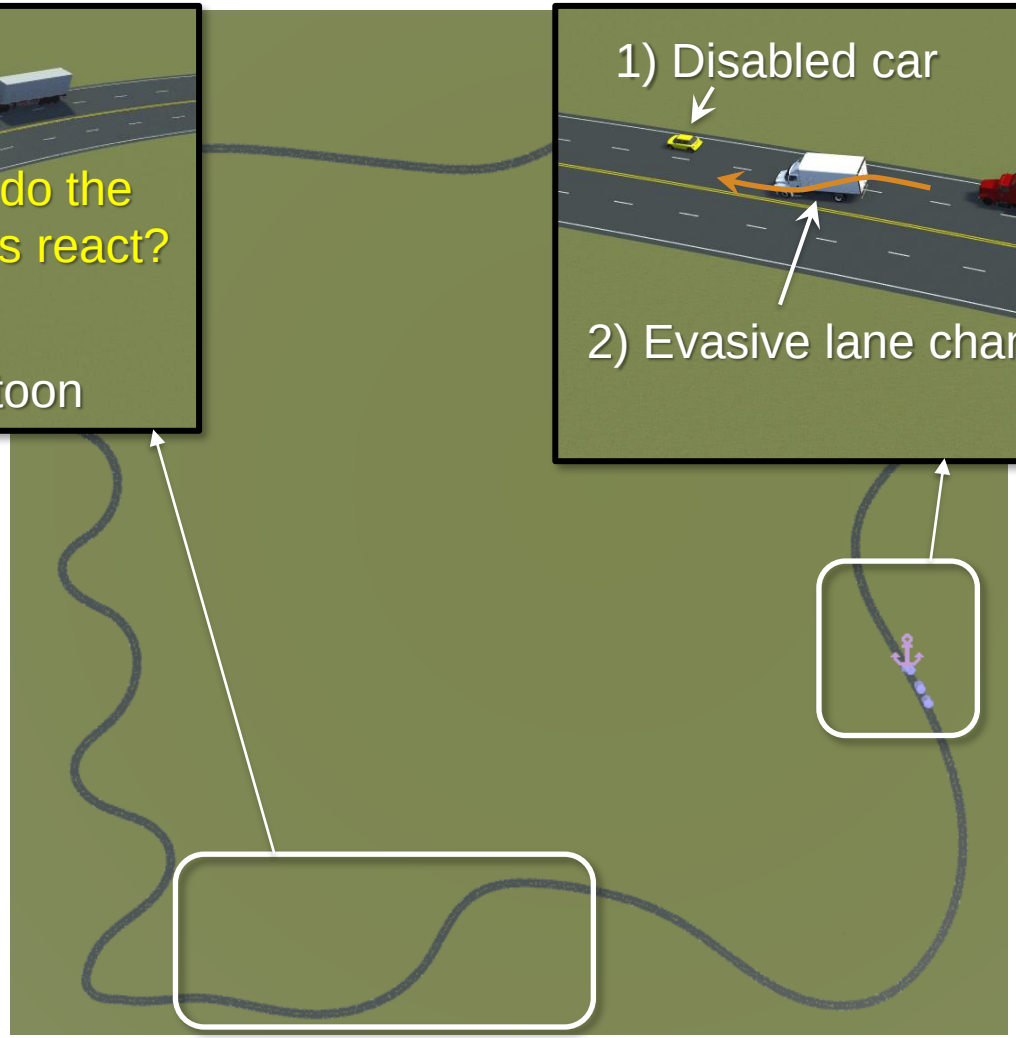
***Control objective**: The truck follows a lane center of a curved road while maintaining a predefined space between vehicles in a platoon.*

scenario_Platooning_04_CutInFrontOfLeader



scenario_Platooning_03_DecelAndStop



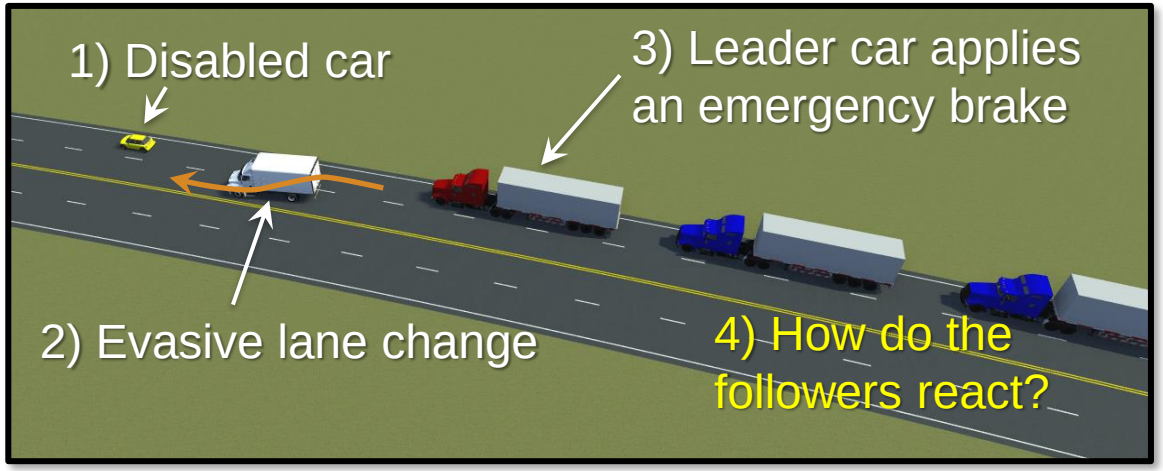


RoadRunner scene equivalent to [Unreal default scene – Curved Road]

Scenario authoring using RoadRunner Scenario

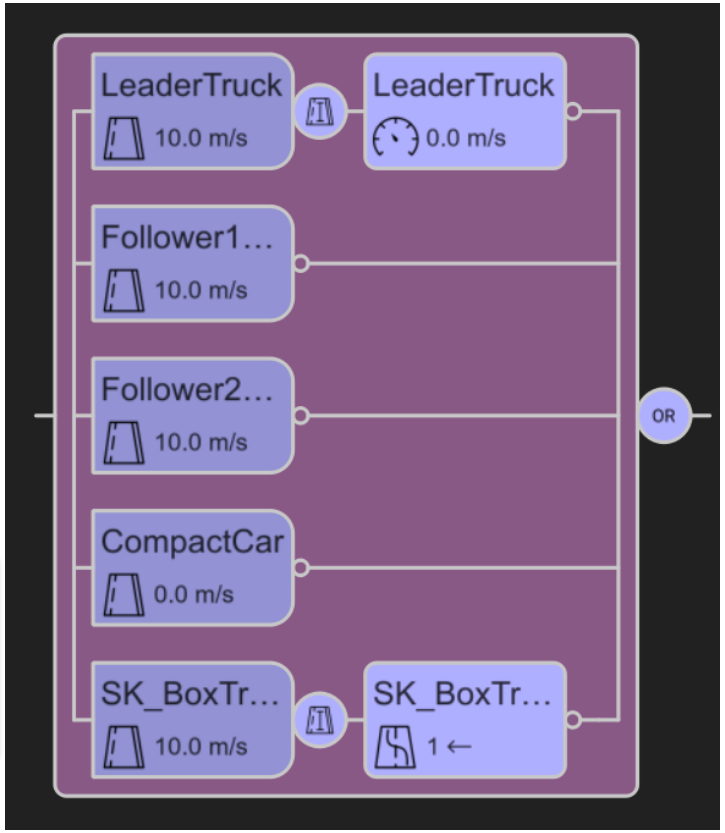
"How to author scenarios using RoadRunner Scenario?"

scenario_Platooning_03_DecelAndStop

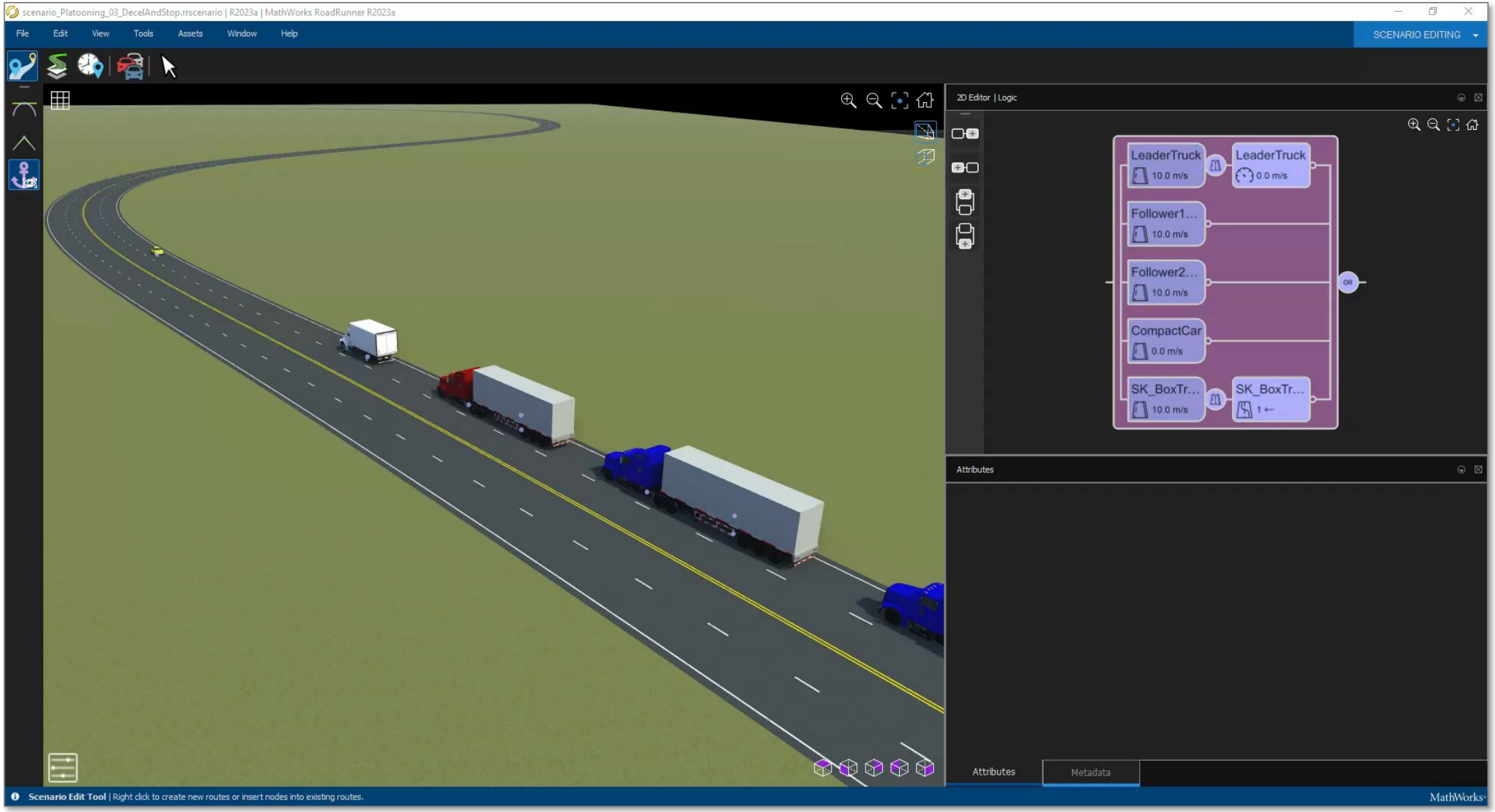


RoadRunner

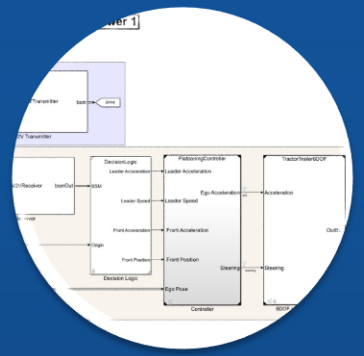
Scenario Logic



Scenario authoring using RoadRunner Scenario

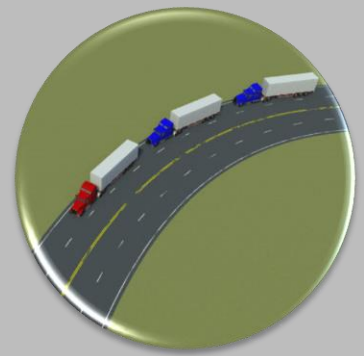


Workflow



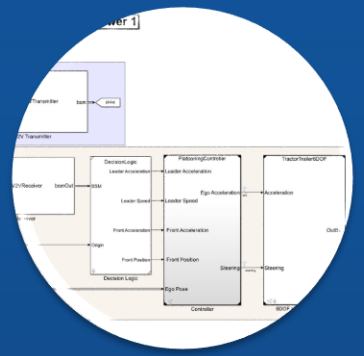
Platooning Test Bench

Scenario Authoring



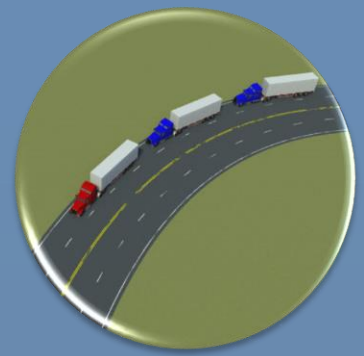
Scenario Simulation

Workflow



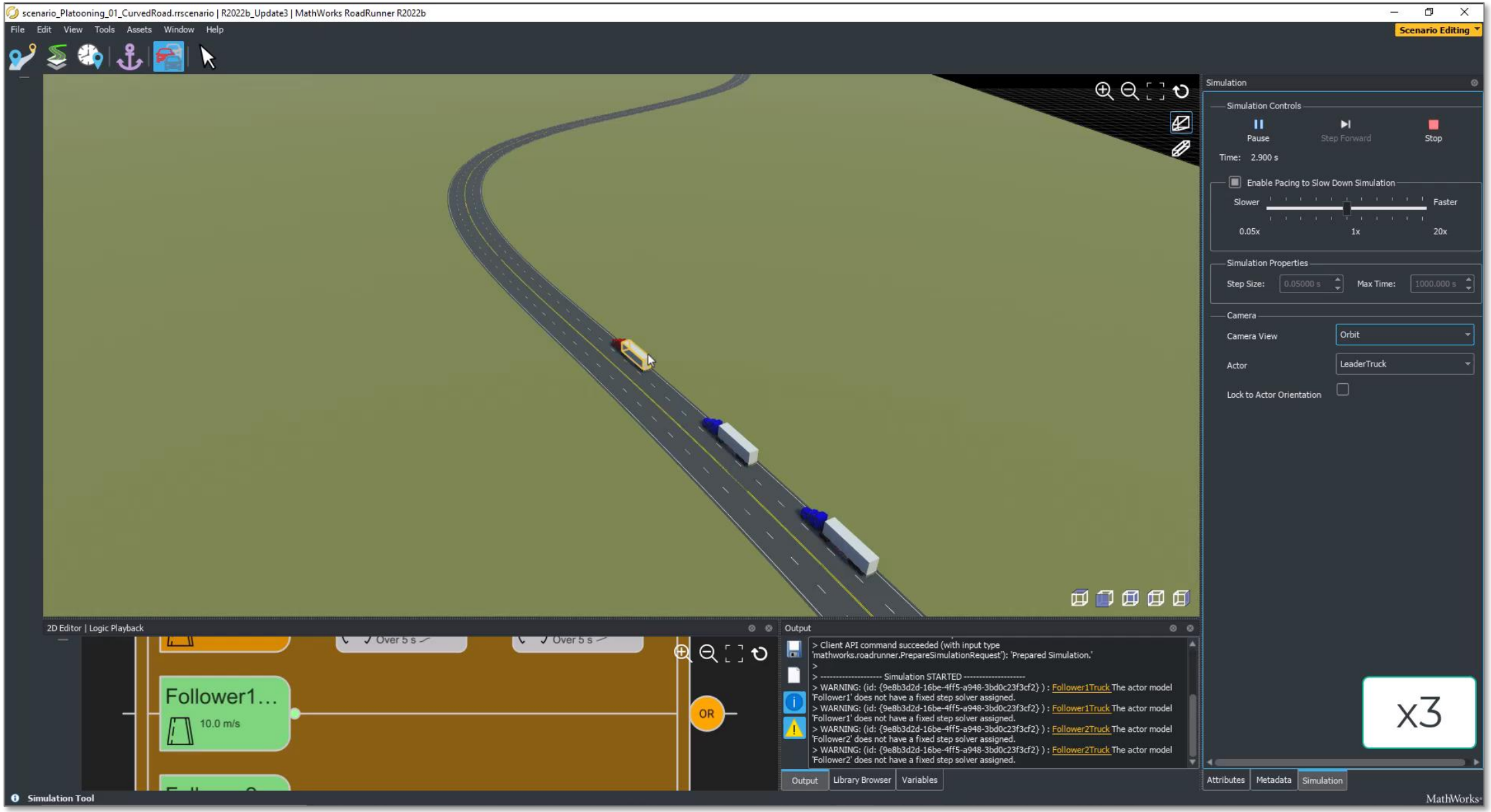
Platooning Test Bench

Scenario Authoring

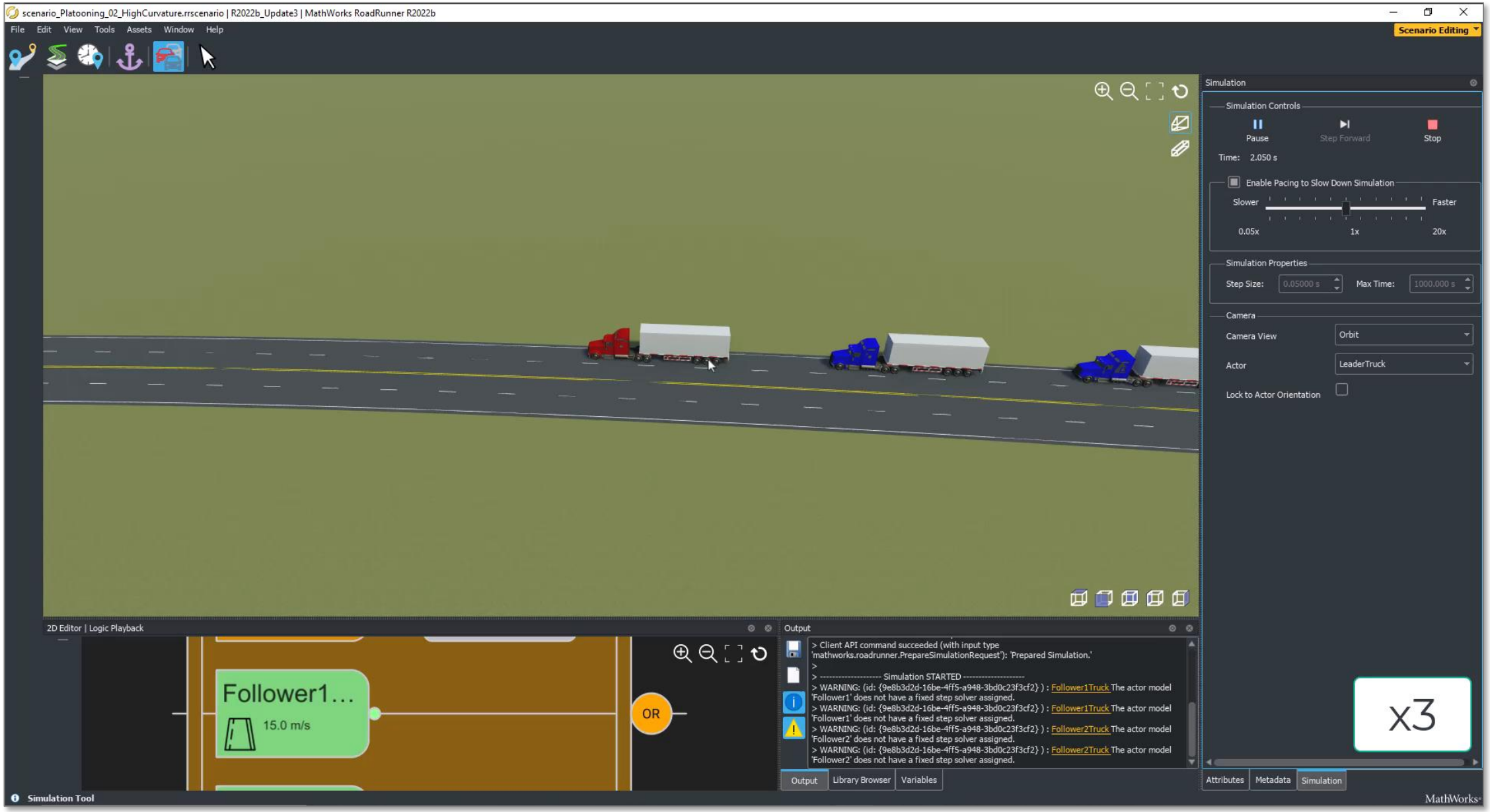


Scenario Simulation

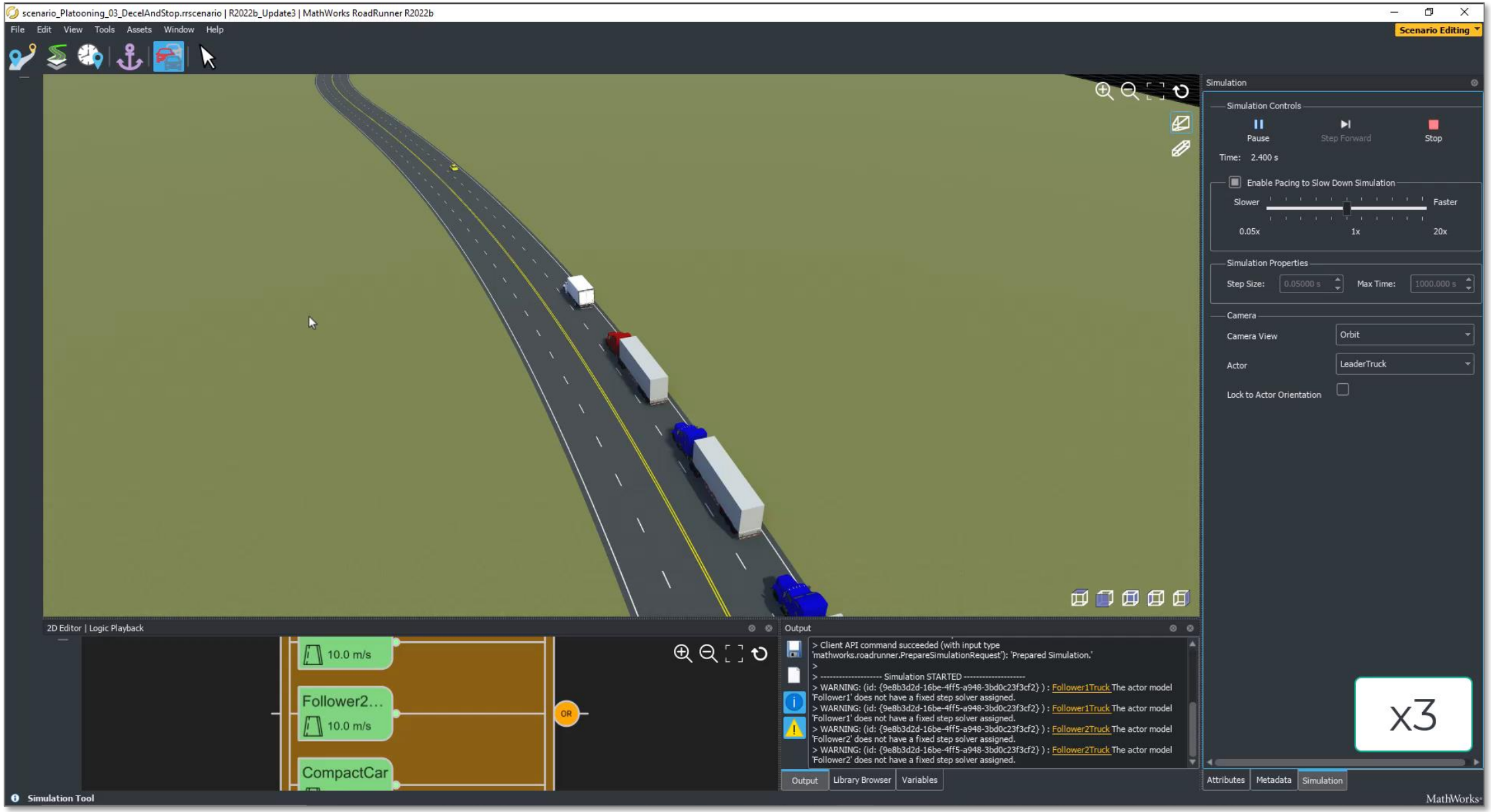
scenario_Platooning_01_CurvedRoad



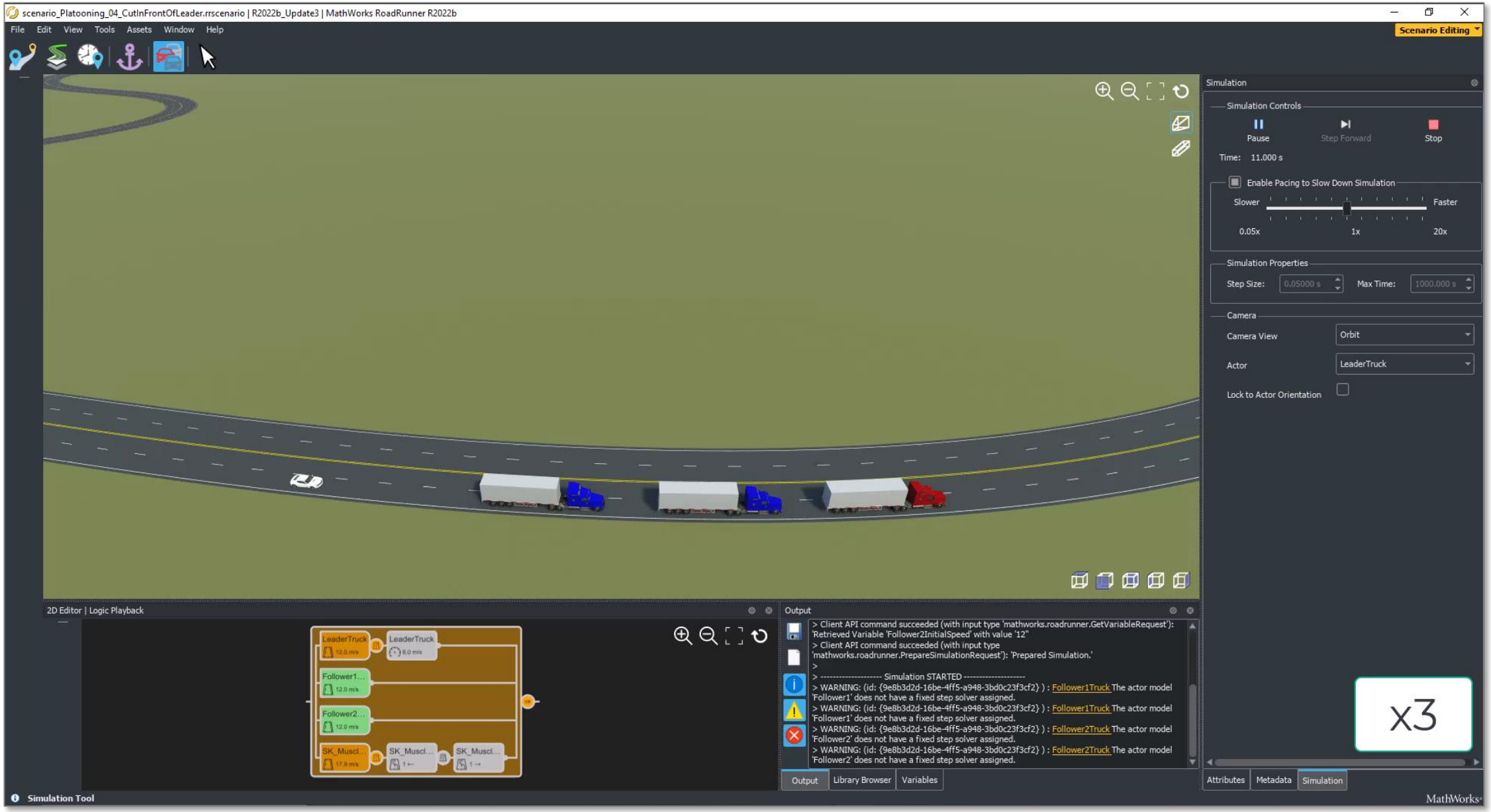
scenario_Platooning_02_HighCurvature



scenario_Platooning_03_DecelAndStop



scenario_Platooning_04_CutInFrontOfLeader



Key takeaways:

Lateral Control of Truck Platooning With RoadRunner Scenario

- Demonstrated how to design a platooning test bench model consisting of
  - Platooning longitudinal and lateral controller
  - High-fidelity 6 DOF tractor-trailer model
  - V2V communication

  - *Automated Driving Toolbox*
  - *Vehicle Dynamics Blockset*
  - *Simulink*

- Implemented the platooning lateral controller using
  - Lane-keeping assist Model Predictive Control
  - Linearized truck-trailer lateral dynamics

  - *Model Predictive Control Toolbox*

- Simulated the Simulink test bench with RoadRunner Scenario

  - *RoadRunner*
  - *RoadRunner Scenario*
  - *RoadRunner Asset Library*

MathWorks
AUTOMOTIVE CONFERENCE 2023
North America

Thank you

Please contact me at spark@mathworks.com
with questions

© 2023 The MathWorks, Inc. MATLAB and Simulink are registered trademarks of The MathWorks, Inc.
See *mathworks.com/trademarks* for a list of additional trademarks. Other product or brand names may
be trademarks or registered trademarks of their respective holders.