

MathWorks
**AUTOMOTIVE
CONFERENCE 2023**
North America

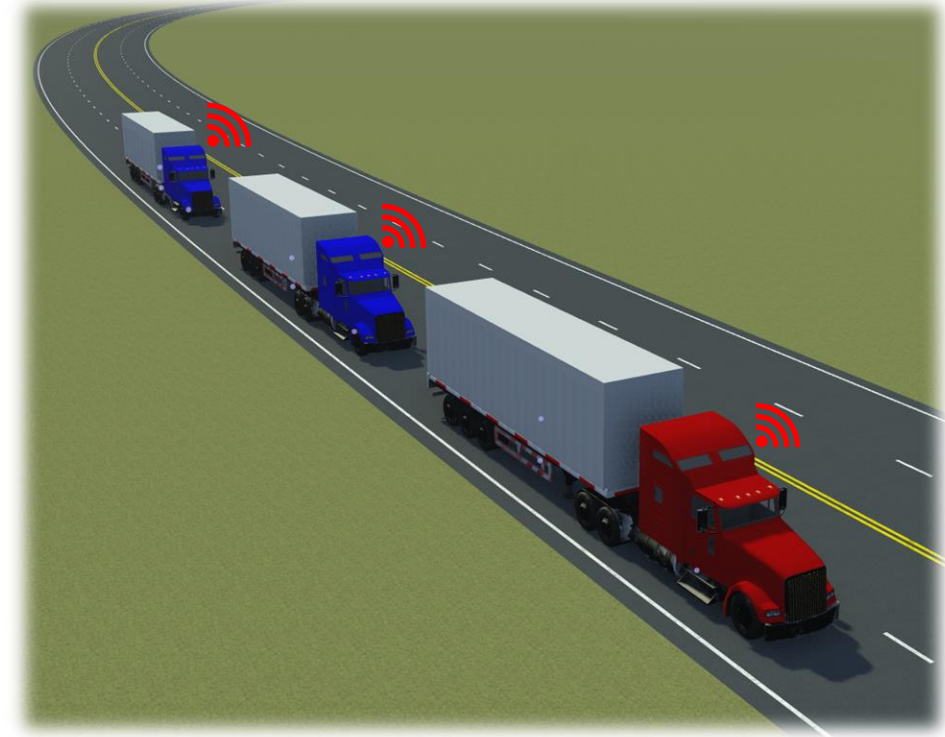
Lateral Control of Truck Platooning With RoadRunner Scenario

Seo-Wook Park, MathWorks



Why “Truck Platooning”?

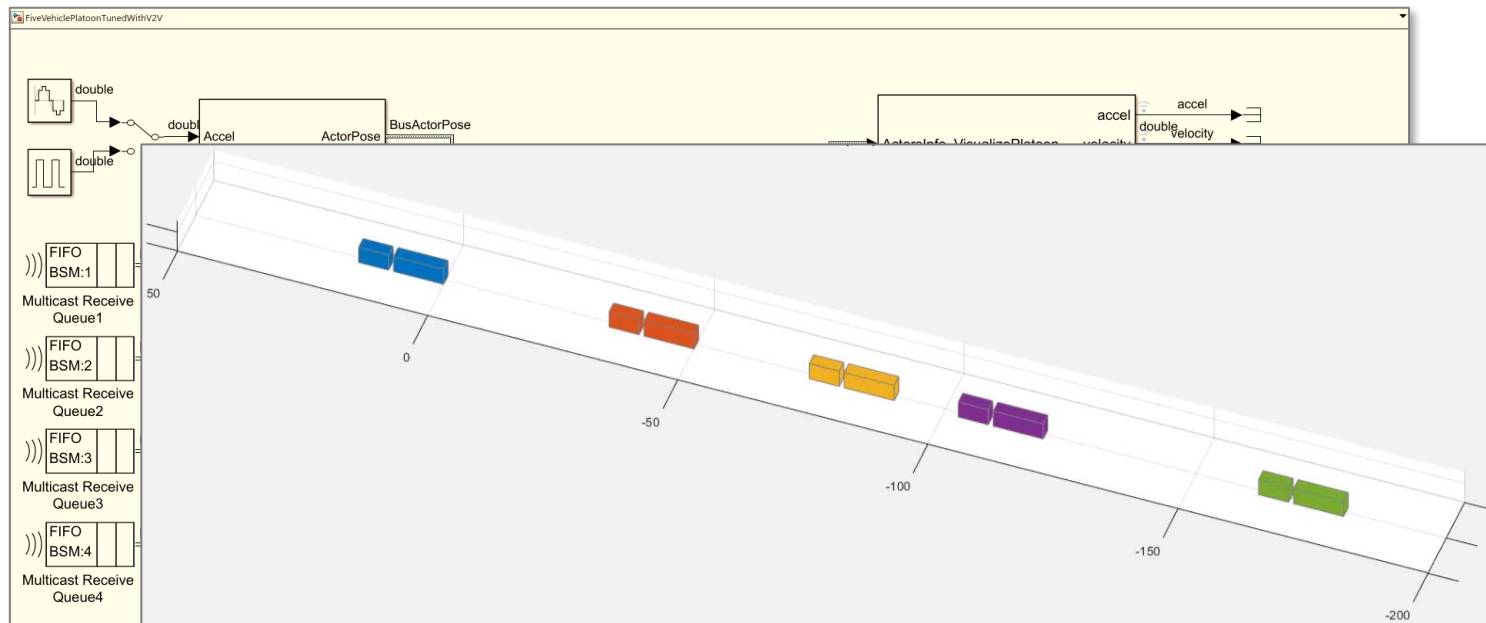
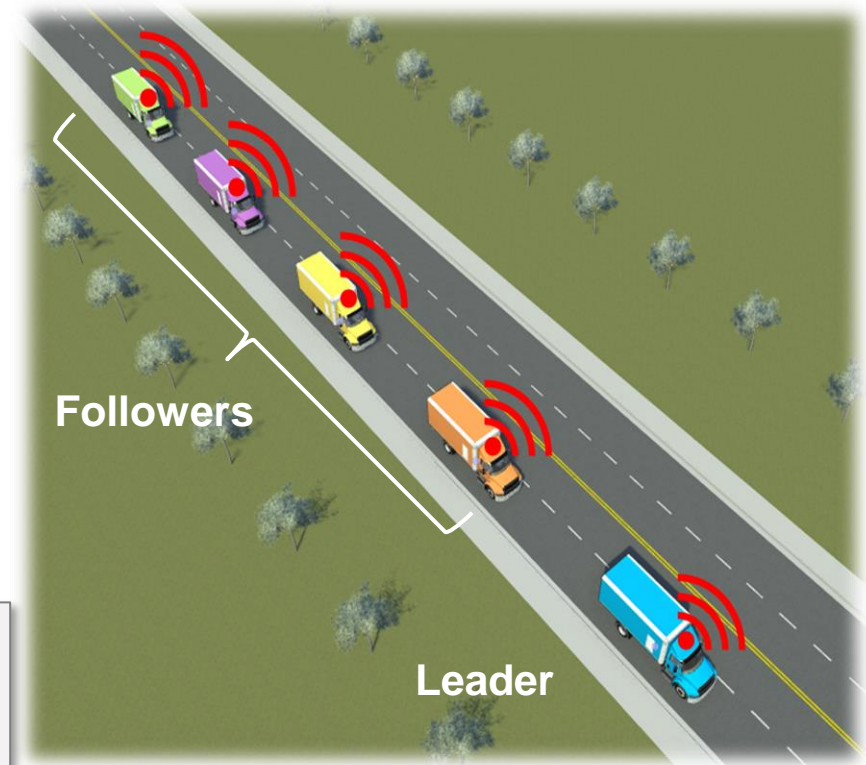
- Truck platooning allows trucks to follow each other closely, thereby **reducing air drag** and **improving fuel economy**.
- Platooning also has the potential to **increase vehicle capacity** on highways.
- **V2V** allows the truck platooning to form an **electronically “coupled”** two or more trucks.



Design of vehicle platooning controller with V2V communication

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

MathWorks AUTOMOTIVE CONFERENCE 2022



Truck platooning reference examples

R2022b



Truck Platooning Using Vehicle-to-Vehicle Communication

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

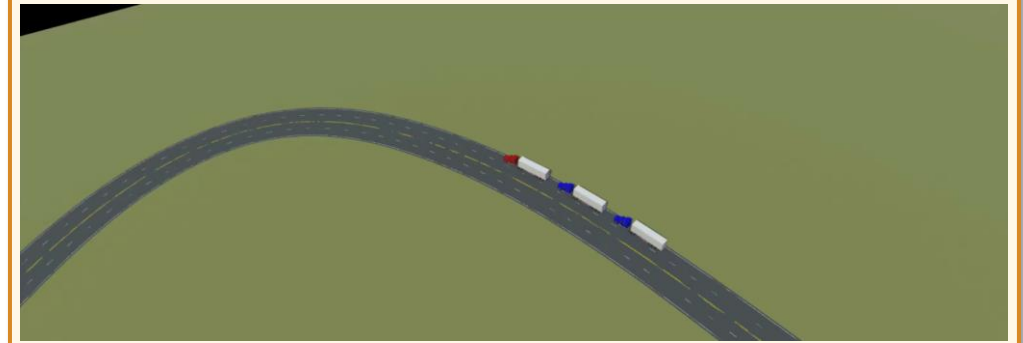
*Vehicle Dynamics Blockset
Automated Driving Toolbox*

+ 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*

Add Truck with Trailer to Scenario

R2022b RoadRunner Scenario

The screenshot displays the MathWorks RoadRunner R2023a Scenario Editor interface. The main view shows a 2D perspective of a road with yellow lane markings and green grass. The interface includes a menu bar (File, Edit, View, Tools, Assets, Window, Help) and a toolbar with icons for navigation and editing. On the right, the 'Attributes' panel for a 'Vehicle (Sedan.fbx)' is visible, showing properties such as Category (Car), Mass (1500.00 kg), Max Speed (65.00 m/s), Max Acceleration (5.00 m/s^2), Max Deceleration (5.00 m/s^2), Max Steering Angle (40.00°), and Default Color. Below the main view, the '2D Editor | Logic' panel shows a purple rectangular node and a clock icon. The 'Library Browser' panel on the bottom right lists various vehicle models, including Sedan, SemiTruck, and several SemiTruck_T railer variants. A white sedan is shown driving on the road in the bottom right corner. A large black box with the text 'Add a truck' is overlaid on the bottom center of the interface.

Add a truck

Scenario Edit Tool | Right click to create new routes or insert nodes into existing routes.

Lateral Control of Truck platooning with RoadRunner Scenario

The image displays two windows from the MATLAB environment. The left window is the MATLAB Editor, showing a script named 'RunPlatooningWithRRScenario.m'. The right window is the RoadRunner Scene Editor, showing a 3D visualization of a curved road scene.

Code Snippet (MATLAB Editor):

```

16
17 %% Open RoadRunner Scene
18 % The scene contains a two-way, four-lane, curved highway road. The road
19 % centers and lane markings in this scene closely match a section of curved
20 % road scene provided with the Unreal Engine simulation environment. Open
21 % the scene.
22 openScene(rrApp, "CurvedRoad.rrscene")
23
24 % copyfile(fullfile(projectRootFolder, "PlatooningWithRRScenario/TestBench/Follower1.rrbehav
25 % copyfile(fullfile(projectRootFolder, "PlatooningWithRRScenario/TestBench/Follower2.rrbehav
26 % copyfile(fullfile(projectRootFolder, "PlatooningTestScenarios/RoadRunner/Vehicles/Trailer1
27
28 %% Open RoadRunner Scenario
29 testNum = 1;
30 switch testNum
31     case 1
32         testName = "scenario_Platooning_01_CurvedRoad";
33     case 2
34         testName = "scenario_Platooning_02_HighCurvature";
35     case 3
36         testName = "scenario_Platooning_03_DecelAndStop";
37     case 4
38         testName = "scenario_Platooning_04_CutInFrontOfLeader";
39 end
40
41 scenarioName = strcat(testName, '.rrscenario');
42 openScenario(rrApp, scenarioName);
43
44 %% Connect to the RoadRunner Scenario server for co-simulation by using the
45 % createSimulation function, and enable data logging.
46 rrSim = rrApp.createSimulation;
47 rrSim.set('Logging', 'on');
48
49 %% Set the platooning simulation to run at a step size of 0.05.
50 Ts = 0.05;
51 set(rrSim, StepSize=Ts)
52
53 %% Open the follower 1 & 2 models
54 open_system("Follower1")
55 open_system("Follower2")

```

RoadRunner Scene Editor: The scene shows a 3D view of a curved road with lane markings. The 'Attributes' panel on the right indicates 'Selected Roads' Total Length: 0.00 and 'Driving Direction' set to 'Right'. The 'Output' window at the bottom right shows the following log messages:

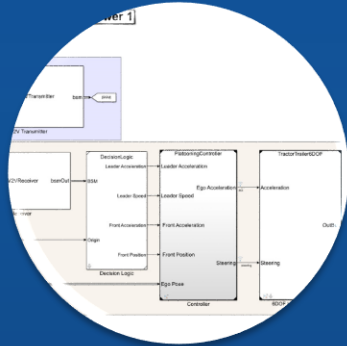
```

> Started RoadRunner API server on port 31017.
> Client API command succeeded (with input type
'mathworks.roadrunner.LoadSceneRequest'):
'Loaded Scene C:/RRProject/R2022b_Update3/
Scenes/CurvedRoad.rrscene'.

```

Open RoadRunner Scenario

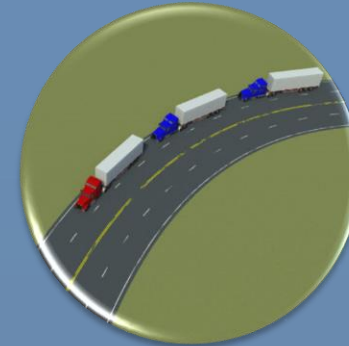
Workflow



**Platooning
Test Bench**



**Scenario
Authoring**

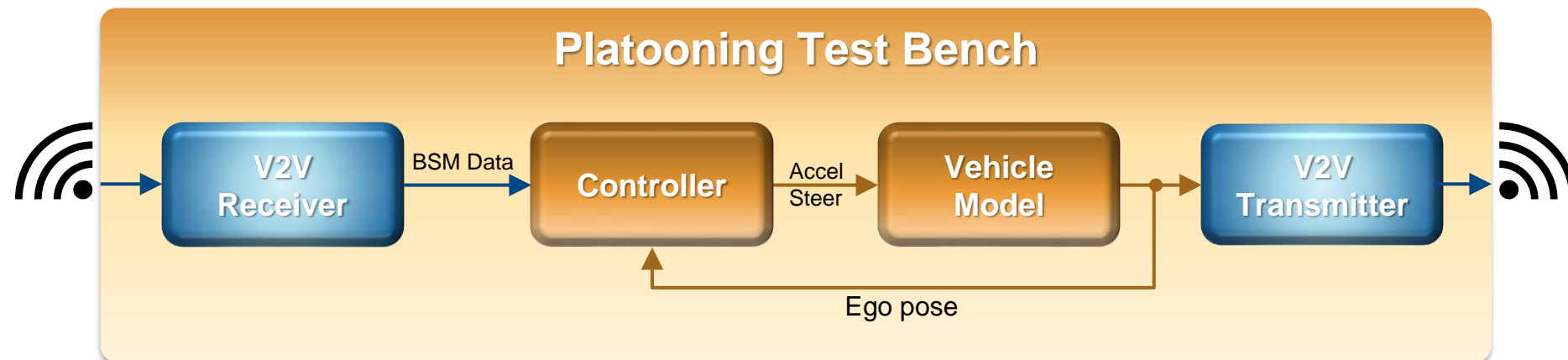


**Scenario
Simulation**

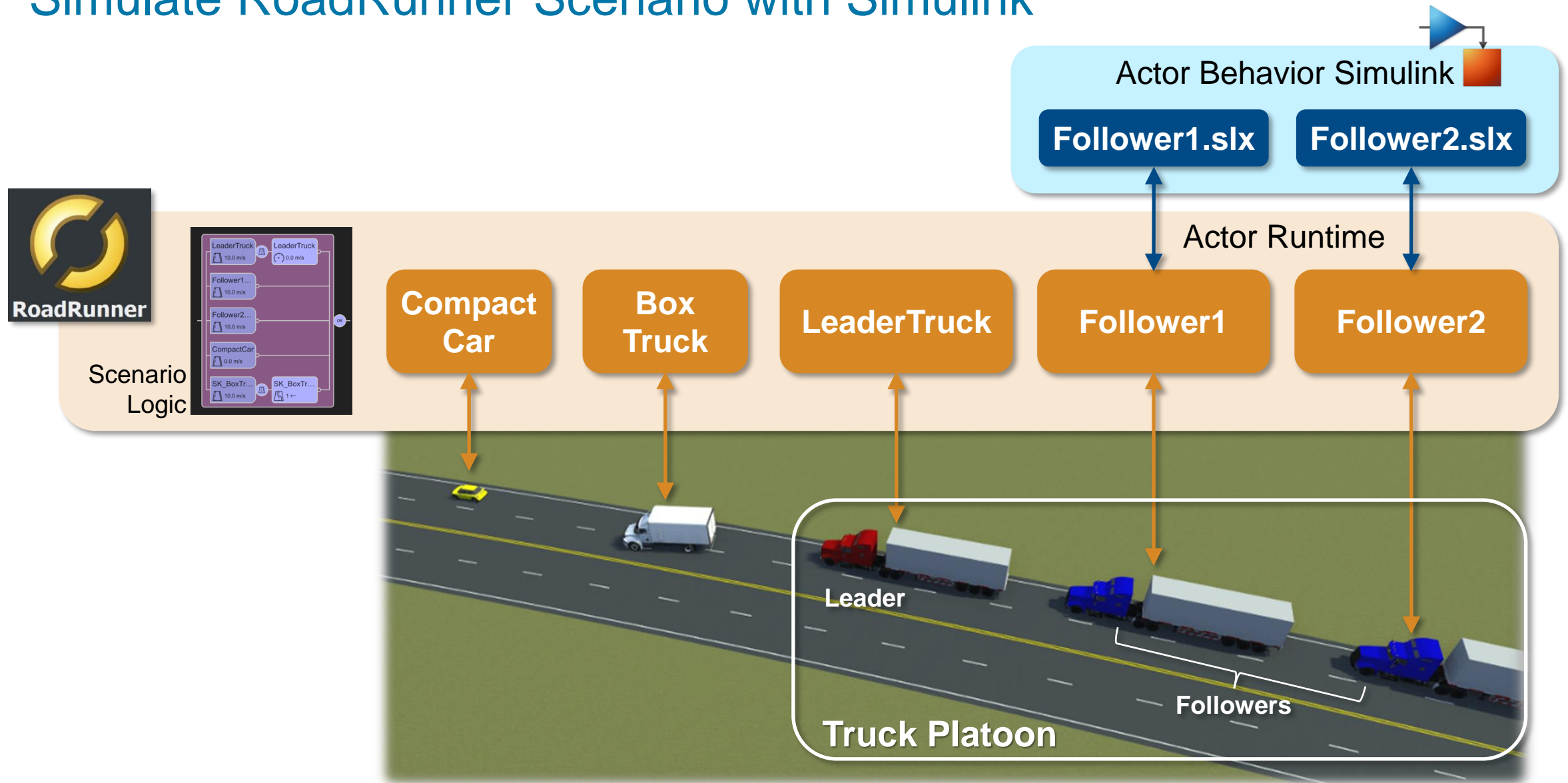


Platooning Test Bench

- **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

Follower 1

Actor Behavior Simulink

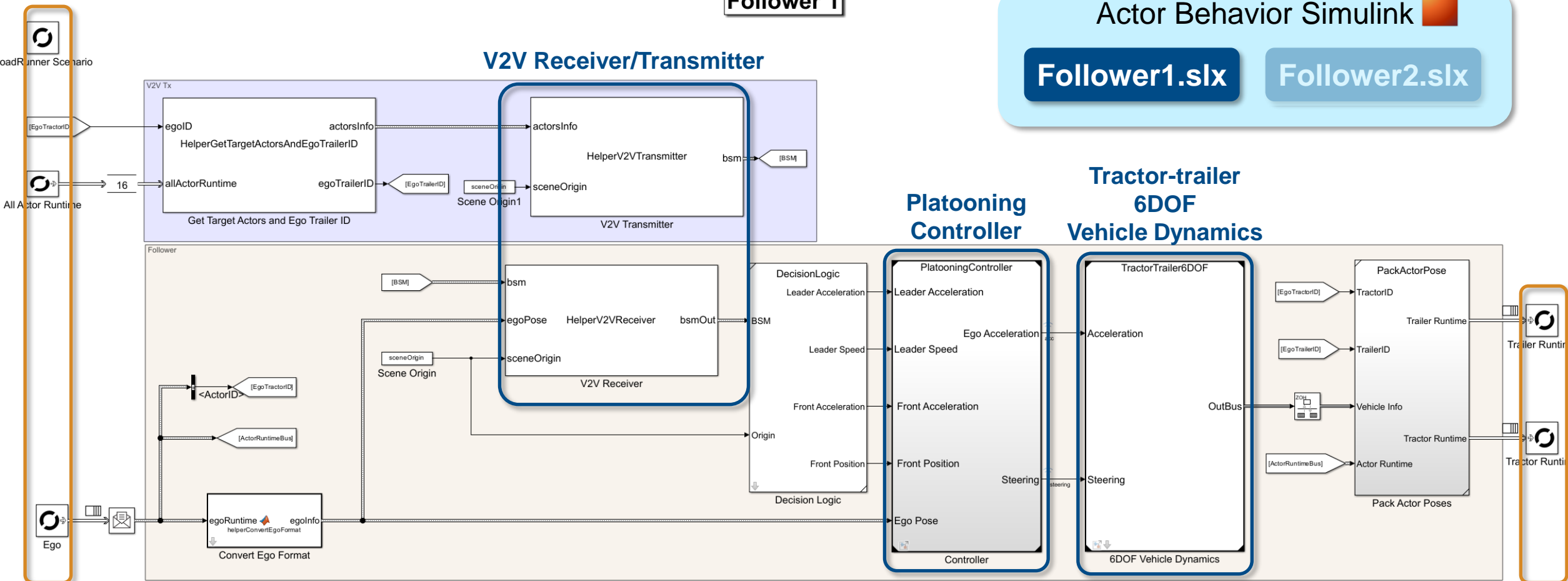
Follower1.slx

Follower2.slx

V2V Receiver/Transmitter

Platooning Controller

Tractor-trailer 6DOF Vehicle Dynamics




RoadRunner Scenario Reader

RoadRunner Scenario interfaces

RoadRunner Scenario Writer

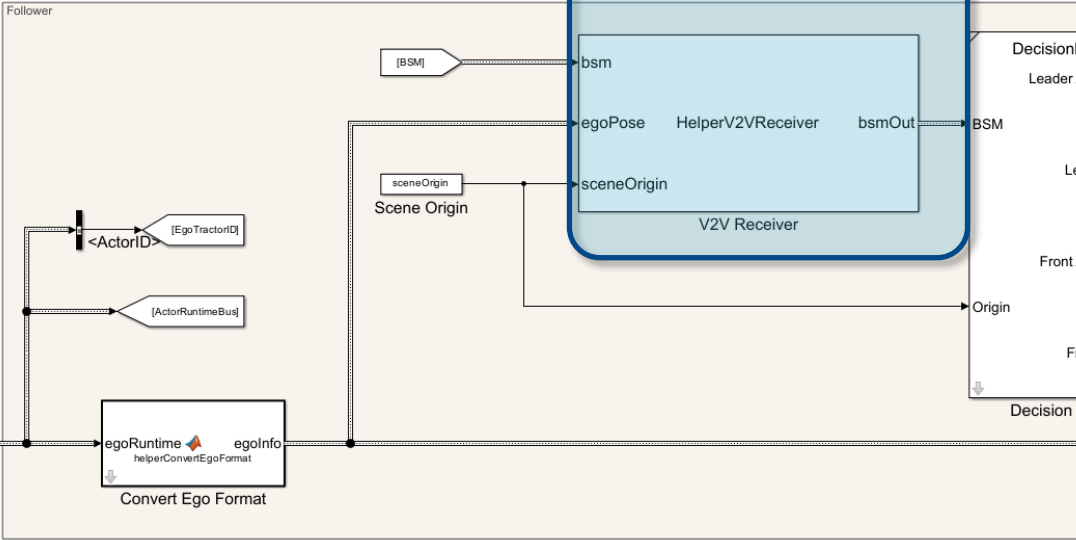
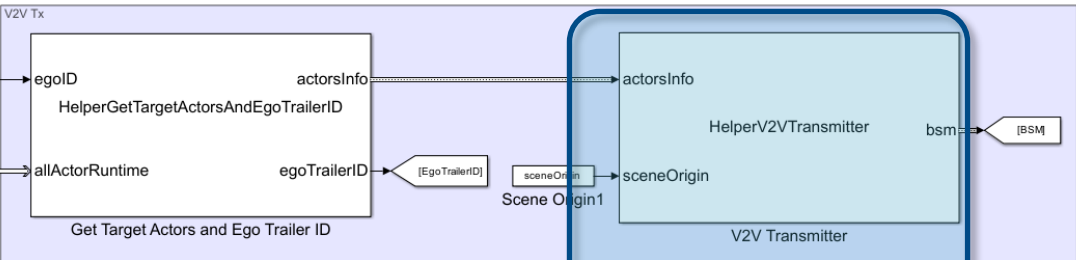
Actor Behavior Simulink Model for Follower

Follower 1

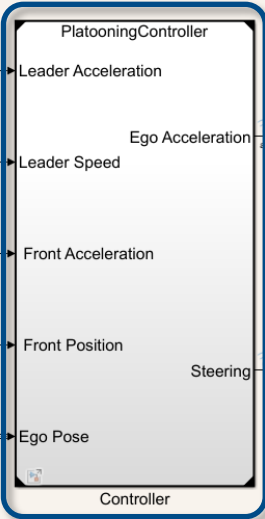
Actor Behavior Simulink 

Follower1.slx **Follower2.slx**

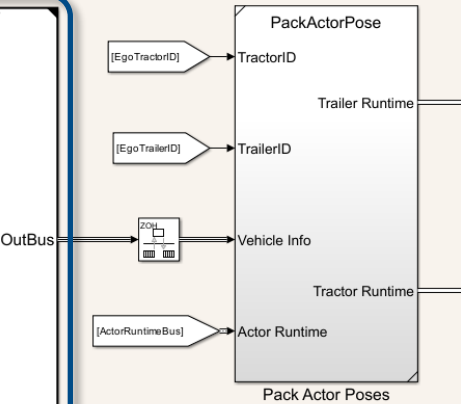
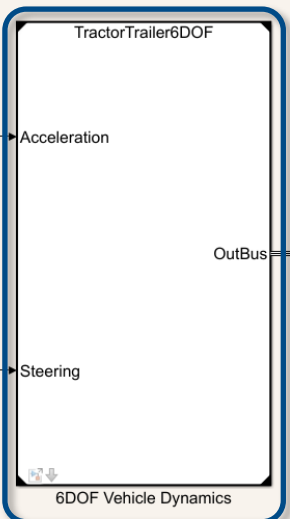
V2V Receiver/Transmitter



Platooning Controller



Tractor-trailer 6DOF Vehicle Dynamics

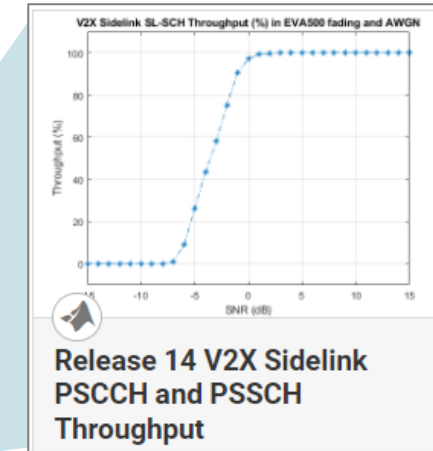
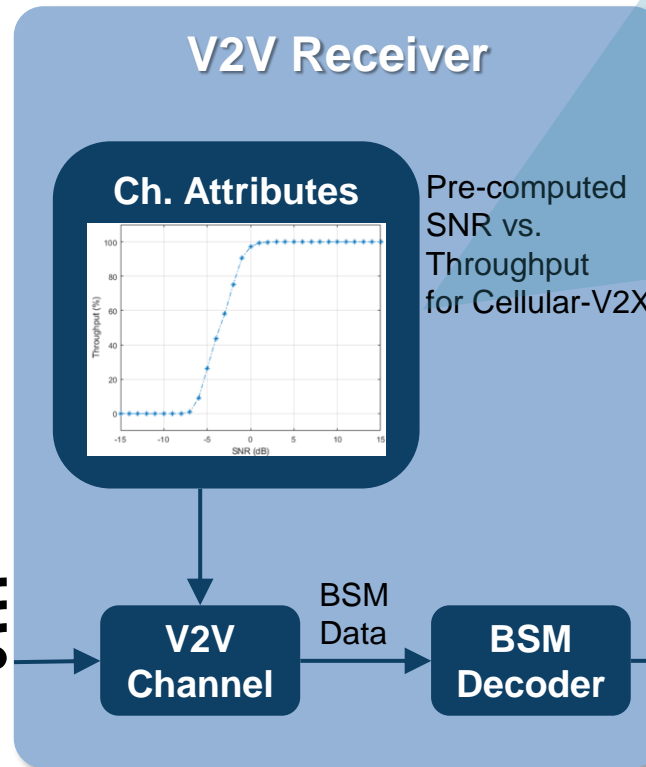
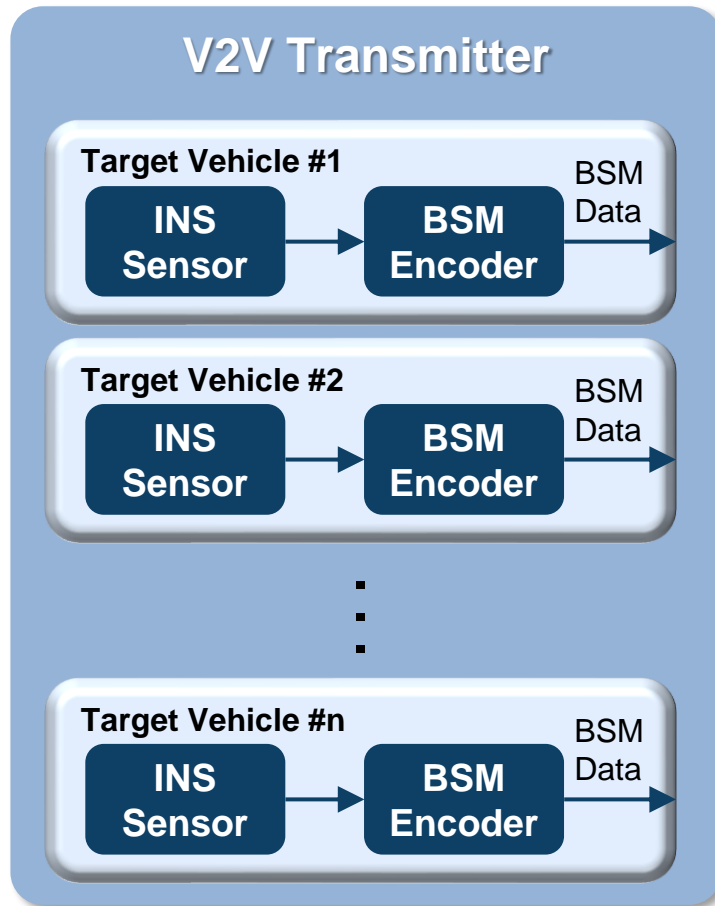


RoadRunner Scenario Reader

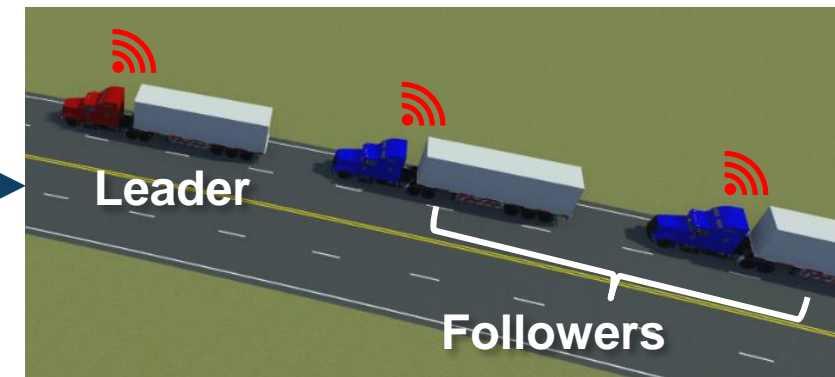
RoadRunner Scenario interfaces

RoadRunner Scenario Writer

V2V Transmitter and Receiver



LTE Toolbox™




Platooning with V2V

BSM (Basic Safety Message) by SAE J2735

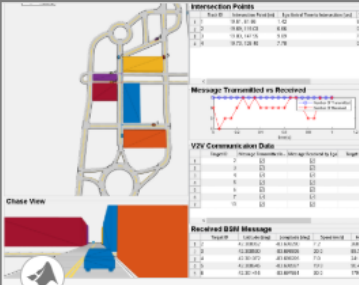
Basic Safety Message (BSM) by SAE J2735

- 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

	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



Intersection Movement Assist Using Vehicle-to-Vehicle Communication

Design intersection movement assist application using V2V communication.

[Open Example](#)

Automated Driving Toolbox™
R2022a

Actor Behavior Simulink Model for Follower

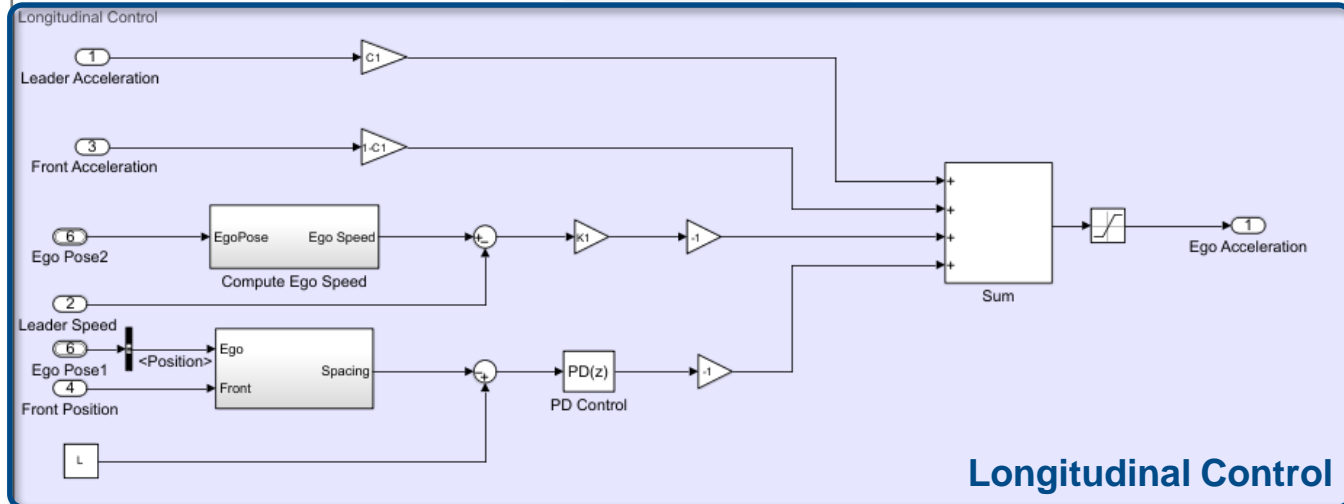
Follower 1

Actor Behavior Simulink

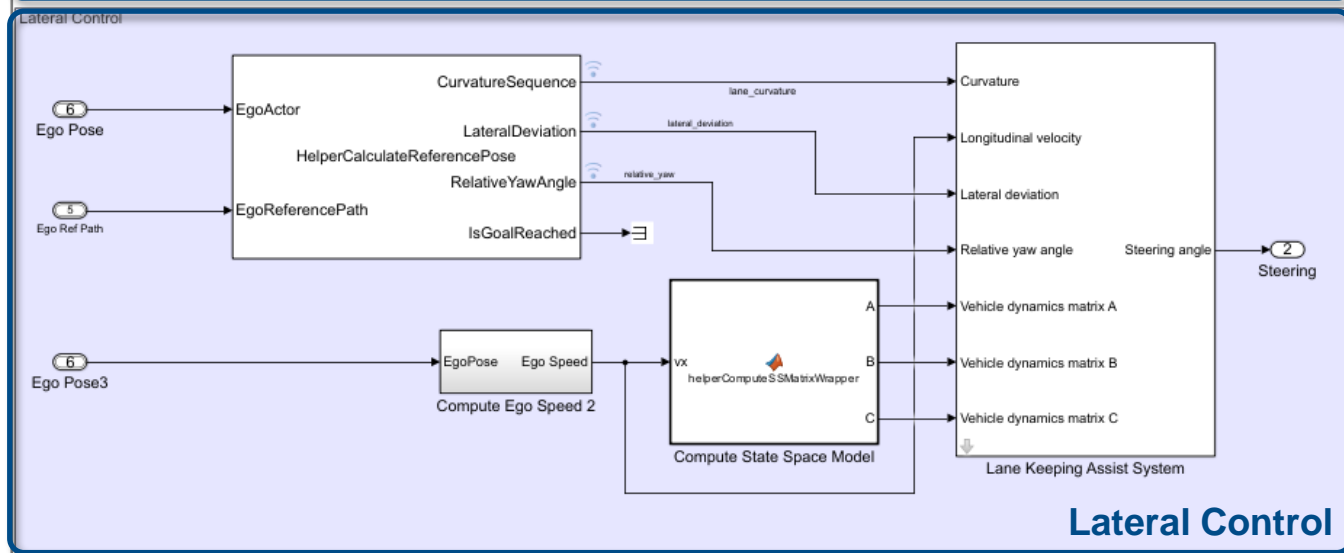
Follower1.slx

Follower2.slx

Platooning Controller

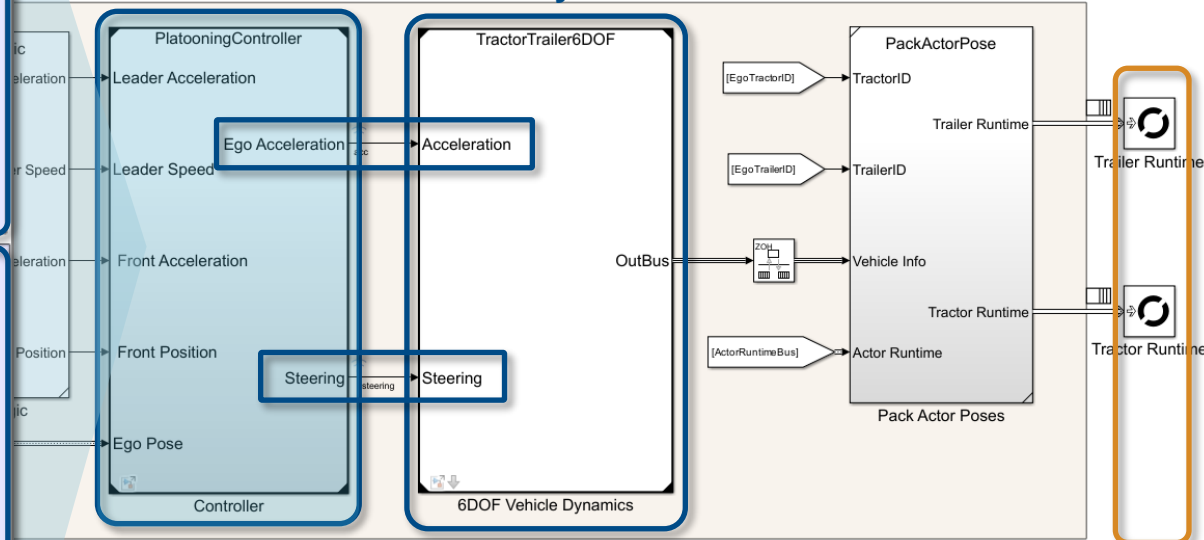


Longitudinal Control



Lateral Control

Platooning Controller
Tractor-trailer 6DOF Vehicle Dynamics

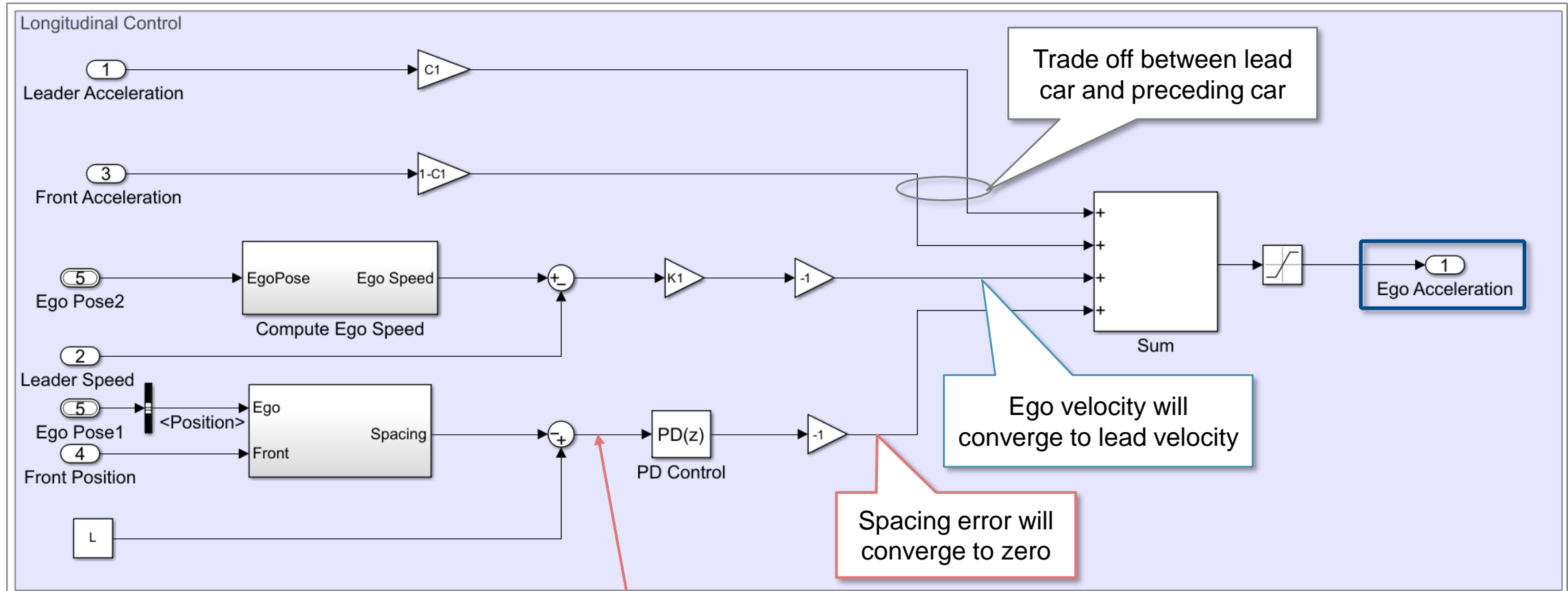


Scenario interfaces

RoadRunner Scenario Writer

Longitudinal control

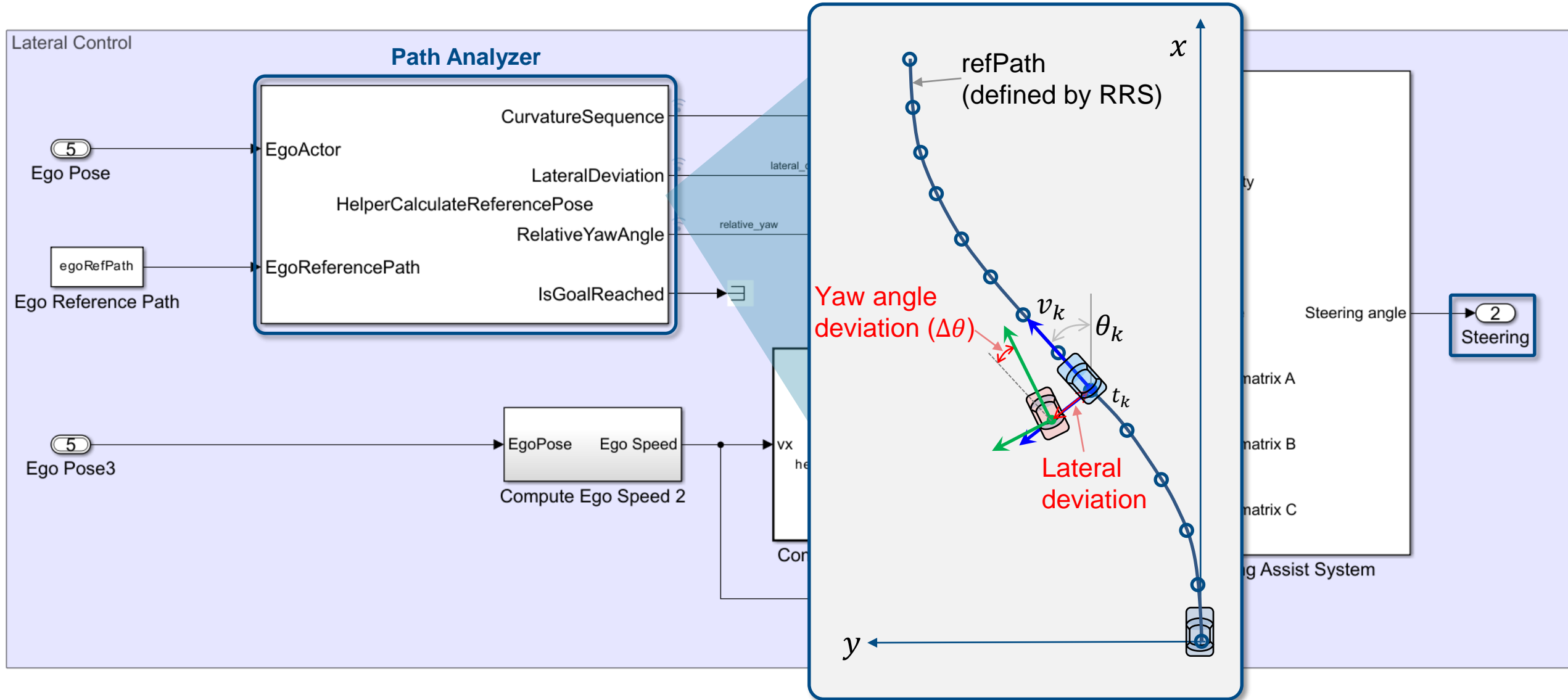
$$a_{ego} = C_1 a_{lead} + (1 - C_1) a_{front} - K_1 (v_{ego} - v_{lead}) - K_2 \left(L - \sqrt{(x_{ego} - x_{front})^2 + (y_{ego} - y_{front})^2} \right)$$



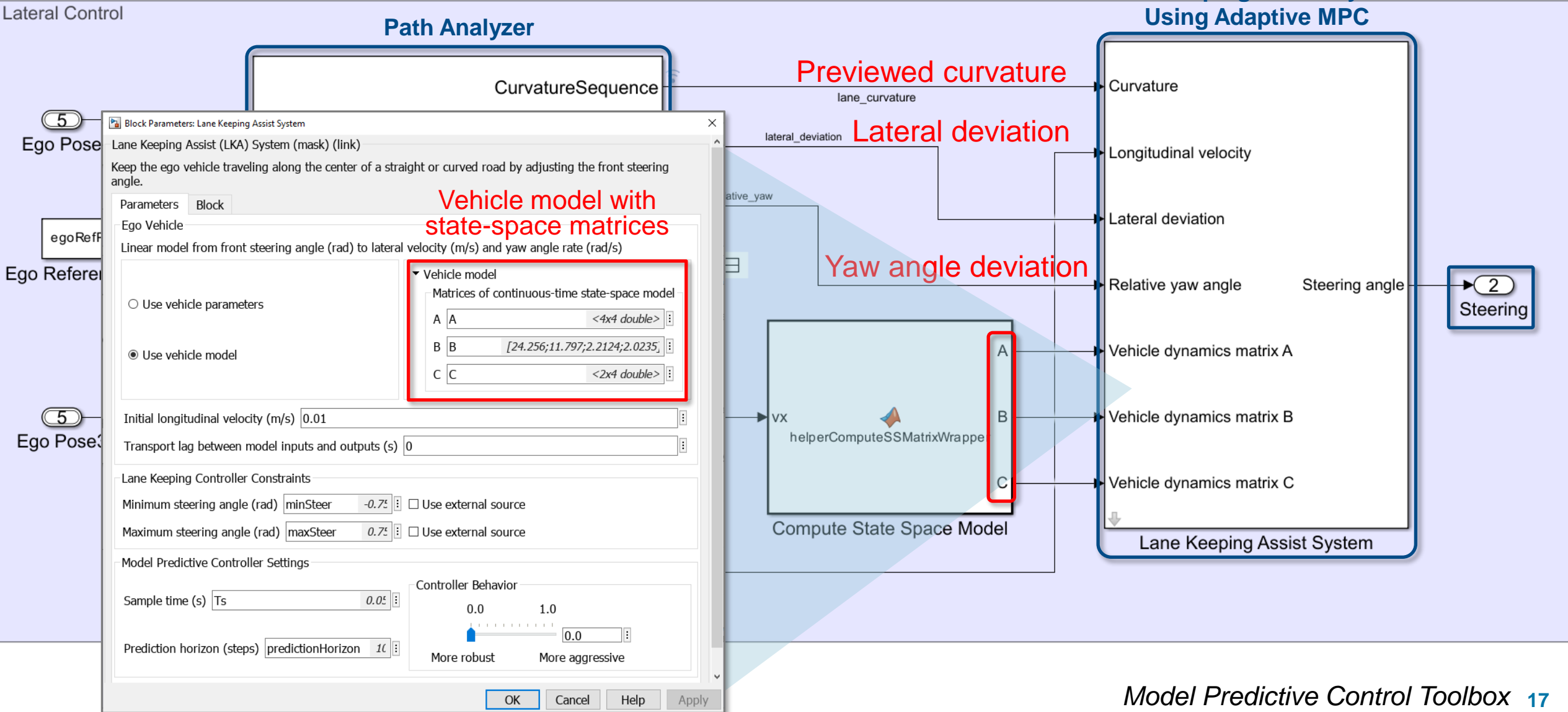
$$\varepsilon_i = L - \sqrt{(x_{ego} - x_{front})^2 + (y_{ego} - y_{front})^2}$$

Spacing error = ego - preceding car position

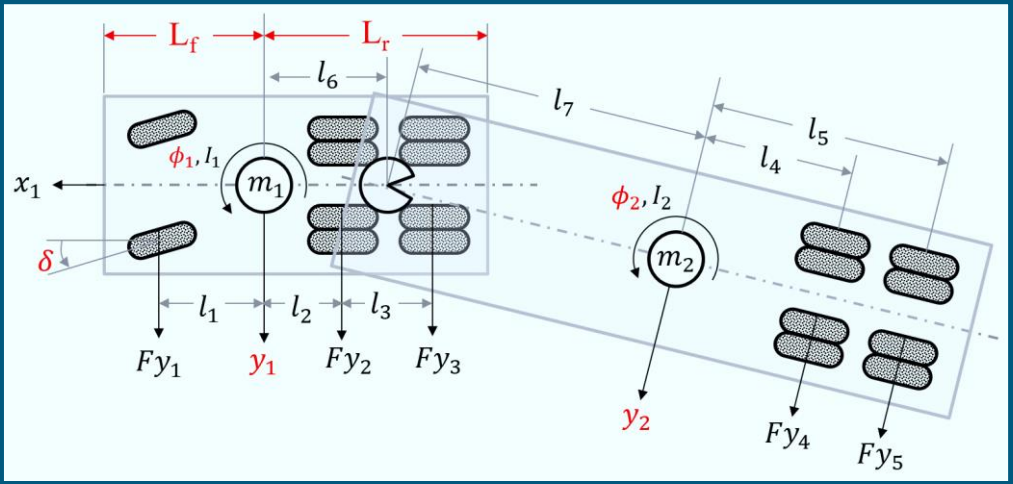
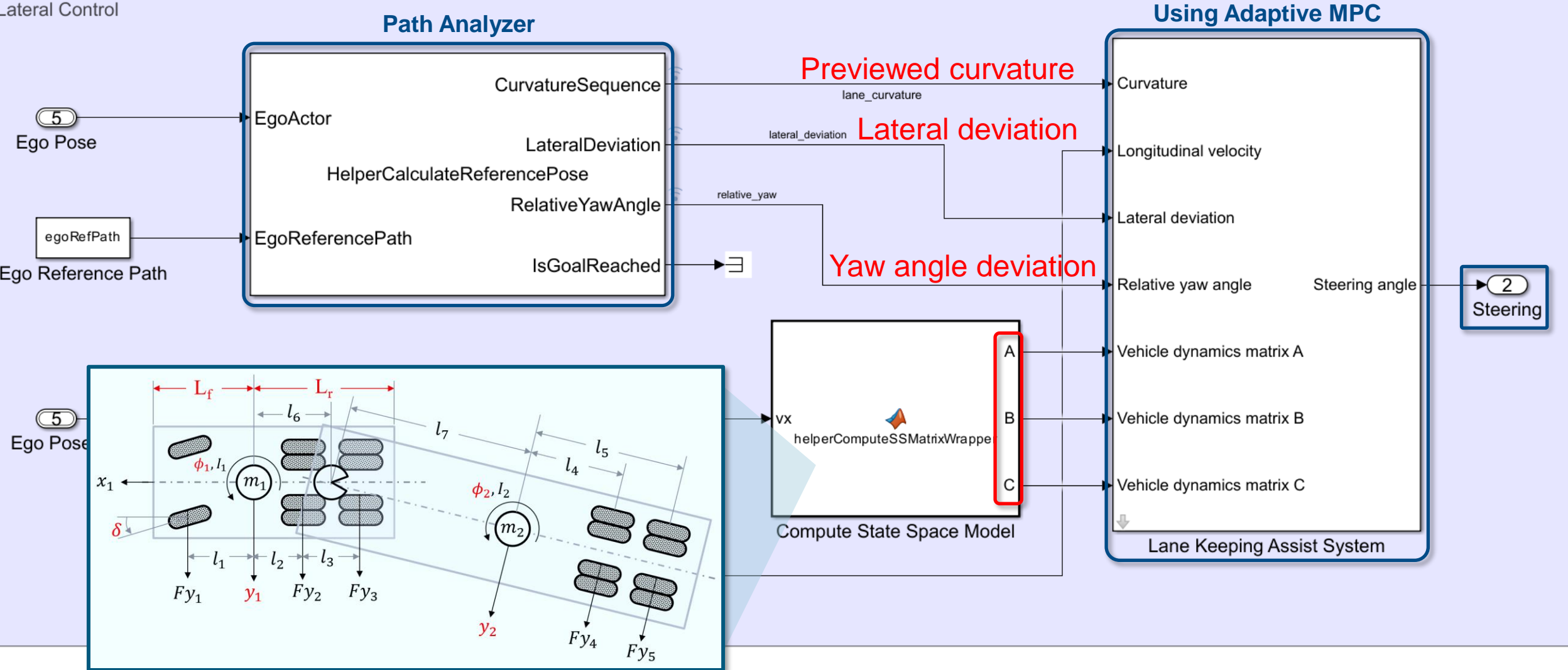
Lateral control



Lateral control



Lateral control



Linearized truck-trailer lateral dynamics

Plant Model - Truck-trailer lateral dynamics

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

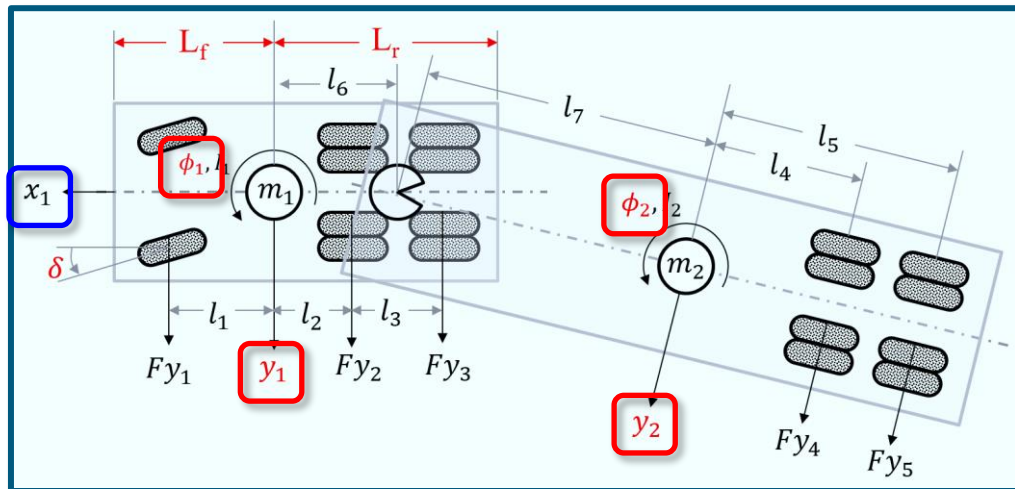
$$z = Cx$$

$$M = \begin{bmatrix} m_1 & 0 & m_2 & 0 \\ 0 & I_1 & -l_6 m_2 & 0 \\ 0 & 0 & -l_7 m_2 & I_2 \\ 1 & -l_6 & -1 & -l_6 \end{bmatrix}$$

$$x = \begin{bmatrix} \dot{y}_1 \\ \dot{\phi}_1 \\ \dot{y}_2 \\ \dot{\phi}_2 \end{bmatrix} \quad u = [\delta]$$

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

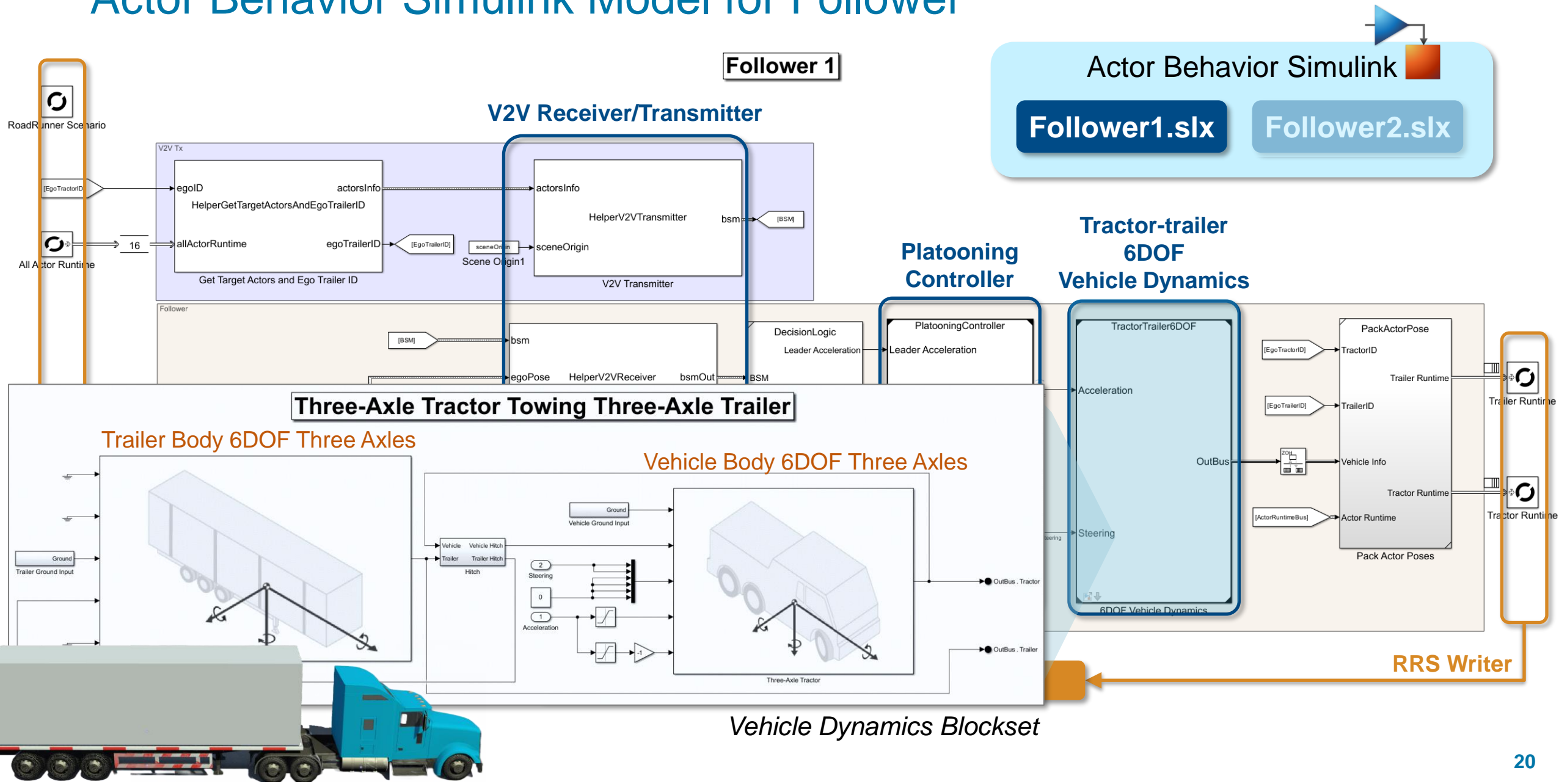
$$C = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$



Linearized truck-trailer lateral dynamics

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

Actor Behavior Simulink Model for Follower



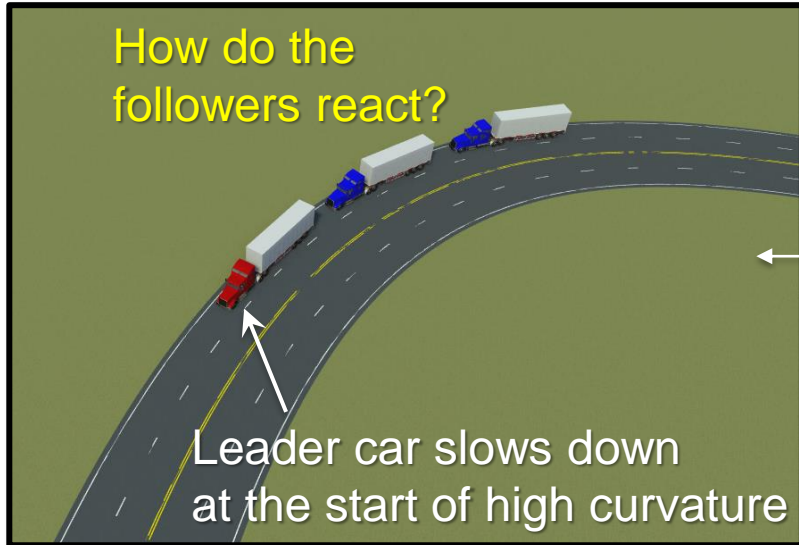
↗ *Lateral control*

RoadRunner Scene & Scenarios

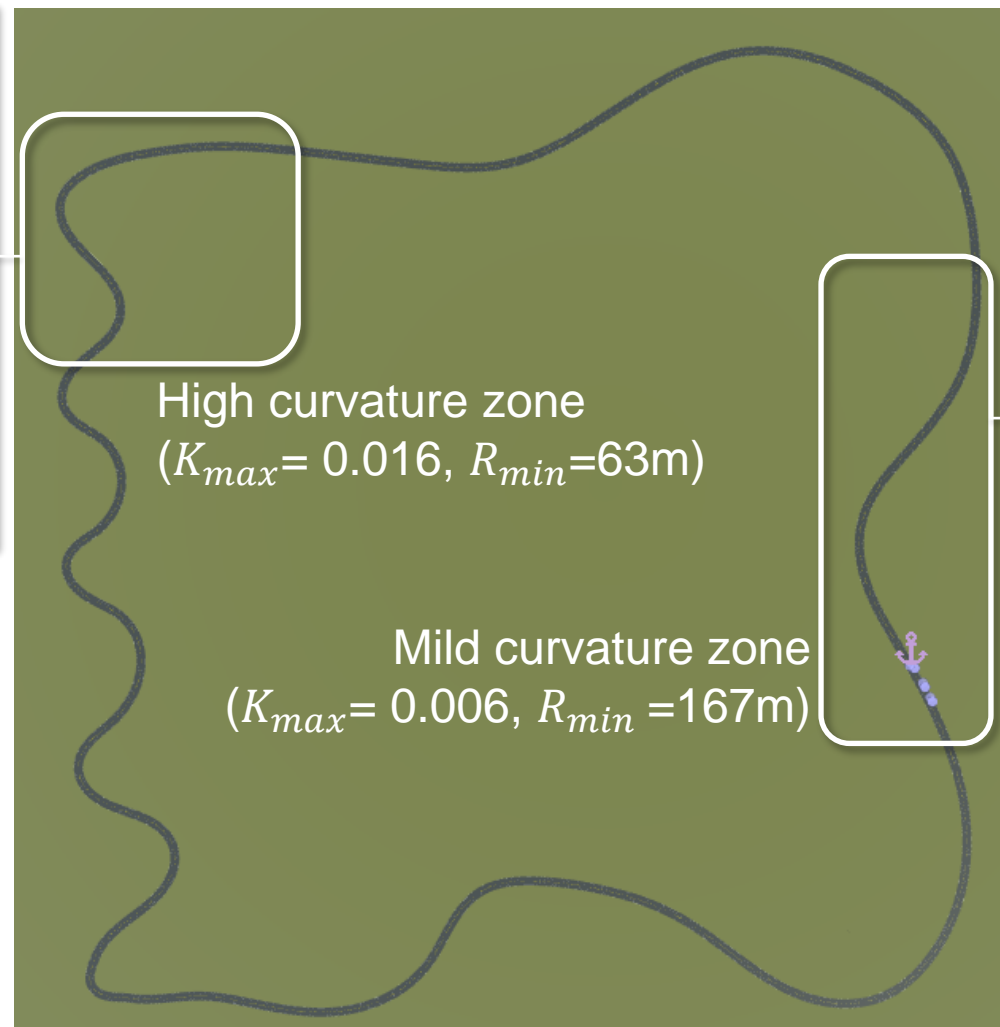
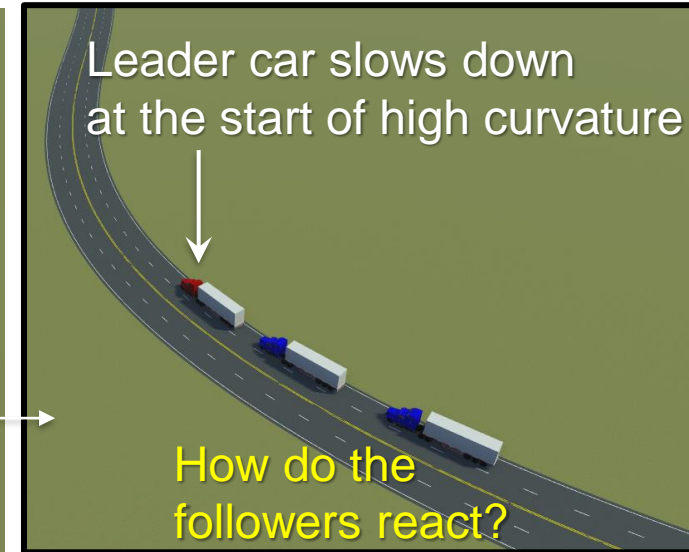
Control objective: *The truck follows a lane center of a curved road while maintaining a predefined space between vehicles in a platoon.*

↘ *Longitudinal control*

scenario_Platooning_02_HighCurvature



scenario_Platooning_01_CurvedRoad

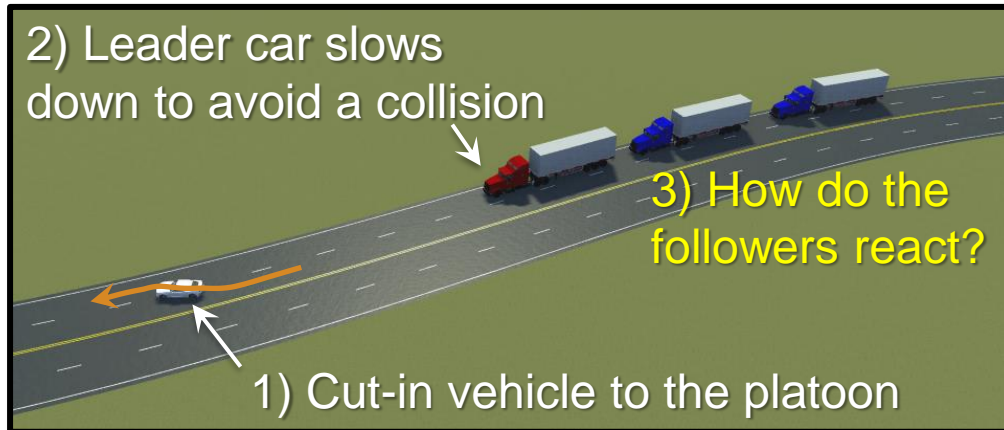


RoadRunner scene equivalent to [Unreal default scene – Curved Road](#)

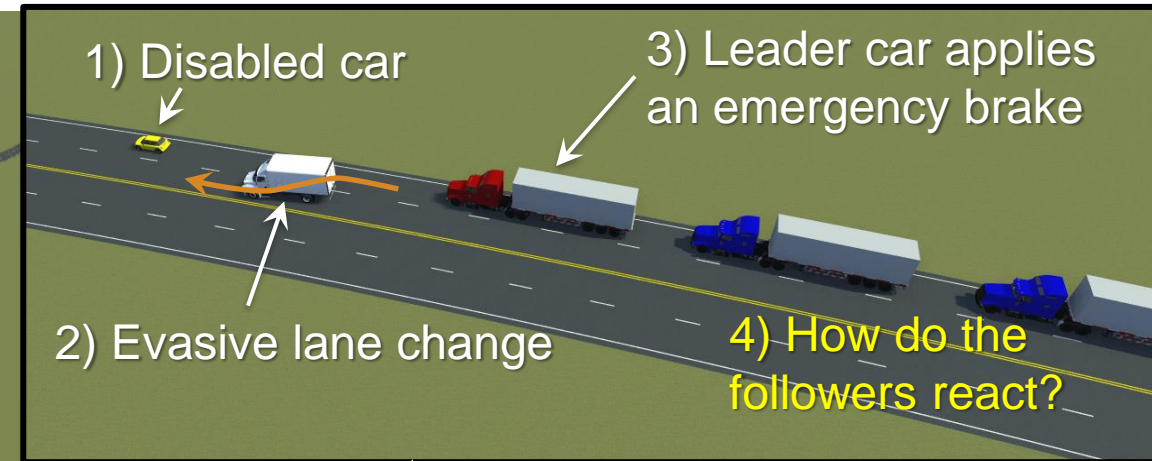
RoadRunner Scene & Scenarios

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

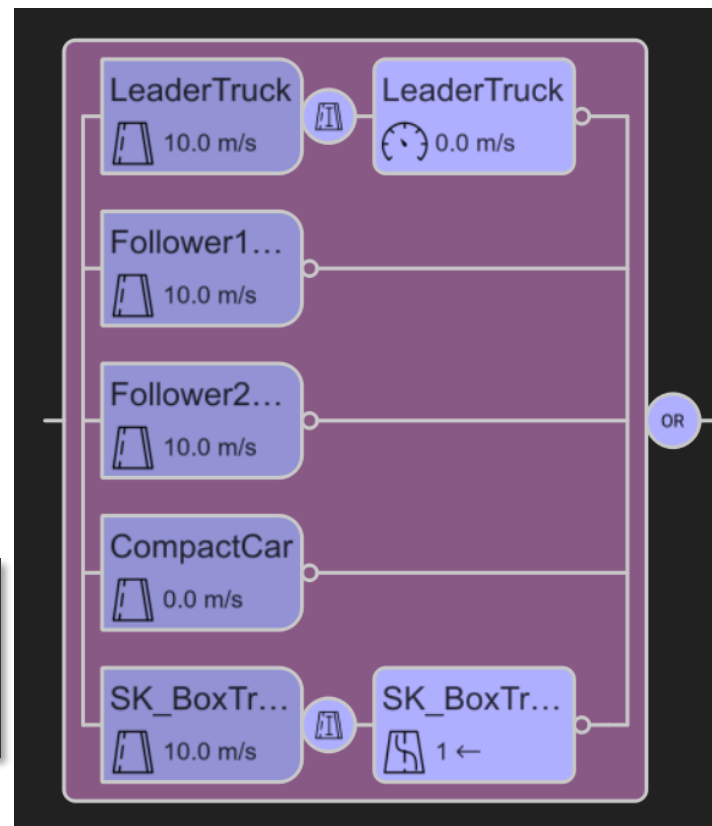
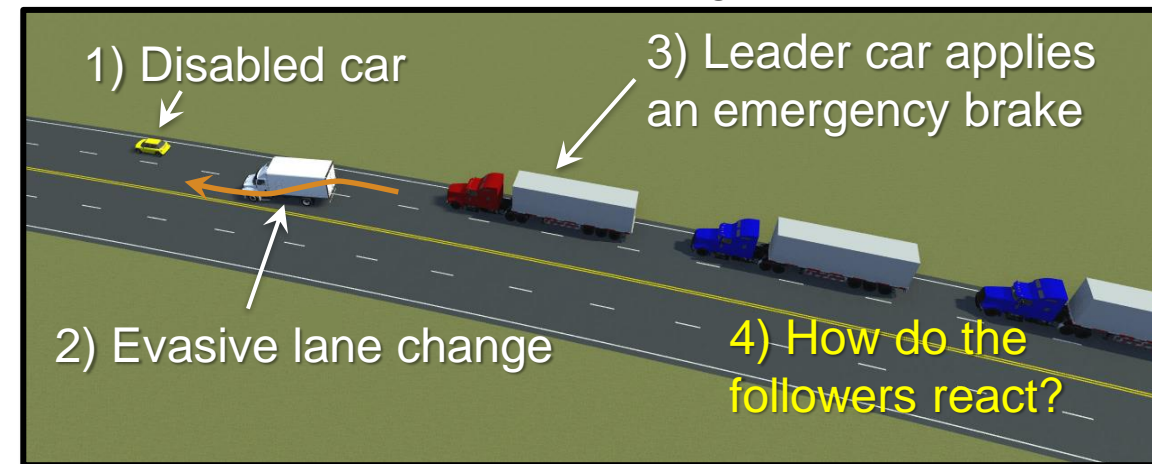


RoadRunner scene equivalent to
[Unreal default scene – Curved Road](#)

Scenario authoring using RoadRunner Scenario

“How to author scenarios using RoadRunner Scenario?”

scenario_Platooning_03_DecelAndStop



Scenario Logic

Scenario authoring using RoadRunner Scenario

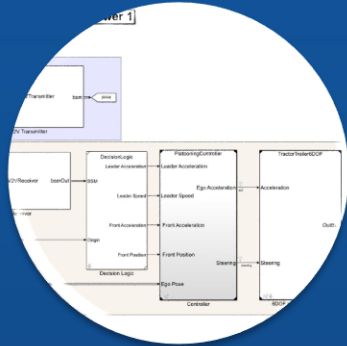
The screenshot displays the MathWorks RoadRunner Scenario Editor interface. The main window shows a 3D simulation of a road with a platoon of vehicles: a yellow car, a white truck, a red truck, a blue truck, and a blue car. The interface includes a menu bar (File, Edit, View, Tools, Assets, Window, Help) and a toolbar with various icons. The right side of the interface is divided into two panels: the "2D Editor | Logic" panel and the "Attributes" panel.

The "2D Editor | Logic" panel shows a logic diagram with several nodes connected to a central "OR" node. The nodes are:

- LeaderTruck (10.0 m/s)
- LeaderTruck (0.0 m/s)
- Follower1... (10.0 m/s)
- Follower2... (10.0 m/s)
- CompactCar (0.0 m/s)
- SK_BoxTr... (10.0 m/s)
- SK_BoxTr... (1 ←)

The "Attributes" panel is currently empty. The bottom status bar indicates "Scenario Edit Tool | Right click to create new routes or insert nodes into existing routes." The MathWorks logo is visible in the bottom right corner.

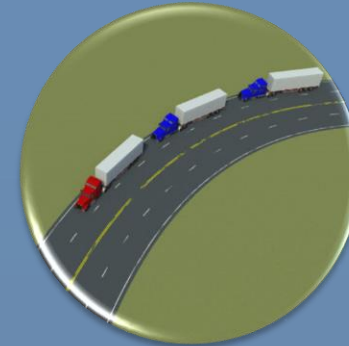
Workflow



**Platooning
Test Bench**



**Scenario
Authoring**



**Scenario
Simulation**



scenario_Platooning_01_CurvedRoad

The screenshot displays the MathWorks RoadRunner simulation environment. The main window shows a 3D perspective view of a curved road with three trucks in a platoon. The lead truck is yellow, and the two following trucks are white. The simulation is running at 2.900 seconds. The interface includes a menu bar (File, Edit, View, Tools, Assets, Window, Help) and a toolbar with various simulation controls. On the right side, the 'Simulation' panel is open, showing 'Simulation Controls' with buttons for Pause, Step Forward, and Stop. Below these are 'Simulation Properties' with fields for Step Size (0.05000 s) and Max Time (1000.000 s). The 'Camera' section shows 'Camera View' set to 'Orbit' and 'Actor' set to 'LeaderTruck'. At the bottom, the '2D Editor | Logic Playback' window shows a logic diagram with a block labeled 'Follower1...' and a speed of 10.0 m/s. The 'Output' window displays simulation logs, including a success message and several warnings about step solvers for the follower trucks. A large 'x3' multiplier is visible in the bottom right corner of the simulation area.

scenario_Platooning_01_CurvedRoad.rsscenario | R2022b_Update3 | MathWorks RoadRunner R2022b

File Edit View Tools Assets Window Help

Simulation

Simulation Controls

Pause Step Forward Stop

Time: 2.900 s

Enable Pacing to Slow Down Simulation

Slower 0.05x 1x 20x Faster

Simulation Properties

Step Size: 0.05000 s Max Time: 1000.000 s

Camera

Camera View: Orbit

Actor: LeaderTruck

Lock to Actor Orientation

2D Editor | Logic Playback

Follower1... 10.0 m/s

Output

```
> Client API command succeeded (with input type 'mathworks.roadrunner.PrepareSimulationRequest'): 'Prepared Simulation.'
>
> Simulation STARTED -----
> WARNING: (id: {9e8b3d2d-16be-4ff5-a948-3bd0c23f3cf2}) : Follower1Truck The actor model 'Follower1' does not have a fixed step solver assigned.
> WARNING: (id: {9e8b3d2d-16be-4ff5-a948-3bd0c23f3cf2}) : Follower1Truck The actor model 'Follower1' does not have a fixed step solver assigned.
> WARNING: (id: {9e8b3d2d-16be-4ff5-a948-3bd0c23f3cf2}) : Follower2Truck The actor model 'Follower2' does not have a fixed step solver assigned.
> WARNING: (id: {9e8b3d2d-16be-4ff5-a948-3bd0c23f3cf2}) : Follower2Truck The actor model 'Follower2' does not have a fixed step solver assigned.
```

Simulation Tool

Attributes Metadata Simulation

MathWorks

x3

scenario_Platooning_02_HighCurvature

The screenshot displays the MathWorks RoadRunner simulation environment. The main window shows a 3D view of a truck platoon on a curved road. The interface includes a menu bar (File, Edit, View, Tools, Assets, Window, Help) and a toolbar with various icons. The simulation is running at 2.050 s. The Simulation Controls panel on the right includes buttons for Pause, Step Forward, and Stop, along with a speed slider ranging from 0.05x to 20x. The Simulation Properties panel shows Step Size: 0.05000 s and Max Time: 1000.000 s. The Camera panel shows Camera View: Orbit and Actor: LeaderTruck. The Output console at the bottom right displays the following text:

```
> Client API command succeeded (with input type 'mathworks.roadrunner.PrepareSimulationRequest'): 'Prepared Simulation.'  
>  
> Simulation STARTED -----  
> WARNING: (id: {9e8b3d2d-16be-4ff5-a948-3bd0c23f3cf2}) : Follower1Truck.The actor model 'Follower1' does not have a fixed step solver assigned.  
> WARNING: (id: {9e8b3d2d-16be-4ff5-a948-3bd0c23f3cf2}) : Follower1Truck.The actor model 'Follower1' does not have a fixed step solver assigned.  
> WARNING: (id: {9e8b3d2d-16be-4ff5-a948-3bd0c23f3cf2}) : Follower2Truck.The actor model 'Follower2' does not have a fixed step solver assigned.  
> WARNING: (id: {9e8b3d2d-16be-4ff5-a948-3bd0c23f3cf2}) : Follower2Truck.The actor model 'Follower2' does not have a fixed step solver assigned.
```

The 2D Editor at the bottom left shows a logic block for 'Follower1...' with a speed of 15.0 m/s. The Simulation Tool status bar at the bottom left indicates the current tool. The MathWorks logo is visible in the bottom right corner.

scenario_Platooning_03_DecelAndStop

The screenshot displays the MathWorks RoadRunner simulation environment. The main window shows a 3D perspective view of a road with a platoon of vehicles: a yellow compact car, a white truck, a red truck, a blue truck, and another blue truck. The simulation is running at 2.400 s. The right-hand panel contains simulation controls, including a 'Simulation Controls' section with 'Pause', 'Step Forward', and 'Stop' buttons, and a 'Simulation Properties' section with 'Step Size' set to 0.05000 s and 'Max Time' set to 1000.000 s. Below the simulation view is a '2D Editor | Logic Playback' window showing a logic diagram with three green blocks labeled '10.0 m/s', 'Follower2...', and 'CompactCar', connected by lines and an 'OR' gate. The bottom right corner features an 'Output' window with a log of simulation events, including warnings about step solvers for 'Follower1Truck' and 'Follower2Truck'. A large 'x3' watermark is visible in the bottom right corner of the interface.

scenario_Platooning_04_CutInFrontOfLeader

The screenshot displays the MathWorks RoadRunner simulation environment. The main window shows a 2D perspective view of a road with a platoon of vehicles: a white car, followed by three blue trucks, and a red truck. The simulation is running at 11.000 seconds. The right-hand panel contains simulation controls, including a speed slider set to 1x, and simulation properties like a step size of 0.05000 s and a maximum time of 1000.000 s. The bottom-left panel shows a logic editor with blocks for 'LeaderTruck' (12.0 m/s), 'Follower1...', 'Follower2...', and 'SK_Muscl...' (17.8 m/s). The bottom-right panel is the output console, showing a series of warnings for 'Follower1' and 'Follower2' not having fixed step solvers assigned. A large 'x3' watermark is visible in the bottom right corner of the simulation area.

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
 - Implemented the platooning lateral controller using
 - Lane-keeping assist Model Predictive Control
 - Linearized truck-trailer lateral dynamics
 - Simulated the Simulink test bench with RoadRunner Scenario
- *Automated Driving Toolbox*
 - *Vehicle Dynamics Blockset*
 - *Simulink*
 - *Model Predictive Control Toolbox*
 - *RoadRunner*
 - *RoadRunner Scenario*
 - *RoadRunner Asset Library*

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Thank you

Please contact me at spark@mathworks.com
with questions

