MathWorks
AUTOMOTIVE CONFERENCE 2022
India

Environment modeling and Virtual Validation for ADAS/AD features

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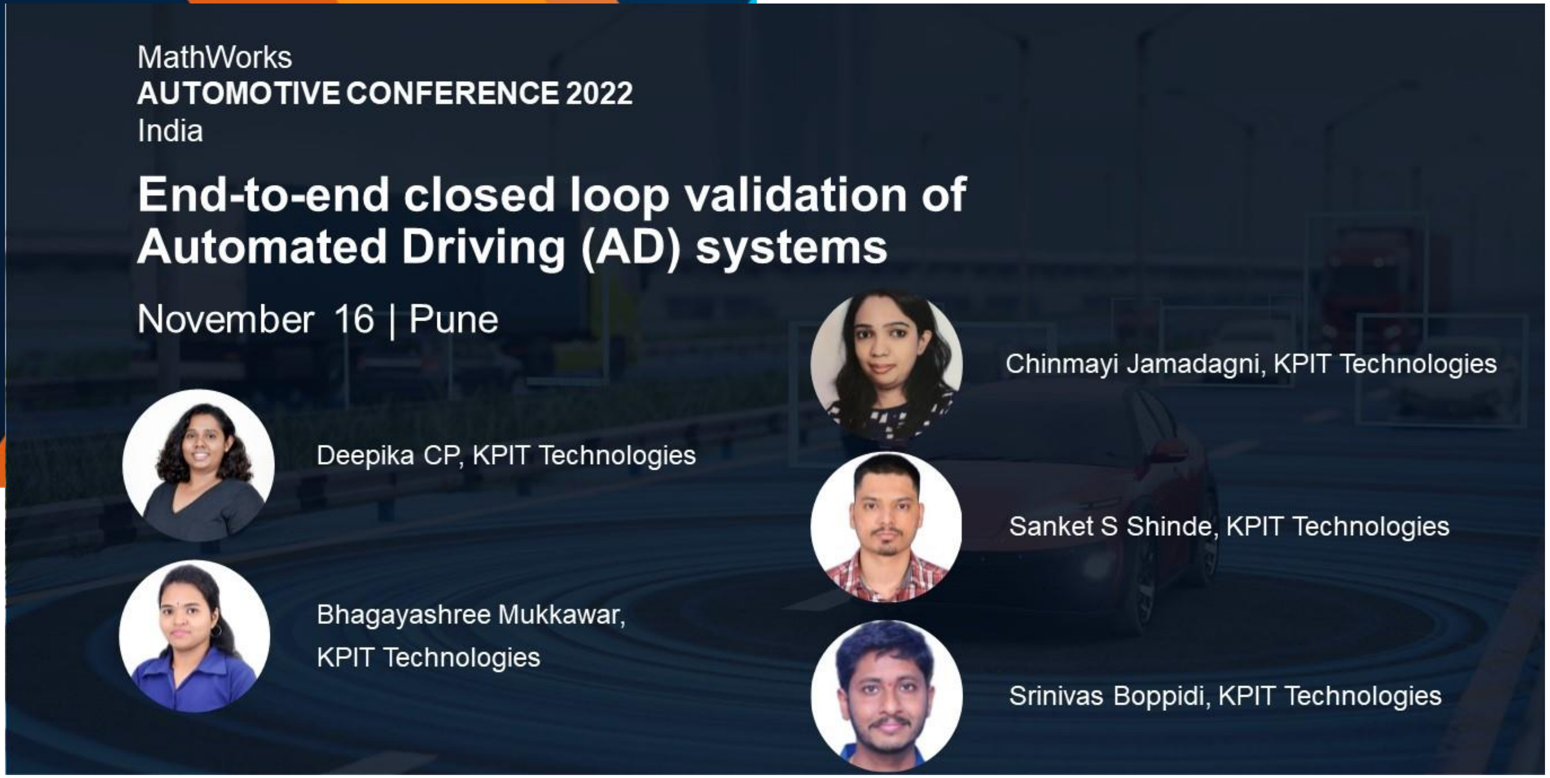
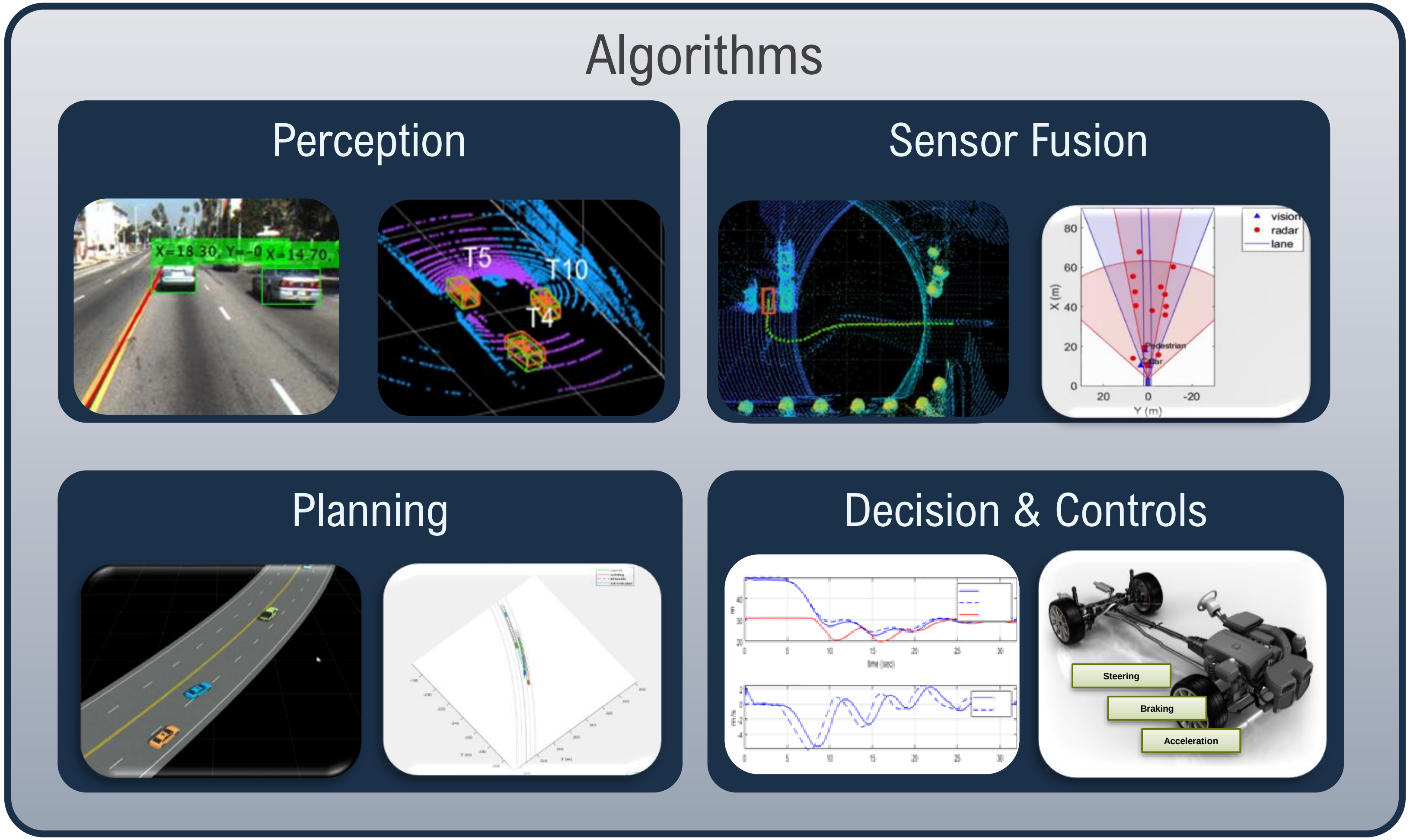
References from Today’s MAC

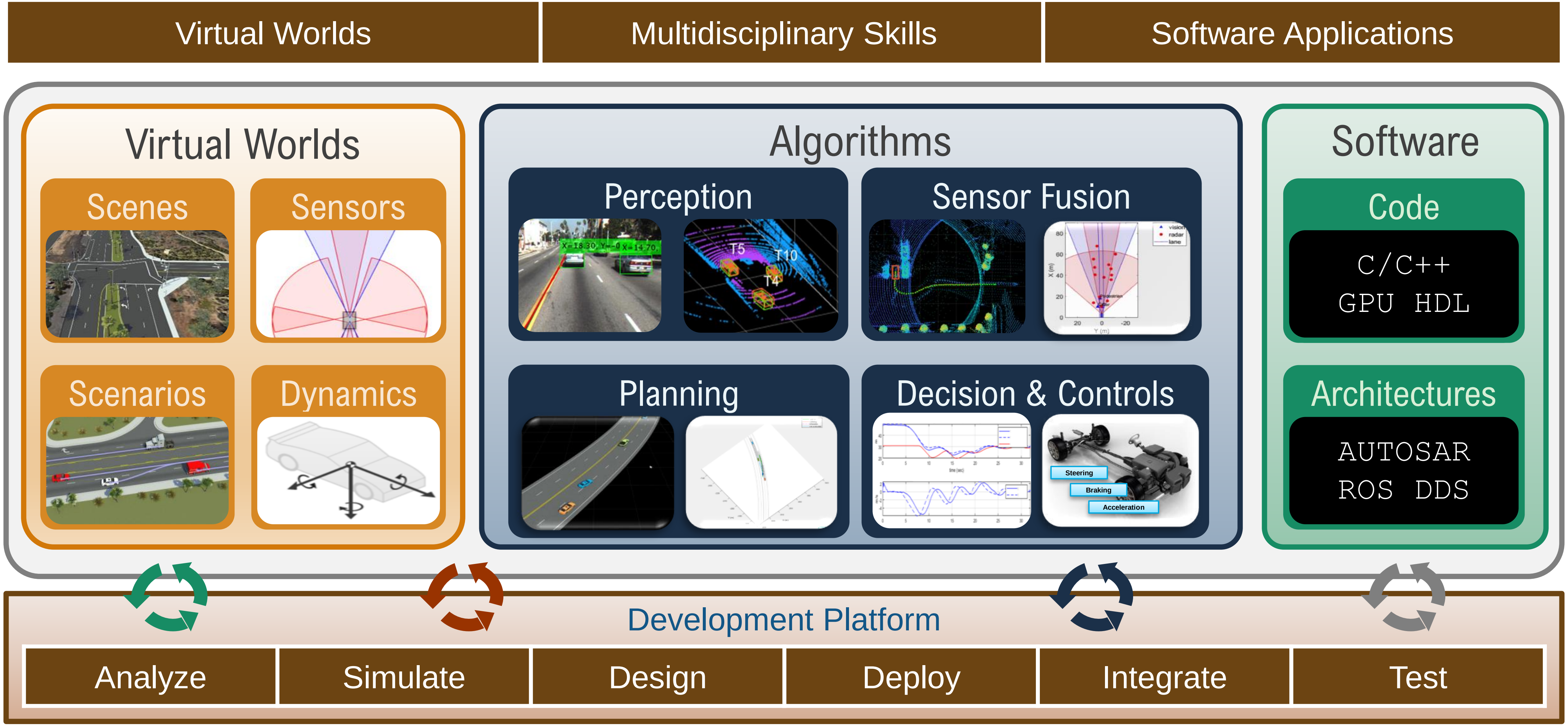


Key subsystems of an automated driving system



Virtual Validation of Automated Driving Applications

with MATLAB, Simulink, & RoadRunner



Today’s Agenda

ENVIRONMENT MODELLING

Create Virtual Scenes and Scenarios

Recreating real world for virtual simulation

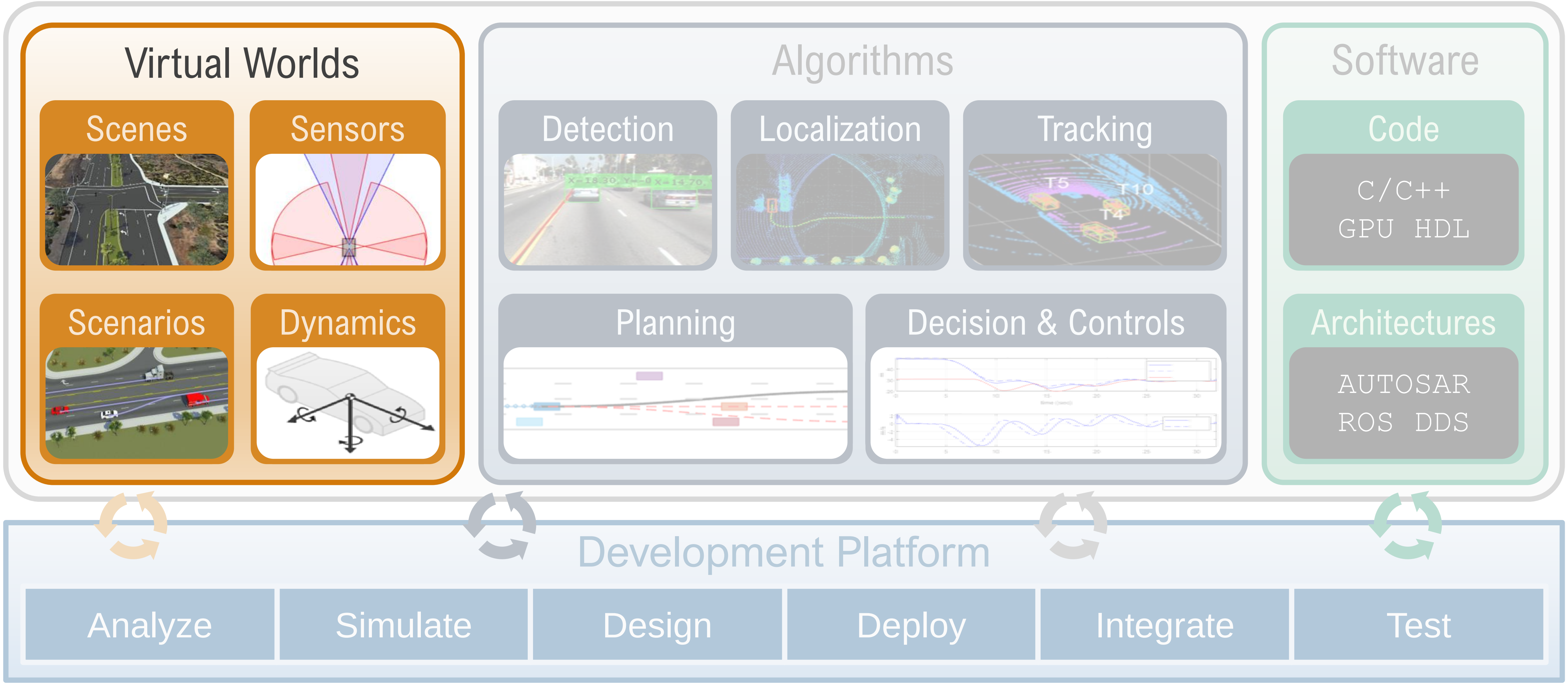
VIRTUAL VALIDATION

Open/ Close loop testing

Test Automation for AD/ADAS

Develop Automated Driving Applications

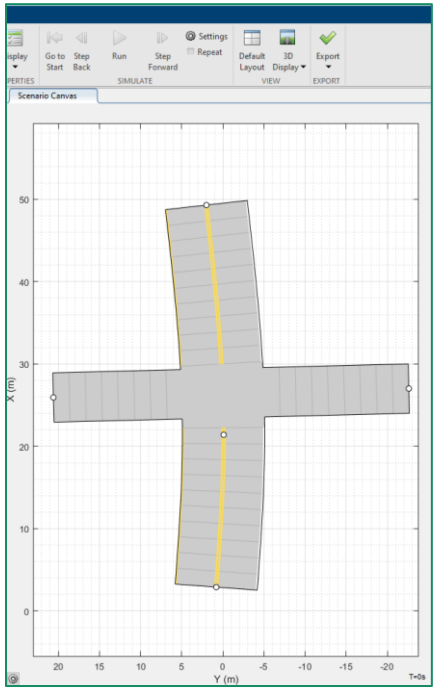
with MATLAB, Simulink, & RoadRunner



A Virtual world is made up of Scenes and Scenarios

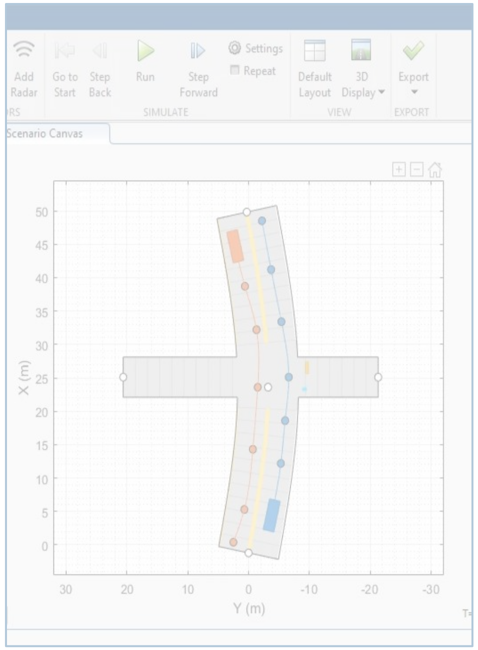
Scenes

- Static elements of the environment
- Roads, lanes, signs, traffic cones, etc.

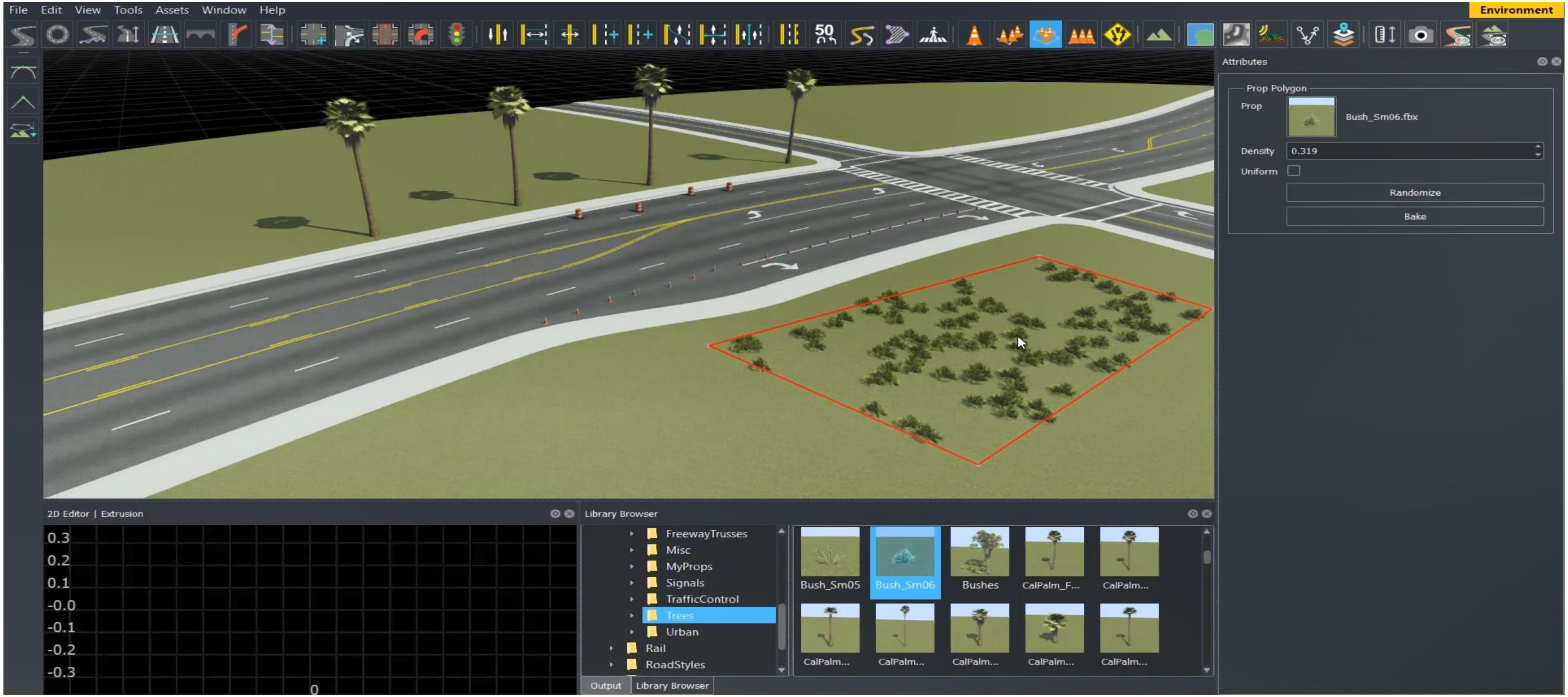


Scenarios

- Description of dynamic elements in driving simulation
- Vehicle trajectories, pedestrian/cyclist movement, traffic light changes, etc.



RoadRunner enables Engineers to create Scenes



Here HD Live Map
TomTom HD Maps
Custom HD Maps

OpenDRIVE
OpenStreetMap
OpenCRG
Zenrin SD Maps

Geographic Information System (GIS) Files
- Point clouds
- Orthoimagery
- Vector data
- Elevation data

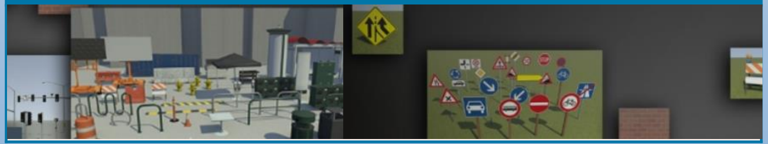
Custom Assets

RoadRunner Platform

RoadRunner Scene Builder

RoadRunner

RoadRunner Asset Library

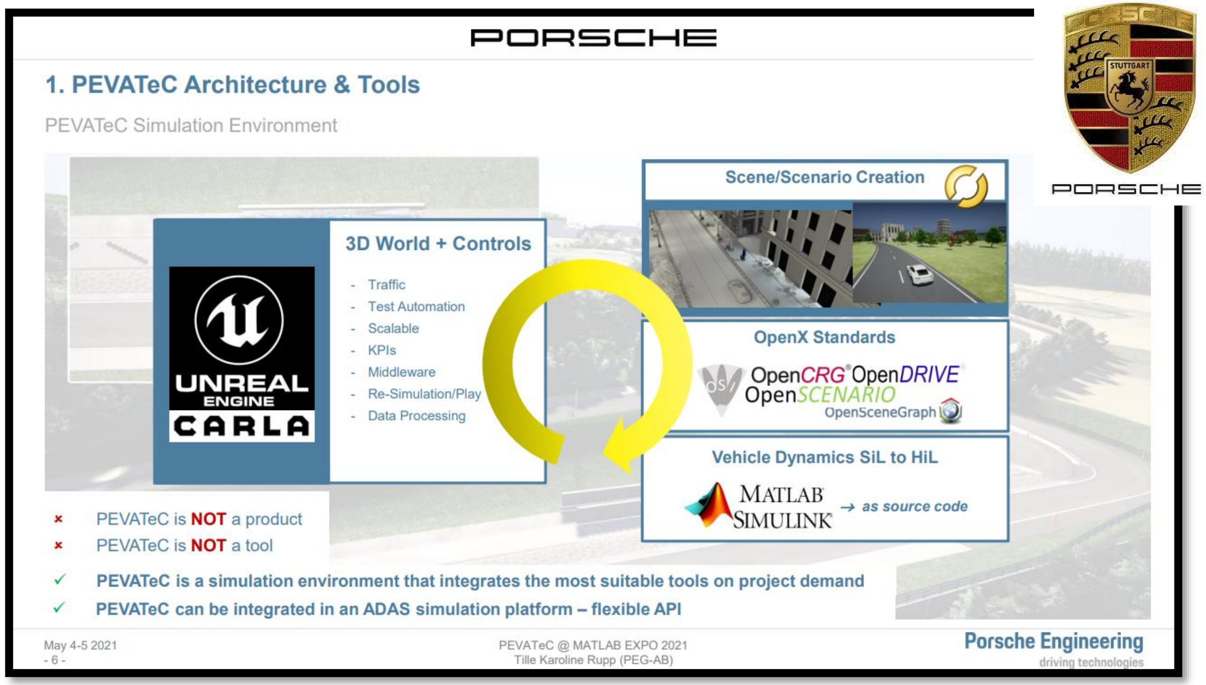


OpenDRIVE

Filmbox

Third Party Simulators
- CARLA
- Unreal Engine®
- Unity®
- LGSVL
- VIRES Virtual Test Drive
- Metamoto
- IPG Carmaker
- Cognata
- Baidu Apollo
- Tesis Dynaware
- TaSS PreScan
- NVIDIA DRIVE Sim through Universal Scene Description (USD)

Porsche and NVIDIA use RoadRunner

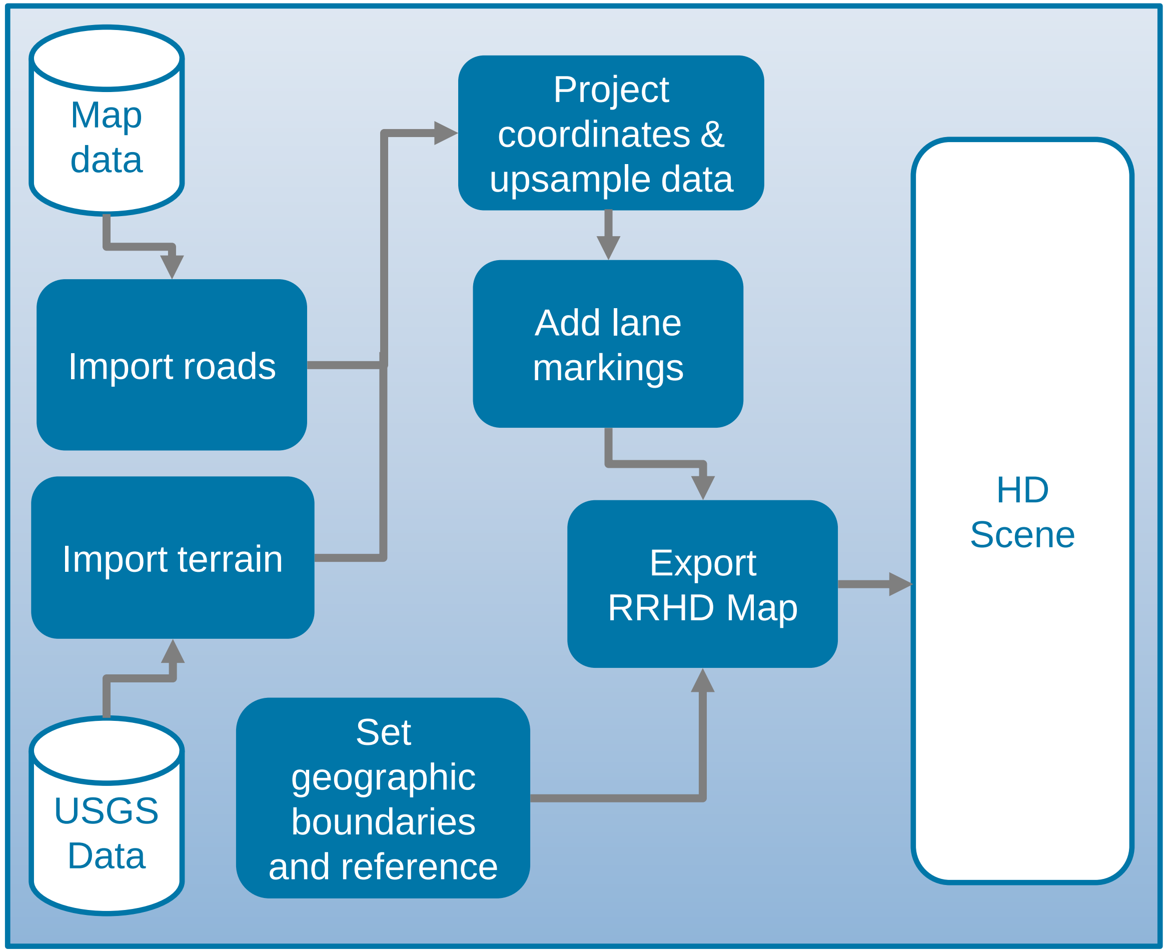


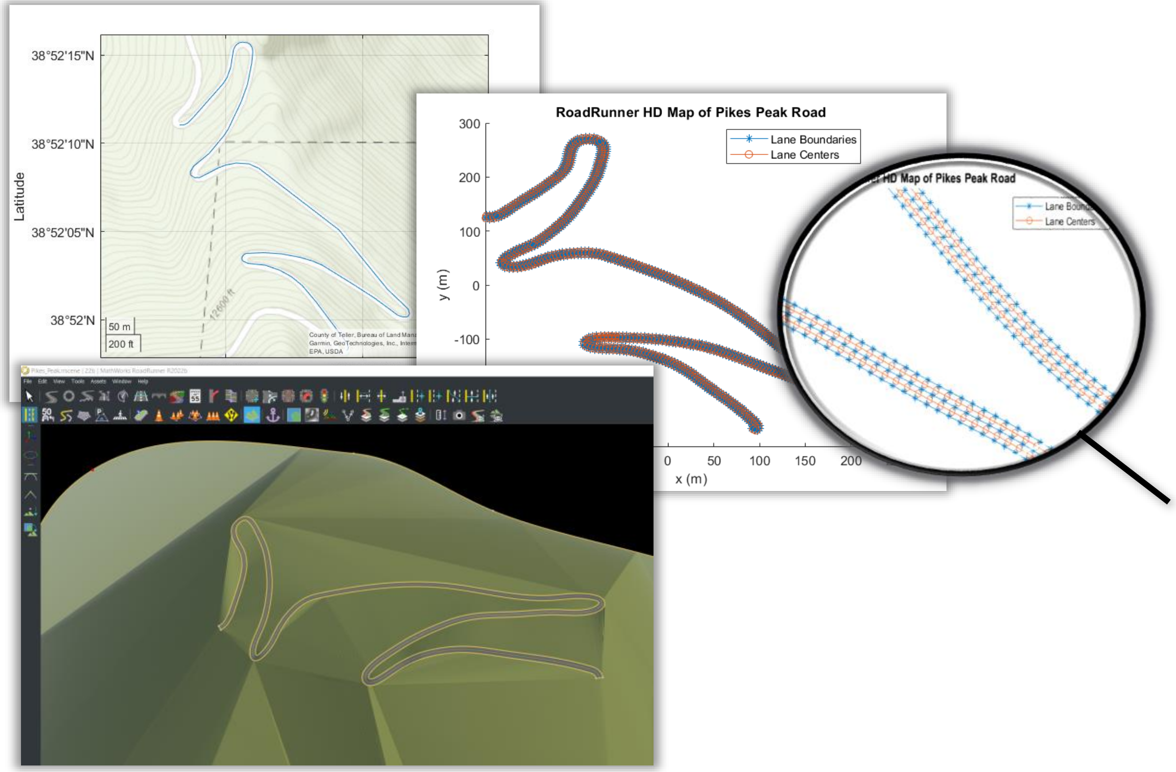
[PORSCHE: ADAS/AD virtual platform for end-to-end software development, testing and validation]

[NVIDIA: Connecting in the omniverse- The making of GTC Keynote] ([Blog])

[CARLA: Roadrunner recommended software to create scenes]

Programmatically create RoadRunner HD Map from real world map data





- Import map and elevation data into MATLAB
- Upsample data and create RoadRunner HD Map
- Import into RoadRunner

[Build Pikes Peak RoadRunner 3D Scene](#)

Automated Driving Toolbox, Mapping Toolbox

R2022b

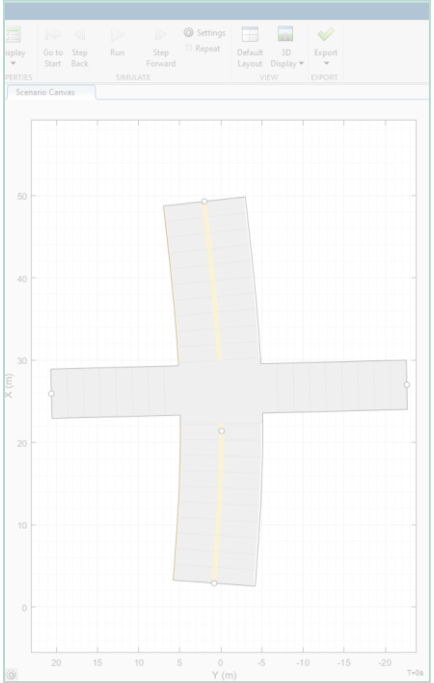
A Virtual world is made up of Scenes and Scenarios

Scenes

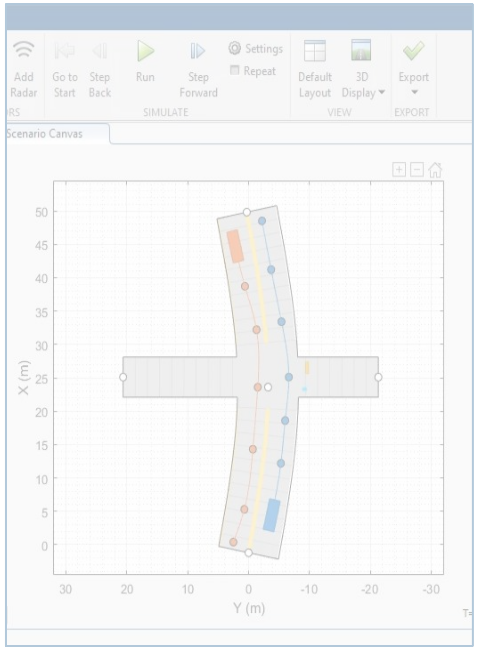
- Static elements of the environment
- Roads, lanes, signs, traffic cones, etc.

Scenarios

- Description of dynamic elements in driving simulation
- Vehicle trajectories, pedestrian/cyclist movement, traffic light changes, etc.

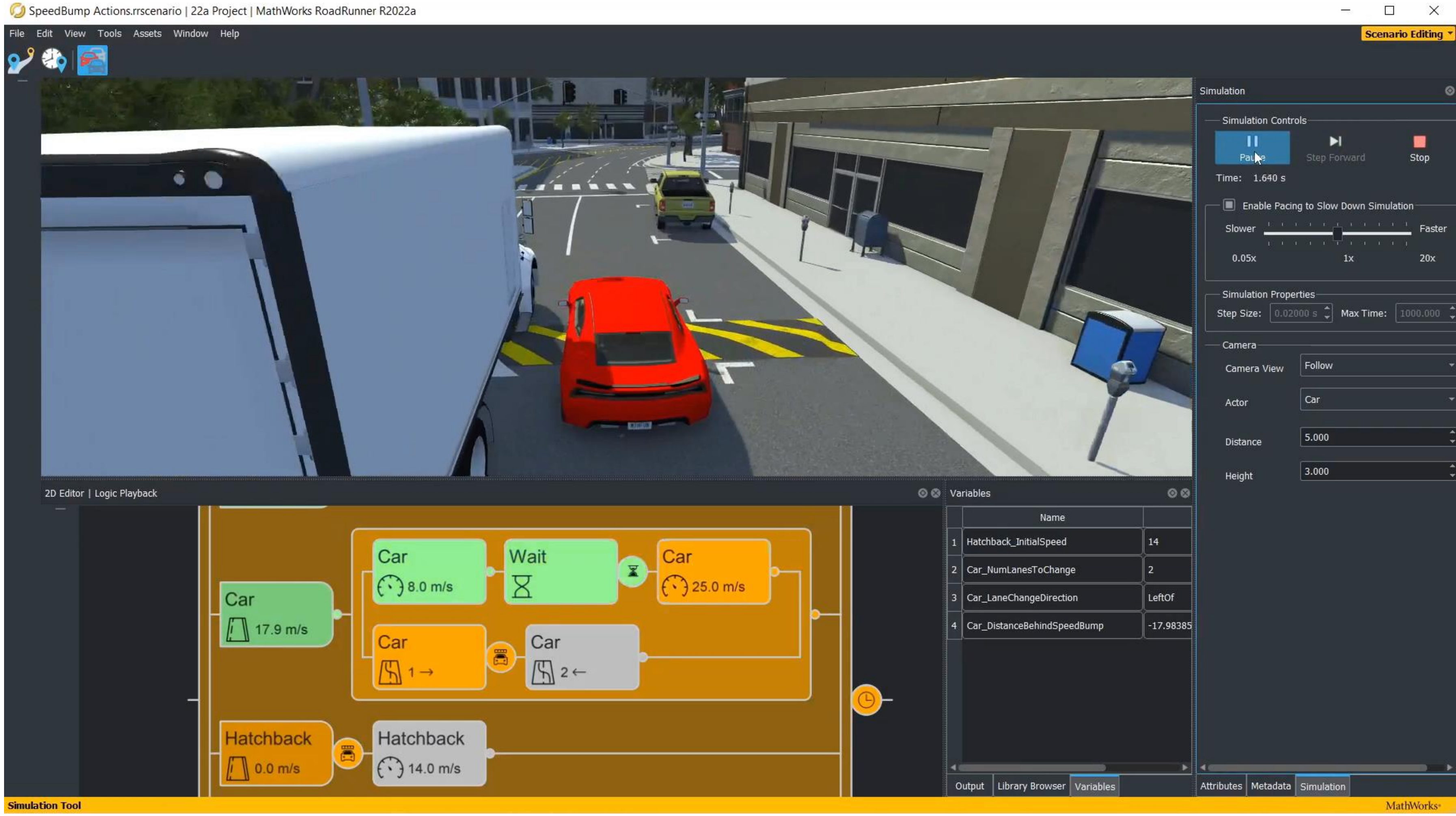






Interactively design scenarios with RoadRunner Scenario

- Add various vehicles
- Author trajectories
- Specify actions and logic
- Parameterize variations



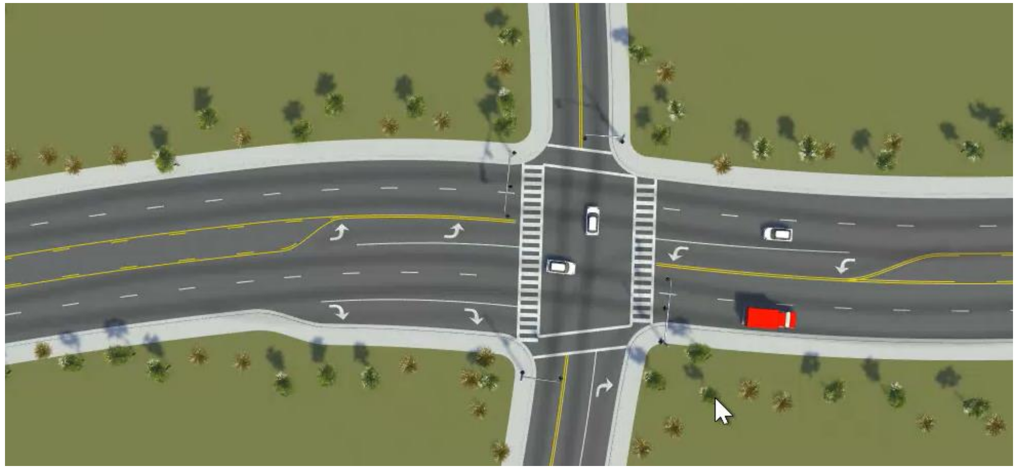
Scenario Edit Tool

RoadRunner Scenario

R2022a

Simulate map-aware paths and scenario logic

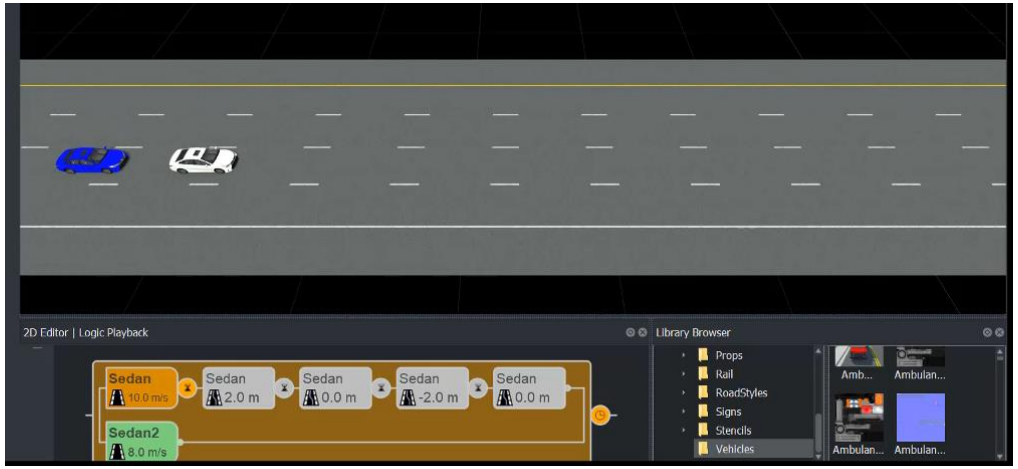
Follow lanes when no path is specified



Speed actions

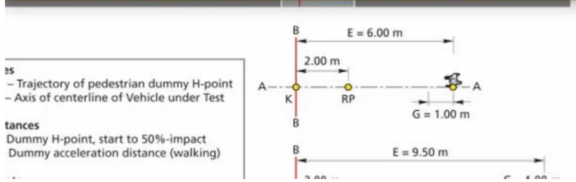
Lane change actions

Lateral offset actions



Create complicated scenarios accurately

- Cubic interpolation
- Clothoid interpolation
- EuroNCAP
  (clothoid-arc-clothoid)



Test speed	Part 1 (clothoid)			Part 2 (constant radius)			Part 3 (clothoid)		
	Start Radius R1 [m]	End Radius R2 [m]	Angle α [deg]	Start Radius R2 [m]	End Radius R2 [m]	Angle β [deg]	Start Radius R2 [m]	End Radius R1 [m]	Angle α [deg]
10 km/h to Farside	1500	9.00	20.62	9.00	9.00	48.76	9.00	1500	20.62
15 km/h to Farside	1500	11.75	20.93	11.75	11.75	48.14	11.75	1500	20.93
20 km/h to Farside	1500	14.75	21.79	14.75	14.75	46.42	14.75	1500	21.79
10 km/h to Nearside	1500	8.00	22.85	8.00	8.00	44.30	8.00	1500	22.85

Route Timing Tool

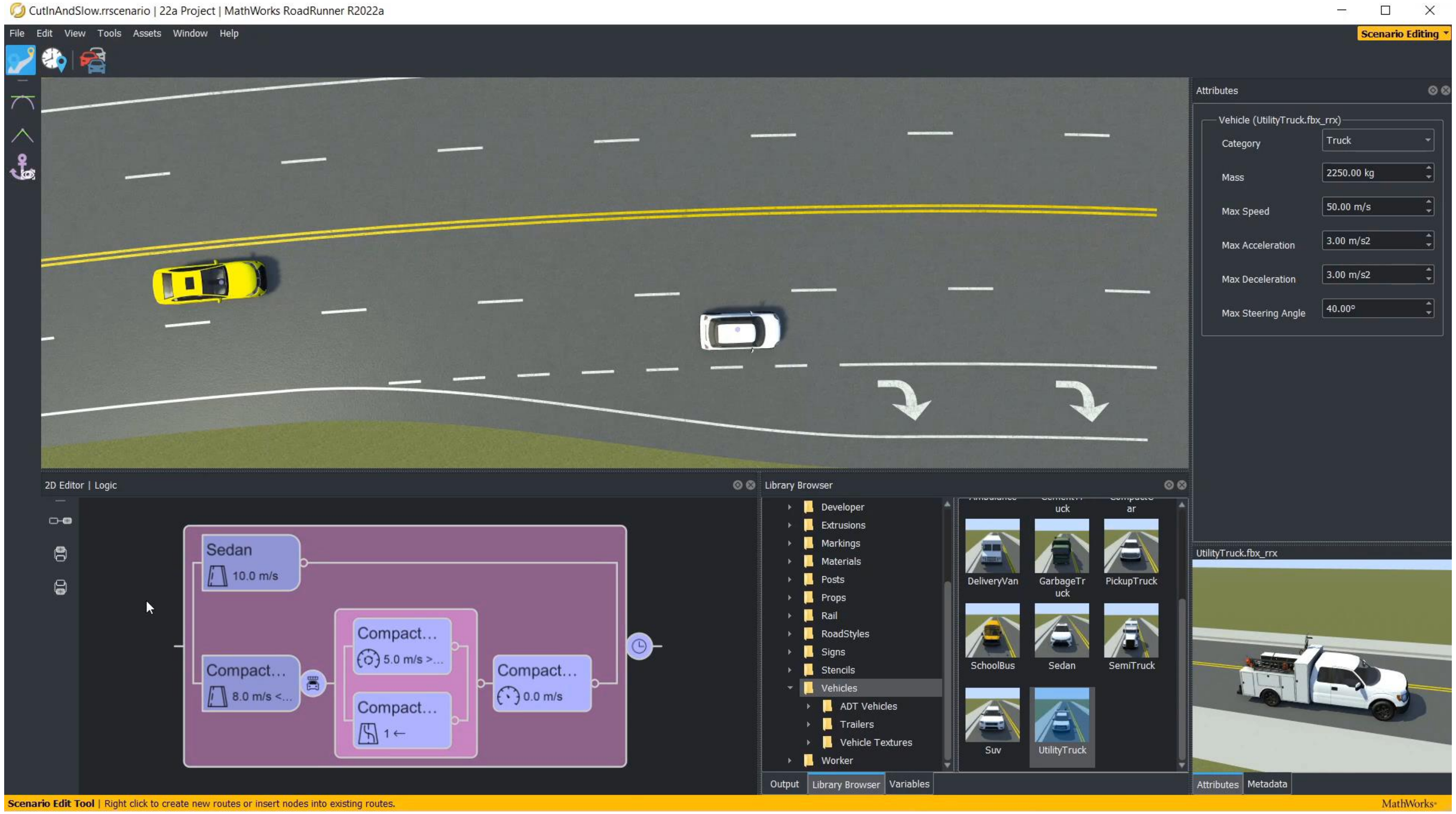
RoadRunner Scenario

R2022a

Programmatically vary scenario parameters

MATLAB, gRPC, and Command-line APIs

- Define scenario variables in editor
- Set variables programmatically from API
- Run simulations
- Export to OpenSCENARIO

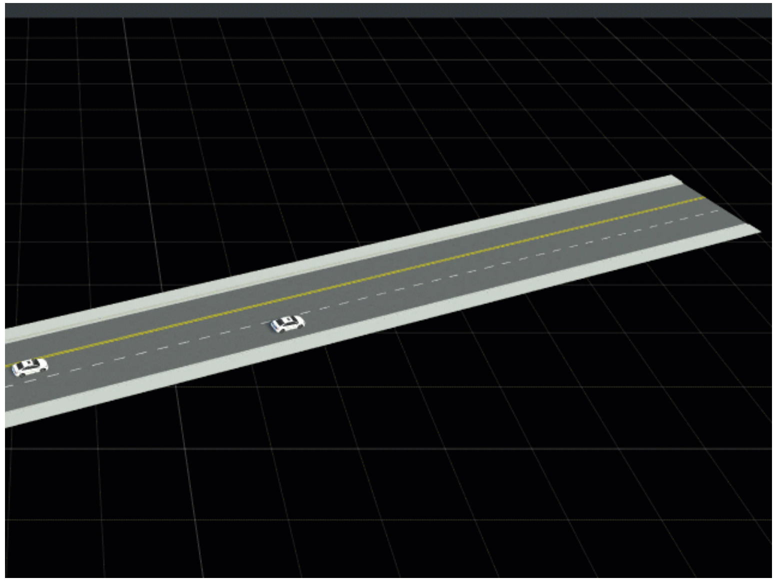


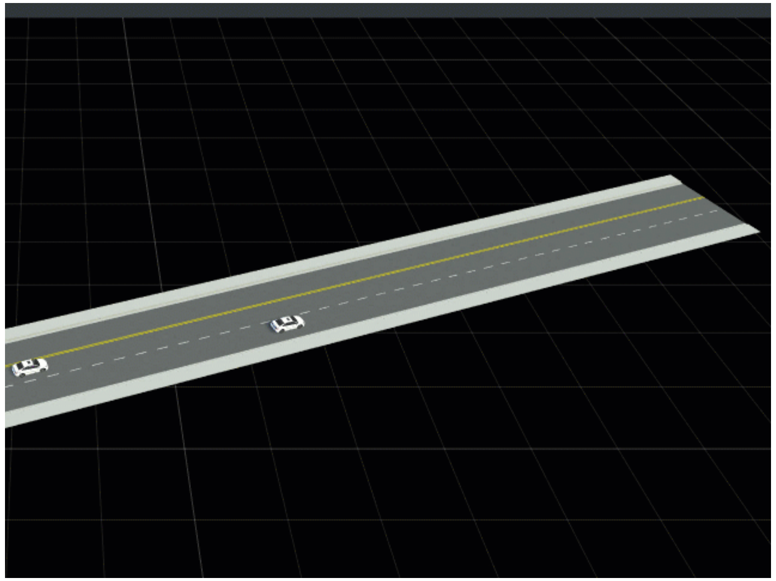
[Programmatic Scenario Interfaces](#)

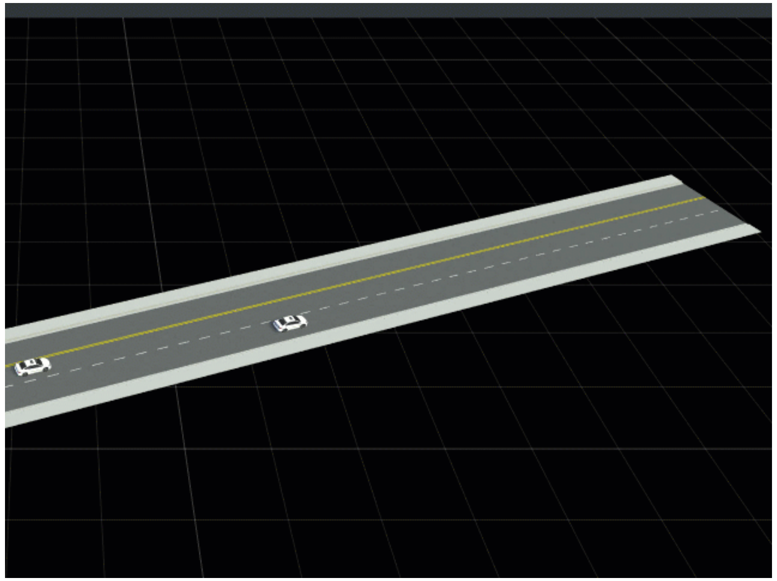
RoadRunner Scenario

R2022a

Adjusting Scenario Variables with MATLAB Programs





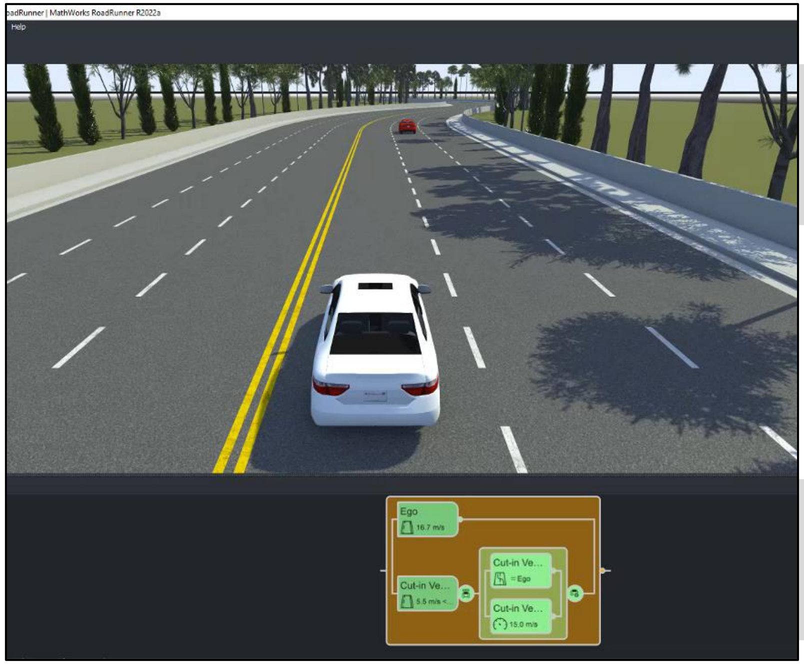


```
rrApp = roadrunner(rrProj);
rrApp.setScenarioVariable('Threshold','5');
```

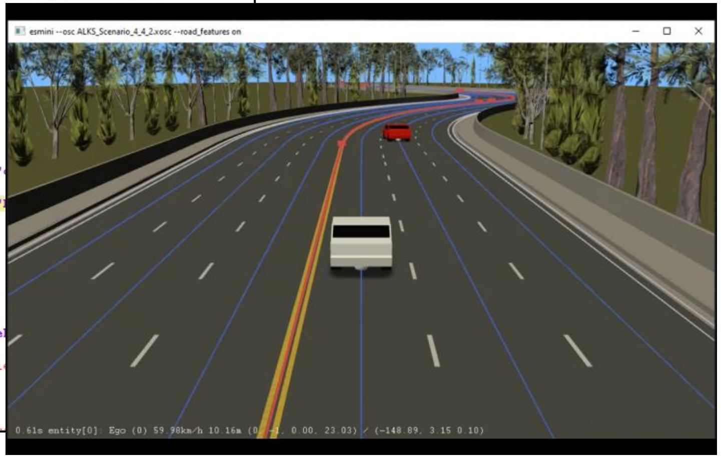
```
rrApp = roadrunner(rrProj);
rrApp.setScenarioVariable('Threshold','15');
```

```
rrApp = roadrunner(rrProj);
rrApp.setScenarioVariable('Threshold','25');
```

Export scenarios to OpenSCENARIO V1.x and V2.0

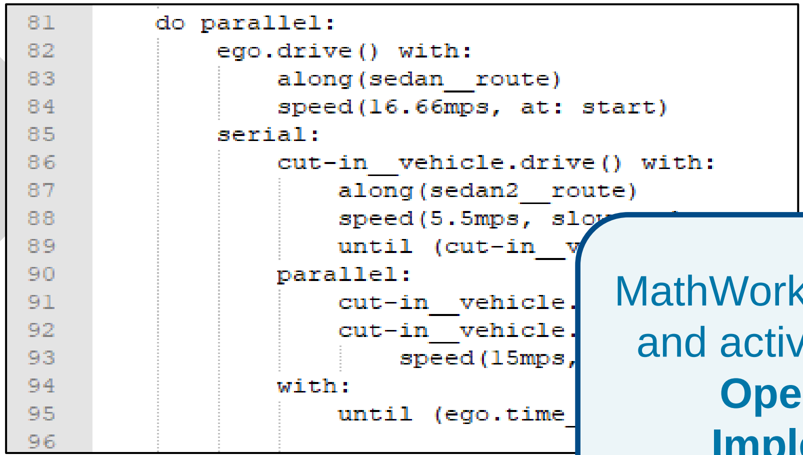


OpenSCENARIO V1.x



https://github.com/esmini/esmini

OpenSCENARIO V2.0



MathWorks is an ASAM Member and actively participates in the **OpenSCENARIO 2.0 Implementers Forum**

[Export to ASAM OpenSCENARIO](#)

RoadRunner Scenario

R2022a

RoadRunner Scenario's simulation engine enables simulation with agents in multiple simulators

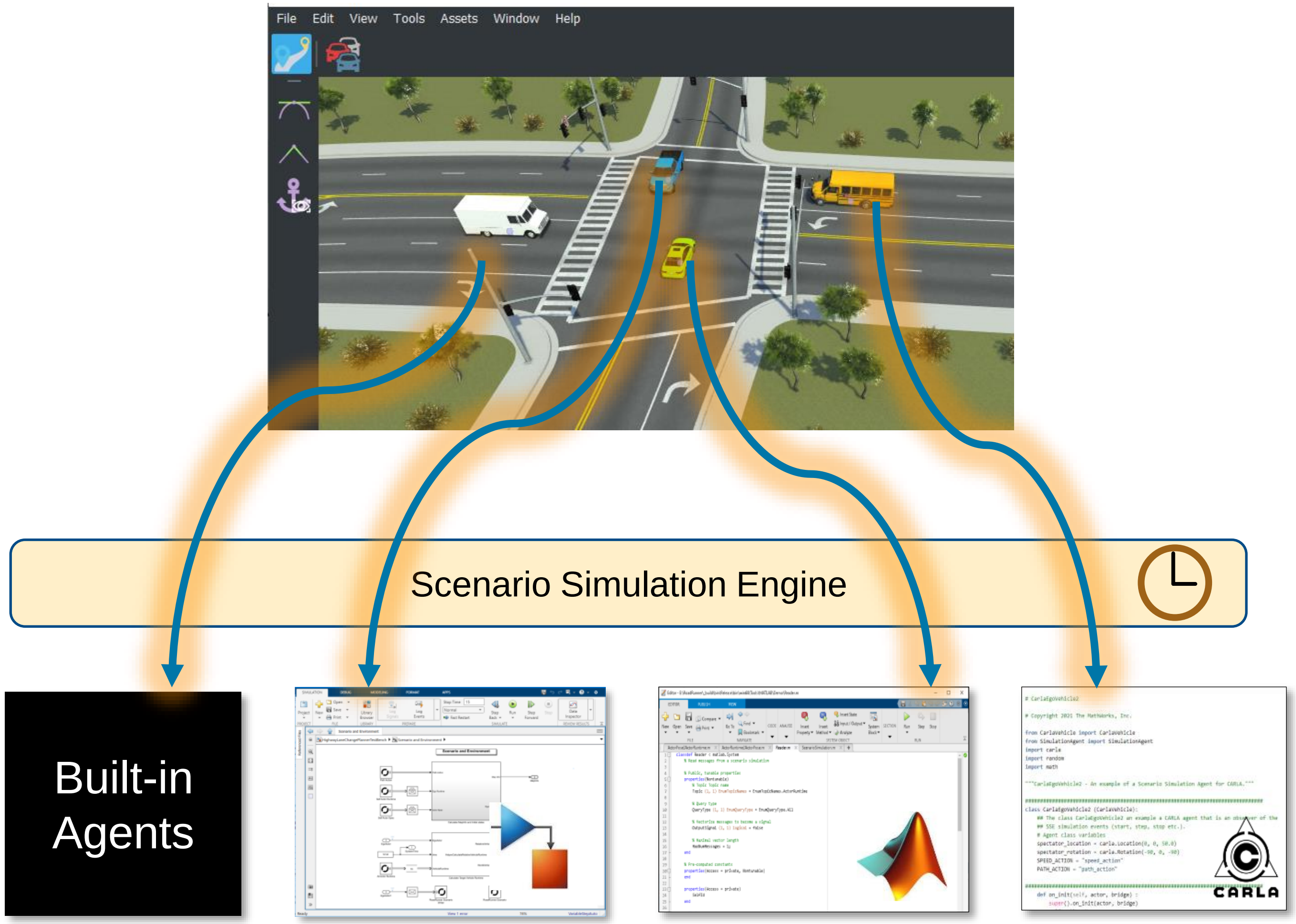
RoadRunner Scenario connects Agents in MATLAB, Simulink, and CARLA through a Scenario Simulation Engine (SSE)

Agents write scenario states

- Their pose and velocity for each scenario simulation step

Agents can read scenario states

- Action commands (path, speed, lane change, lateral offset)
- Pose and velocity of all actors in the scenario
- Dimensions of all actors
- Map lanes and lane boundaries

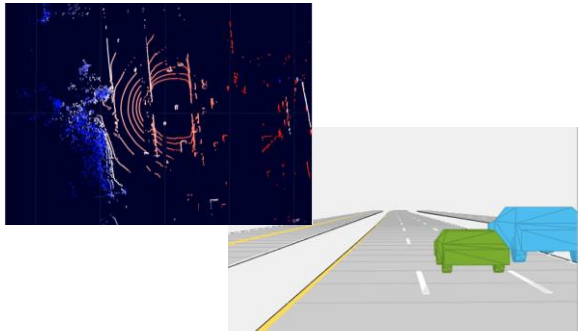


Today’s Agenda

ENVIRONMENT MODELLING

Create Virtual Scenes and Scenarios

Recreating real world for virtual simulation



VIRTUAL VALIDATION

Testing highway lane following application

Setting up Test Automation framework for

Design Scenes for Simulating Virtual Worlds

3D

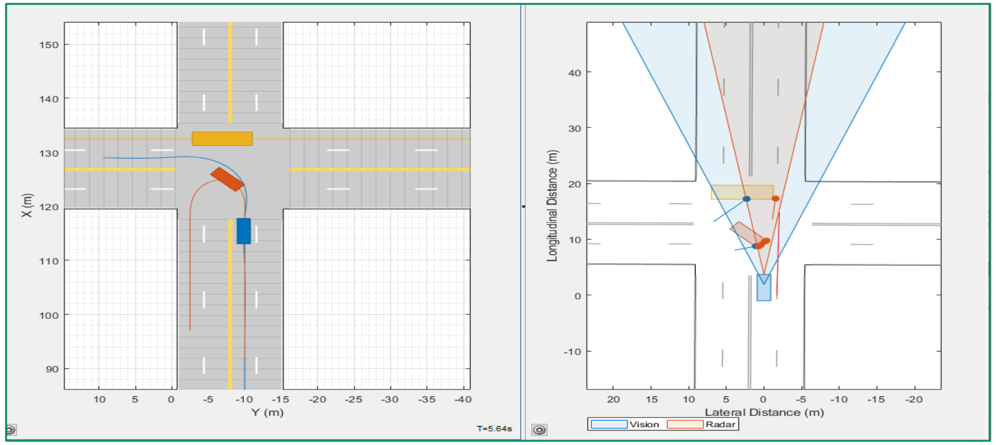
Use Case

- Controls, Sensor Fusion, Planning, *Perception*

Scene Authoring Tool

- RoadRunner

Cuboid



Use Case

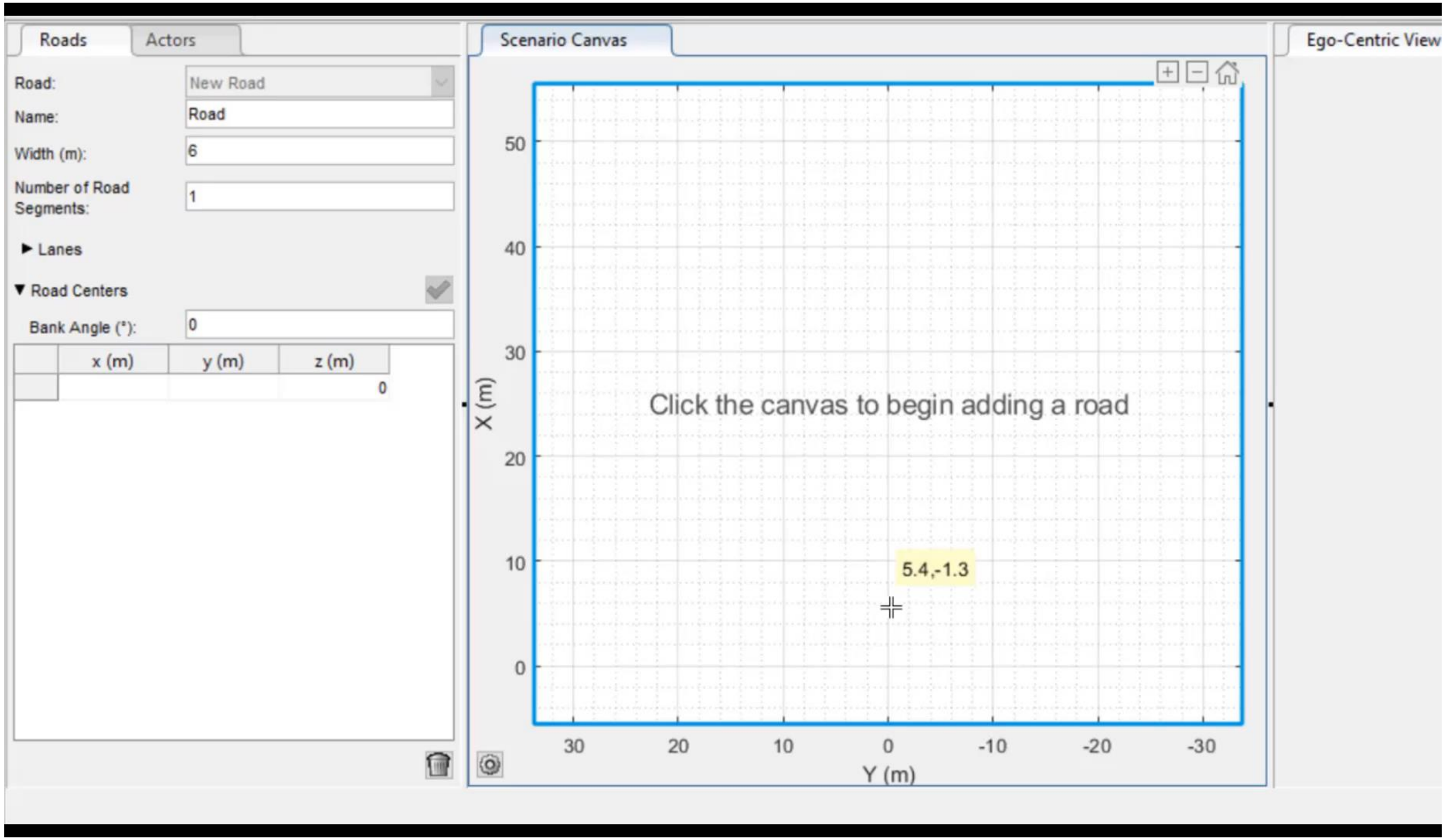
- Controls, Sensor Fusion, Planning

Scene Authoring Tools

- Driving Scenario Designer
- Programmatic API (drivingScenario)

Driving Scenario Designer and API (MATLAB)

1. Create a new driving scenario
   – Add roads, lanes, vehicles, trajectories, pedestrians, sensors
2. Generate synthetic detections
   – Bird’s eye plot
   – Run Scenario
   – Export scenario to MATLAB/Simulink



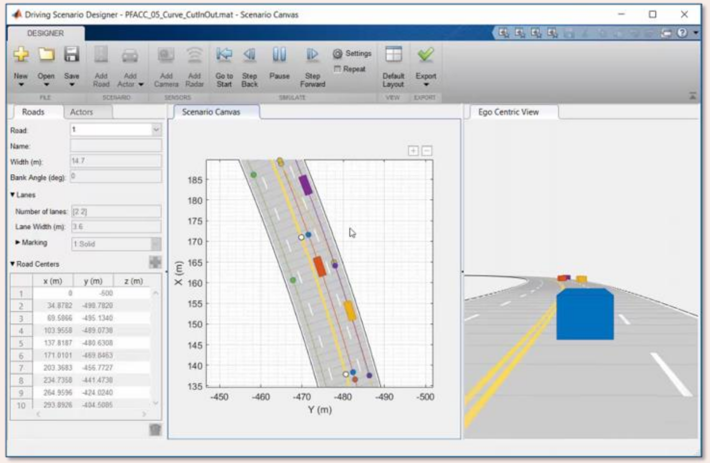
Design scenes and scenarios for automated driving

OpenDRIVE
OpenStreetMap
HERE HD Maps
Zenrin SD

Custom meshes

Design Driving Scenarios

Driving Scenario Designer App



Driving Scenario API

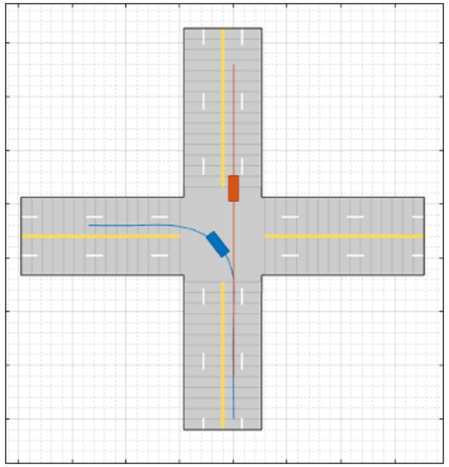
```
ds = drivingScenario();
```

Driving scenario
- Roads
- Lane markings
- Barriers & guardrails
- Vehicle trajectories

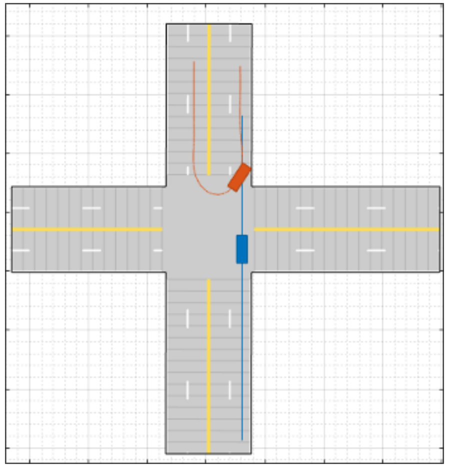
OpenDRIVE

OpenSCENARIO

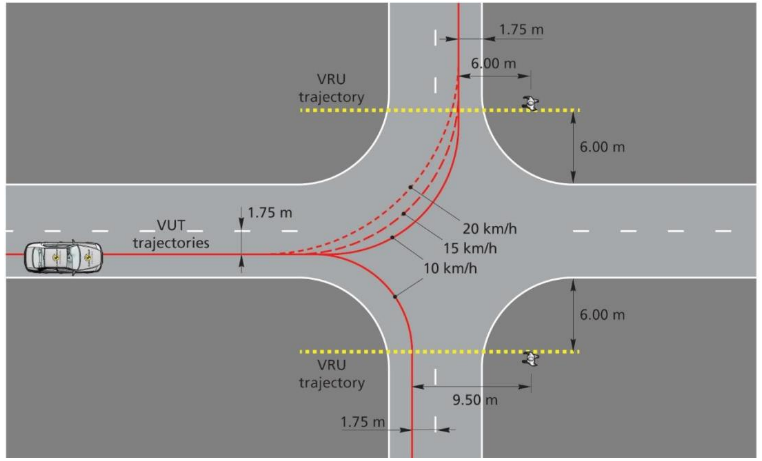
Pre-Build Scenarios Available



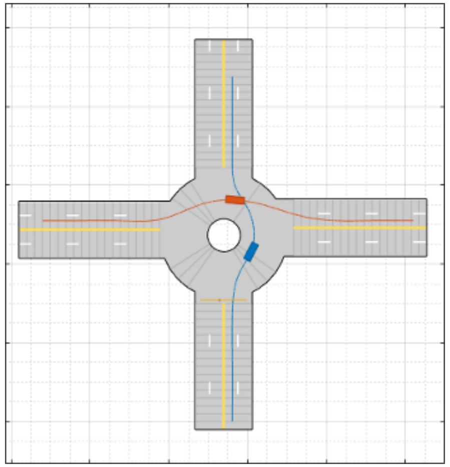
Turns



U-Turns



Euro NCAP



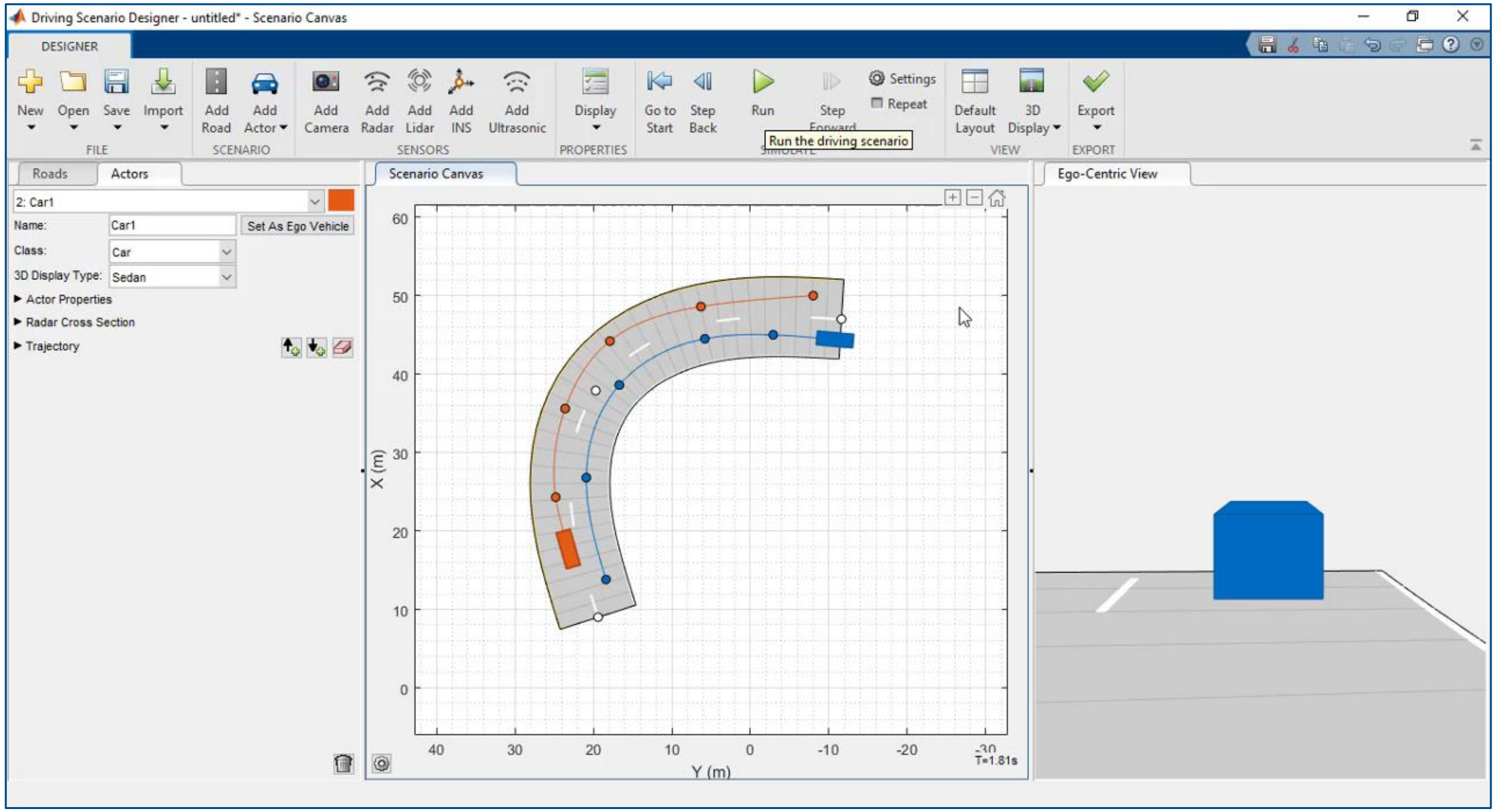
Intersections

Cuboid replicas of 3D simulation scenes

Migrate paths from Driving Scenario Designer (DSD) to RoadRunner Scenario

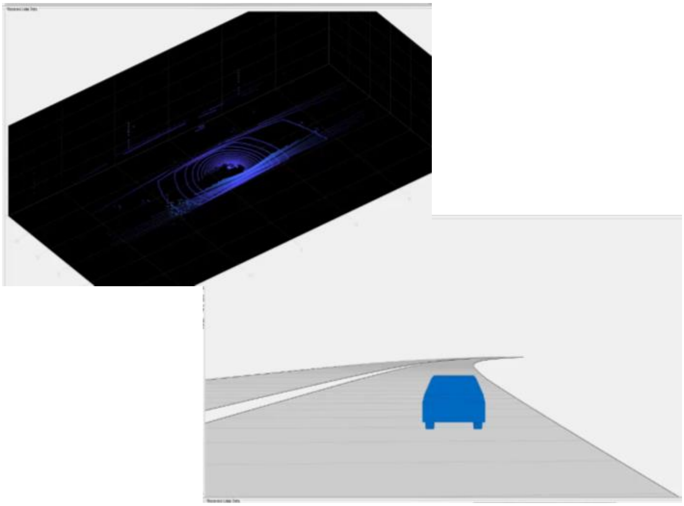
Introduction	Design trajectories in DSD	Export OpenSCENARIO from DSD	Import OpenSCENARIO to RoadRunner Scenario	Edit trajectories in RoadRunner Scenario

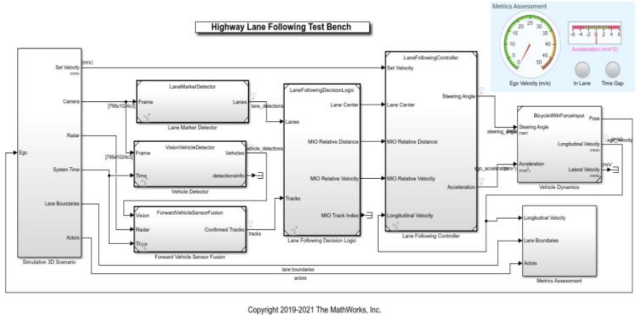
RoadRunner Scenario can import paths and initial velocities from OpenSCENARIO 1.0 files. You can leverage this to migrate paths designed in Driving Scenario Designer into RoadRunner Scenario.



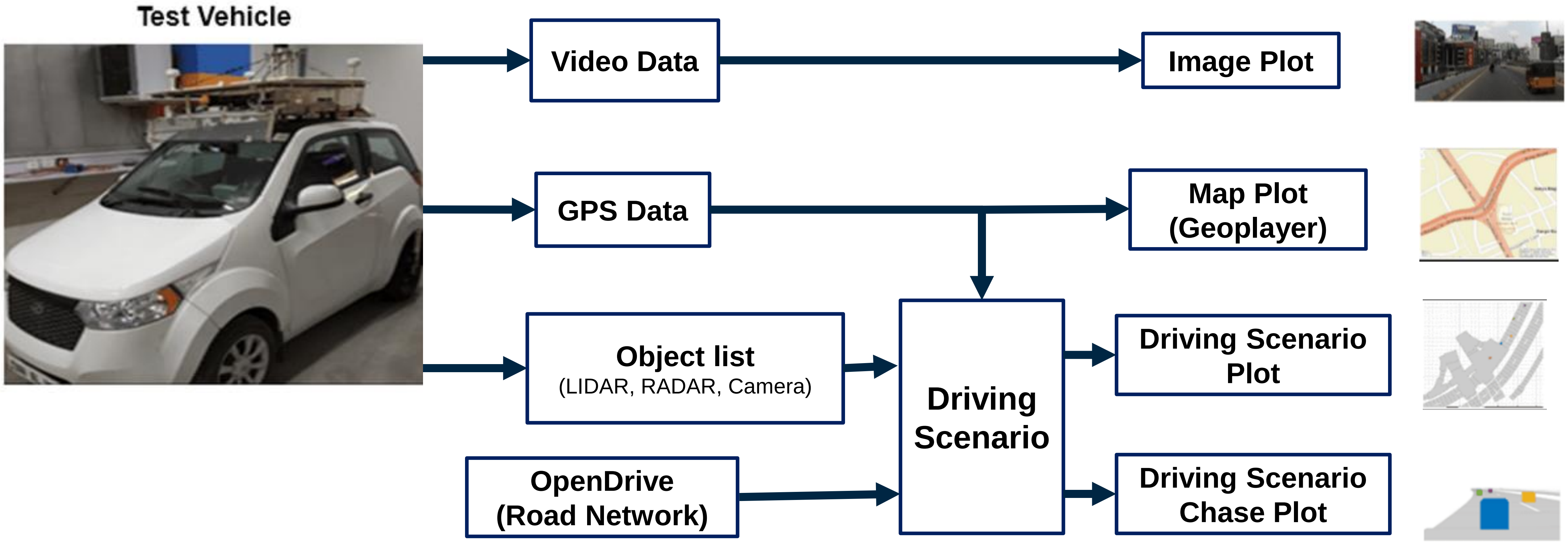
Simulating real world environment for virtual testing in ADAS

Vehicle sensor data collection → Recreating real world in simulation → Virtual testing for ADAS



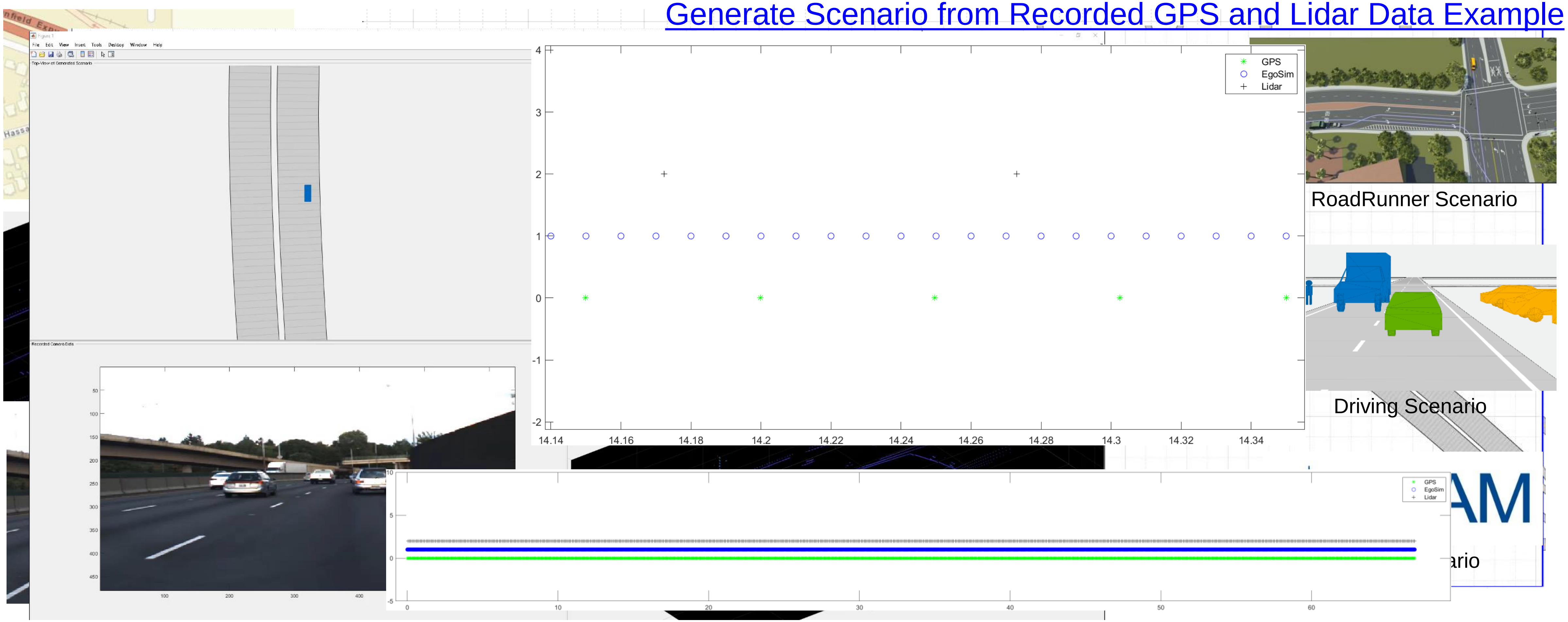


Creating scenario from real world sensor data



Creating scenario from real world sensor data

[Generate Lane Information from Recorded Data Example](#)
[Generate Scenario from Recorded GPS and Lidar Data Example](#)



Recorded time stamped data → **Sensor Data Preprocessing** → **Scene Creation (map import/ Create road network)** → **Localize Ego Trajectory** → **Reconstruct Non-Ego Actors** → **Synchronize Visualization** → **Save Scenario**

[Creating Driving Scenarios from Recorded Vehicle Data for Validating Lane Centering System in Highway Traffic](#)

SCENARIO VARIANT GENERATION- can generate many scenarios from the scenario

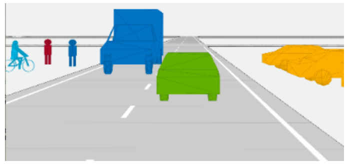
Recorded time stamped data

1 **Sensor to Scenario**

2 **Scenario Variants**

Generate Scenario

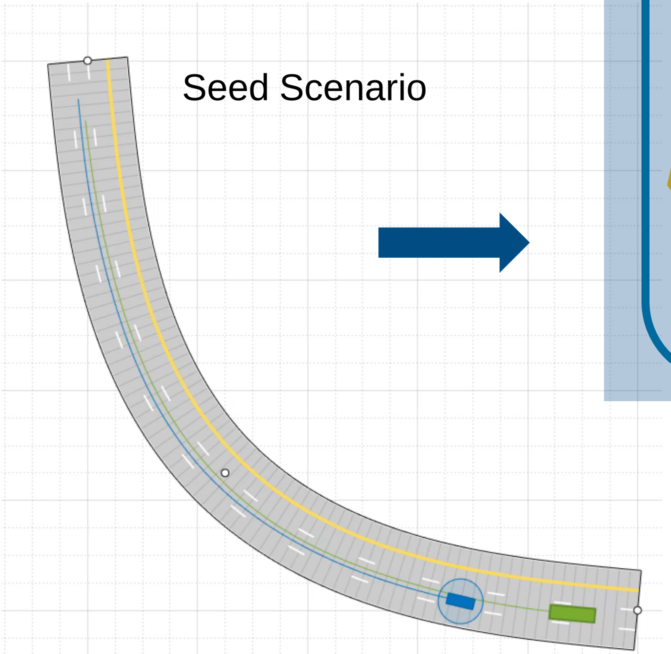
RoadRunner Scenario



DS Scenario

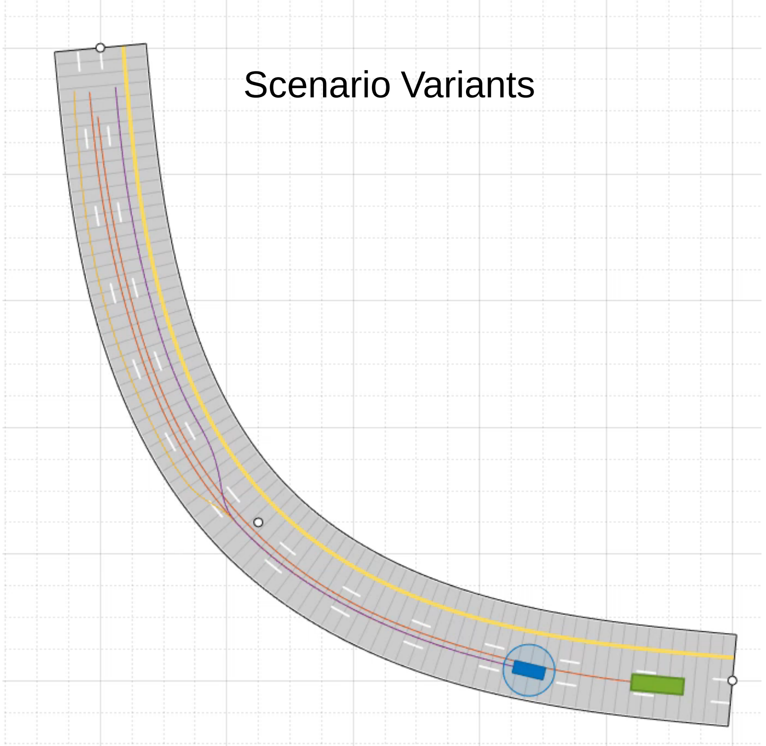
ASAM

Open Scenario



Seed Scenario

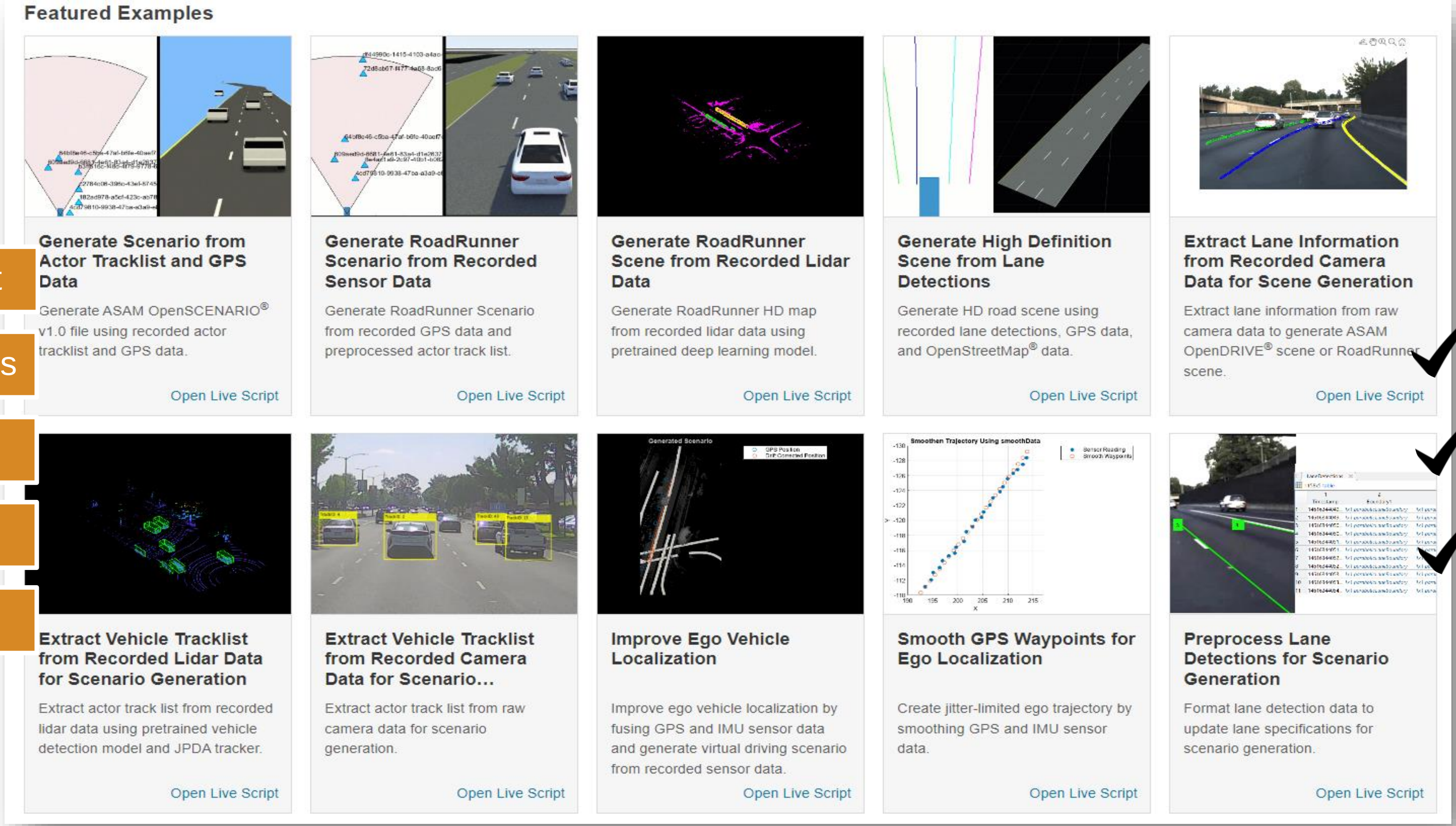
Generate Variants



Scenario Variants

Learn about generating scenes and scenarios from recorded sensor data

MathWorks R2022b



- ✓ Actor Tracklist
- ✓ Lane Detections
- ✓ GPS, IMU
- ✓ Camera
- ✓ Lidar

- ✓ ASAM OpenDRIVE & OpenSCENARIO
- ✓ RoadRunner Scene & Scenario
- ✓ drivingScenario

[Scenario Builder support package]

Automated Driving Toolbox

Parameters fueling scenario variant generation

https://wiki.unece.org/download/attachments/78741915/VMAD-02-05%20Japan.pptx

- Actor Parameters
  - Speed, waypoint, yaw
  - Actor dimension and type
  - Other properties
  - Driving behavior

    Aggressive / Safe
- Event Parameters
  - Collision
  - Driving manoeuvres

    Lead, Follow, Lane keep, Lane change, Overtake, Merge, Exit
  - Road object interaction
- Scene Parameters
  - Road Network

    Lane marking
  - Roadside details
  - Traffic density
  - Lighting or Weather
  - Sensor coverage

EURO NCAP – Parameter table

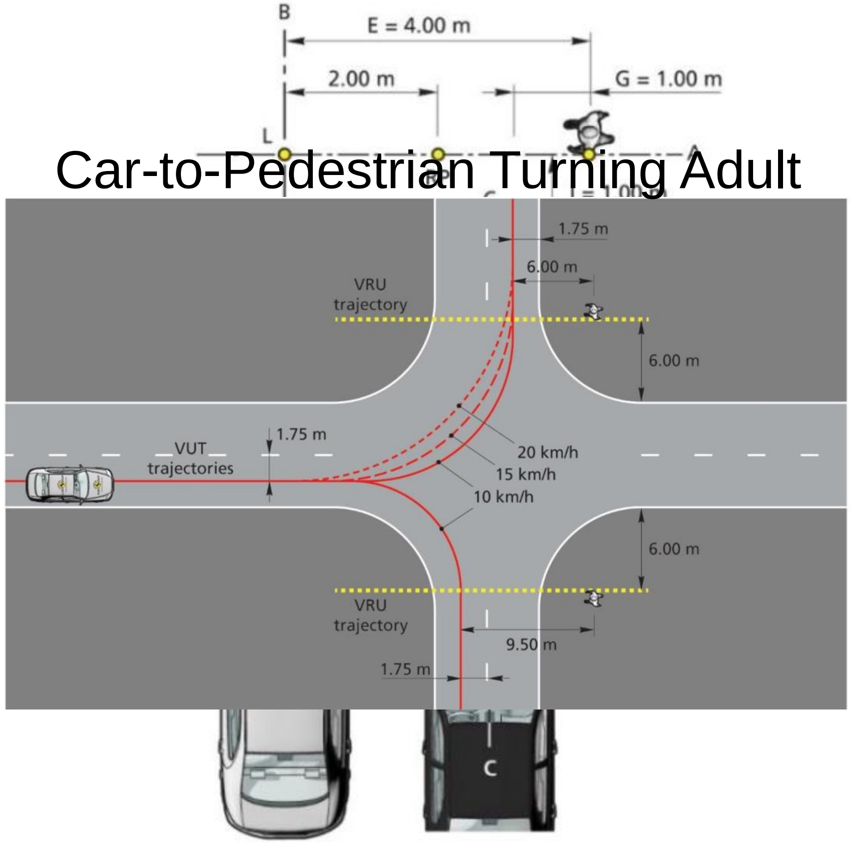
Simulation is becoming important for homologation

AEB Pedestrian	CPFA	CPNA	CPNC	CPTA		CPRA		CPLA	
Type of test		AEB		AEB		AEB		AEB	FCW
VUT speed [km/h]		10-60		10,15,20	10	4,8		20-60	50-80
VUT direction		Forward		Farside turn	Nearside turn	Rearward		Forward	Forward
Target speed [km/h]	8	5		5		0	5	5	5
Impact location [%]	50	25,75	50	50		25,50,75	50	50	25
Lighting condition	Day	Day/Night	Day	Day		Day		Day/Night	
Vehicle lights (night)		Low beam						High beam	
Streetlights (night)		Streetlights						No streetlights	

AEB Bicyclist	CBNA		CBFA	CBLA	
Type of test	AEB		AEB	AEB	FCW
VUT speed [km/h]	10-60		10-60	25-60	50-80
VUT direction	Forward		Forward	Forward	Forward
Obstruction	No	Yes	No	No	No
Target speed [km/h]	15	10	20	15	20
Impact location [%]	50		50	50	25
Lighting condition	Day		Day	Day	

Car-to-Pedestrian Nearside Child

Car-to-Pedestrian Turning Adult



https://www.daimler.com/documents/innovation/other/safety-first-for-automated-driving.pdf

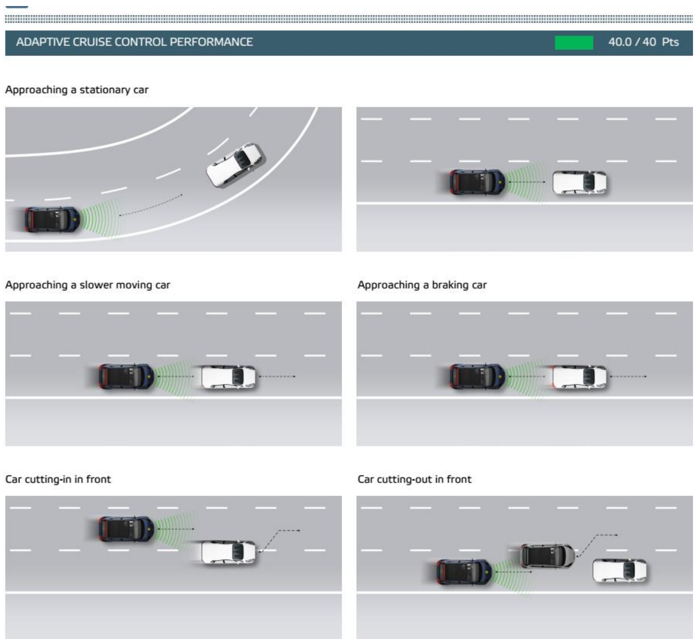
https://cdn.euroncap.com/media/62795/euro-ncap-aeb-vru-test-protocol-v304.pdf

Scenario Variants support many AD Workflows

	Variation parameters ->	Actor					Event				Scene			Perception		
Test Scenario Categories	Workflow | V	Speed	Dimension	Waypoint	Acceleration /breaking	Driving behavior	Collision	Driving maneuvers	Rerouting	Translocate	Road	Roadside Articles	Count of actors	Lighting	Weather	Sensor types
Crash	Adaptive Cruise Control	✓	✓	✓	✓		✓				✓					✓
	AEB test on straight roads	✓	✓		✓		✓				✓	✓		✓		
	AEB test on turns	✓	✓	✓	✓		✓				✓	✓		✓		
Other ADAS	Lane Keep Assist	✓		✓							✓					
	Lane change, Overtaking	✓		✓				✓	✓		✓					
	Traffic Jam Assist	✓	✓	✓		✓	✓	✓	✓		✓		✓			
	Parking helper L1/L2	✓	✓	✓												✓
Sensor	Sensor coverage	✓	✓	✓	✓			✓	✓	✓	✓		✓		✓	✓
	Object detection	✓	✓	✓	✓			✓				✓	✓		✓	✓
	V2X test	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓		✓	✓
AD stack	Urban, rural, highway	✓		✓	✓	✓	✓	✓			✓	✓		✓	✓	
	Auto parking valet	✓	✓	✓												✓
	Increase traffic density	✓	✓	✓		✓		✓	✓				✓			
	Complete self driving	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

Euro NCAP driven Portfolio to test scenarios for

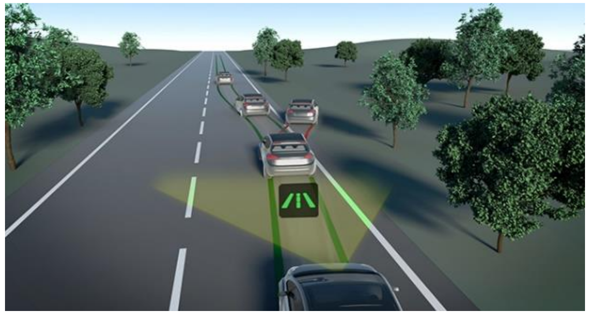
ACC

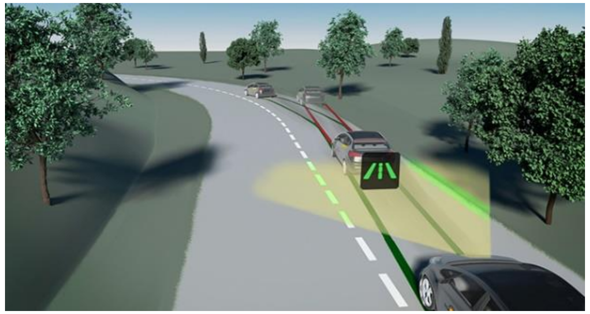


Variant parameters for testing ACC

- Ego speed
- Non-ego Trajectory (cut-in)
- Road Variation

LKA

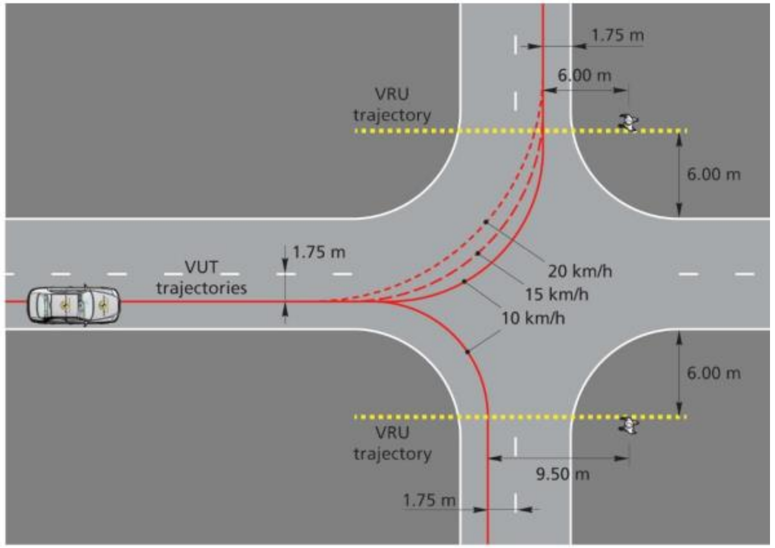




Variant parameters for testing LKA

- Ego speed
- Target Trajectory
- Road Variation

AEB

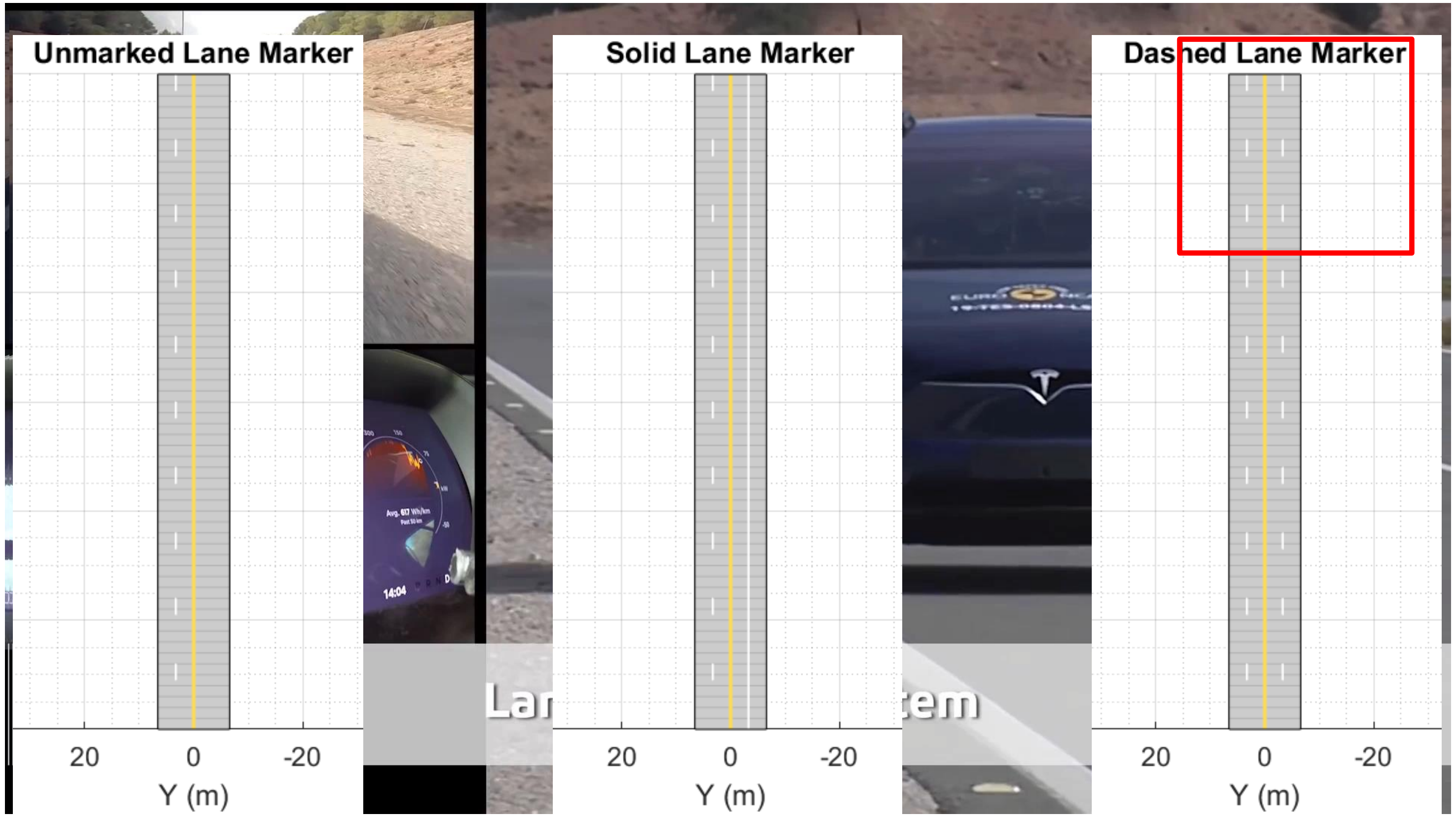


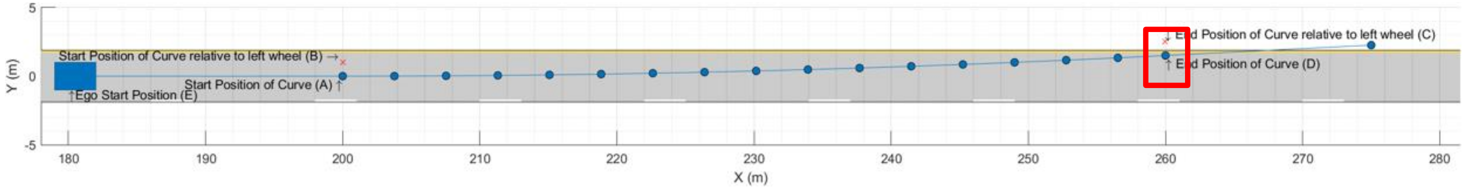
Variant parameters for testing AEB

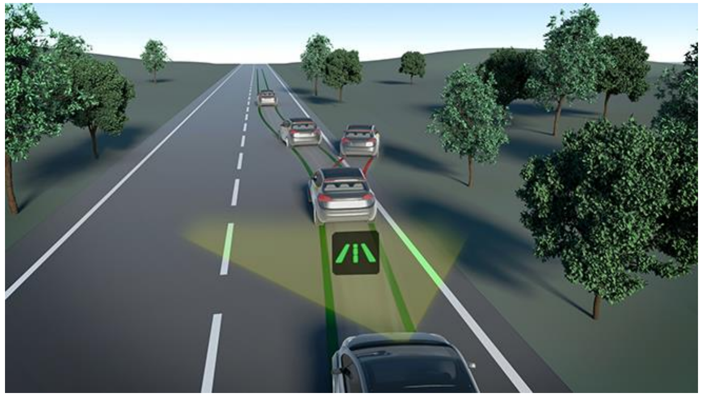
- Ego speed variation
- Ego trajectory variation on turns
- Actor dimension variation
- Impact location variation

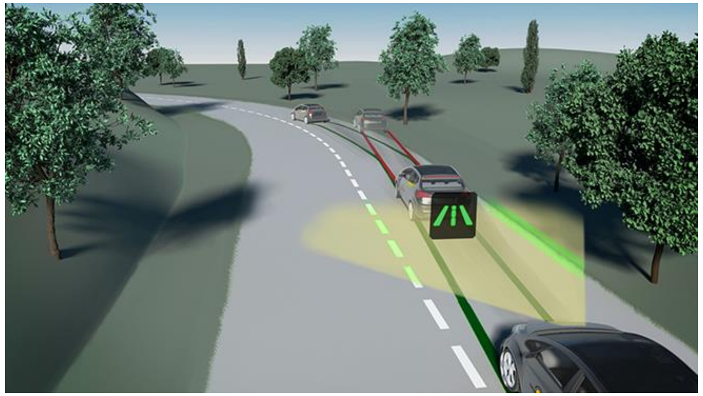
Source:

Test scenario variant generation for LKA









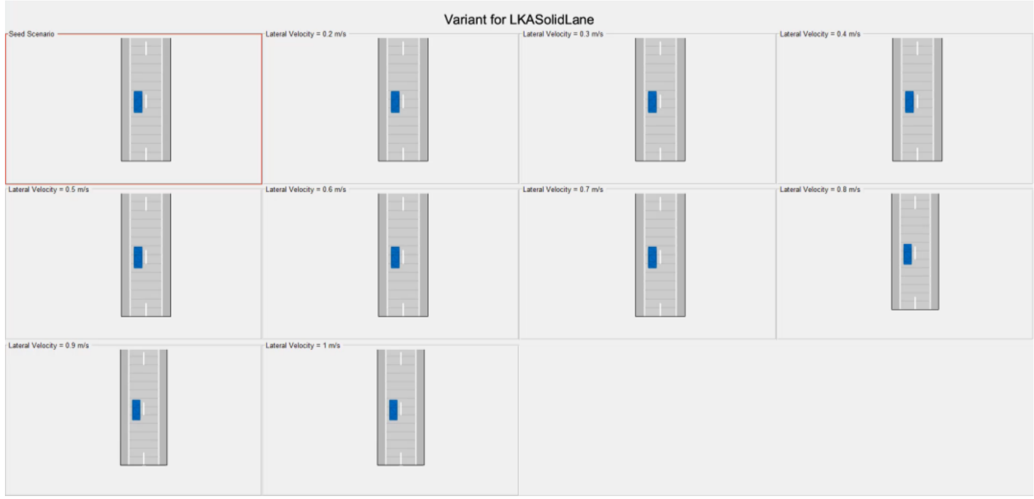
Parameters for LKA Variants

- Ego speed
- Road Variation

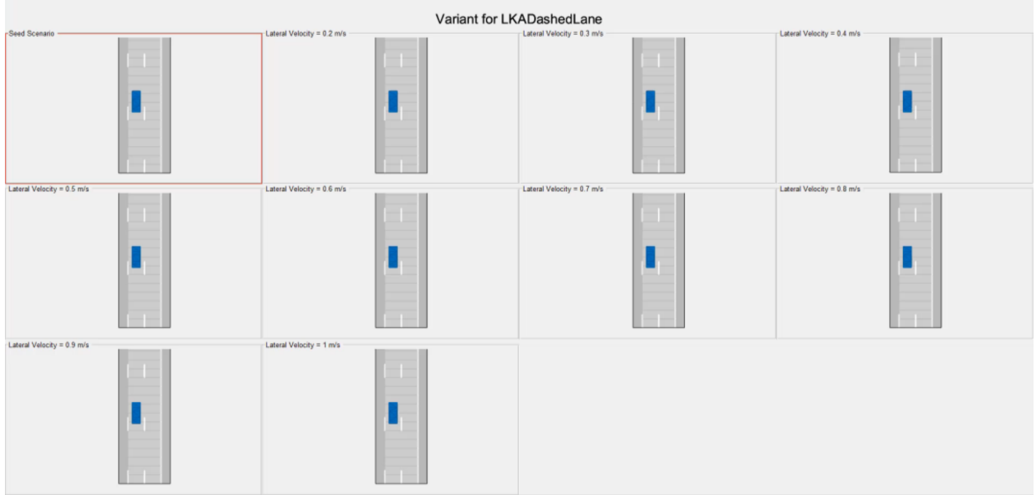
Lane-support

Test scenario variant for Lane Keep Assist Testing (LKA)

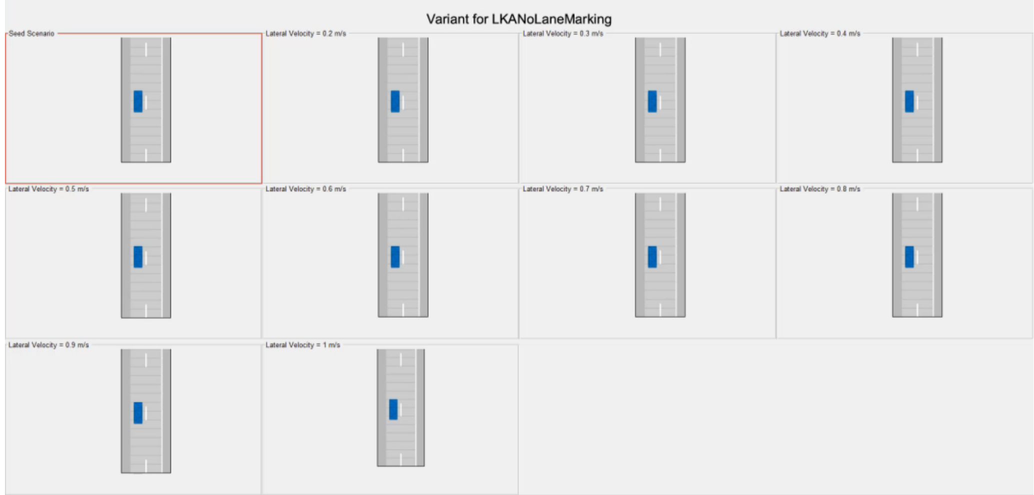
R2022b



LKASolidLane



LKADashedLane

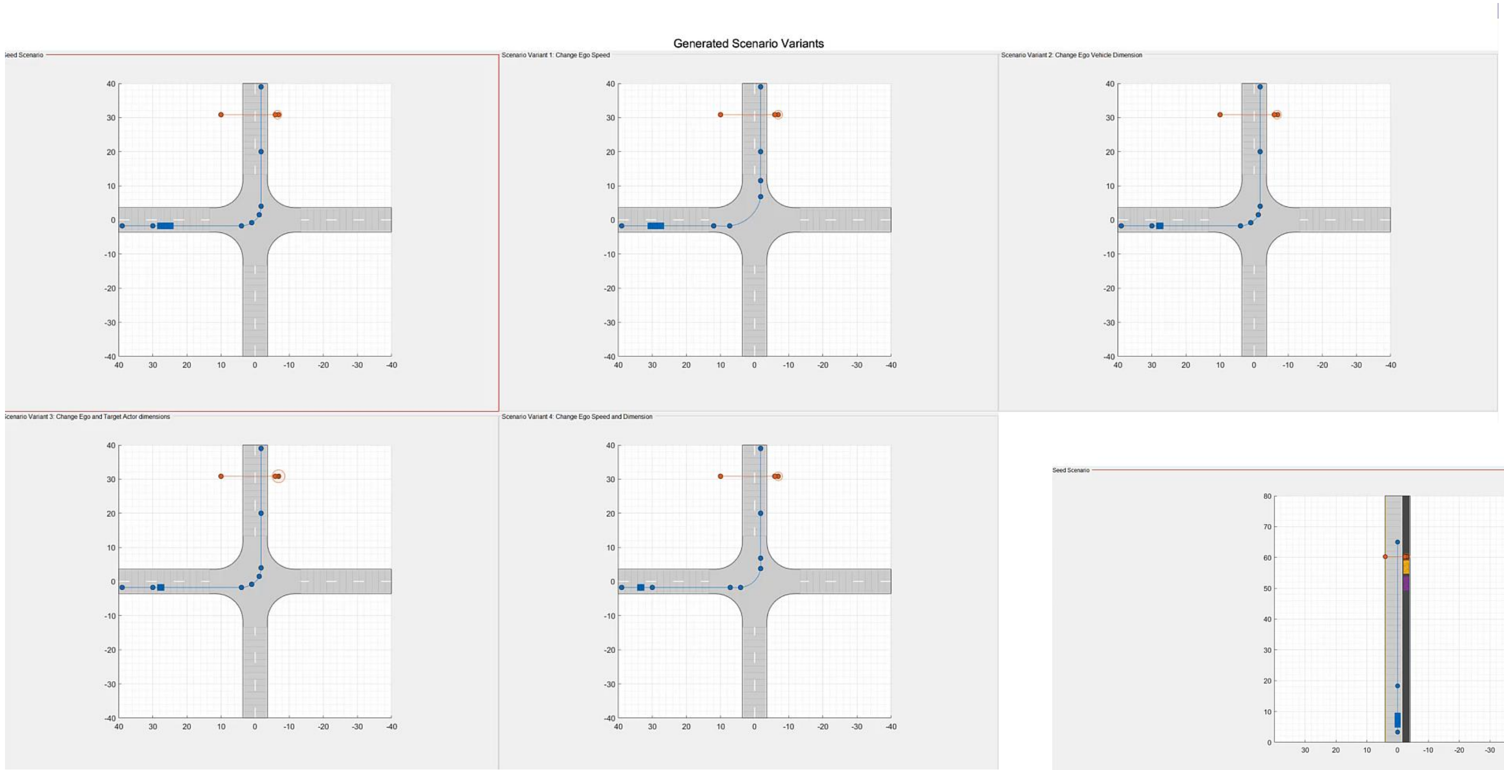


LKANoLaneMarking

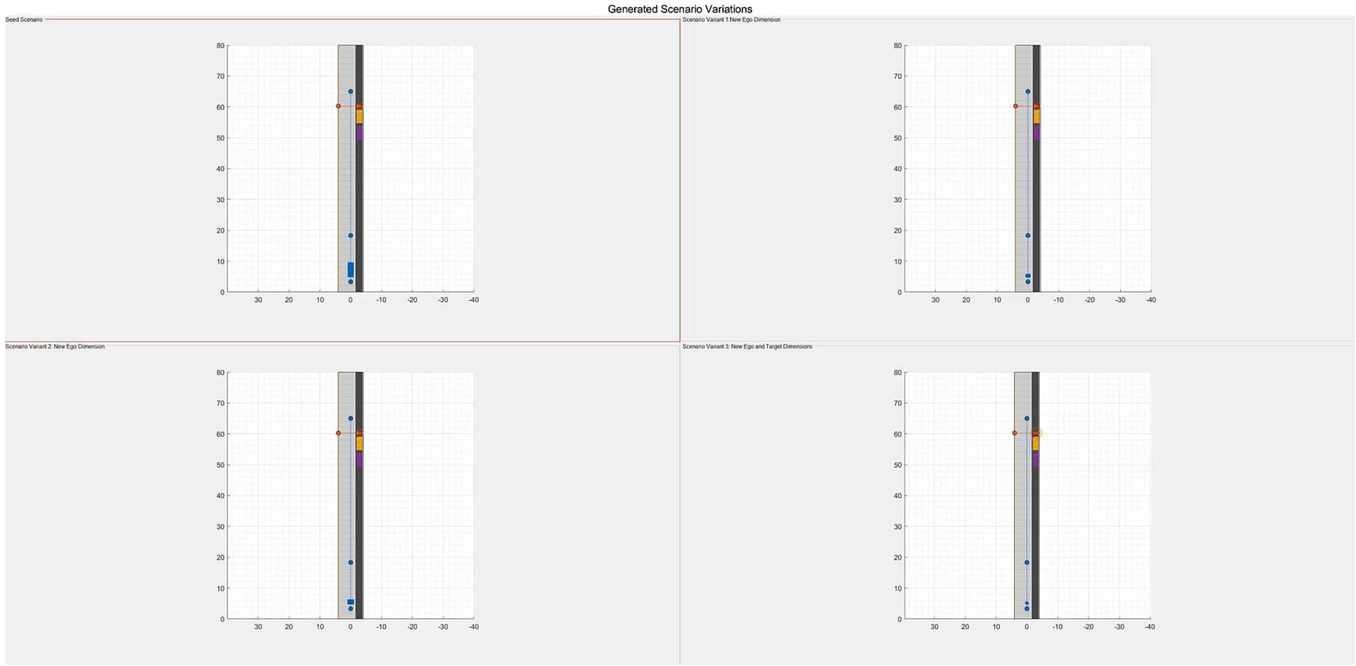
[Generate Scenario Variants for Lane Keep Assist Testing]

Test scenario variant for AEB and dimension variation

R2022b



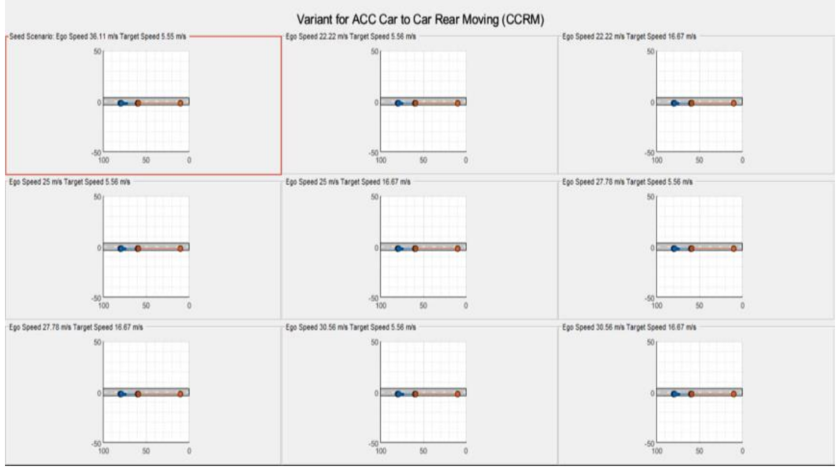
Generate Scenario Variants for Testing AEB Pedestrian Systems



Generate Scenario Variants by Modifying Actor Dimensions

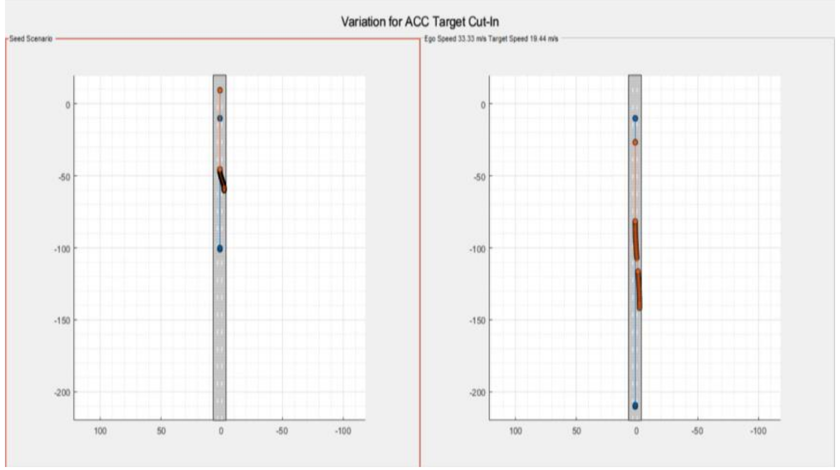
Test scenario variant for Adaptive Cruise Control (ACC)

Car-to-car rear stationary (CCRs)



Car-to-car rear moving (CCRm)

[Generate Scenario Variants for Testing ACC Systems]



[Generate Variants of ACC Target Cut-In Scenario]

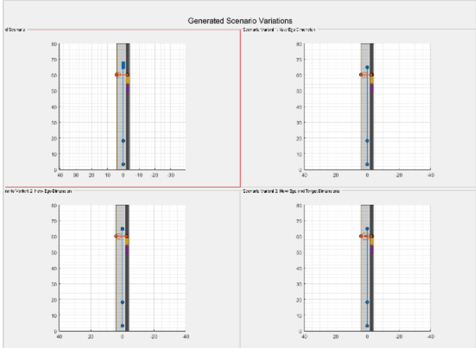
Scenario Variation Generation

Scenario Variant Generator for Automated Driving Toolbox

by MathWorks Automated Driving Toolbox Team STAFF

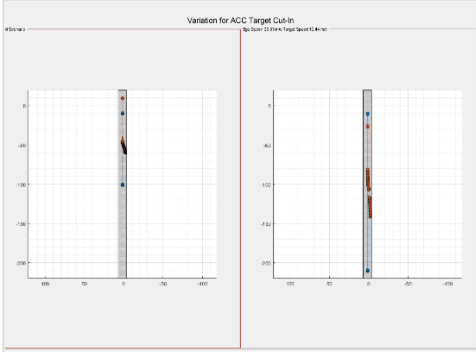
Generate multiple variants from a seed scenario that is either manually created or generated from recorded sensor data

- Read the seed scenario and extract its parameters
- Modify static/dynamic parameters of the seed scenario
- Generate variant scenarios



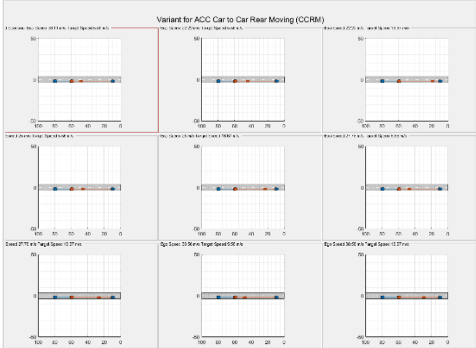
Generate Scenario Variants by Modifying Actor Dimensions

Generate scenario variants from seed scenario by modifying actor dimensions.



Generate Variants of ACC Target Cut-In Scenario

Generate scenario variants to test adaptive cruise control (ACC) application using European New Car Assessment Programme (Euro

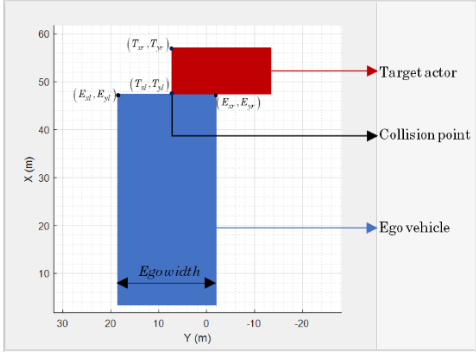


Generate Scenario Variants for Testing ACC Systems

Modify speeds of the ego and target vehicles to generate scenario variants for testing adaptive cruise control (ACC) application using

Generate Scenario Variants for Lane Keep Assist Testing

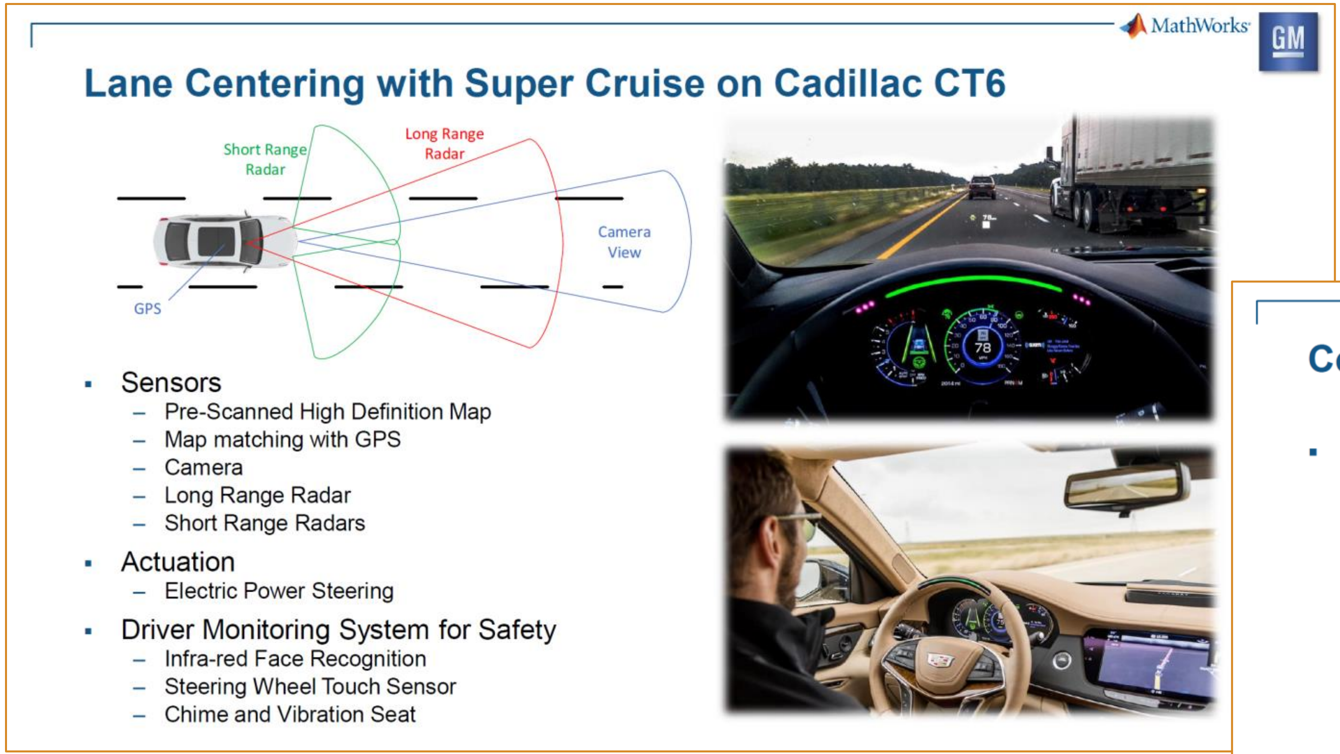
Generate scenario variants to test lane keep assist (LKA) system using European New Car Assessment Programme (Euro NCAP) test

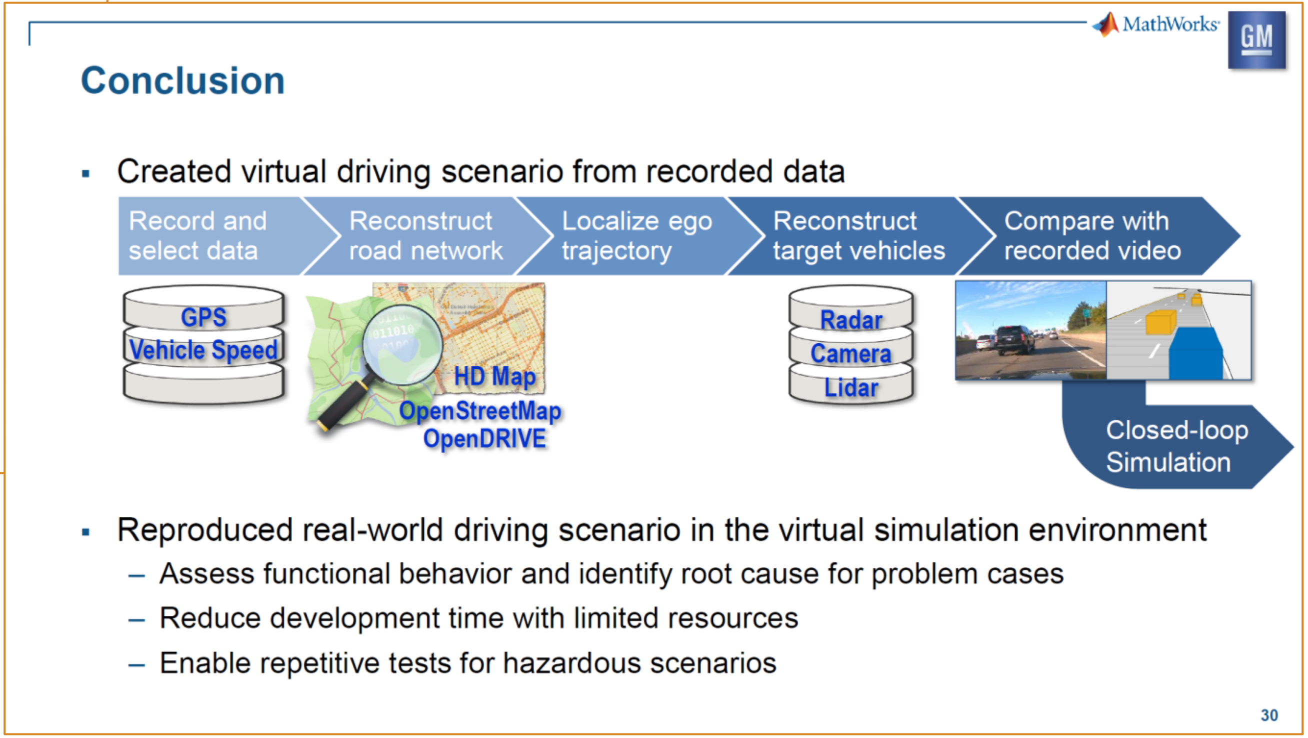


Generate Scenario Variants for Testing AEB Pedestrian Systems

Generate scenario variants to test automated emergency braking (AEB) system using car-to-pedestrian European New Car Assessment

GM synthesizes scenarios from recorded data to validate lane centering system





[MathWorks Automotive Conference 2020 video & slides]()

SAE Paper 2020-01-0718: Creating Driving Scenarios from Recorded Vehicle Data for Validating Lane Centering System in Highway Traffic

Today’s Agenda

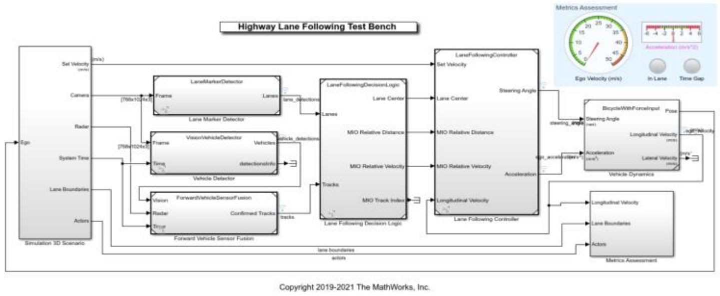
ENVIRONMENT MODELLING

Create Virtual Scenes and Scenarios

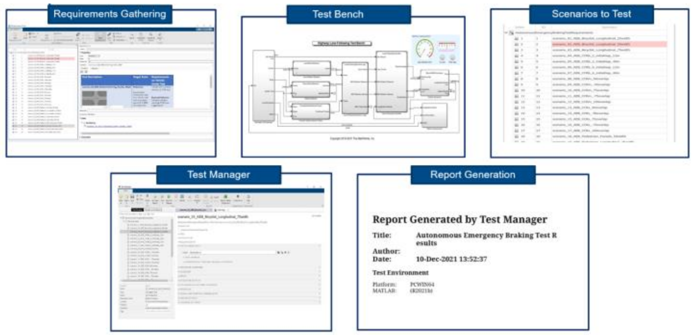
Recreating real world for virtual simulation

VIRTUAL VALIDATION

Testing highway lane following application



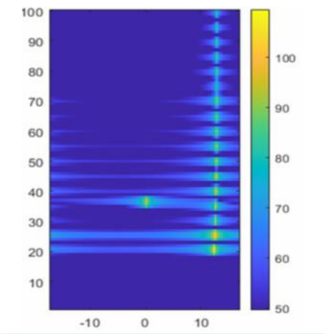
Setting up Test Automation framework for



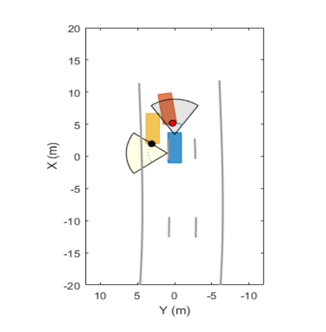
Simulate sensors for automated driving applications

Cuboid Sensors

Radar IQ Signals

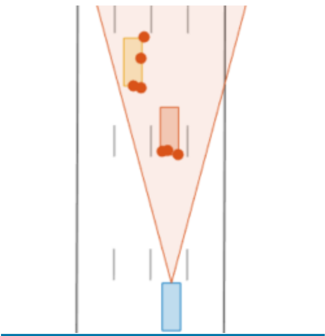


Ultrasonic Detections

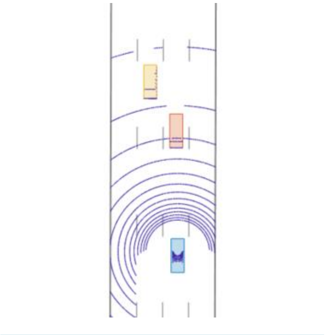


Cuboid & Unreal Engine

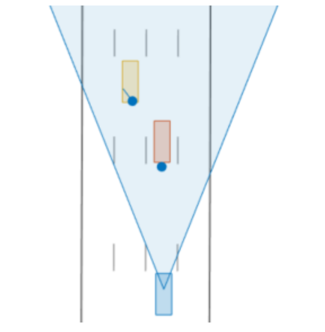
Radar Detections



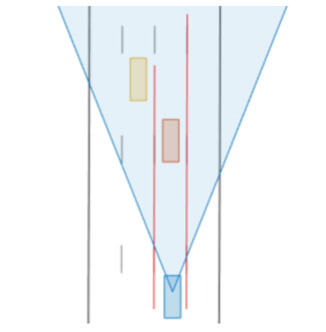
Lidar



Vision Detections



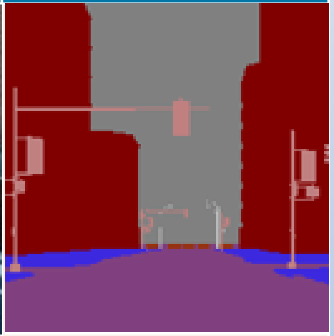
Lane Detections



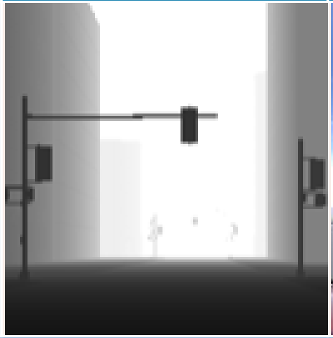
Unreal Engine Sensors

Monocular Camera

Semantic Segmentation



Depth



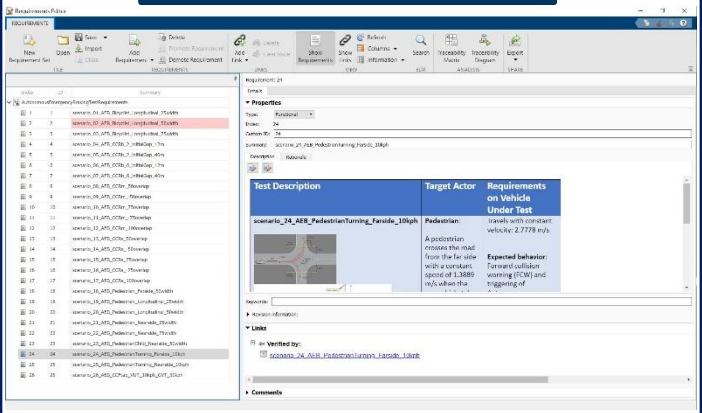
Fisheye Camera

Positional Sensors

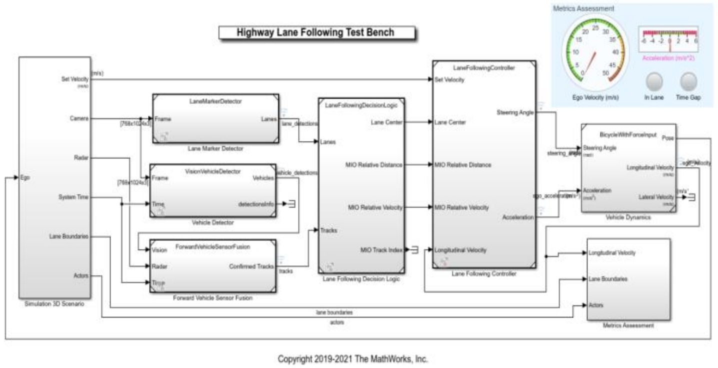
- Wheel Encoder
- Global Positioning System (GPS)
- Inertial Measurement Unit (IMU)
- Inertial Navigation System (INS)

Virtual Validation

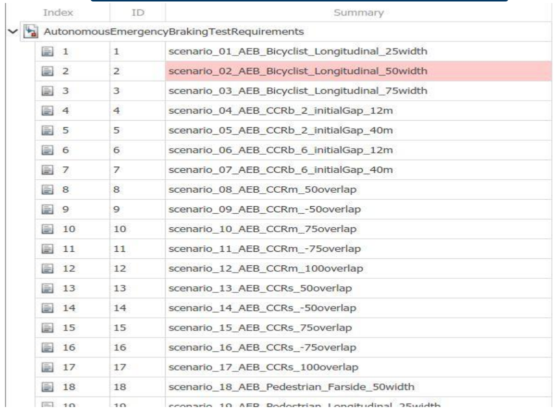
Requirements Gathering



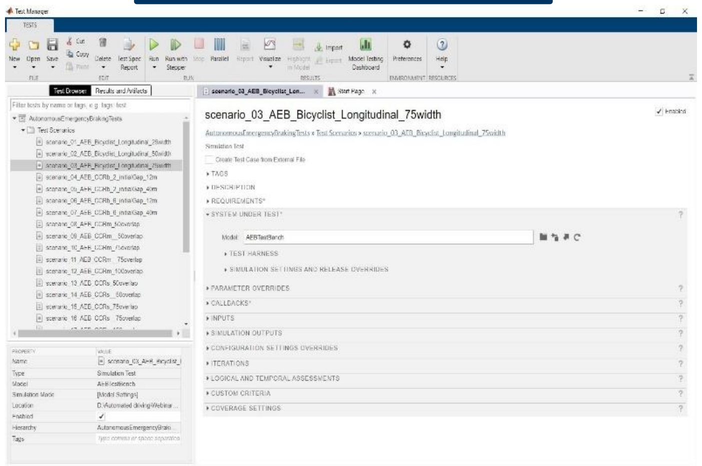
Test Bench



Scenarios to Test



Test Manager



Report Generation

Report Generated by Test Manager

Title: Autonomous Emergency Braking Test Results

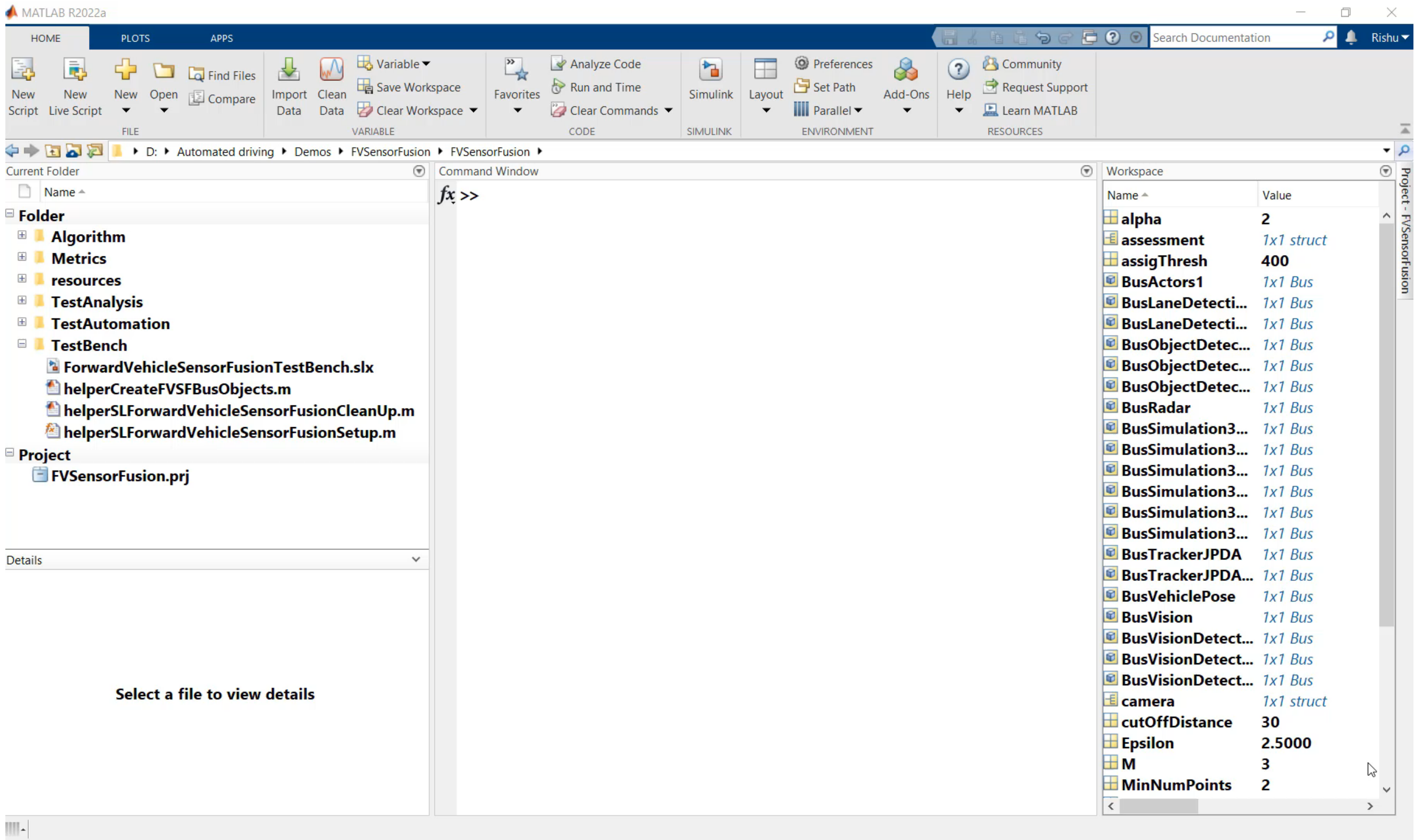
Author:

Date: 10-Dec-2021 13:52:37

Test Environment

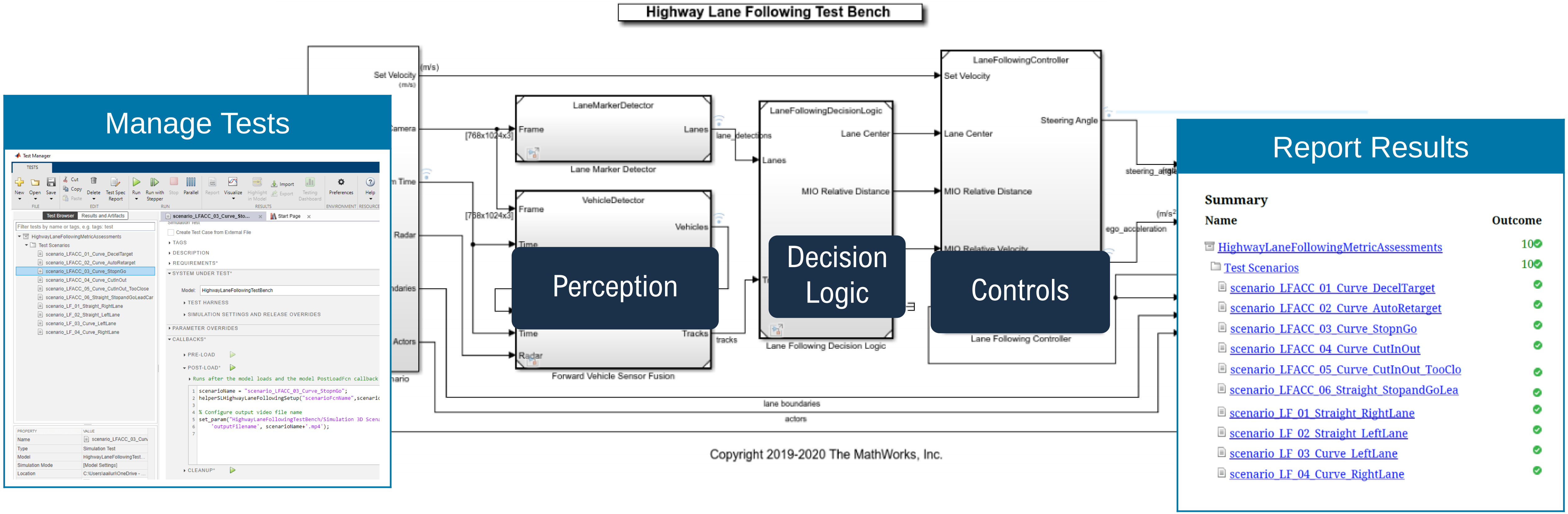
Platform: PCWIN64
MATLAB: (R2021b)

Sensor fusion algorithm test bench for **Open Loop Testing**

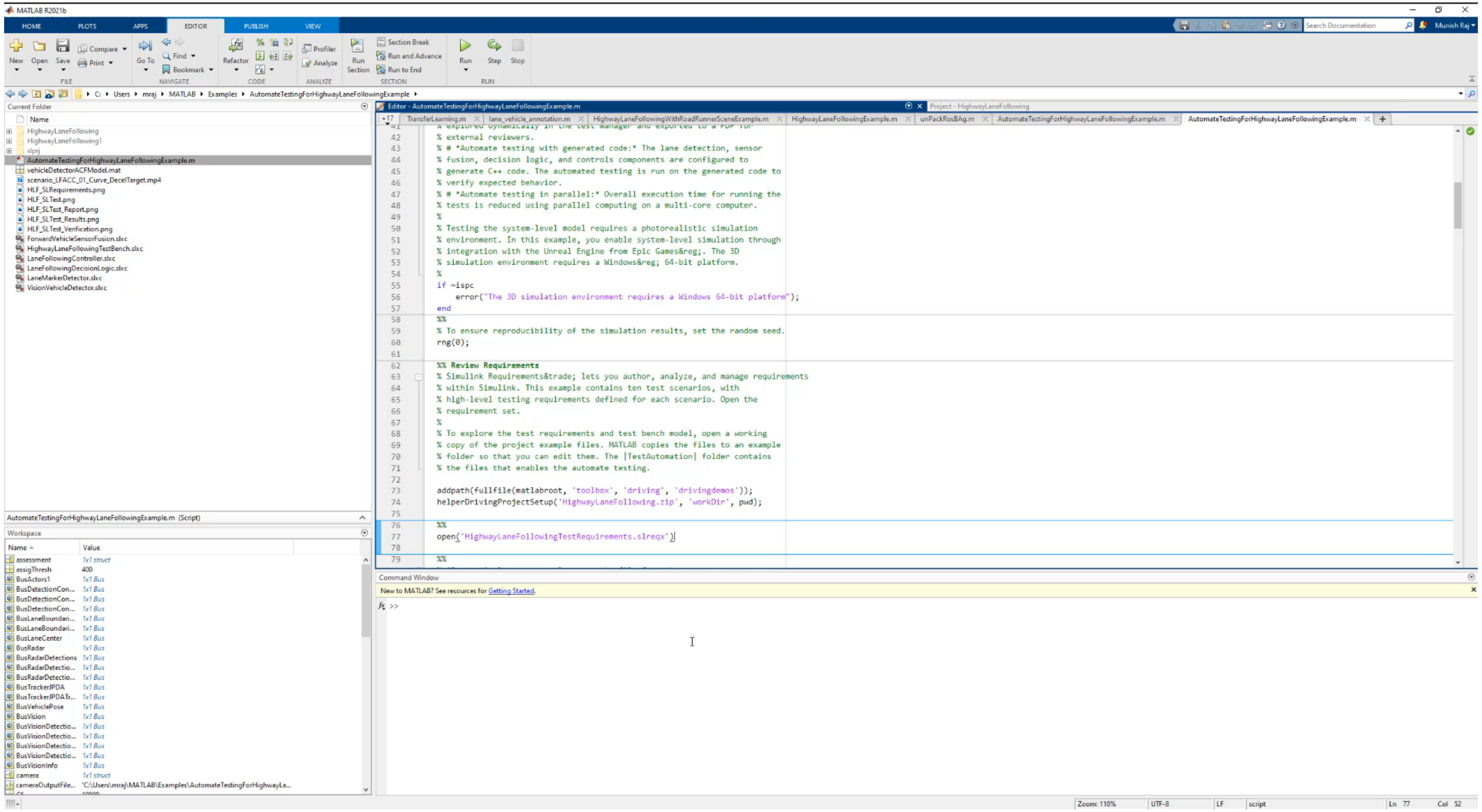


AEB with sensor fusion test bench- **Closed loop testing**

Reference Examples



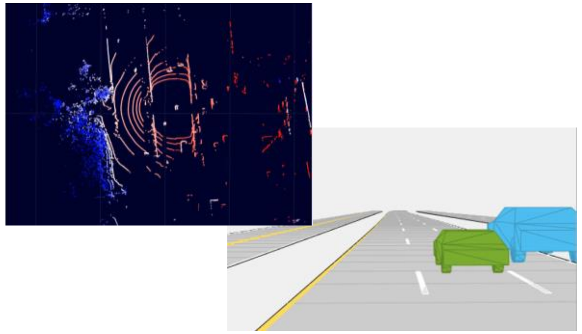
Automate testing for the closed loop AEB testbench



ENVIRONMENT MODELLING

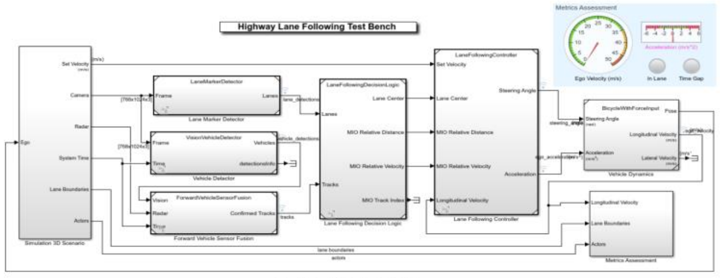
Create Virtual Scenes and Scenarios

Recreating real world for virtual simulation

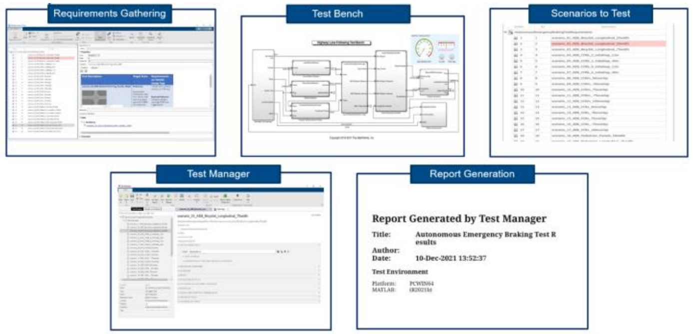


VIRTUAL VALIDATION

Open/ Closed loop testing



Test Automation for AD/ADAS



Call to Action

- Visit us at our demo booth, outside the seminar hall
- Let us know the challenges you face in your AD/ADAS workflow
- MathWorks would be happy to collaborate with you for developing your AD/ADAS workflow

MathWorks®

Accelerating the pace of engineering and science

For further details, Q&A and feedback kindly reach out to

Munish Raj
Email id: mraj@mathworks.com
LinkedIn

Dr Rishu Gupta
Email id: rishug@mathworks.com
LinkedIn

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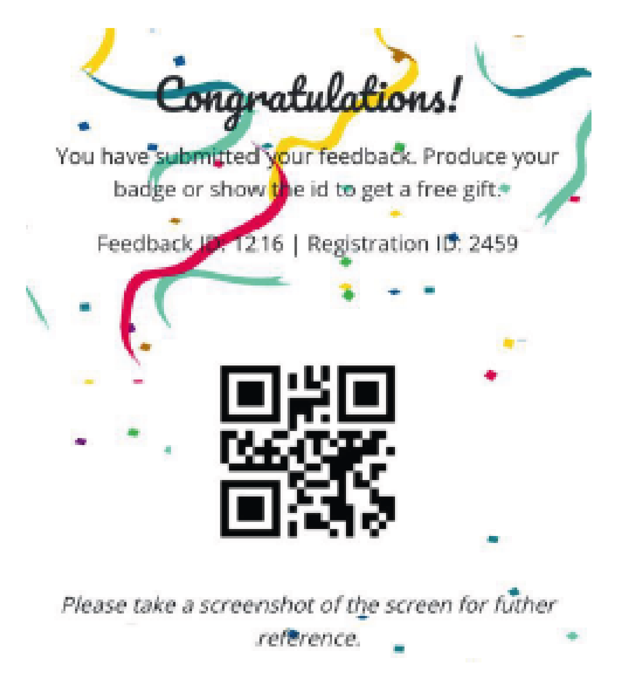
MathWorks

Please provide your Feedback for this Session.
You will also receive a Feedback Link via SMS on your registered Mobile Number

https://tinyurl.com/ypr9z7rx



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