

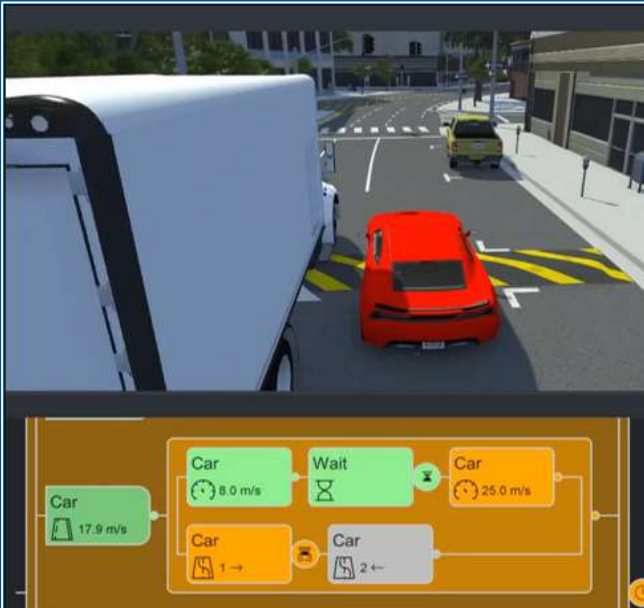
MathWorks
**AUTOMOTIVE
CONFERENCE 2024**
Korea

ADAS 자율주행을 위한 RoadRunner Test Case 자동 생성

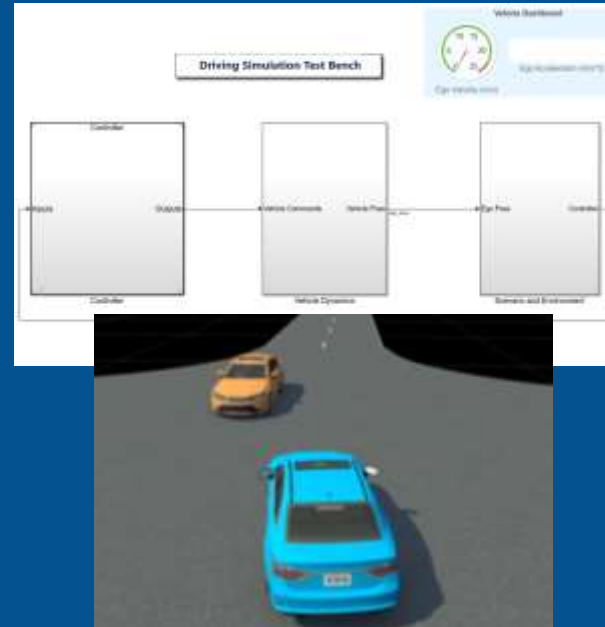
김종헌 프로, 매스웍스코리아



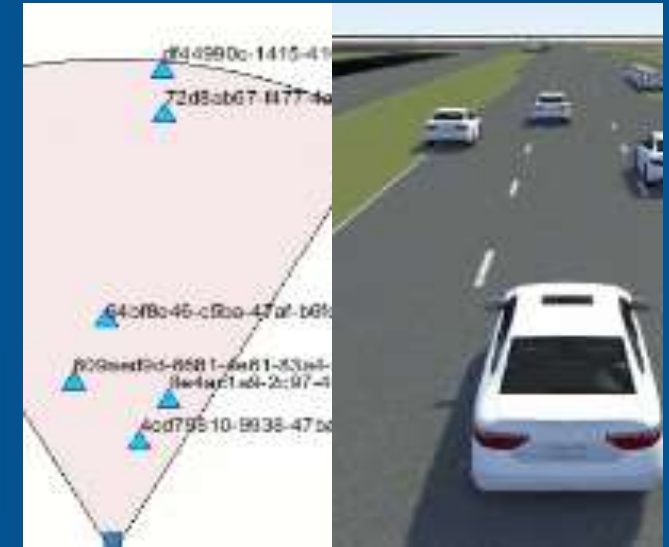
Develop automated driving scenarios with MATLAB, Simulink, and RoadRunner



Design
scenes & scenarios

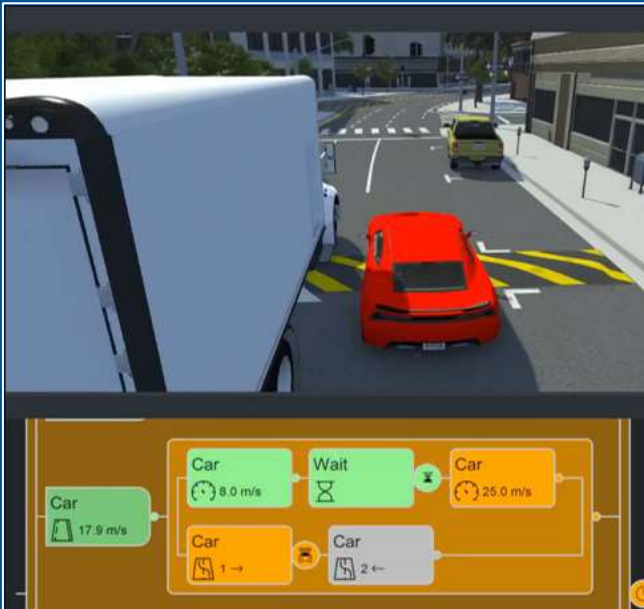


Simulate
driving applications



Build
scenarios

Develop automated driving scenarios with MATLAB, Simulink, and RoadRunner



Design
scenes & scenarios



Simulate
driving applications



Build
scenarios

Design Scenes using RoadRunner



- Makes driving environment modeling easier than the editors of game engines
- Export to common driving simulation environments

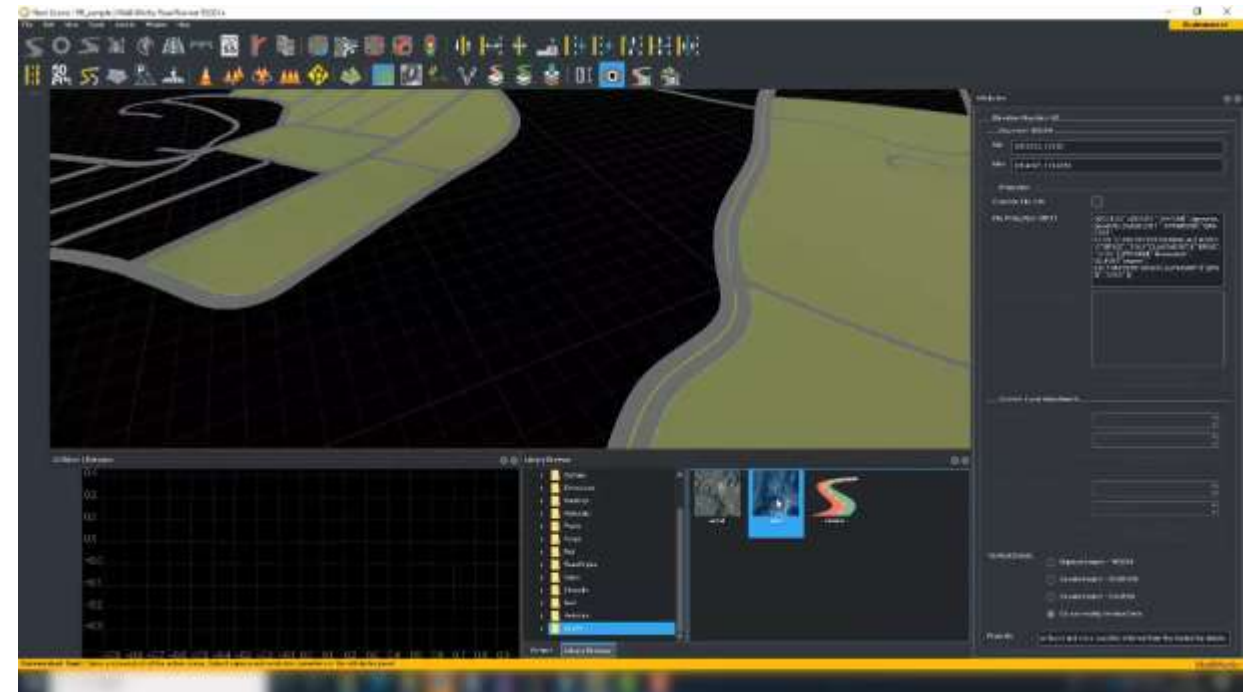
Design Scenes using RoadRunner



Modeling an entire scene from scratch is difficult.

GIS Data

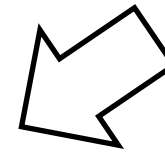
- Point clouds
- Aerial images
- Vector data
- Elevation data



Design Scenes using RoadRunner



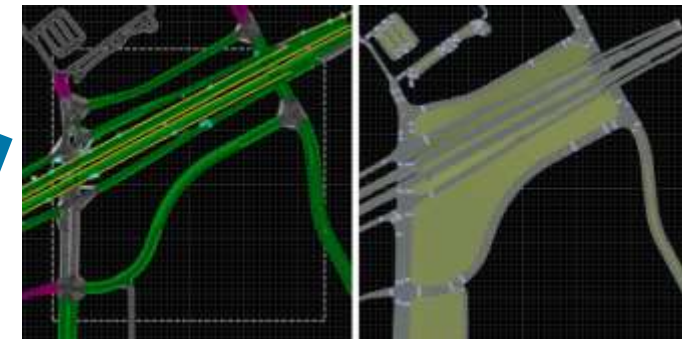
**Modeling a road network
is still difficult**



Map Data

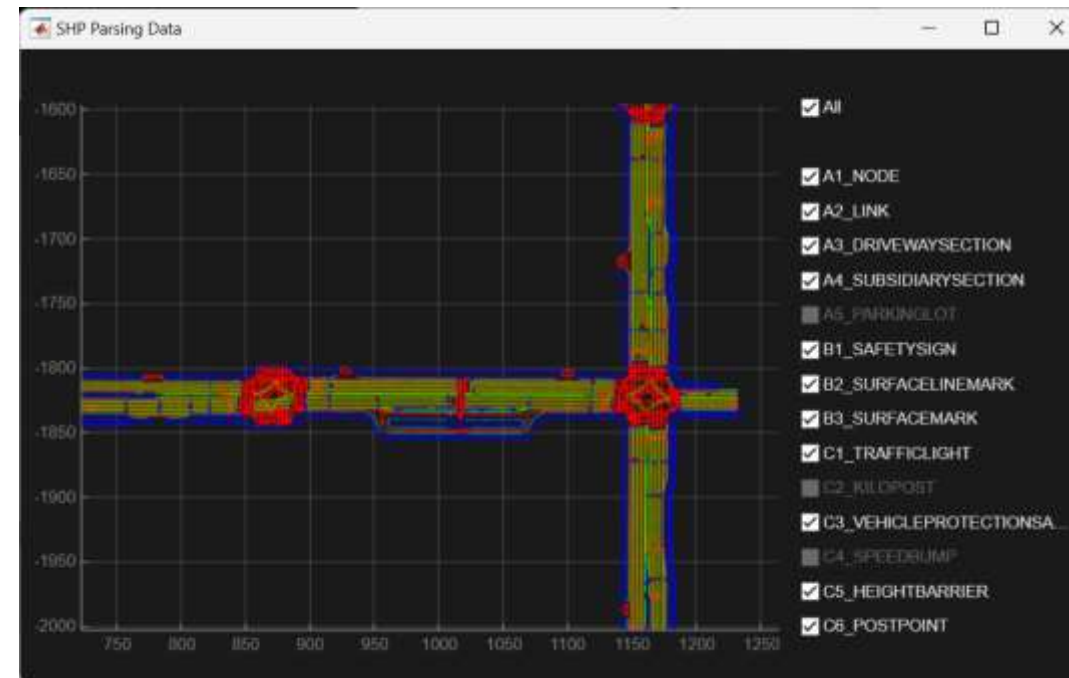
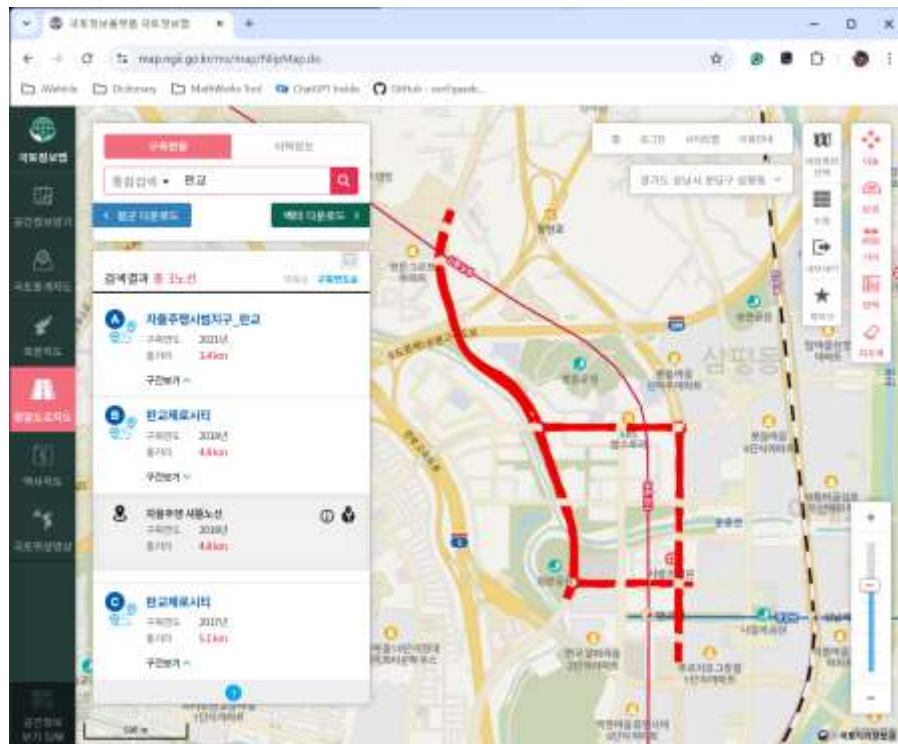
- OpenDrive
- **OpenStreetMap**

RoadRunner Scene Builder



- HERE, TomTom, Apollo Map
- Custom

Recent Work for Generating a RRHD map from NGII HD Map



Design Scenario using RoadRunner Scenario



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

Export Scenarios

- Trajectories and logic
- OpenSCENARIO 1.x
 - OpenSCENARIO 2.0

Simulate Actor Behaviors

- MATLAB
- Simulink
- CARLA

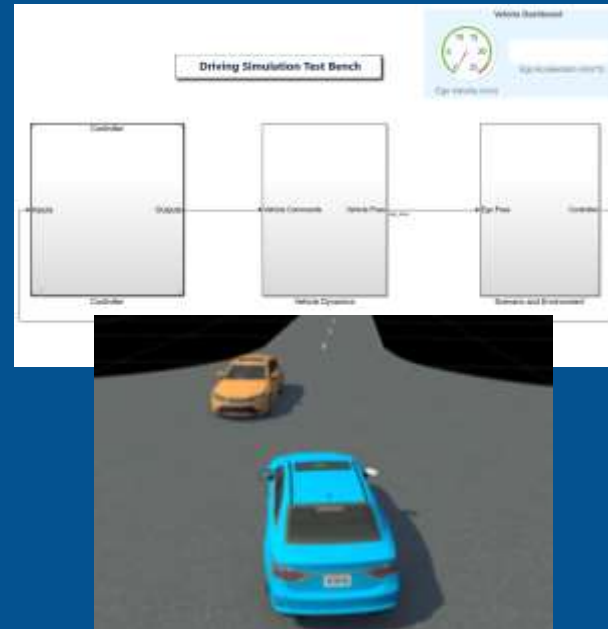
Automate Tasks (import, export, set variables,...)

- MATLAB
- C/C++
- Python
- Any gRPC supported language

Develop automated driving scenarios with MATLAB, Simulink, and RoadRunner



Design
scenes & scenarios



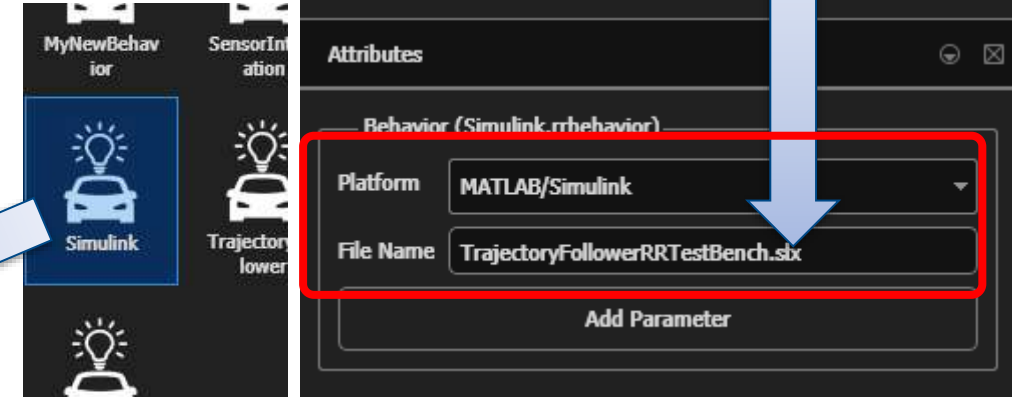
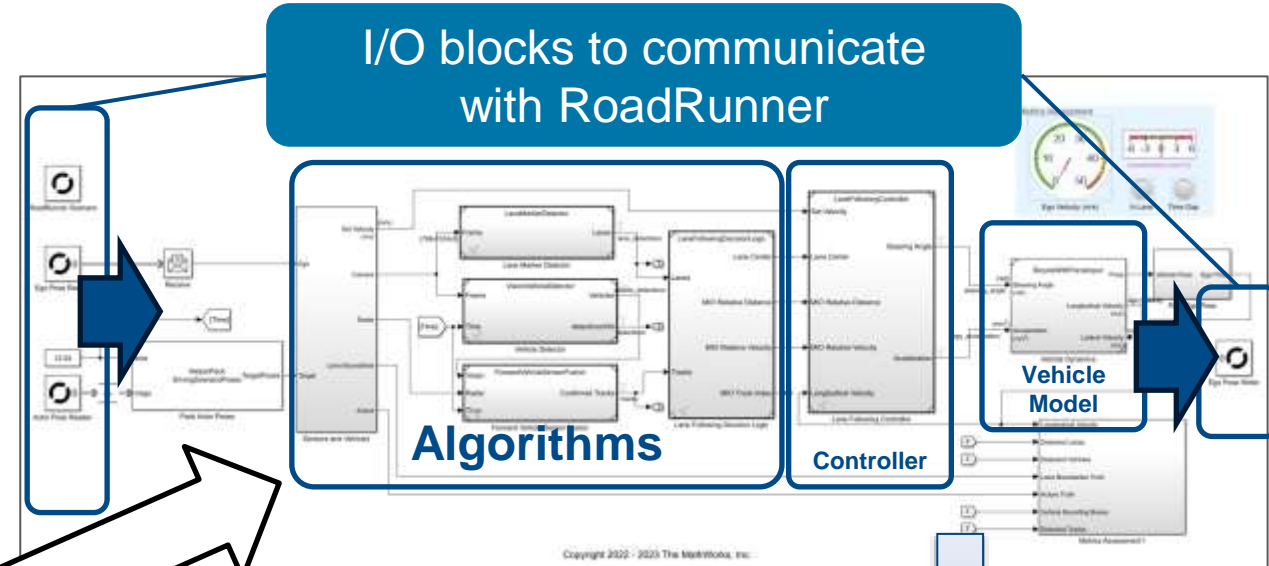
Simulate
driving applications



Build
scenarios

Simulate a Scenario with Simulink

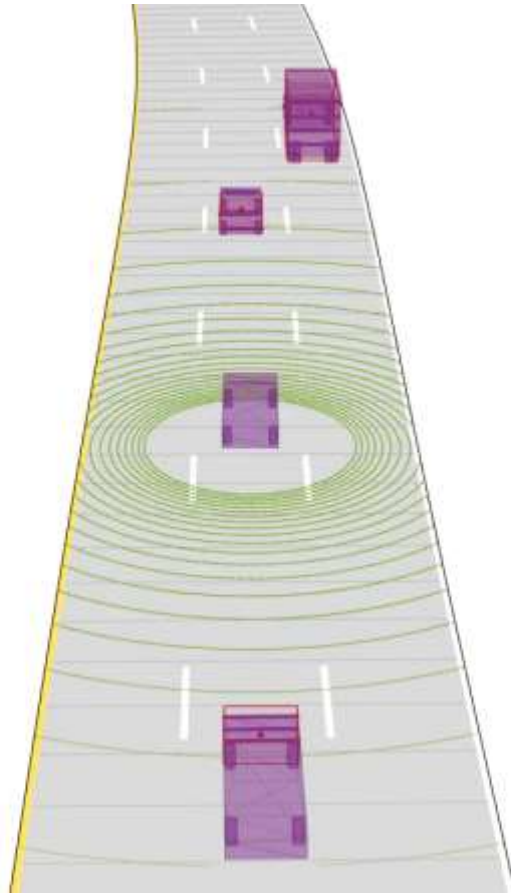
RoadRunner Scenario



Define the actor's behavior using a new behavior

Define actor behavior with Simulink model

2 Simulation Fidelity Options



**Low Fidelity Option
(Driving Scenario Designer)**



**High Fidelity Option
(Co-simulation with Unreal)**

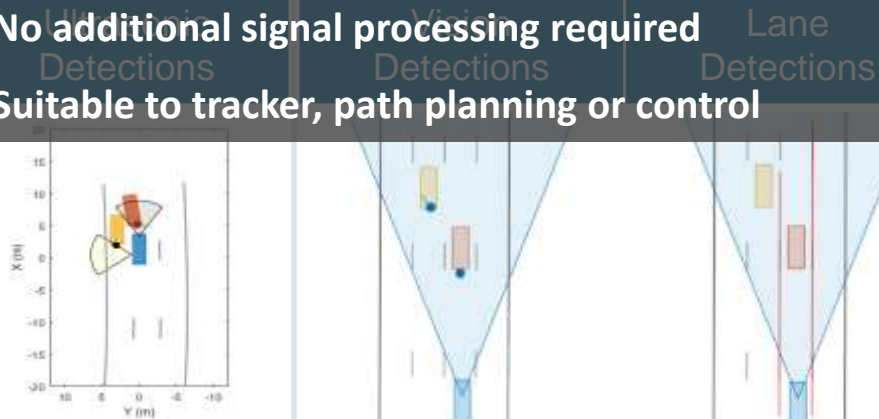
Simulate Sensors for Automated Driving

Low Fidelity Option (Driving Scenario Designer)

Radar Detections	Lidar
------------------	-------

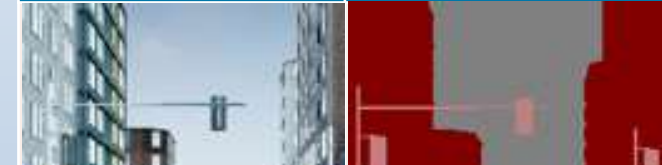


- Polygon mesh or simple box shaped actor
- Output a list of detected objects or tracks
- **No additional signal processing required**
- Suitable to tracker, path planning or control

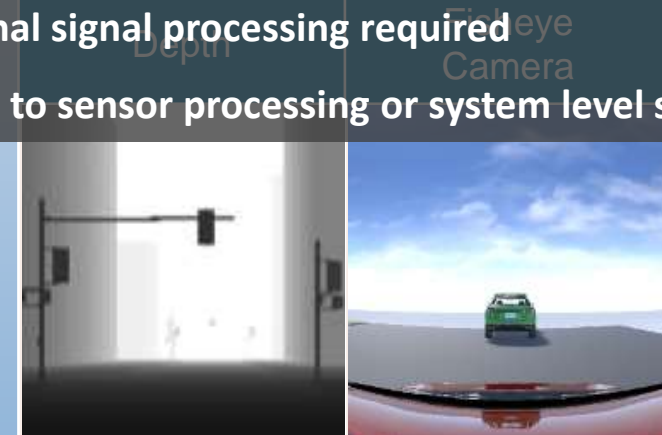


High Fidelity Option (Co-simulation with Unreal)

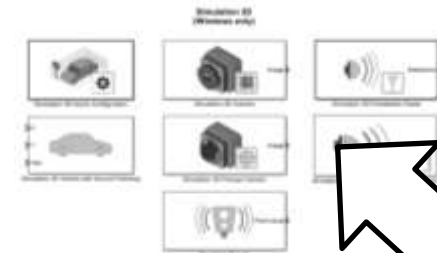
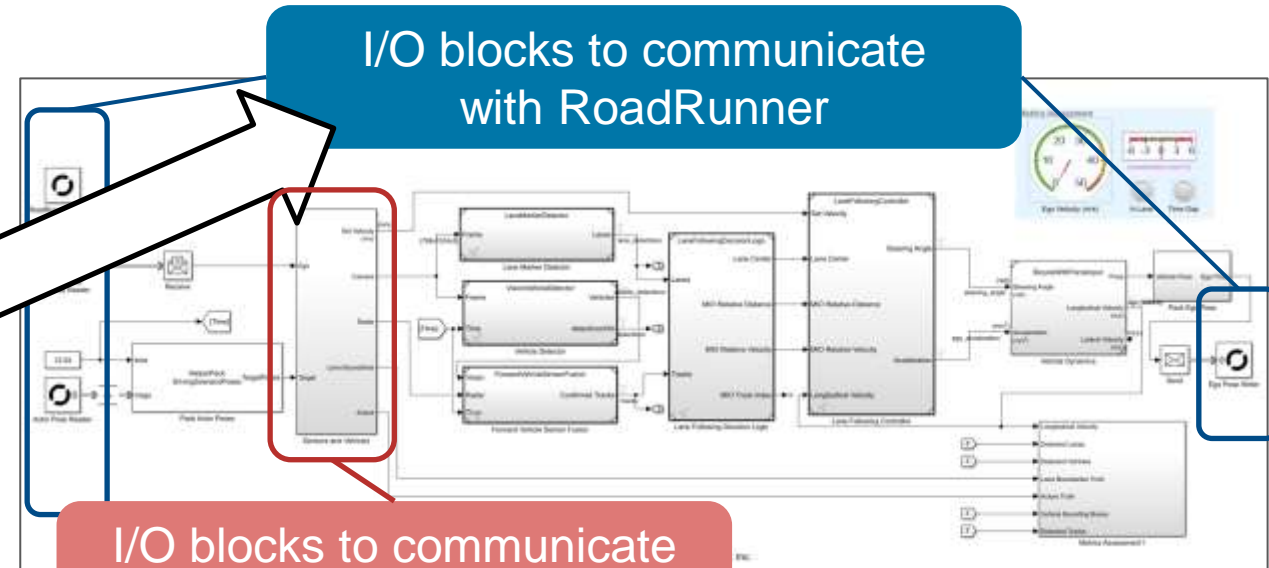
Monocular Camera	Semantic Segmentation
------------------	-----------------------



- Photo-realistic scene/actor representation
- Output sensor signals similar to reality
- Additional signal processing required
- Suitable to sensor processing or system level simulation

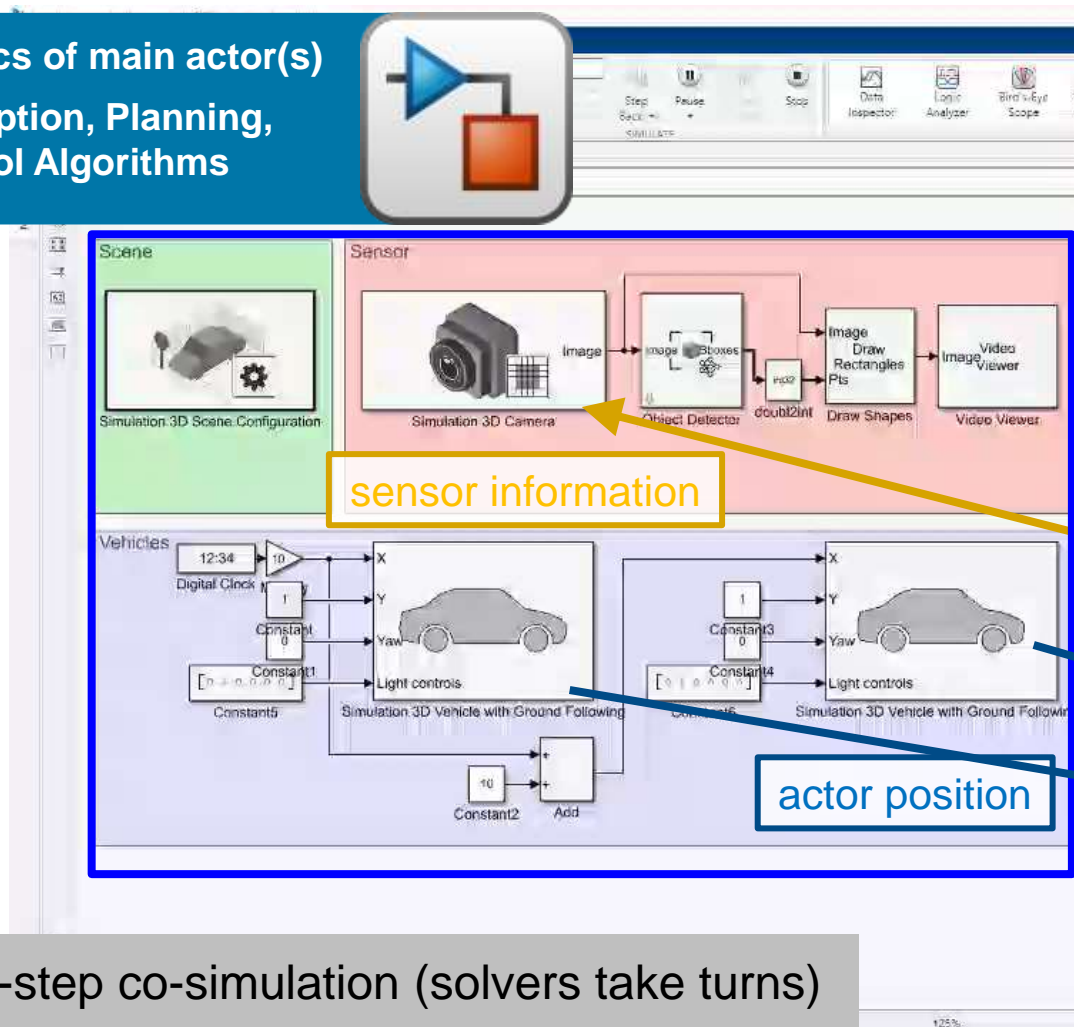


Simulate a Scenario with Simulink and Unreal



Perform closed-loop, deterministic simulations with Unreal Engine

- Physics of main actor(s)
- Perception, Planning, Control Algorithms



Lock-step co-simulation (solvers take turns)
provides **deterministic results**

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



Improvements in Unreal Co-Simulation

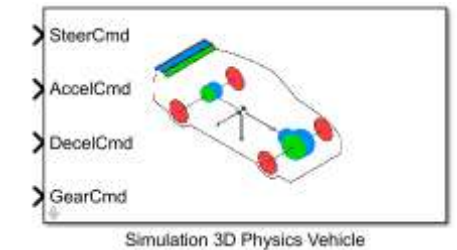
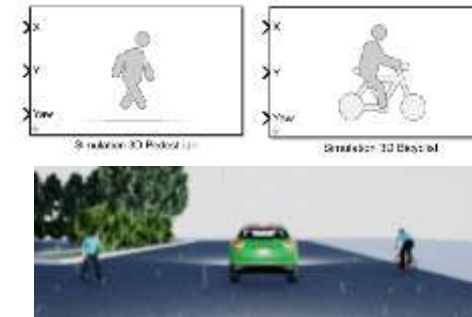
- Unreal Engine 5
 - Efficient rendering and memory usage
- Support for Linux platform
- Weather system
 - Rain particles now interact with camera lens
 - Snow
 - Volumetric clouds using 3D volume textures
 - Geo-location and time-of-day based sun configuration
- 3D Light Simulation
 - Create and add different types of lights
 - Create light array with single Light Actor
- 3D Annotation
 - Create multiple arrows and texts with vectorized inputs



Improvements in Unreal Co-Simulation

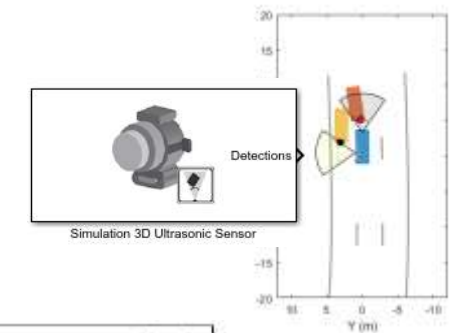
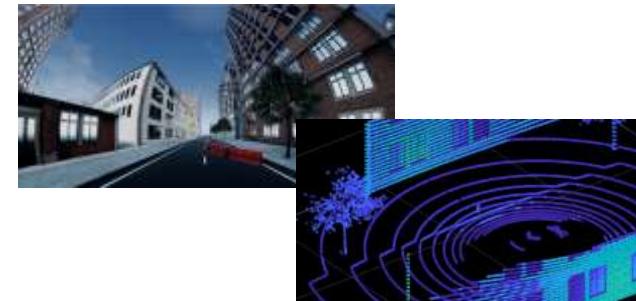
Actors

- Pedestrian, Bicyclist
- **Physics Vehicle:**
evaluate position, velocity, rotation, and force feedback of a vehicle actor using Chaos physics



Enhancement in Sensor Model

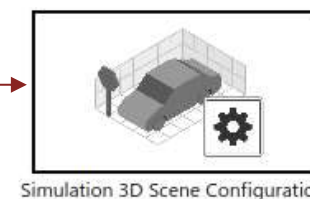
- LIDAR model can output the reflectivity of surface materials
- Ultrasonic sensor
- Ray tracer: ray tracing to get the positions, surface normals, surface identifiers, and distances for objects



Easy scene configuration

- **RoadRunner scene import** in Sim3d Configuration Block
- **OpenDrive file import** in Sim3d Configuration Block

RoadRunner,
OpenDRIVE

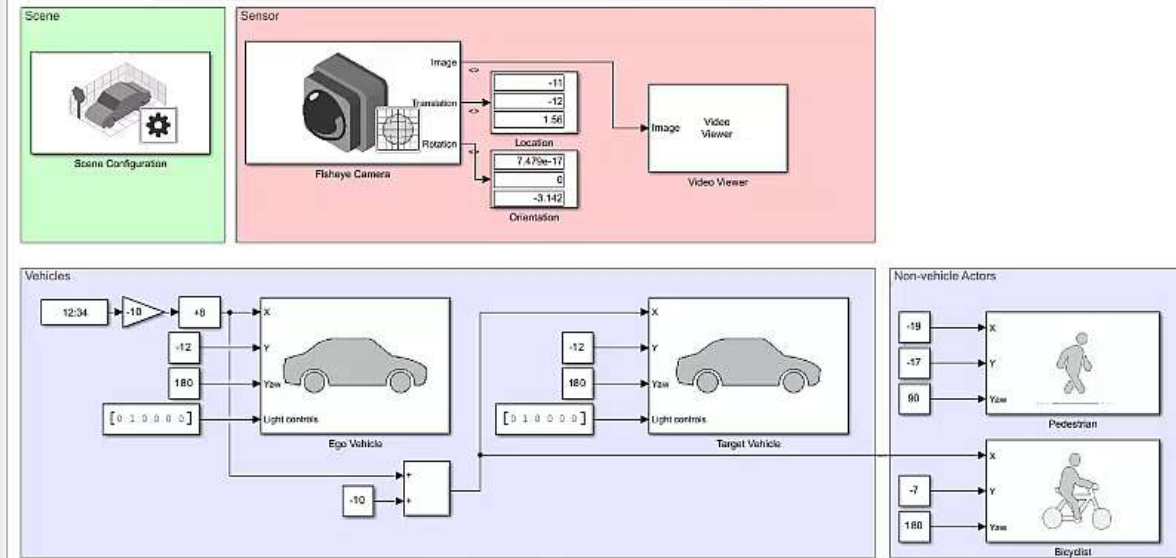


RoadRunner

- **Easy** scene design in **RoadRunner**
- **Direct import** simulation scene
- No additional **installation** process
- **Test automation** using Simulink Test

Simulink

Simple Driving Scenario and Sensor Model for Unreal Engine Simulation



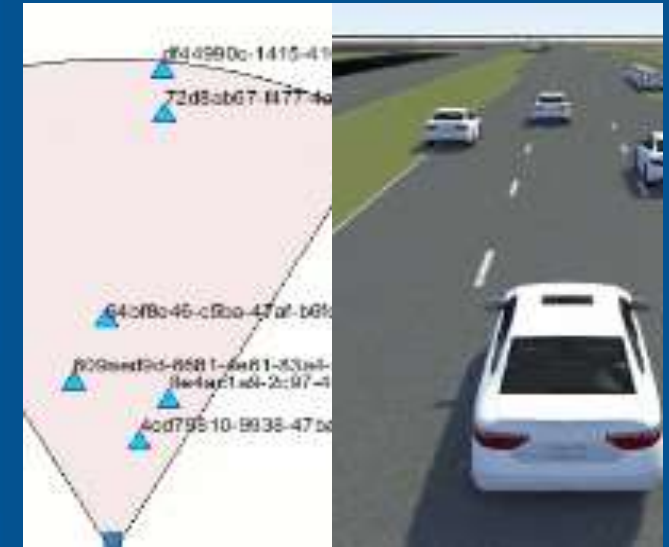
Develop automated driving scenarios with MATLAB, Simulink, and RoadRunner



Design
scenes & scenarios



Simulate
driving applications



Build
scenarios

What types of tests do autonomous driving engineers mainly perform using simulations?



Ideal test cases for functional test



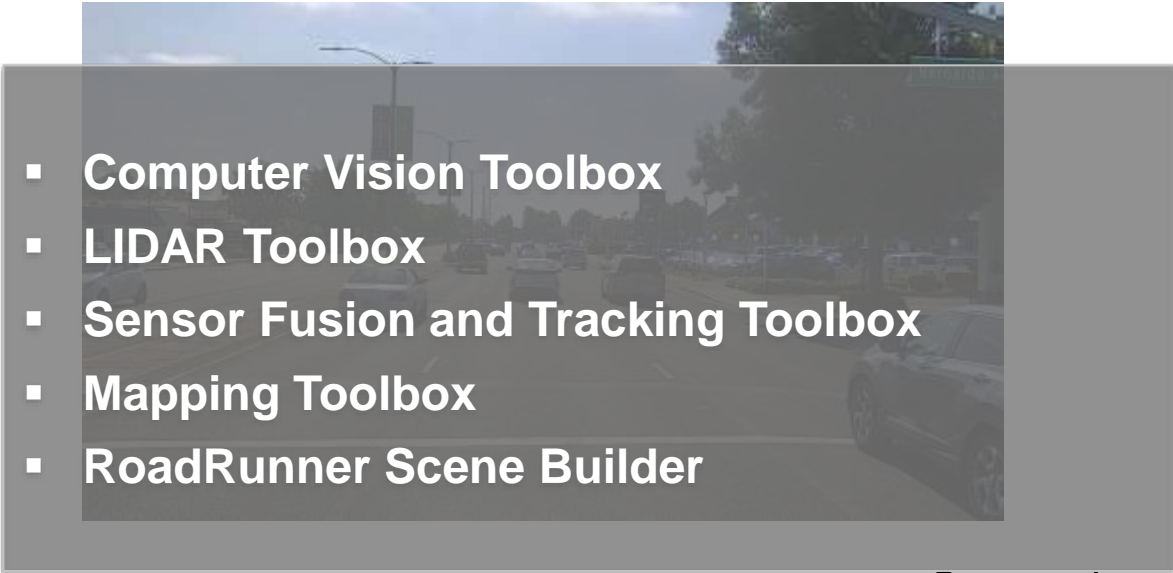
Test cases based on standards



Test cases generated from road driving tests

Generate scenarios from recorded sensor data

Sensor data

- 
- **Computer Vision Toolbox**
 - **LIDAR Toolbox**
 - **Sensor Fusion and Tracking Toolbox**
 - **Mapping Toolbox**
 - **RoadRunner Scene Builder**

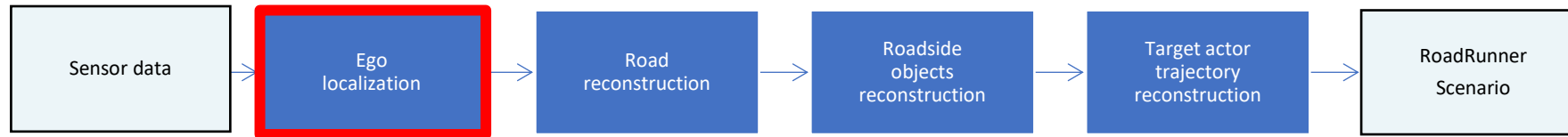
Sensor data used for this reconstruction:

Camera images: Lanes

Lidar point cloud: Vehicles

Labelled data: Trees, Buildings, Poles

Generate scenarios from recorded sensor data

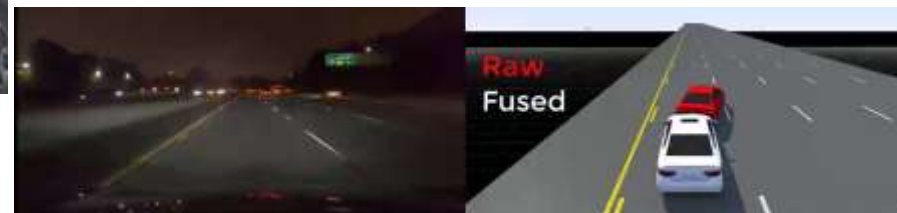


Lane-level Ego Localization



[Ego Localization Using Lane Detections and HD Map](#)

Ego Localization using GPS and IMU



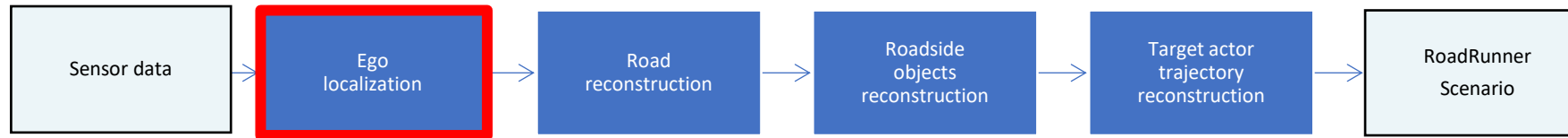
[Ego Vehicle Localization Using GPS and IMU Fusion for Scenario Generation](#)



Scene Builder for Automated Driving Toolbox



Generate scenarios from recorded sensor data

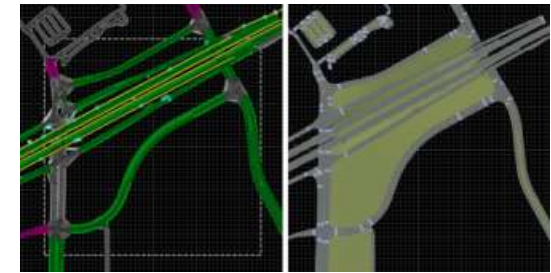


Reconstruct Road



[Generate RoadRunner Scene Using Labeled Camera Images and GPS](#)

RoadRunner Scene Builder



Scene Builder for Automated Driving Toolbox

Scenario Builder for Automated Driving Toolbox

Build realistic scenarios from recorded vehicle data recorded from GPS, IMU, camera, and lidar sensors.

The Scenario Builder for Automated Driving Toolbox allows users to generate realistic scenarios for autonomous driving applications. It provides a graphical user interface to generate the scenarios from recorded sensor data and convert them into the scenario format.

With RoadRunner Scenario Builder, users can visualize the generated scenarios with roads, lanes, and vehicles in the RoadRunner. These scenarios can then be imported to ADAMS (Automated Driving Simulation) for the driver logic. RoadRunner Scenario Builder supports the scenarios of various roads, such as urban, highway, and rural roads. The generated scenarios can be used for testing and validation of autonomous driving applications.

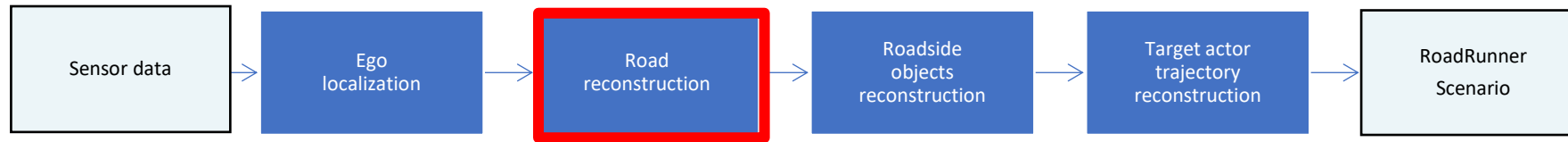
Getting Started

- Overview of Scenario Builder from RoadRunner
- Requirements
- Features

Features

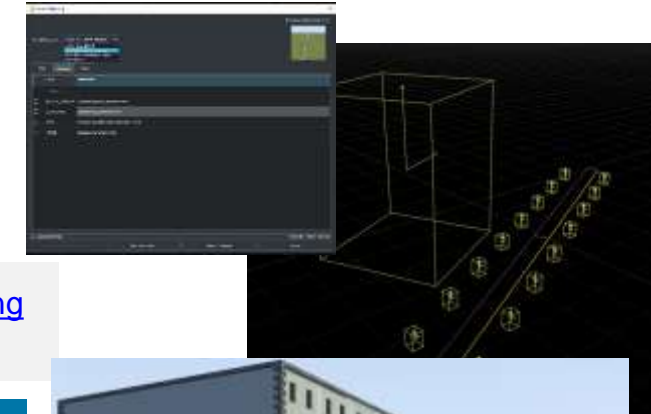
Scenario Builder for Automated Driving Toolbox provides a user-friendly interface to generate scenarios from recorded sensor data and convert them into the scenario format.

Generate scenarios from recorded sensor data



RoadRunner Scene Builder

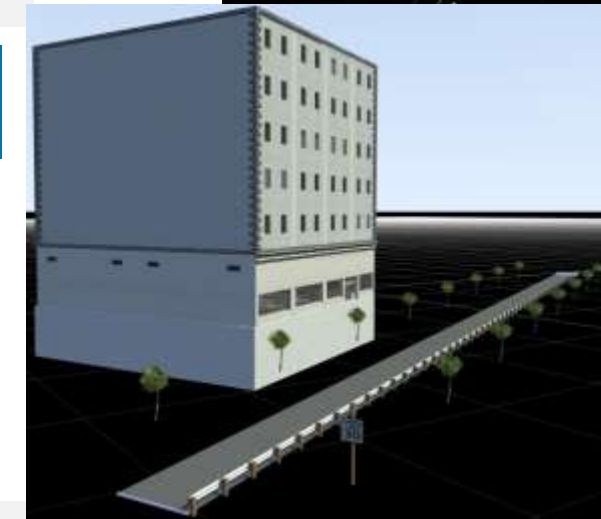
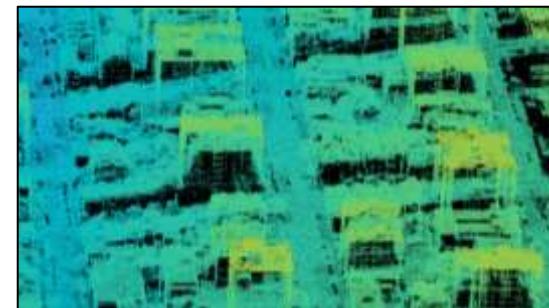
Reconstruct Traffic Signs



[Generate RoadRunner Scene with Traffic Signs Using Recorded Sensor Data](#)

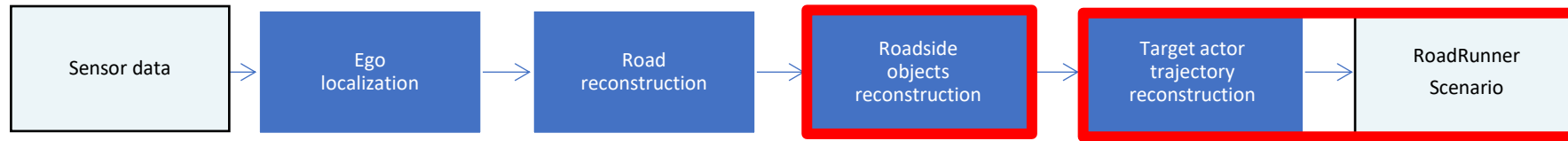


Aerial Data to 3D Scene



[Generate RoadRunner Scene Using Aerial Lidar Data](#)

Generate scenarios from recorded sensor data



Reconstruct Targets



[Generate RoadRunner Scenario from Recorded Sensor Data](#)

Scene Builder for Automated Driving Toolbox



RoadRunner Scenario



What types of tests do autonomous driving engineers mainly perform using simulations?



Ideal test cases for functional test

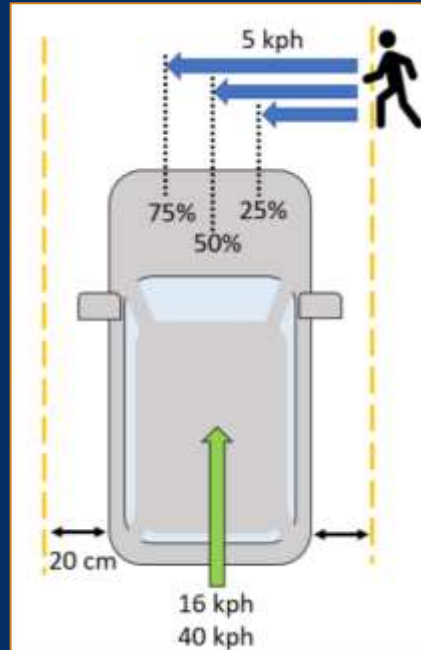


Test cases based on standards

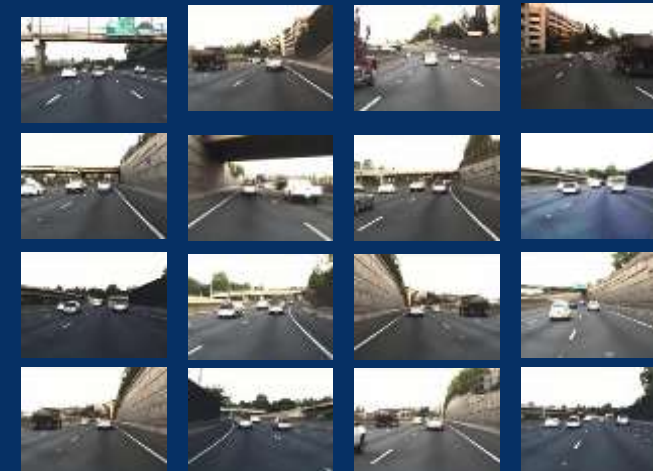
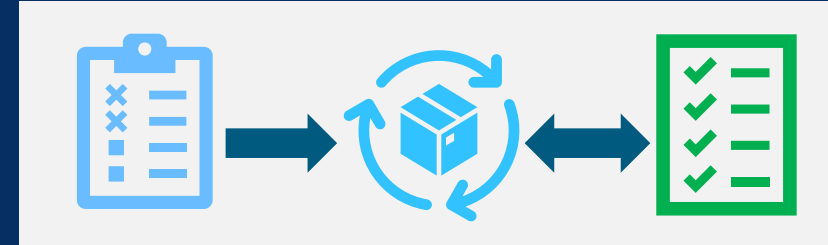


Test cases generated from road driving tests

Challenges in Euro NCAP simulation and testing



Painful to create
NCAP scenarios and
scale them for
different vehicles



Need a test management
framework with insights & analysis

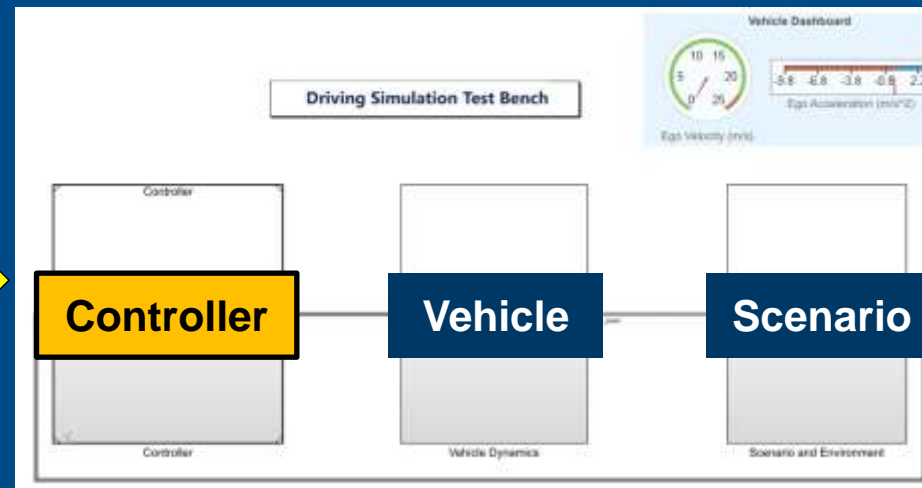
Automated Driving Toolbox Test Suite for Euro NCAP Protocols

Test Suite for Euro NCAP® Protocols

1. Euro NCAP Scenarios

- Car-To-Car Rear Stationary
- Car-To-Car Rear Moving
- Car-To-Car Rear Braking
- Car-to-Car Front Turn-Across-Path
- Car-to-Car Crossing Straight Crossing Path
- Car-to-Car Front Head-On Straight
- Car-to-Car Front Head-On Lane change

2. Test Bench



3. Euro NCAP Report

Euro NCAP Safety Assist AEB CCFtap Report

Test Type	Obtained Score
Collision Avoidance	1

Car-to-Car Front turn across path (CCFtap) scenarios: Collision Avoidance Status

Test Speed (km/h)	GVT @ 30 km/h	GVT @ 45 km/h	GVT @ 60 km/h
10	1	1	1
15	1	1	1
20	1	1	1

Scoring method for CCFtap:

Points	Interpretation
0	No Points for Collision
1	Full Points for Collision Avoidance

[Test Suite for Euro NCAP Protocols](#)

Automated Driving Toolbox

Automated Driving Toolbox Test Suite for Euro NCAP Protocols support package from the Add-On Explorer



MATLAB R2024a

HOME PLOTS APPS

Add-On Explorer

Contribute Manage Add-Ons

Search for add-ons

Automated Driving Toolbox Test Suite for Euro NCAP Protocols

by MathWorks Automated Driving Toolbox Team **STAFF**

169 Downloads Updated 19 Jun 2024

Automatically generate seed scenarios for the Euro NCAP test protocols and generate scenario variants.

Install

Overview Reviews (0) Discussions (0)

The Automated Driving Toolbox™ Test Suite for Euro NCAP® Protocols support package enables you to automatically generate specifications for various Euro NCAP® tests, which include safety assessments of automated driving applications such as Safety Assist Tests and Vulnerable Road User (VRU) Protection Tests. You can create a seed scenario for a Euro NCAP test, and vary scene parameters, actor parameters, and simulator parameters to generate variants of it. Use these scenario variations for safety assessment of different automated driving applications, such as autonomous emergency braking (AEB) car-to-car and AEB car-to-pedestrian scenarios.

Requires

- Automated Driving Toolbox

MATLAB Release Compatibility

Created with R2022b
Compatible with R2022b to R2024b

Platform Compatibility

- Windows macOS (Apple silicon) macOS (Intel) Linux

Tags

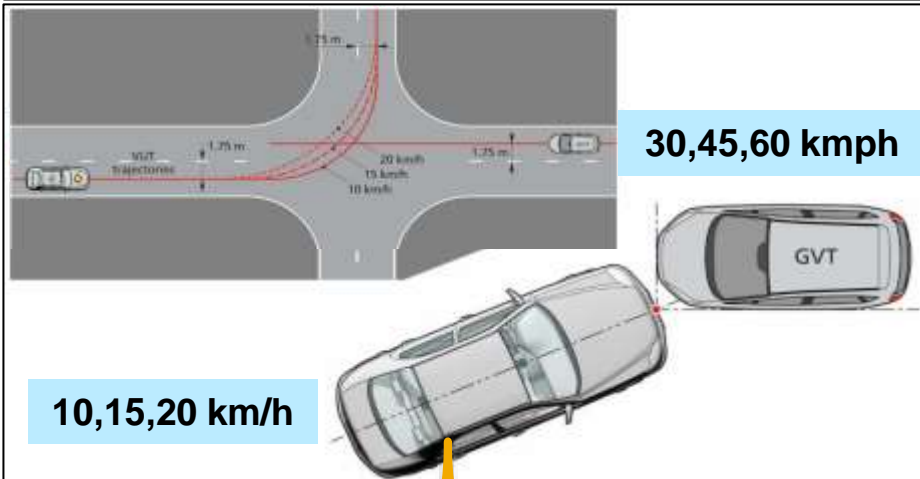
- automated driving
- driving scenario
- euro ncap
- variant

Others Also Downloaded

- Cheetah Optimizer
34 Downloads
- TSP2024
5 Downloads
- モデル予測制御 設計実装ワークフロー
— 紹介, MPC Implementation Example

1. Create Euro NCAP scenarios for different ego assets

Scene & Scenario Specification



Sedan



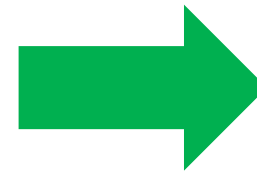
Suv



Hatchback



Muscle Car



Euro NCAP Scenarios



Test Name	Road Type	#
Car-To-Car Rear Stationary (CCRs)	Straight	75
Car-To-Car Rear Moving (CCRm)	Straight	55
Car-To-Car Rear Braking (CCRb)	Straight	4
Car-to-Car Front Turn-Across-Path (CCFtap)	Junction	9
Car-to-Car Crossing Straight Crossing Path (CCCscp)	Junction	25
Car-to-Car Front Head-On Straight (CCFhos)	Straight	2
Car-to-Car Front Head-On Lane change (CCFhol)	Straight	2



ncapSpec - Returns Euro NCAP test specifications

```
[variationSpec, ncapTestSpec, specInfo] = ncapSpec(ncapTestName)
```

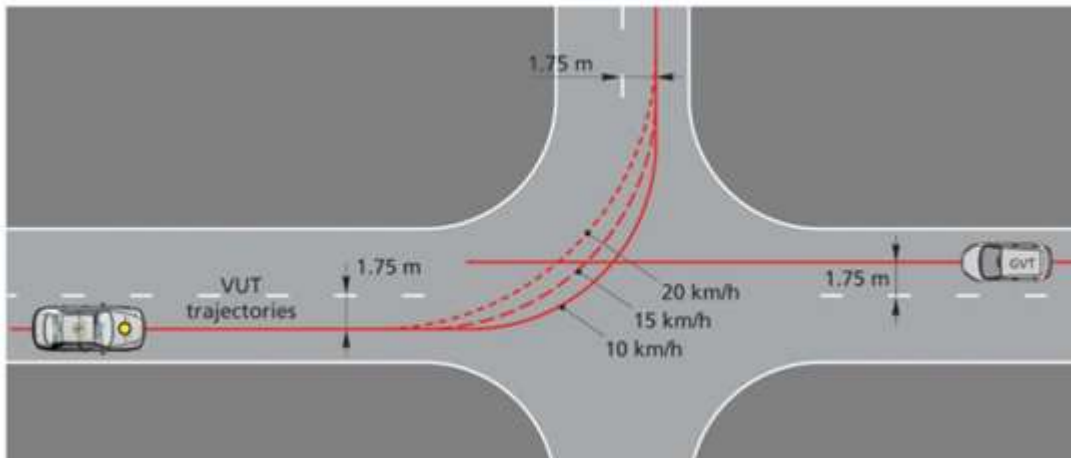
Safety Assist

- "SA AEB CCRs"
- "SA AEB CCRm"
- "SA AEB CCRb"
- "SA AEB CCFtap"
- "SA AEB CCCscp"
- "SA AEB CCFhos"
- "SA AEB CCFhol"
- "SA LSS LKA Solid Line"
- "SA LSS LKA Dashed Line"
- "SA LSS ELK Solid Line"
- "SA LSS ELK Road Edge"
- "SA LSS ELK Oncoming vehicle"
- "SA LSS ELK Overtaking vehicle intentional"
- "SA LSS ELK Overtaking vehicle unintentional"

Vulnerable Road Users

- "VRU AEB Crossing CPFA"
- "VRU AEB Crossing CPNA"
- "VRU AEB Crossing CPNCO"
- "VRU AEB Longitudinal CPLA"
- "VRU AEB Turning CPTAns"
- "VRU AEB Turning CPTAno"
- "VRU AEB Turning CPTAfs"
- "VRU AEB Turning CPTAfo"
- "VRU AEB Reverse CPRs"
- "VRU AEB Reverse CPRm"
- "VRU AEB Crossing CBFA"
- "VRU AEB Crossing CBNA"
- "VRU AEB Longitudinal CBLA"
- "VRU AEB Turning CBTAn"
- "VRU AEB Turning CBTAf"
- "VRU AEB Longitudinal CMRs"
- "VRU AEB Longitudinal CMRb"
- "VRU AEB Turning CMFtap"
- "VRU AEB Lateral CM Oncoming"
- "VRU AEB Lateral CM Overtaking unintentional"
- "VRU AEB Lateral CM Overtaking intentional"

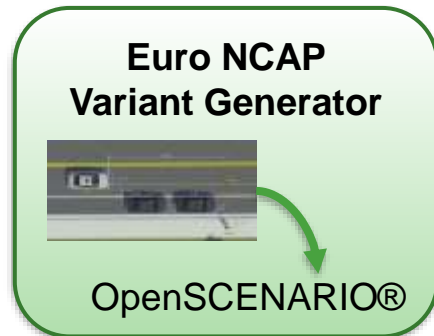
Autonomous Emergency Braking Car-to-Car Front Turn-Across-Path



Generate variant scenarios from seed scenario



Seed Scenario



Variant Scenarios

```
%% Generate seed scenario descriptor for Euro NCAP test
seedScenarioDescriptor = ncapScenario("SA AEB CCFtap")
```

```
%% Select an asset for ego
egoAssetData.AssetPath = fullfile("Vehicles\ADT Vehicles\SK_Hatchback.fbx_rrx");
```

```
%% Extract the Euro NCAP variation parameters
variation = helperNCAPVariationProperties("SA AEB CCFtap", egoAssetInfo=egoAssetData);

%% Generate variant scenario descriptors from seed scenario descriptor using specified variations
[variantDescriptors,info] = generateVariants(seedScenarioDescriptor,variation);
```

```
%% Set Up RoadRunner Scenario - RoadRunner installation and project folder properties
rrApp = roadrunnerSetup;

%% Create a RoadRunner scenario from scenario descriptor.
for i = 1:length(variantDescriptors)
    variantScenario = getScenario(variantDescriptors(i), Simulator="RoadRunner", SimulatorInstance=rrApp);
    scenarioName = sprintf("SA_AEB_CCFtap_%d", i);
    saveScene(rrApp,"SA_AEB_CCFtap");
    saveScenario(rrApp,scenarioName);
    exportScenario(rrApp,scenarioName,"OpenSCENARIO");
end
```

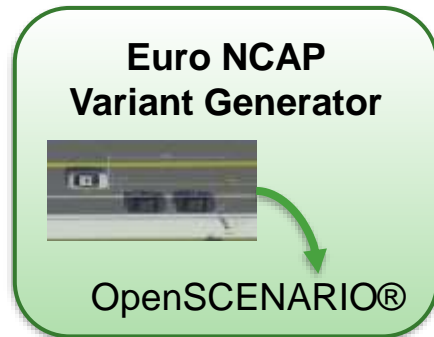
ncapSpec
ncapScenario

generateVariants
getScenario

Generate variant scenarios from seed scenario



Seed Scenario



Variant Scenarios

```
%% Generate seed scenario descriptor for Euro NCAP test
seedScenarioDescriptor = ncapScenario("SA_AEB_CCFtap")
```

```
%% Select an asset for ego
egoAssetData.AssetPath = fullfile("Ve
```

```
%% Extract the Euro NCAP variation pa
variation = helperNCAPVariationPrope
%% Generate variant scenario descript
[variantDescriptors,info] = generateVa
```

```
%% Set Up RoadRunner Scenario - Ro
rrApp = roadrunnerSetup;
```

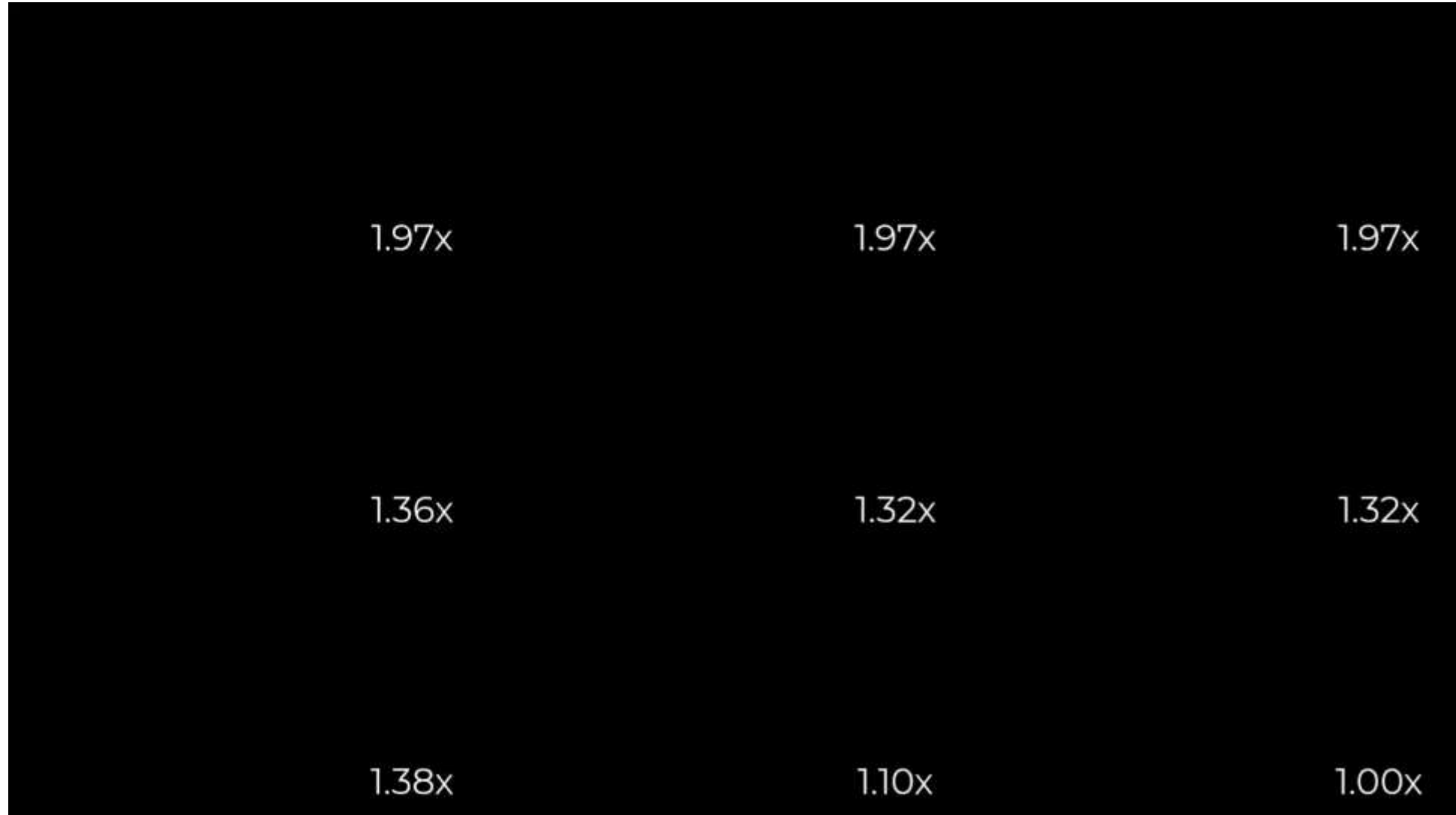
```
%% Create a RoadRunner scenario fro
for i = 1:length(variantDescriptors)
    variantScenario = getScenario(variantDescriptors(i), Simulator="RoadRunner", SimulatorInstance=rrApp);
    scenarioName = sprintf("SA_AEB_CCFtap_%d", i);
    saveScene(rrApp,"SA_AEB_CCFtap");
    saveScenario(rrApp,scenarioName);
    exportScenario(rrApp,scenarioName , "OpenSCENARIO");
end
```

Name	Date modified	Type
variantScenario.rrscenario	8/6/2024 1:58 PM	RRSCENARIO File
SA_AEB_CCFtap_9.rrscenario	8/6/2024 11:46 AM	RRSCENARIO File
SA_AEB_CCFtap_8.rrscenario	8/6/2024 11:46 AM	RRSCENARIO File
SA_AEB_CCFtap_7.rrscenario	8/6/2024 11:46 AM	RRSCENARIO File
SA_AEB_CCFtap_6.rrscenario	8/6/2024 11:46 AM	RRSCENARIO File
SA_AEB_CCFtap_5.rrscenario	8/6/2024 11:46 AM	RRSCENARIO File
SA_AEB_CCFtap_4.rrscenario	8/6/2024 11:46 AM	RRSCENARIO File
SA_AEB_CCFtap_3.rrscenario	8/6/2024 11:46 AM	RRSCENARIO File
SA_AEB_CCFtap_2.rrscenario	8/6/2024 11:46 AM	RRSCENARIO File
SA_AEB_CCFtap_1.rrscenario	8/6/2024 11:46 AM	RRSCENARIO File

[ncapSpec](#)
[ncapScenario](#)

[generateVariants](#)
[getScenario](#)

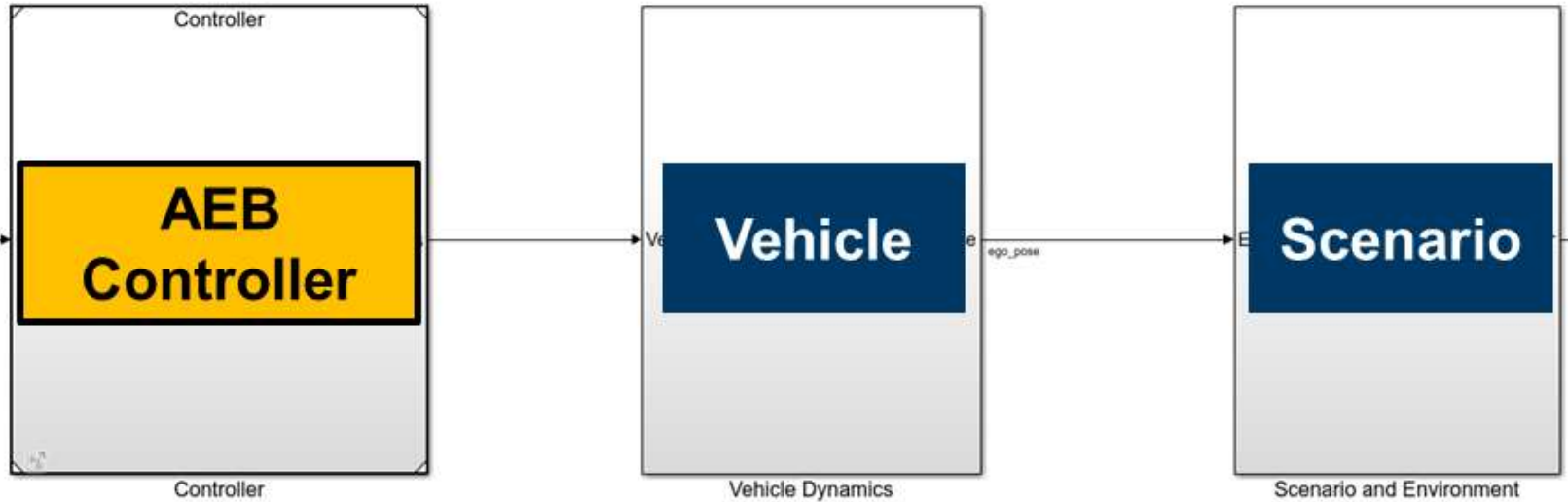
Scenario Variants for Euro NCAP CCFTap for Hatchback as ego



2. Provide a Simulink test bench with high fidelity dynamics

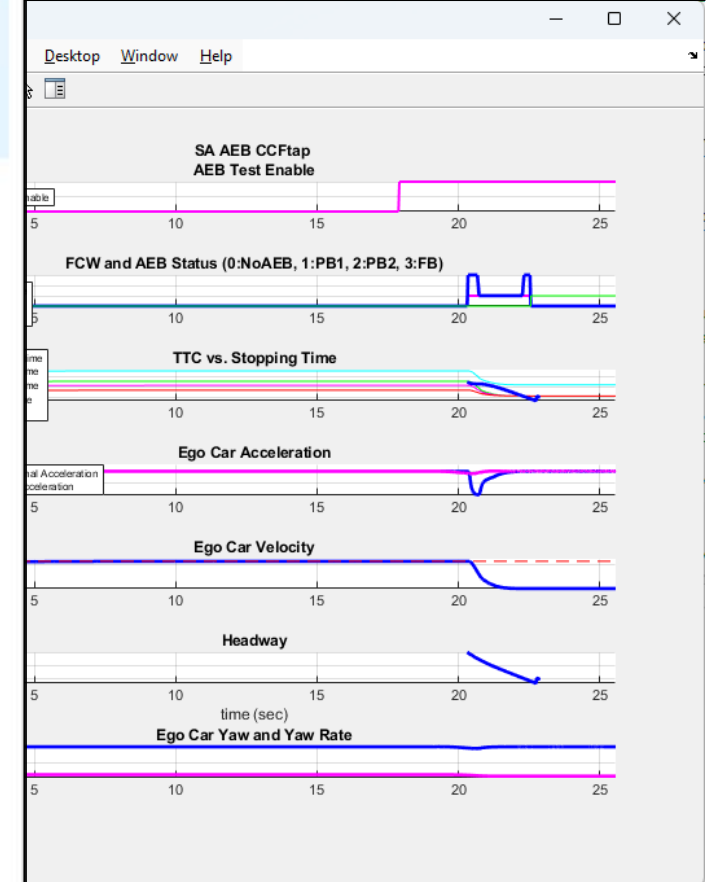
Emergency Braking Simulation test bench for testing controller with dynamics

Driving Simulation Test Bench



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AEB performance results



3. Test automation for Euro NCAP CCFTap scenarios

The screenshot displays the Test Manager application window. The interface is divided into several sections:

- Toolbar:** Contains icons for file operations (New, Open, Save, Cut, Copy, Delete, Paste), test execution (Run, Run with Stepper, Stop, Parallel), and reporting (Report, Visualize, Highlight in Model, Export, Import).
- Test Browser:** A tree view on the left showing the test hierarchy. The selected test is "SA AEB CCFTap" under the session "Session_24A9643B127C2C49EA1966DE1BD48CAC".
- Property Grid:** A table at the bottom left listing test properties and their values.
- Configuration Panel:** The main area on the right, titled "SAAEB CCFTap", showing detailed settings for the test.

PROPERTY	VALUE
Name	SA AEB CCFTap
Type	RoadRunner Test (Simulati...
Model	DrivingTestBench
Simulation Mode	[Model Settings]
Location	C:\Users\rishug\OneDrive - ...
Enabled	<input checked="" type="checkbox"/>
Hierarchy	Session_24A9643B127C2...
Tags	Type comma or space separa...

SAAEB CCFTap Enabled

Session_24A9643B127C2C49EA1966DE1BD48CAC » SA AEB Car-to-Car Front Turn-Across-Path (CCFTap) » SA AEB CCFTap

RoadRunner Test (Simulation Test)

- TAGS
- DESCRIPTION
- REQUIREMENTS
- ROADRUNNER*

Console Mode

Force Pacing Off

RoadRunner Scenario: 24A9643B127C2C49EA1966DE1BD48CAC\SA_AEB_CCFTap_1

Override RoadRunner Setup Settings

RoadRunner Project Folder: C:\Roadrunner\TestProjects\Project1

RoadRunner Installation Folder: C:\Program Files\RoadRunner R2024a\bin\win64

- SYSTEM UNDER TEST*

Model: DrivingTestBench

- PARAMETER OVERRIDES
- CALLBACKS*
- INPUTS
- SIMULATION OUTPUTS

What types of tests do autonomous driving engineers mainly perform using simulations?



Ideal test cases for functional test



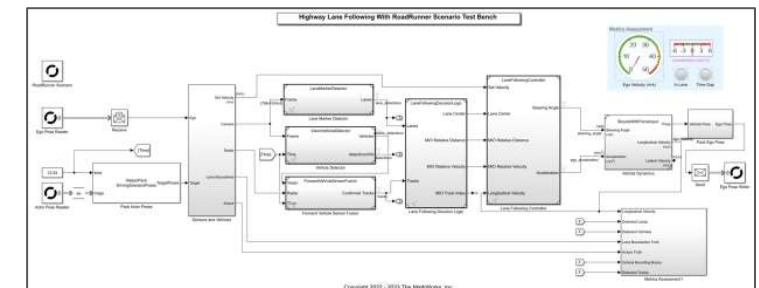
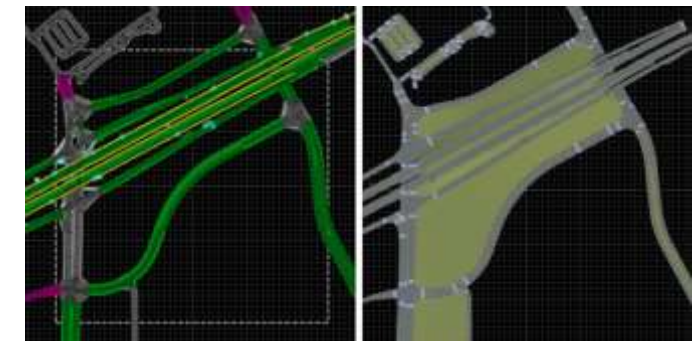
Test cases based on standards



Test cases generated from road driving tests

Key Takeaways

- MATLAB/Simulink/RoadRunner provides the functions necessary to create scenes and scenarios for configuring scenarios for
 - simple scenarios for functional testing,
 - standard-based testing, and
 - testing based on driving data.
- RoadRunner provides features to easily construct the 3D scenes required for these tests such as automatic road network modeling using HD Map.
- Simulink provides an interface that allows you to perform simulations by integrating scenes and scenarios created in RoadRunner with little effort.



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Thank you



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