

MathWorks  
**AUTOMOTIVE  
CONFERENCE 2023**  
Korea

# Scenario Harvesting Using Automated Driving Toolbox and RoadRunner Scenario

*Allen Kim, MathWorks*



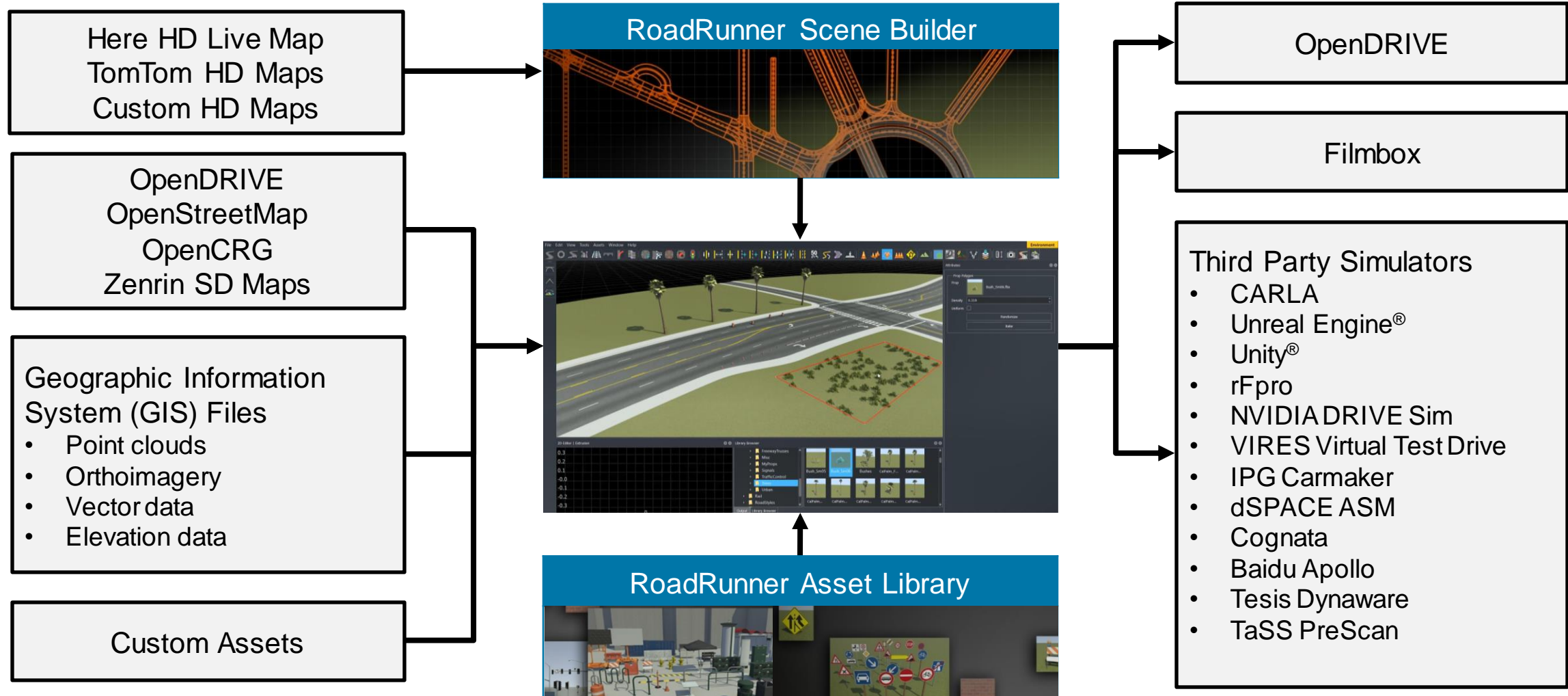
# What You Will Learn Today

- Interactively author scenes
- Build real world scenes from HD and SD maps
- Interactively author scenarios
- Generate scenes and scenarios from recorded sensor data
- Generate variations from a seed scenario

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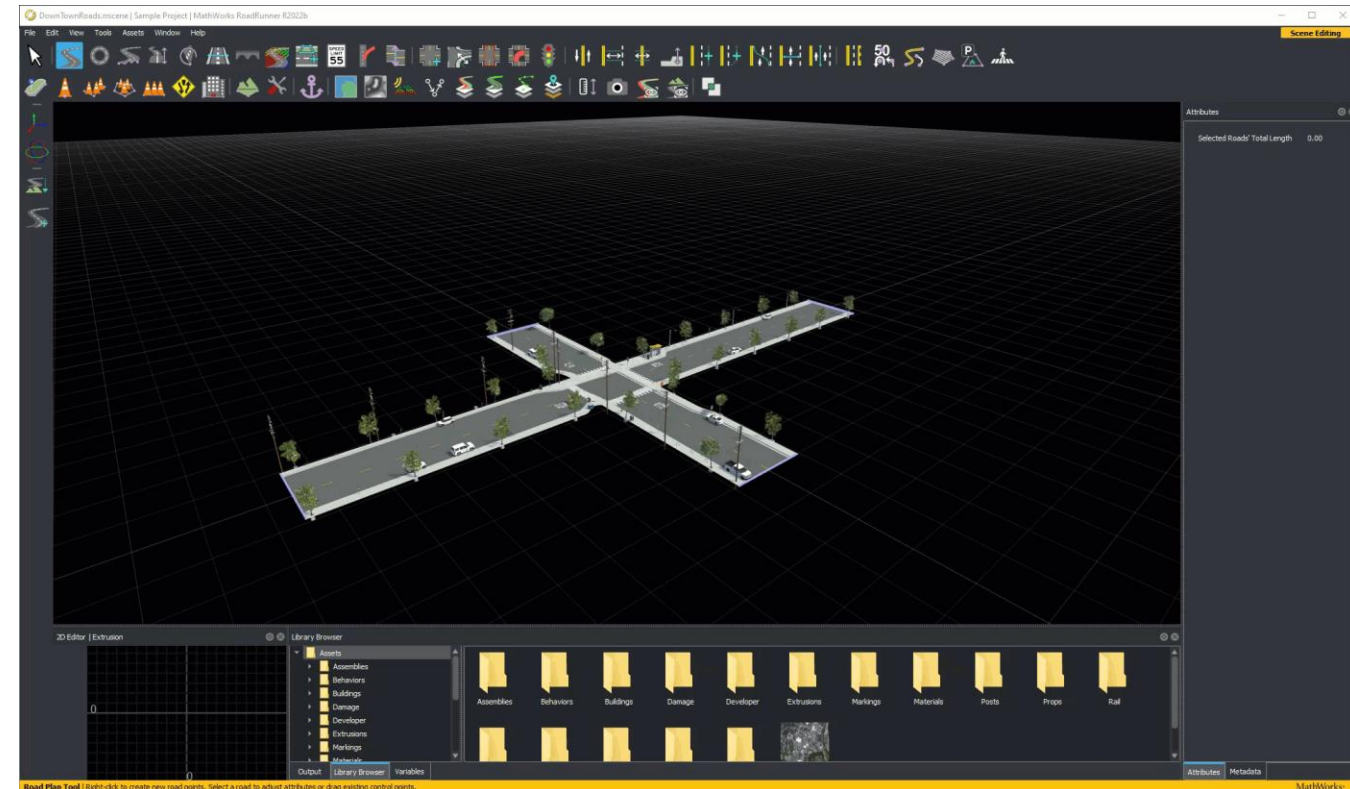
# RoadRunner, RoadRunner Scene Builder and Asset Library



# Enable Multi-User Editing Workflows with the Scene Merge

Import multiple scenes into the RoadRunner canvas

- Provides path for multiple users to combine work into one scene
- Considers georeferenced and non-georeferenced scenes
- Includes transfer of GIS related asset references

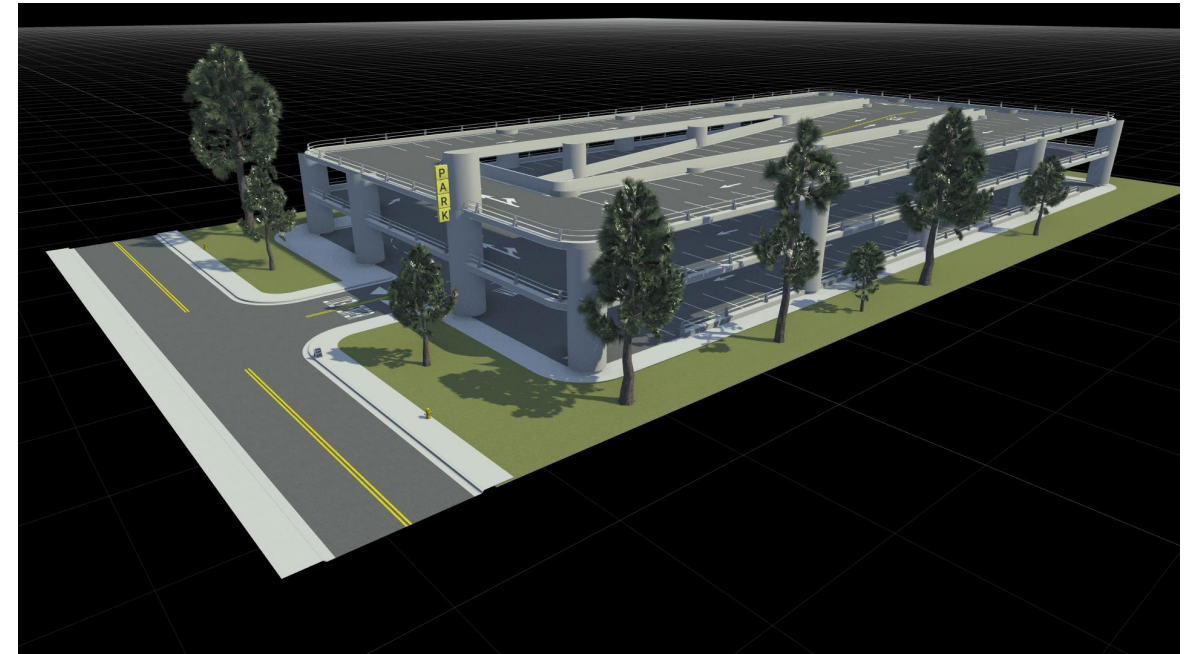
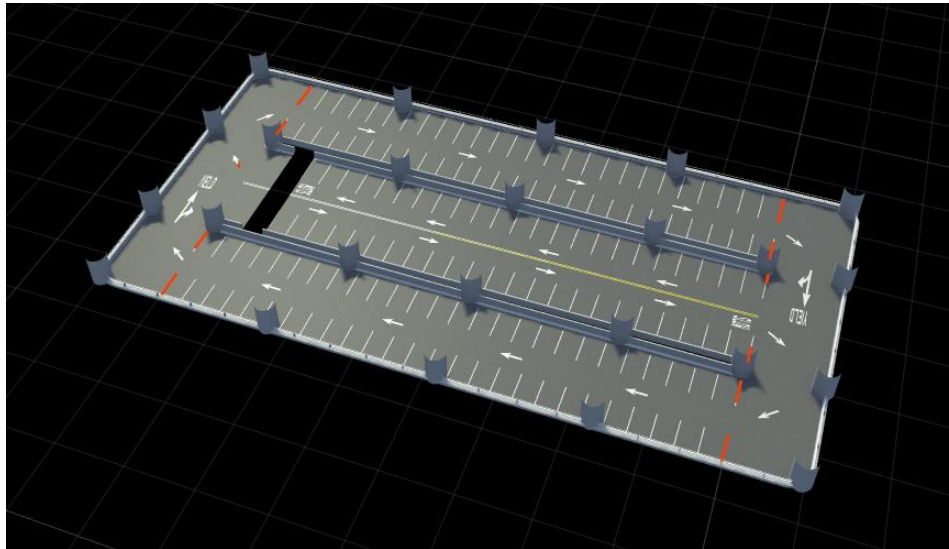


» [Merge Multiple RoadRunner Scenes](#)

# Templates to Repurpose Existing Scene Elements

## Reducing Repetitive Modelling Effort

Templates help to modularize complicated road networks which occur often like cloverleaves and interchanges, or parking spaces

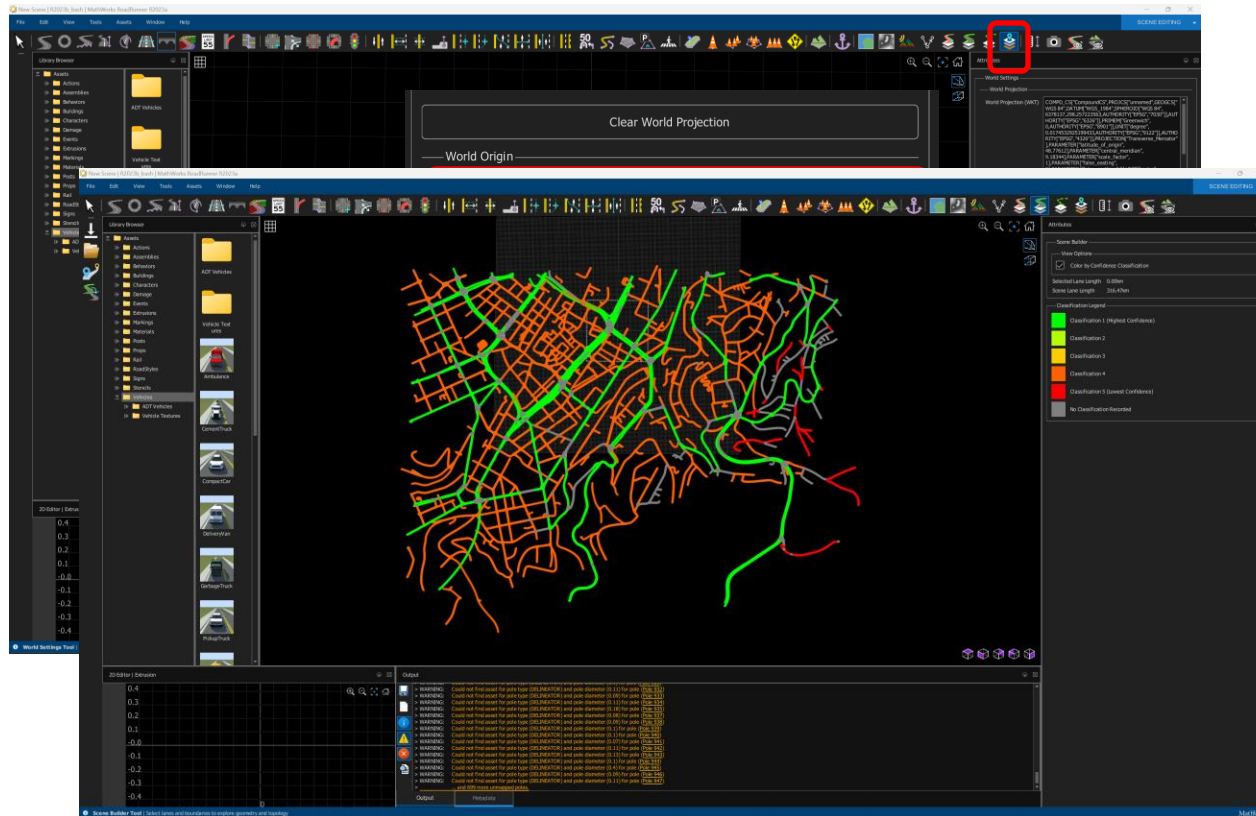


» [Create Parking Garage](#)

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# Automatic Synthesis of 3D Road Models from HD Map Providers



- Generate road networks from Here and TomTom HD maps
- Import data in Apollo or geoJSON\* formats
- Requires additional licenses for HERE or TomTom data access

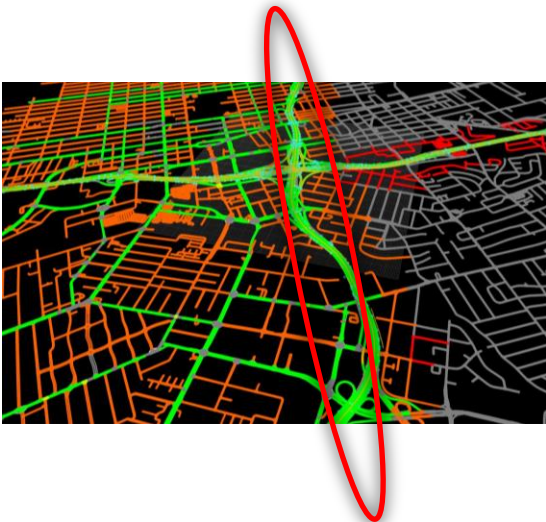
» [RoadRunner Scene Builder](#)

\*geoJSON Import currently available only via MATLAB API. No UI present in the application.



# Automate HD Map Route-based Selection and Scene Building

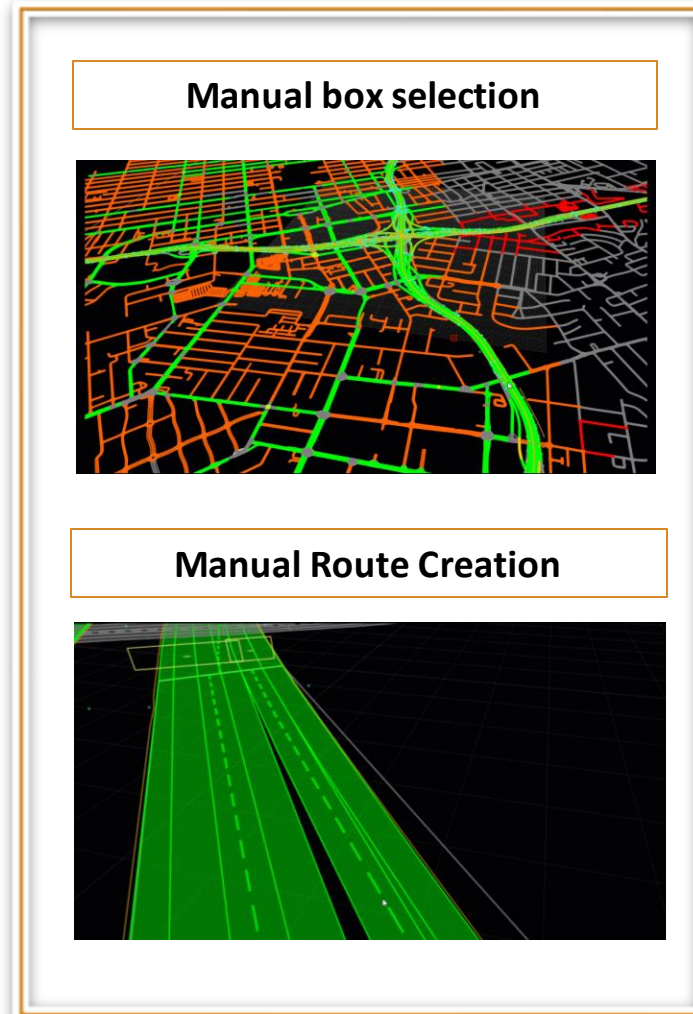
Imported HD Map  
represented in RR HD  
data model



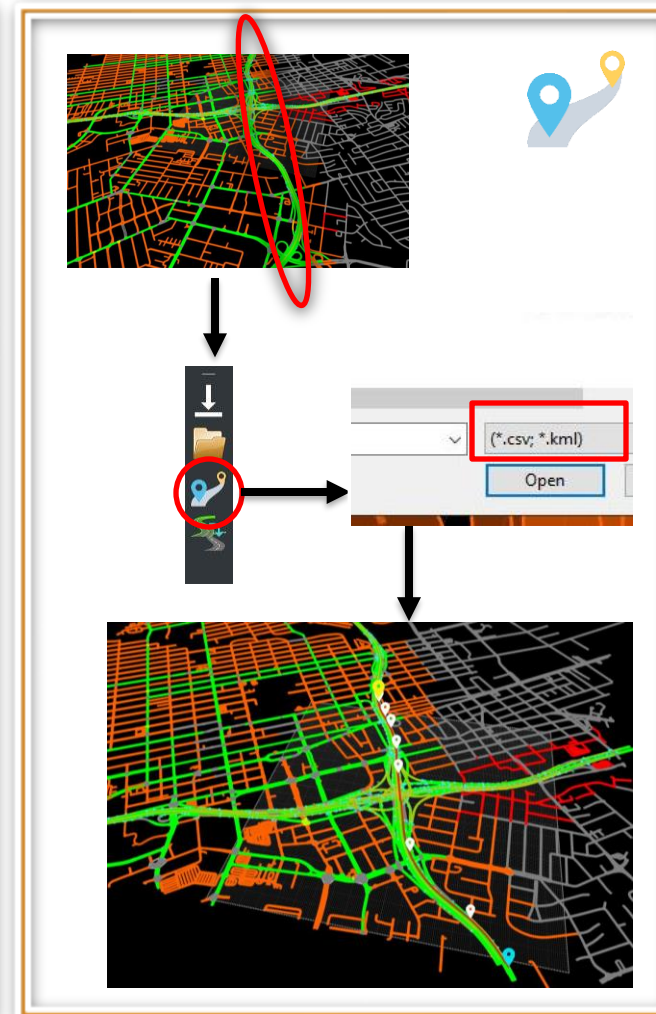
Region of Interest

» [Create Route and Build Scene Using HD Map Data](#)

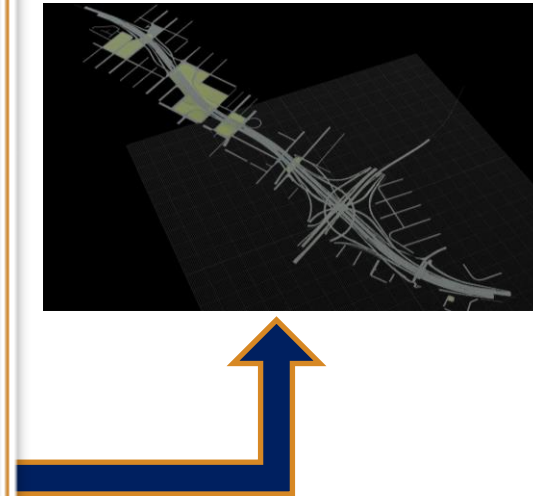
Current workflow



Build Route option

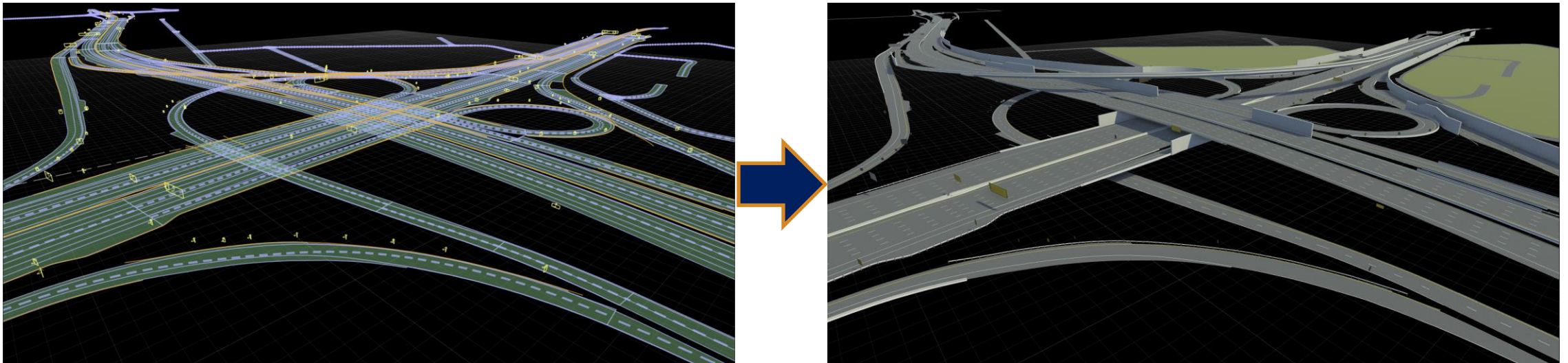


Build Scene with  
RoadRunner  
Scene Builder

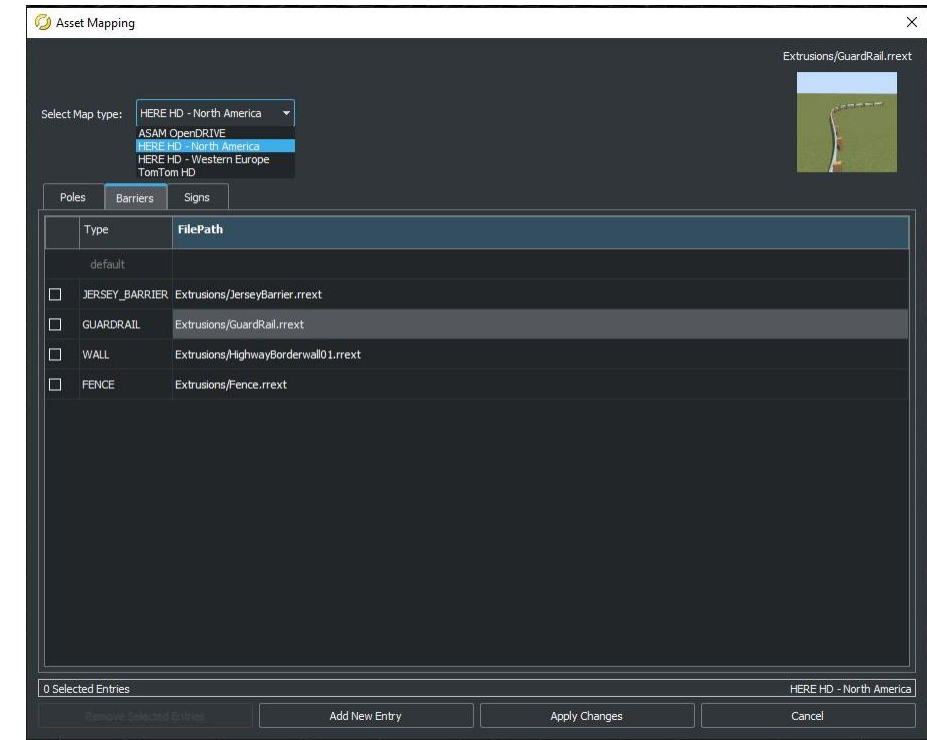
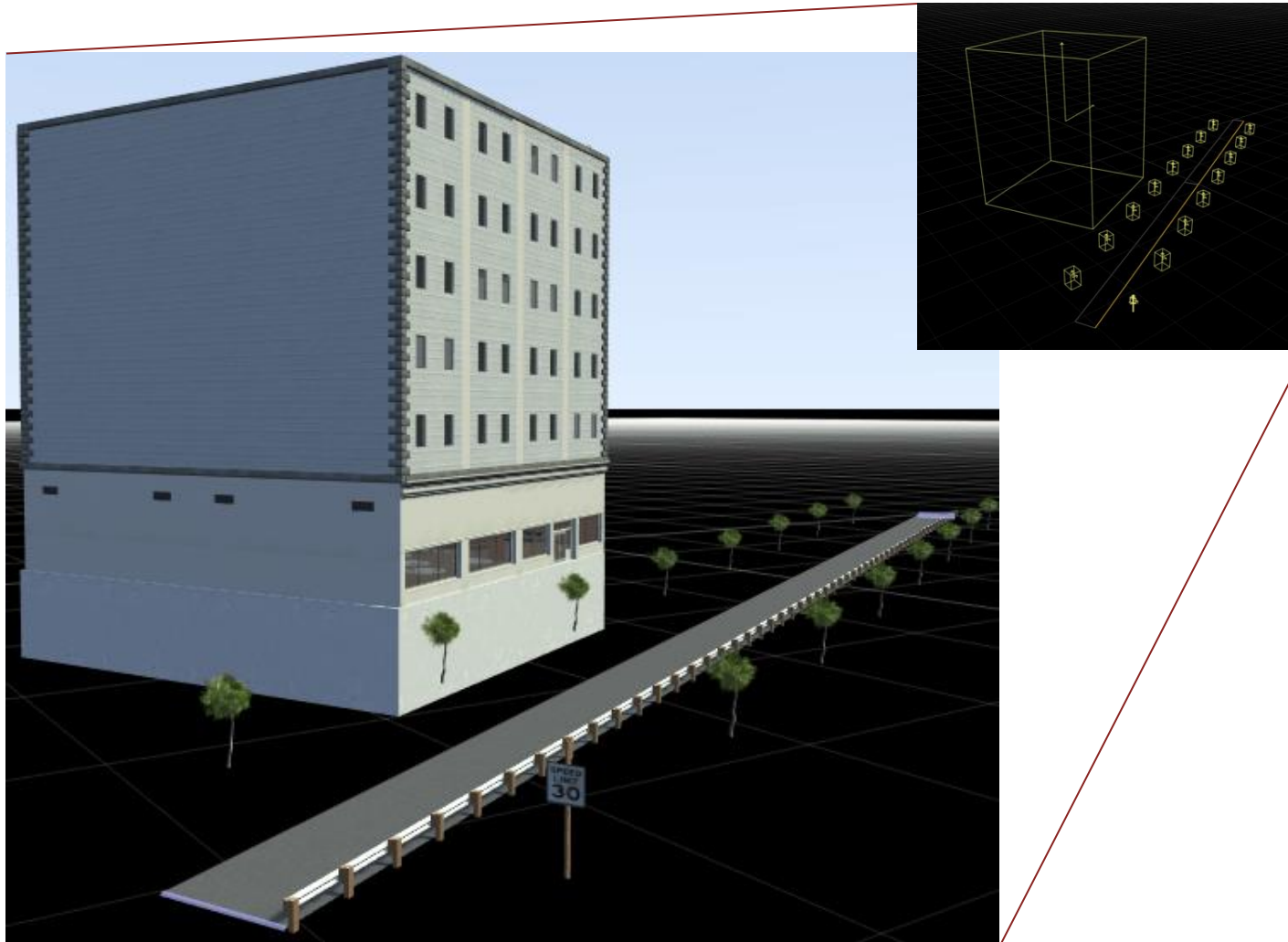


# RoadRunner HD Map for Representing HD Map Data in a scene

- RR HD is a Google protobuf based format that allows precise road information to be created and imported into RoadRunner. It is a documented generic, HD map format.
- Simple data structure to represent road layouts with semantics like lanes, lane boundaries, lane markings and junctions.
- References to existing more complex definitions for signs, barriers, and markings.



# Importing Non-Road Objects such as Buildings and Road Furniture



Any mesh format supported by RoadRunner can be built using Scene Builder

# RR HD Map MATLAB / gRPC APIs Enable Programmatic Creation of Road Networks or Importing Custom Data

RoadRunner also provides MATLAB functions to convert custom data into the RR HD Map data model and import your data.

- Define road semantics via API

- Lanes
- Lane Boundaries
- Lane Groups
- Junctions
- Barriers, Signs and Static Assets

» [Build Simple Roads Programmatically Using RoadRunner HD Map](#)

Create an empty RoadRunner HD Map as a roadrunnerHDMap object.

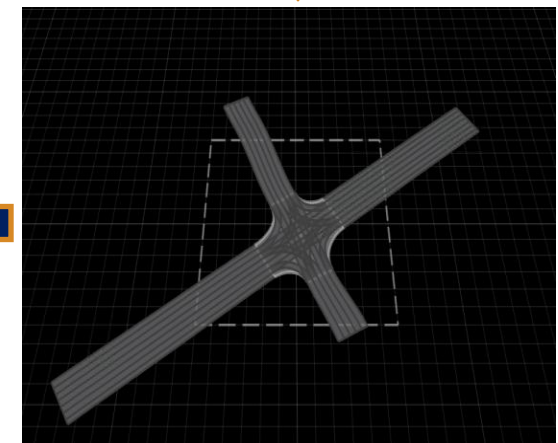
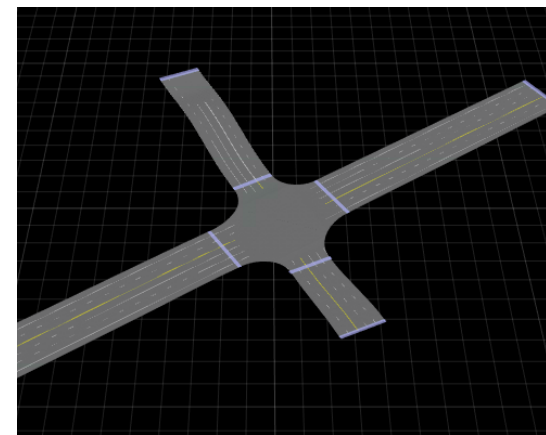
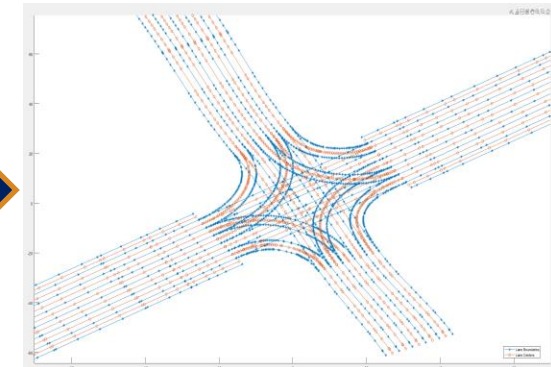
```
rrMap = roadrunnerHDMap;
```

Specify the lane and the lane boundaries. In this example, preinitialization of these values result

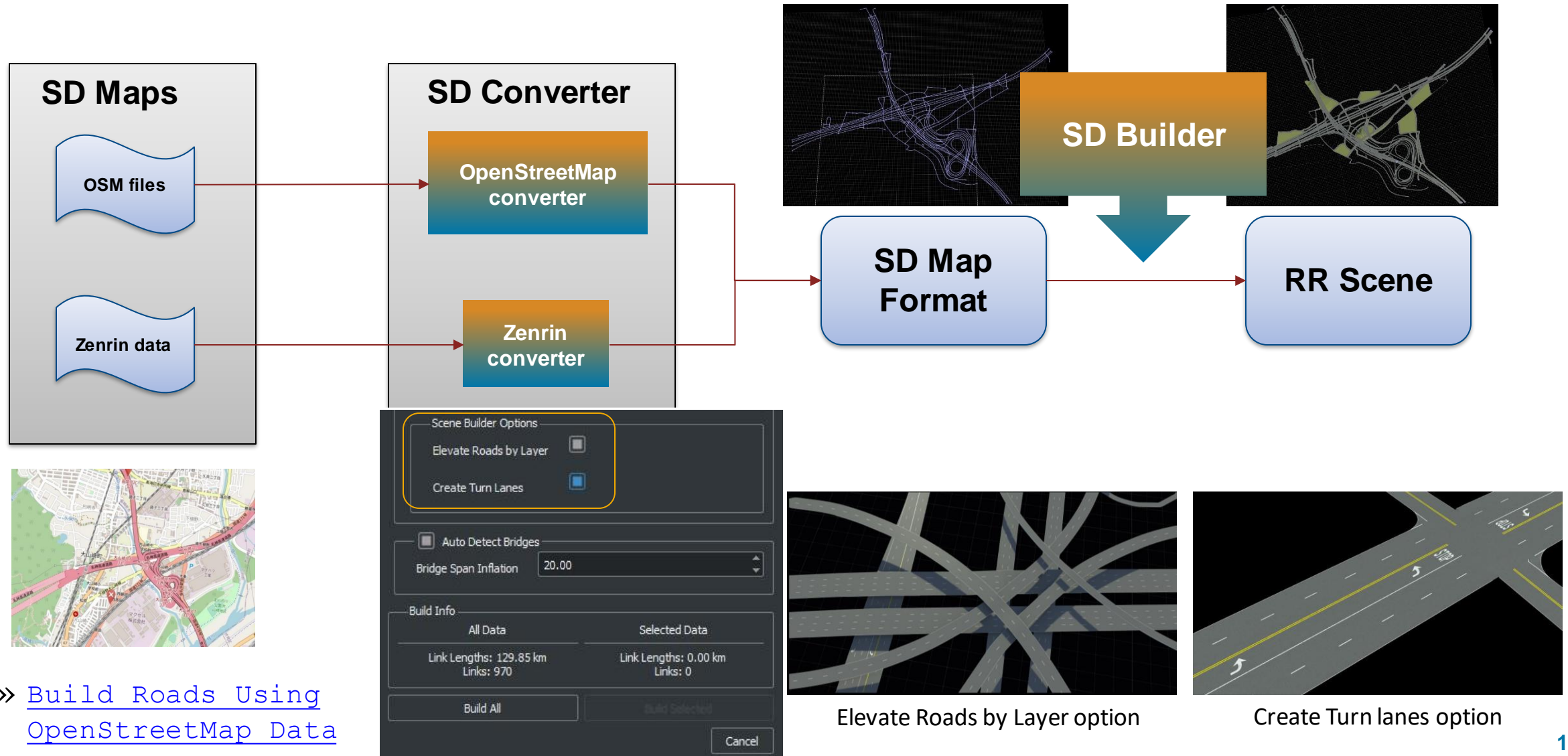
```
rrMap.Lanes(2,1) = roadrunner.hdmap.Lane();  
rrMap.LaneBoundaries(3,1) = roadrunner.hdmap.LaneBoundary();
```

Assign the Lane property values. Use the deal function to match up the input and the output list:

```
roadCenterLeft = roadCenters-[roadWidth/4 0];  
roadCenterRight = roadCenters+[roadWidth/4 0];  
[rrMap.Lanes.ID] = deal("Lane1","Lane2");  
[rrMap.Lanes.Geometry] = deal(roadCenterLeft,roadCenterRight);  
[rrMap.Lanes.TravelDirection] = deal("Backward","Forward");  
[rrMap.Lanes.LaneType] = deal("Driving");
```



# Build Scenes from SD Map Formats like OpenStreetMap<sup>®</sup> and Zenrin<sup>®</sup>



» [Build Roads Using OpenStreetMap Data](#)

# Headless Mode without GUI

```

MINGW64:/c:/Users/hwilliam/Documents/RoadRunner/tracetranst/_build/bin/ReleaseUnoptimized/bin/win64
hwilliam@ah-hwilliam MINGW64 ~/Documents/RoadRunner/tracetranst/_build/bin/ReleaseUnoptimized/bin/win64 (
HW_HdMapApiImport)
$ ./AppRoadRunner.exe --nodisplay
Started RoadRunner API server on port 35707.
Client API command succeeded (with input type 'mathworks.roadrunner.LoadProjectRequest'): 'Loaded Project
'C:\Users\hwilliam\Downloads\test_project'.'
Client API command succeeded (with input type 'mathworks.roadrunner.NewSceneRequest'): 'Created a new Scene.'
Loading OpenDRIVE file 'C:/Users/hwilliam/Downloads/test_project/Assets/opendrive_file.xodr'
Finished loading file 'C:/Users/hwilliam/Downloads/test_project/Assets/opendrive_file.xodr' with 92 roads
WARNING: Projection mode not specified. Setting projection mode to 'Translate Only'.
WARNING: Scene projection has been set to Transverse Mercator centered at zero degrees latitude and longitude.
WARNING: World location has been set to center of OpenDRIVE file data.
Client API command succeeded (with input type 'mathworks.roadrunner.ImportRequest'): 'Imported 'C:/Users/h
william/Downloads/test_project/Assets/opendrive_file.xodr'.'
Exported 'C:/Users/hwilliam/Downloads/test_project/Exports/filmbox_file.fbx'
Client API command succeeded (with input type 'mathworks.roadrunner.ExportRequest'): 'Exported 'C:/Users/h
william/Downloads/test_project/Exports/filmbox_file.fbx'.'
Client API command succeeded (with input type 'mathworks.roadrunner.ExitRequest'): 'Application will exit
now.'

```



- Allows for improved integration with CI systems
- Enables running multiple instances of RoadRunner without graphics overhead
- Invokable via command line argument or MATLAB function

## Performance Tests

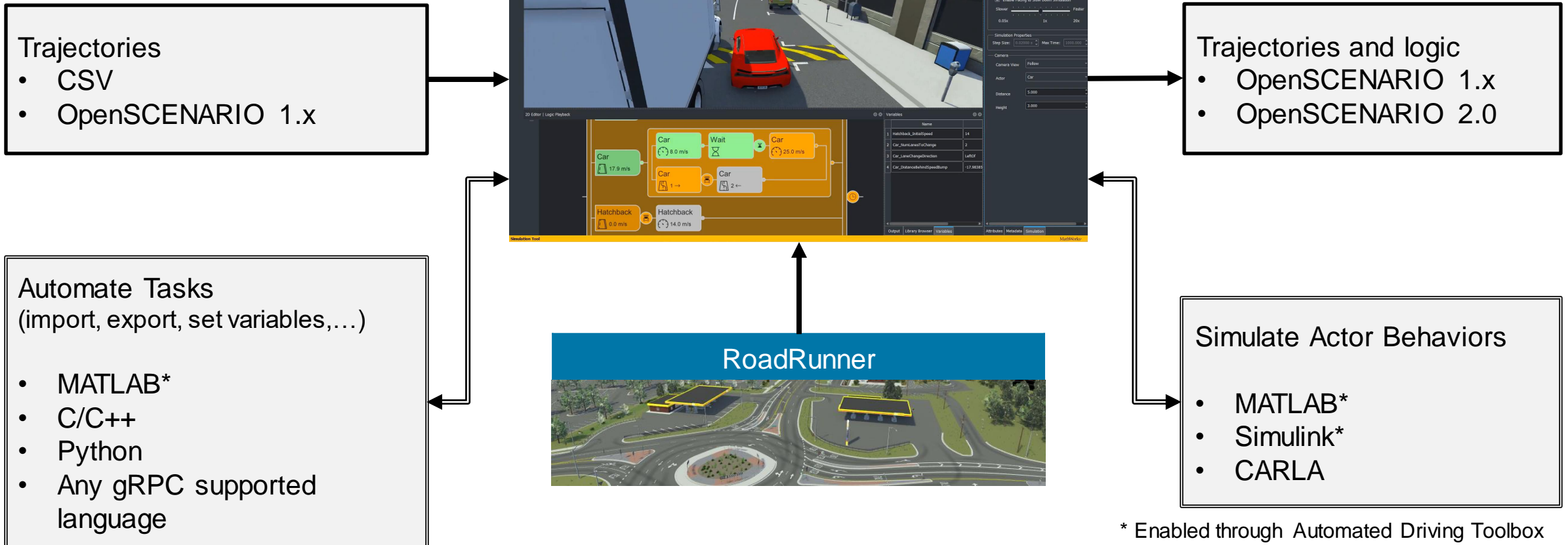
| Mode     | Opening SafetyCity.rrscene |
|----------|----------------------------|
| Headless | 27 seconds                 |
| GUI      | 122 seconds                |

» [Control RoadRunner Programmatically in Console Mode](#)

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# Design Scenarios for Automated Driving Applications





# Interactively Design Scenarios with RoadRunner Scenario

The screenshot displays the MathWorks RoadRunner Scenario Editor interface. The main window shows a 3D perspective view of a road scene with a speed bump. A red car is positioned on the road, and a blue arrow indicates its path. The interface includes a menu bar (File, Edit, View, Tools, Assets, Window, Help) and a toolbar. The bottom section is divided into three panels: a 2D Editor/Logic panel showing a logic node for 'SK\_MuscleCar' with a speed of 17.9 m/s, a Library Browser panel listing various assets like 'SK\_BoxTruck', 'SK\_Hatchback', 'SK\_MuscleCar', and 'SK\_Pickup Truck', and an Attributes panel for the selected 'SK\_MuscleCar' actor. The Attributes panel includes fields for Name, Actor Id, Color, Vehicle Type, Behavior, Point Offsets (Enable Anchoring, Anchor, Lock To Anchor, Forward Offset), Reference Line (Front, Origin, Back), Lane Offset (Relative To, Offset From, Lane Offset), and With Road Anchor.

SpeedBump Actions.rsscenario | 22a Project | MathWorks RoadRunner R2022a

File Edit View Tools Assets Window Help

Scenario Editing

Attributes

Vehicle

Name SK\_MuscleCar

Actor Id 1

Color

Vehicle Type SK\_MuscleCar.fbx\_rn

Behavior

Point Offsets

Enable Anchoring

Anchor SpeedBump

Lock To Anchor

Forward Offset

Forward Offset -20.17 m

Reference Line

Front

Origin

Back

Lane Offset

Relative To Road Edge

Offset From

Left Lane

Right Lane

Lane Offset 1 lane(s)

With Road Anchor

2D Editor | Logic

Library Browser

Assets

Actions

Assemblies

Behaviors

Buildings

Damage

Developer

Extrusions

Markings

Materials

Posts

Props

Rail

Vehicles Textures

SK\_BoxTruck

SK\_Hatchback

SK\_MuscleCar

SK\_Pickup Truck

SK\_Sedan

SK\_SUV

SK\_MuscleCar

17.9 m/s

Place Actors

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

MathWorks

# Interactively Design Scenarios with RoadRunner Scenario

The screenshot displays the MathWorks RoadRunner Scenario Editor interface. The main window shows a 3D perspective view of a road intersection with several vehicles (a white truck, a red car, a yellow car, and a white car) and a speed bump. A purple anchor icon is visible on the road. The interface includes a menu bar (File, Edit, View, Tools, Assets, Window, Help) and a toolbar. The bottom-left pane shows a logic editor with a flowchart containing nodes for 'Truck' (2.0 m/s), 'Car' (17.9 m/s), 'Hatchback' (0.0 m/s), 'Sedan' (0.0 m/s), and 'Pickup' (17.9 m/s). A context menu is open over the 'Car' node, listing options: 'Add Action Phase After', 'Add Action Phase Above', 'Add Action Phase Below', 'Delete Selection', and 'Set as Initial Phase'. The bottom-right pane shows the 'Attributes' panel for the selected 'Car' actor, with settings for 'Action Type' (Change Speed), 'Relative to' (Absolute), 'Speed' (8.00 m/s), 'Dynamics Type' (With acceleration), and 'Acceleration' (4.00 m/s<sup>2</sup>). The bottom status bar reads 'Scenario Edit Tool | Right click to create new routes or insert nodes into existing routes.' and 'MathWorks'.

SpeedBump Actions.rsscenario | 22a Project | MathWorks RoadRunner R2022a

File Edit View Tools Assets Window Help

Scenario Editing

Attributes

Action Phase

Name

Action Type Change Speed

Actor Car

Change Speed

Relative to Absolute

Speed 8.00 m/s

Dynamics

Dynamics Type With acceleration

Acceleration 4.00 m/s<sup>2</sup>

2D Editor | Logic

Library Browser

Assets

- Actions
- Assemblies
- Behaviors
- Buildings
- Damage
- Developer
- Extrusions
- Markings
- Materials
- Posts
- Rail
- RoadStyles
- Signs
- Stencils
- Vehicles
  - ADT Vehicles
  - Trailers

ADT Vehicles

Trailers

Vehicle Textures

Ambulance

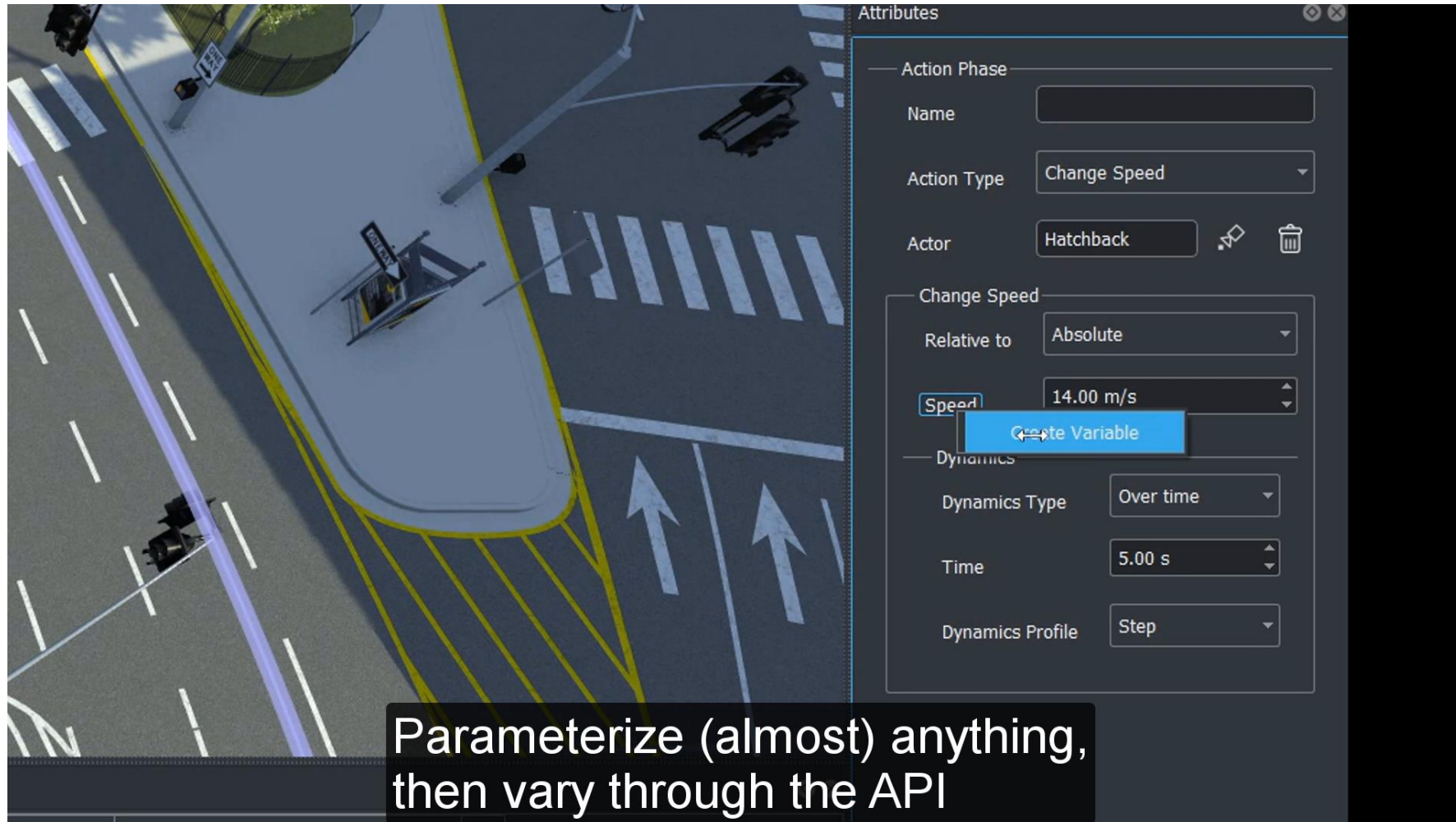
Output Library Browser Variables Attributes Metadata

MathWorks

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

**Add Actions**

# Interactively Design Scenarios with RoadRunner Scenario



The image displays a 3D simulation of a road intersection with a car and a truck. An 'Attributes' panel is overlaid on the right side, showing the configuration for a 'Change Speed' action. The panel includes fields for Name, Action Type (Change Speed), Actor (Hatchback), and Change Speed settings (Relative to: Absolute, Speed: 14.00 m/s). A 'Dynamics' section shows Dynamics Type (Over time), Time (5.00 s), and Dynamics Profile (Step). A 'Create Variable' button is highlighted over the Speed field.

Parameterize (almost) anything,  
then vary through the API

# Interactively Design Scenarios with RoadRunner Scenario

SpeedBump Actions.rsscenario | 22a Project | MathWorks RoadRunner R2022a

File Edit View Tools Assets Window Help

Scenario Editing

Simulation

Simulation Controls

Pause Step Forward Stop

Time: 1.640 s

Enable Facing to Slow Down Simulation

Slower  Faster

0.05x 1x 20x

Simulation Properties

Step Size: 0.02000 s Max Time: 1000.000

Camera

Camera View: Follow

Actor: Car

Distance: 5.000

Height: 3.000

2D Editor | Logic Playback

Variables

| Name                        | Value     |
|-----------------------------|-----------|
| Hatchback_InitialSpeed      | 14        |
| Car_NumLanesToChange        | 2         |
| Car_LaneChangeDirection     | LeftOf    |
| Car_DistanceBehindSpeedBump | -17.98385 |

Simulation Tool

MathWorks

The logic editor shows a flowchart with the following elements:

- A green 'Car' block with a speed of 17.9 m/s.
- A green 'Car' block with a speed of 8.0 m/s.
- A green 'Wait' block.
- An orange 'Car' block with a speed of 25.0 m/s.
- An orange 'Car' block with a lane change icon (1 →).
- A grey 'Car' block with a lane change icon (2 ←).
- An orange 'Hatchback' block with a speed of 0.0 m/s.
- A grey 'Hatchback' block with a speed of 14.0 m/s.

# Learn About New Features to Design Scenarios

## Pedestrian Actors



[Character Assets](#)  
*RoadRunner Scenario*

## Actor Groups



[Truck & Trailer Scenario](#)  
*RoadRunner Scenario*

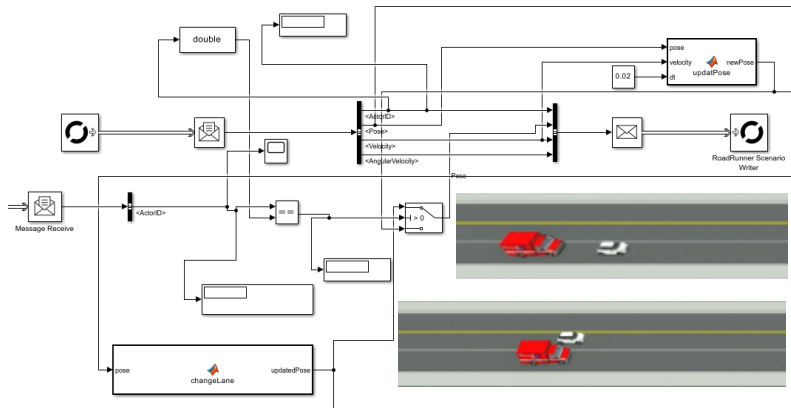
## Reverse Motion



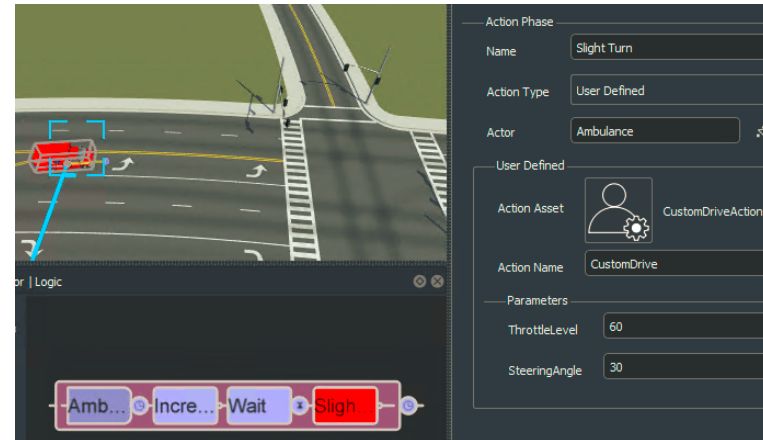
[Reverse Motion Along Lane](#)  
*RoadRunner Scenario*

# Learn About New Features to Design Scenarios

## User-Defined Events



## User-Defined Actions



## Offline Simulation Playback



[Design Vehicle Following User-Defined Events Scenario](#)  
RoadRunner Scenario, Automated Driving Toolbox

[Design Vehicle Following User-Defined Actions Scenario](#)  
RoadRunner Scenario

[Replay Simulation from Saved File](#)  
RoadRunner Scenario, Automated Driving Toolbox

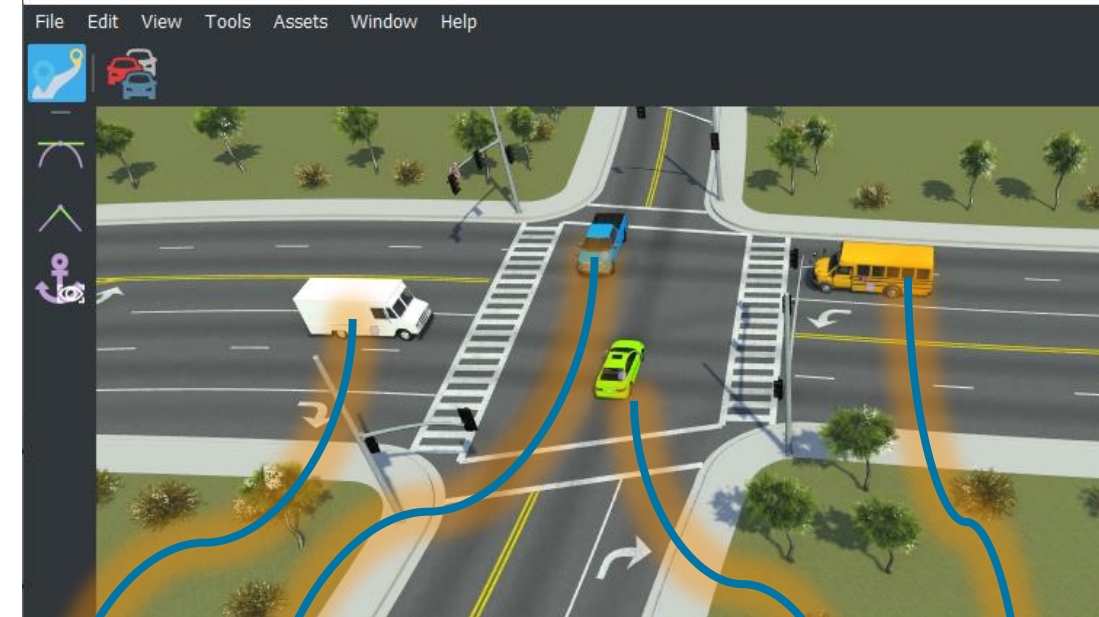
# Simulate Scenarios with Actor Behaviors in Multiple Simulators

## Simulate Actors with MATLAB and Simulink

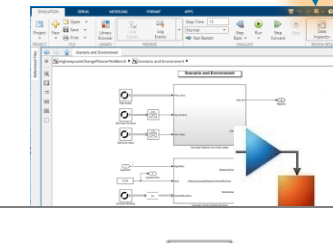
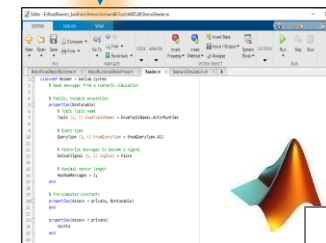
- Author MATLAB System objects or Simulink models to define actor behavior
- Tune parameters defined in MATLAB or Simulink
- Optionally, publish actor behavior as proto file or package

## Cosimulate Actors with CARLA

- Associate CARLA behavior with vehicles
- Export scenes and visualizations to CARLA
- Run cosimulation with CARLA



Built-in  
Actors



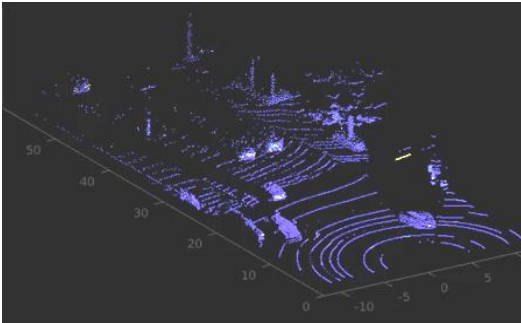
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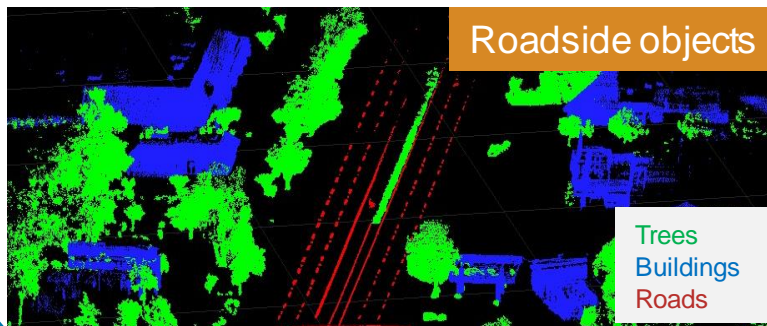
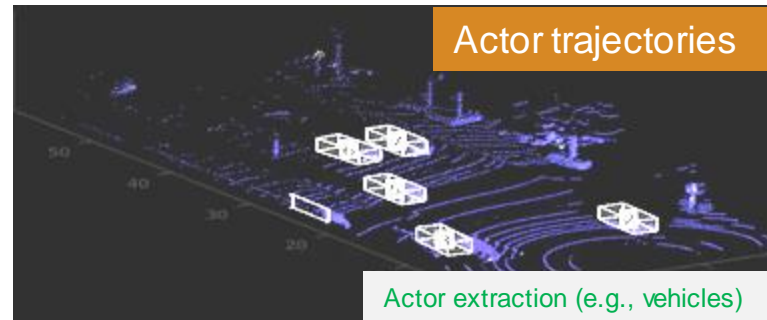


# Scenario Builder Support Package: Virtualizing Real-World Sensor Data

## Recorded sensor data

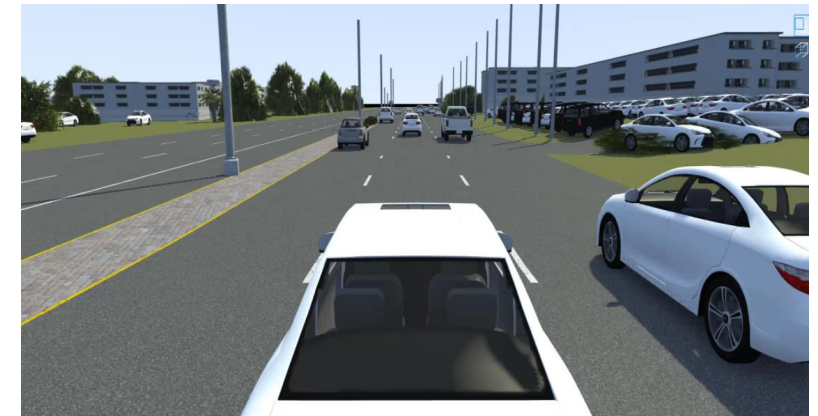


## Scenario Builder



Analysis, Extraction and Localization of static and dynamic objects

## Reconstructed RoadRunner Scenario



Virtual scenarios mimicking real-world sensor data

# Use Real-World Sensor Data Processing Tools to Create Virtual Scenarios by Leveraging Vehicle Test Logs



Recorded sensor data



RoadRunner Scenario

Type of objects extracted from recorded sensor data:

- **Camera (raw):** Lanes,
- **Lidar (raw):** Vehicles,
- **Lidar (labelled):** Traffic cones, trees, buildings, traffic lights, medians

# Scenario Builder Support Package

Provide real-world sensor data processing tools to create virtual scenarios



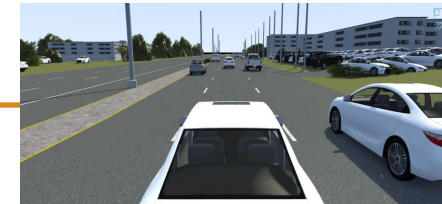
Recorded  
sensor data

**Ego  
localization**

**Road  
reconstruction**

**Roadside  
objects  
reconstruction**

**Target actor  
trajectory  
reconstruction**



RoadRunner  
Scenario

**Scenario Builder for Automated Driving Toolbox**  
by MathWorks Automated Driving Toolbox Team **STAFF**  
Build simulation scenarios from real-world vehicle data recorded from GPS, IMU, camera, and lidar sensors

138 Downloads  
Updated 14 Jun 2023

+ Follow Download

Overview Reviews (0) Discussions (1)

The Scenario Builder for Automated Driving Toolbox, allows users to generate simulation scenarios for automated driving applications. It provides functions that help to generate scenarios from both raw real-world vehicle data and processed object data.

With RoadRunner Scene Builder, users can visualize the generated scenes with roads, lanes, and roadside objects. The generated scenes can then be exported to ASAM OpenDRIVE® format. On the other hand, RoadRunner Scenario tool can generate scenario actors, such as vehicles, along their trajectories. The resulting scenarios can be exported to ASAM formats.

The generated scenes and scenarios can be used for designing and testing automated driving applications.

**Getting Started**

- Overview of Scenario Generation from Recorded Data
- Documentation
- Examples

**Features**

Scenario generation using recorded sensor data is accomplished using below workflow:

## Programmatic APIs

actorprops  
actorTracklist  
laneData  
laneBoundaryTracker

## Ease of use tools



## AI based Automation



<https://www.mathworks.com/matlabcentral/fileexchange/117450-scenario-builder-for-automated-driving-toolbox>

# Ego Localization

Sensor data

**Ego  
localization**

Road  
reconstruction

Roadside  
objects  
reconstruction

Target actor  
trajectory  
reconstruction

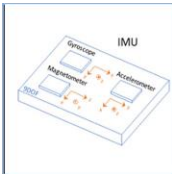
RoadRunner  
Scenario

**Pose correction**

**Offset correction**



GPS



IMU



Lanes



HD Map

- Correct position and orientation of ego actor using GPS and IMU fusion
- Correct single/multi-lane level offsets using GPS, lane information and HD maps

# Road Reconstruction

Sensor data

Ego  
localization

Road  
reconstruction

Roadside  
objects  
reconstruction

Target actor  
trajectory  
reconstruction

RoadRunner  
Scenario



GPS



Camera



LiDAR



- Extract lanes, road boundaries from camera and lidar data
- Reconstruct road with lane add/drop, road curvature and junctions

# Roadside Objects Reconstruction

Sensor data

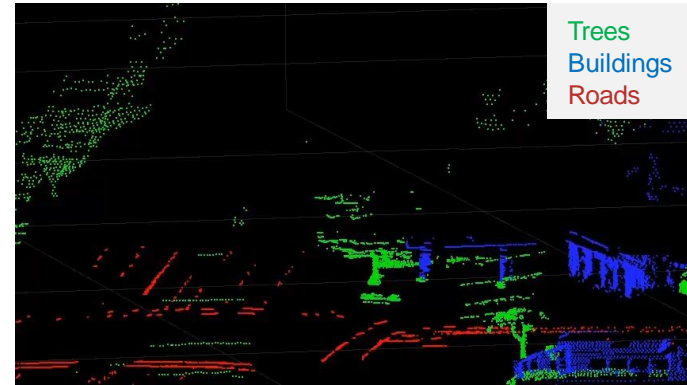
Ego  
localization

Road  
reconstruction

Roadside  
objects  
reconstruction

Target actor  
trajectory  
reconstruction

RoadRunner  
Scenario



GPS



Camera



LiDAR

- Labelled Lidar data is used to reconstruct trees, buildings and other roadside objects.
  - Labels supported: buildings, trees, bushes, traffic cones, pylons, barricades, and electric poles

# Trajectory Reconstruction

Sensor data

Ego  
localization

Road  
reconstruction

Roadside  
objects  
reconstruction

**Target actor  
trajectory  
reconstruction**

RoadRunner  
Scenario



Camera



LiDAR



RADAR



- Reconstruct dynamic actors from raw sensor data or track lists.
- Lidar sensor data can enable extraction of objects from all the sides of the ego vehicle whereas radar sensor data can enable farther objects.
- Camera sensor data can help identify object classes (car, truck etc.)

# “Scenario Harvesting” from Recorded Sensor Data



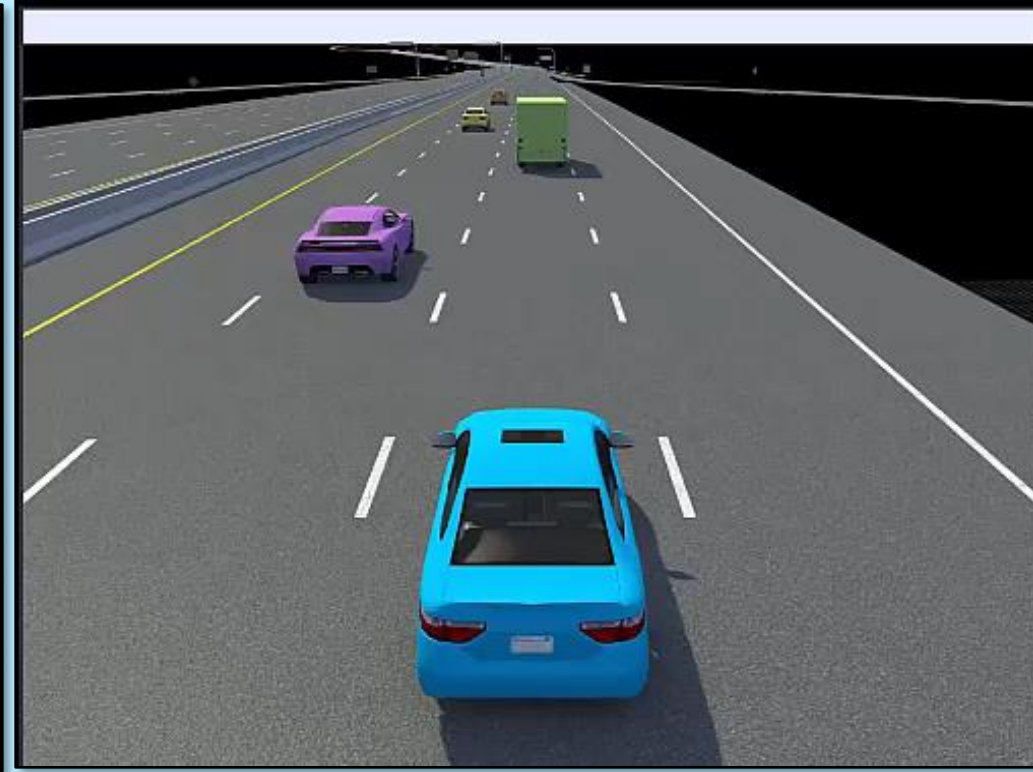
Recorded sensor data from test drive

Windshield Camera



Goal: Create cloud scenario database for ADAS/AD

RoadRunner Scenario



our customers

ASAM  
OpenSCENARIO®

Type of objects extracted from recorded sensor data:

**Camera:** Lanes, **Lidar/Radar:** Vehicles



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# Scenario Variant Generator

## 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



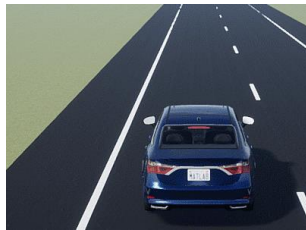
[Generate Scenario Variants by Modifying Actor Dimensions](#)



[Generate Variants of ACC Target Cut-In Scenario](#)



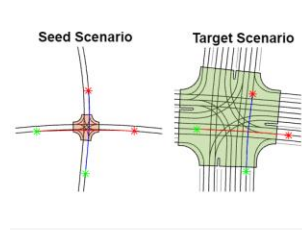
[Generate Scenario Variants for Testing ACC Systems](#)



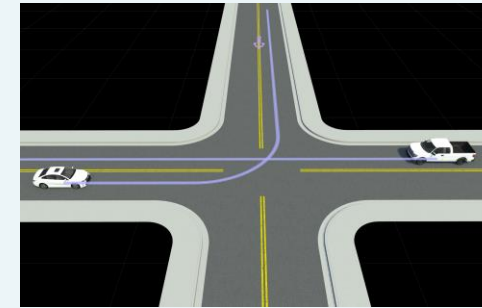
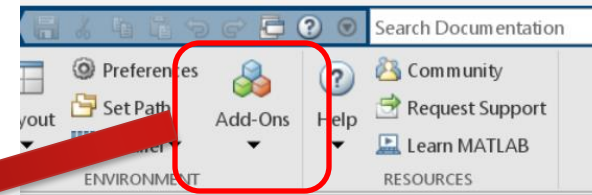
[Generate Scenario Variants for Lane Keep Assist Testing](#)



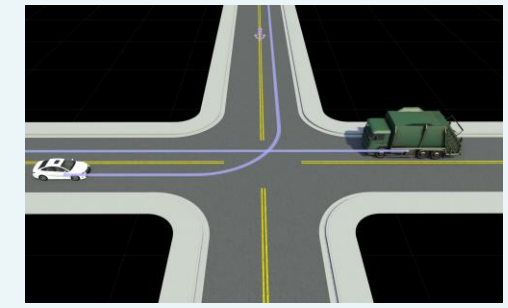
[Generate Scenario Variants for Testing AEB Pedestrian Systems](#)



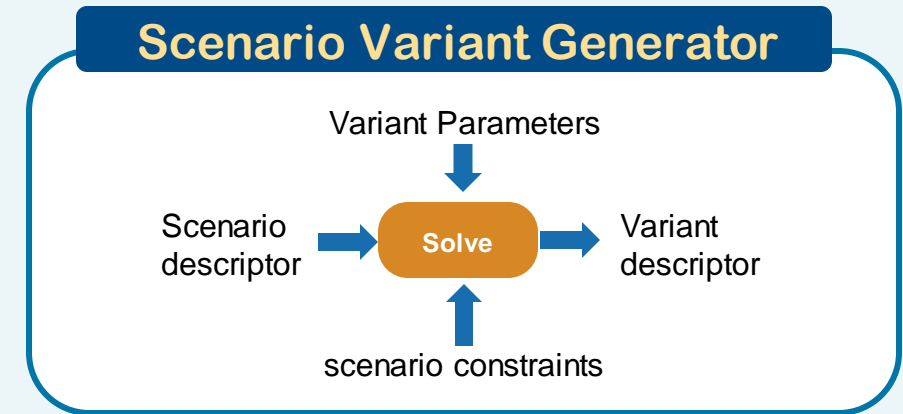
[Translocate Collision from Seed Scenario to Target Scene](#)



Seed Scenario



Variant Scenario

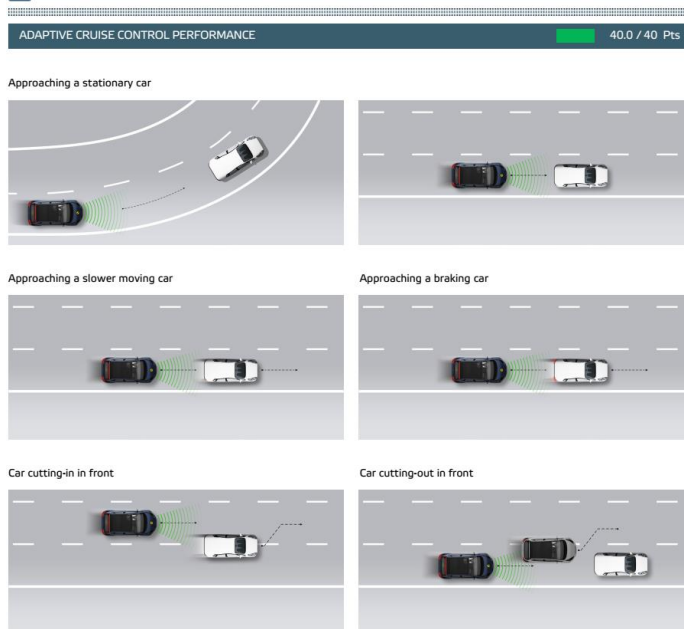


Generate variants from seed scenario

# Generate EURO NCAP scenario variants



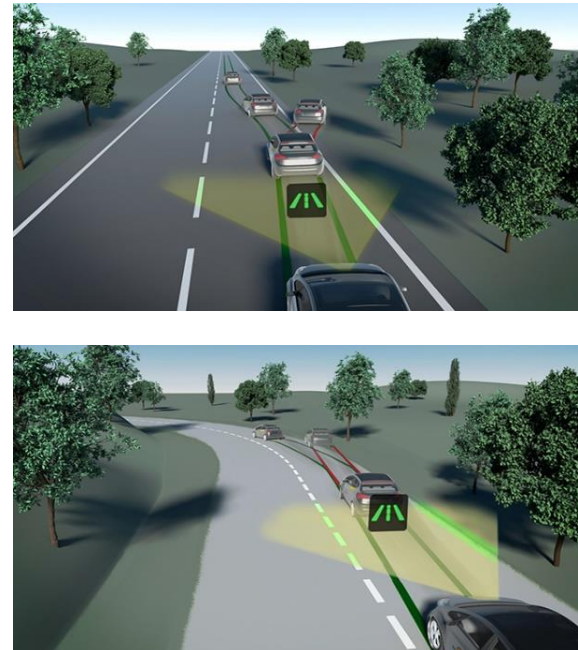
## ACC



### Variant parameters for testing ACC

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

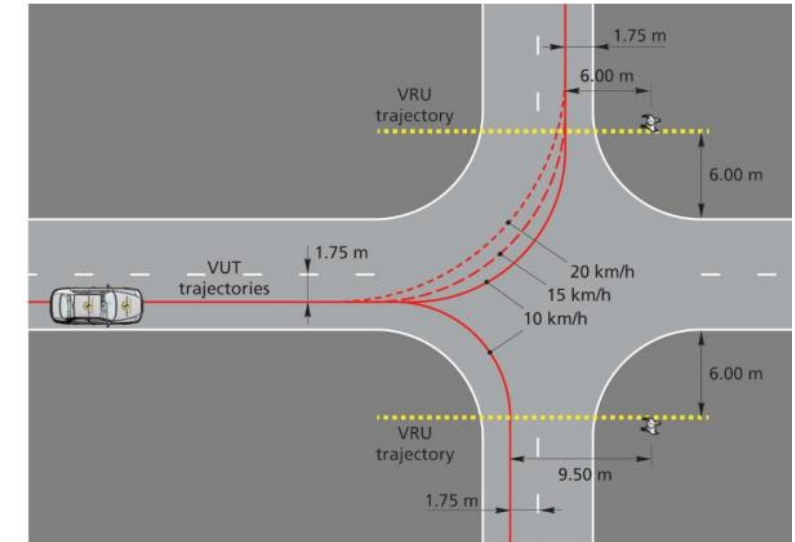
## LKA



### Variant parameters for testing LKA

- Ego speed
- Road Variation

## AEB



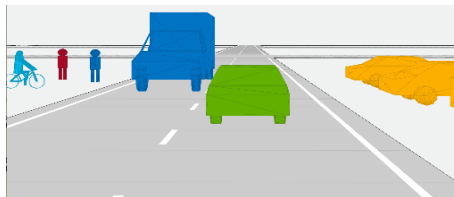
### Variant parameters for testing AEB

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

# Variant generation workflow from seed scenario data

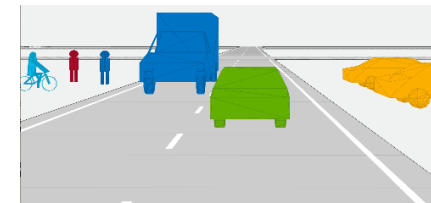


RoadRunner Scenario



DS Scenario

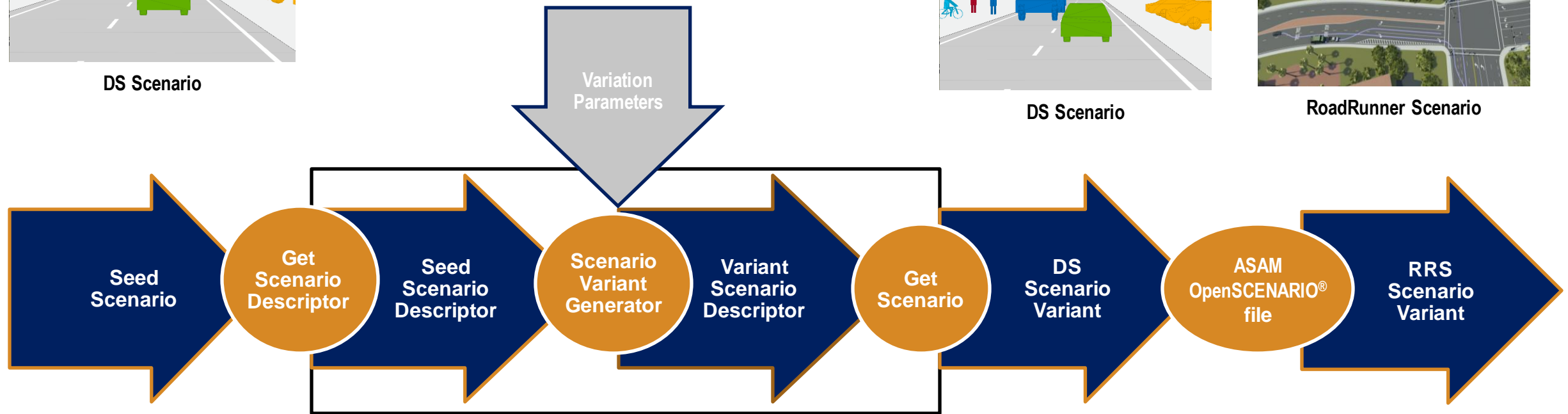
Support both drivingScenario and RoadRunner Scenario



DS Scenario



RoadRunner Scenario



## Key Takeaways

- Collaborate with other users for distributed scene modelling.
- API based scene creation or convert custom HD formats with RR HD.
- Import SD and HD maps to build scenes for real world locations.
- User-defined events and actions for complex scenario logic.
- Generate scene and scenario from real sensor data.
- Generate variants based on seed scenario.



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**Thank you**

