2024 MathWorks
中国汽车年会

Automated Driving in the Urban Environment with RoadRunner Scenario

Seo-Wook Park, MathWorks

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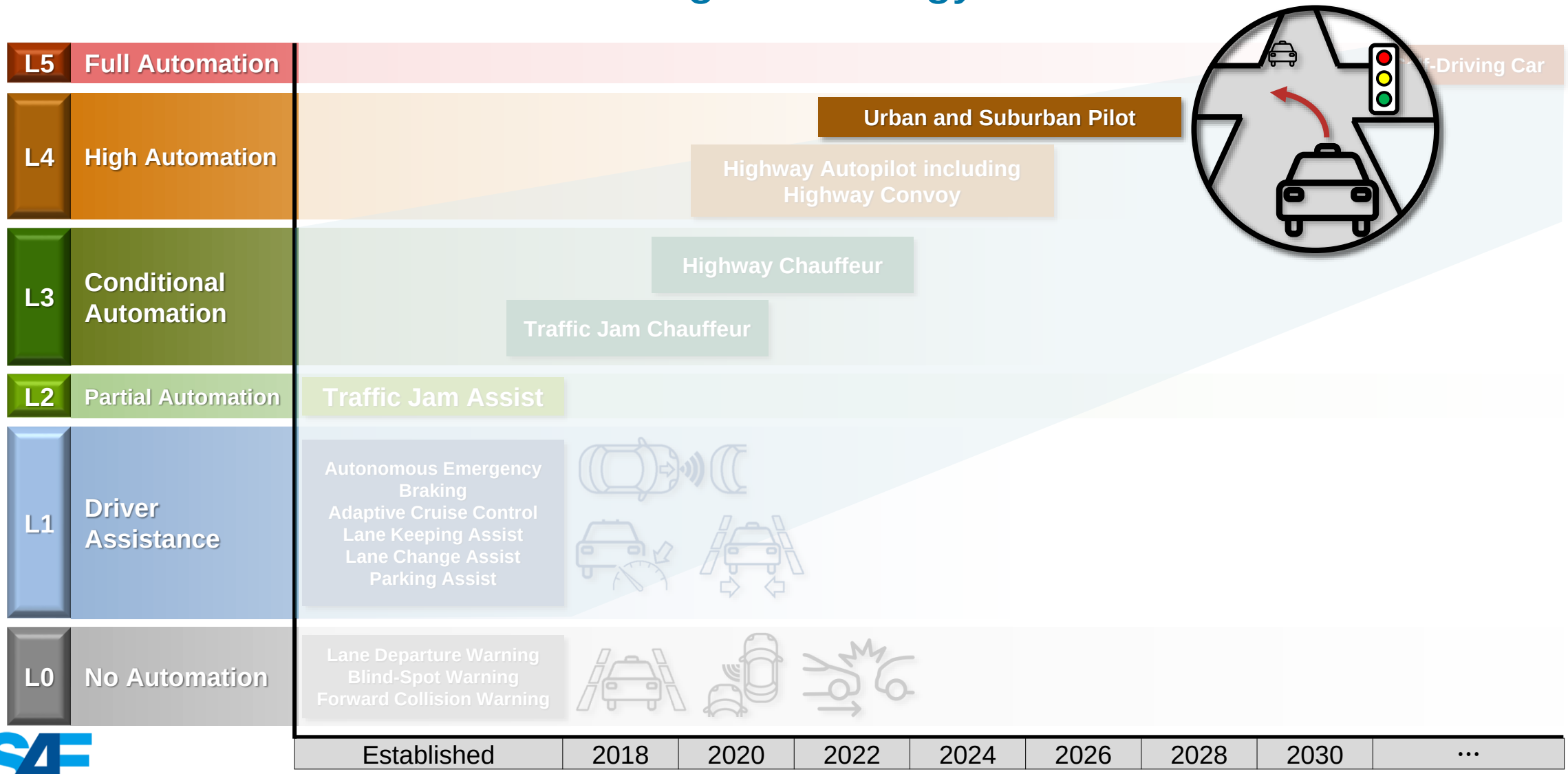
Evolution of Automated driving technology

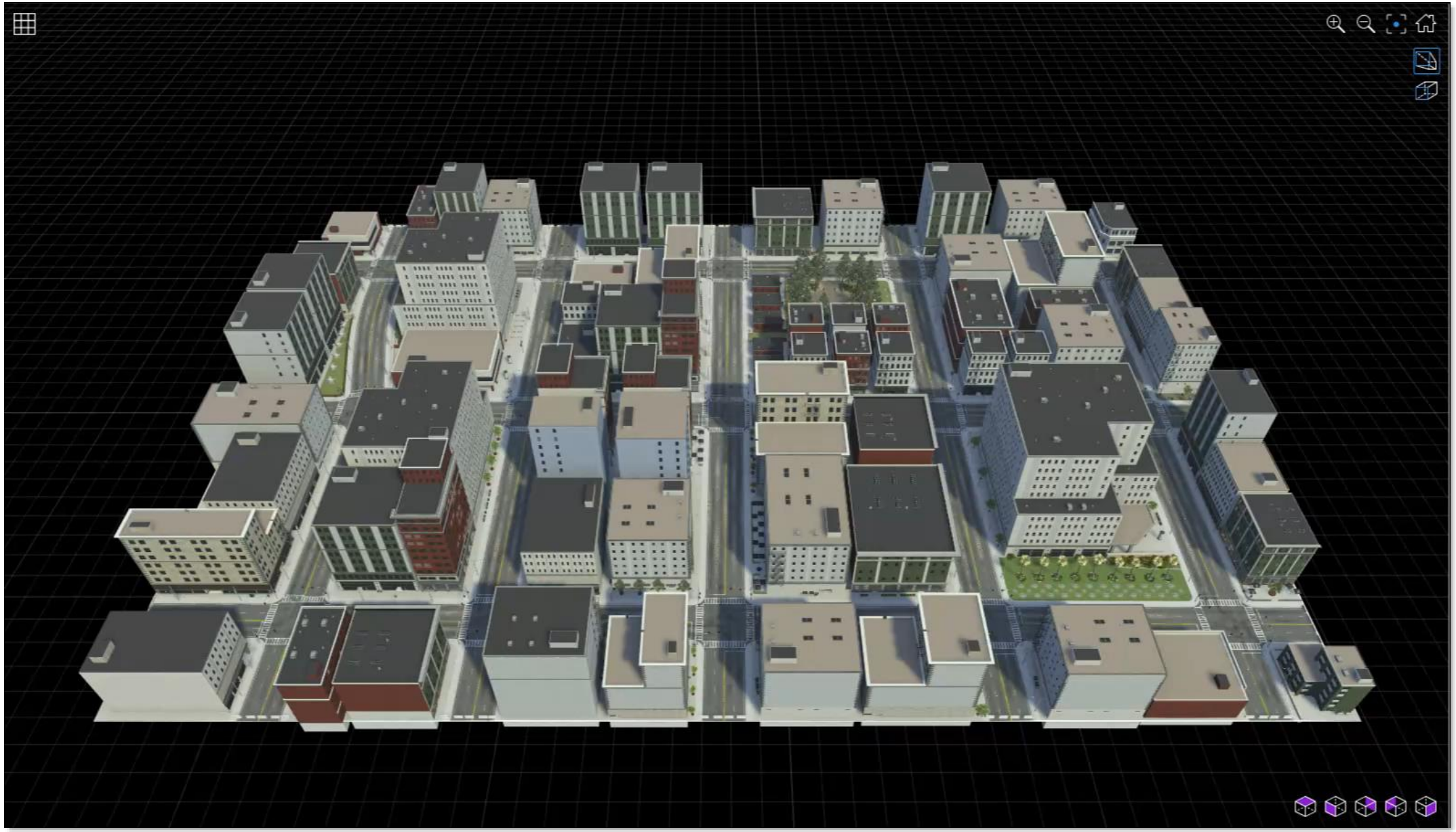


Source: https://www.ertrac.org/wp-content/uploads/2022/07/ERTRAC-CAD-Roadmap-2019.pdf

Challenges for Automated Driving in the Urban Environment

- Complex road geometry and maneuvering in the intersections with traffic signals
- Sensor and perception limitations
  - Limited sensor FoV, Sensor occlusion
- Communication and connectivity issues
  - GPS signal loss, V2X communication
- Infrastructure, regulatory, and standard considerations
  - V2X standards SAE J2735, ETSI TS 101 539, T/CSAE 53-2020
  - DSRC, Cellular-V2X, LTE C-V2X, 5G C-V2X
  - AV regulations

Traffic light follower at urban intersections

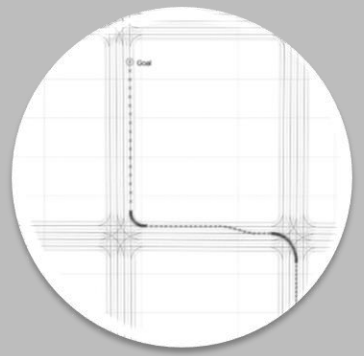


Workflow

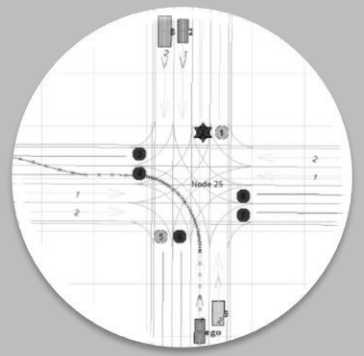
Note) V2X: Vehicle-To-Everything, SPaT: Signal Phase and Timing

Workflow

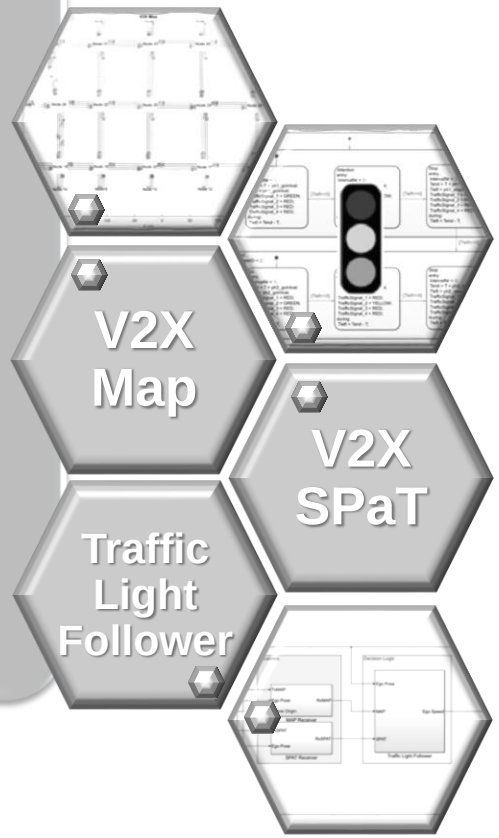
Create Urban Scene



Path Planner

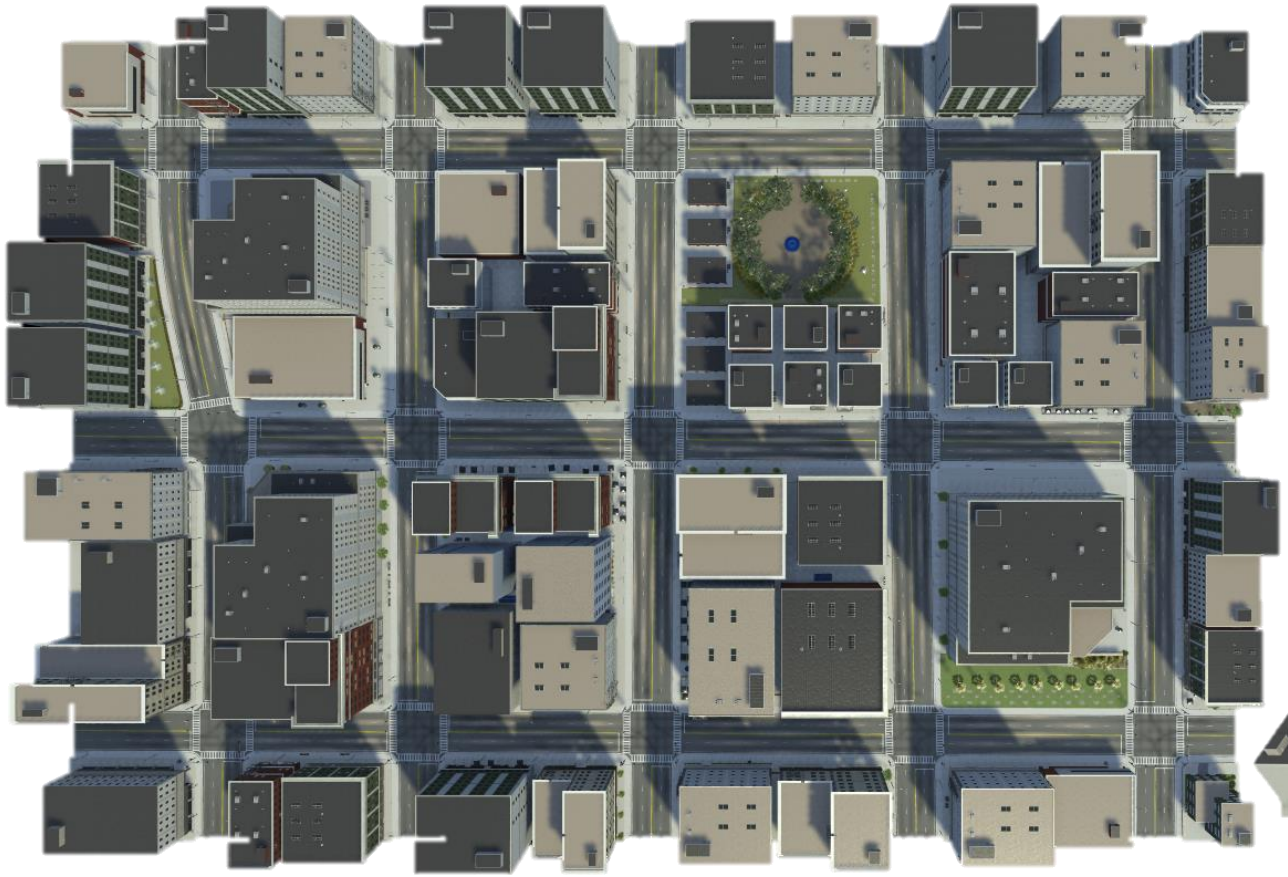


Behavioral Planner



Create a complex urban scene

- 3D environment of a US City Block containing 15 intersections with traffic lights.
- All roads in the scene are two-way roads with four lanes.



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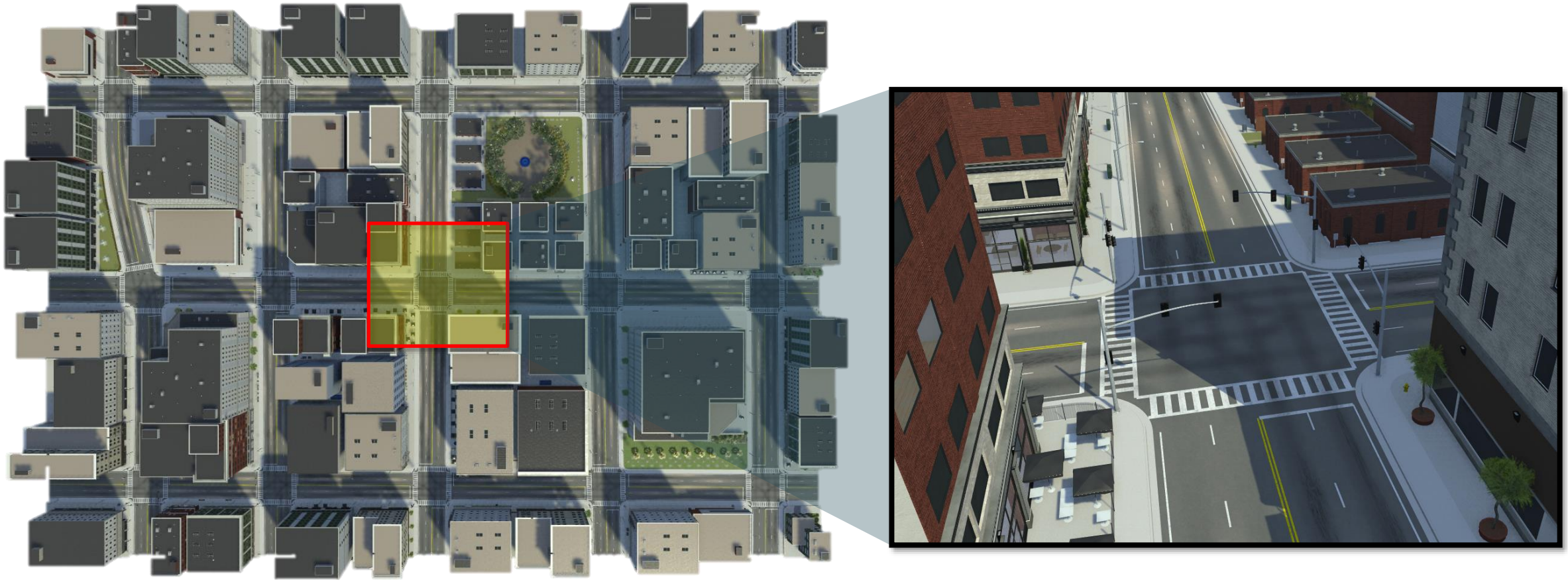
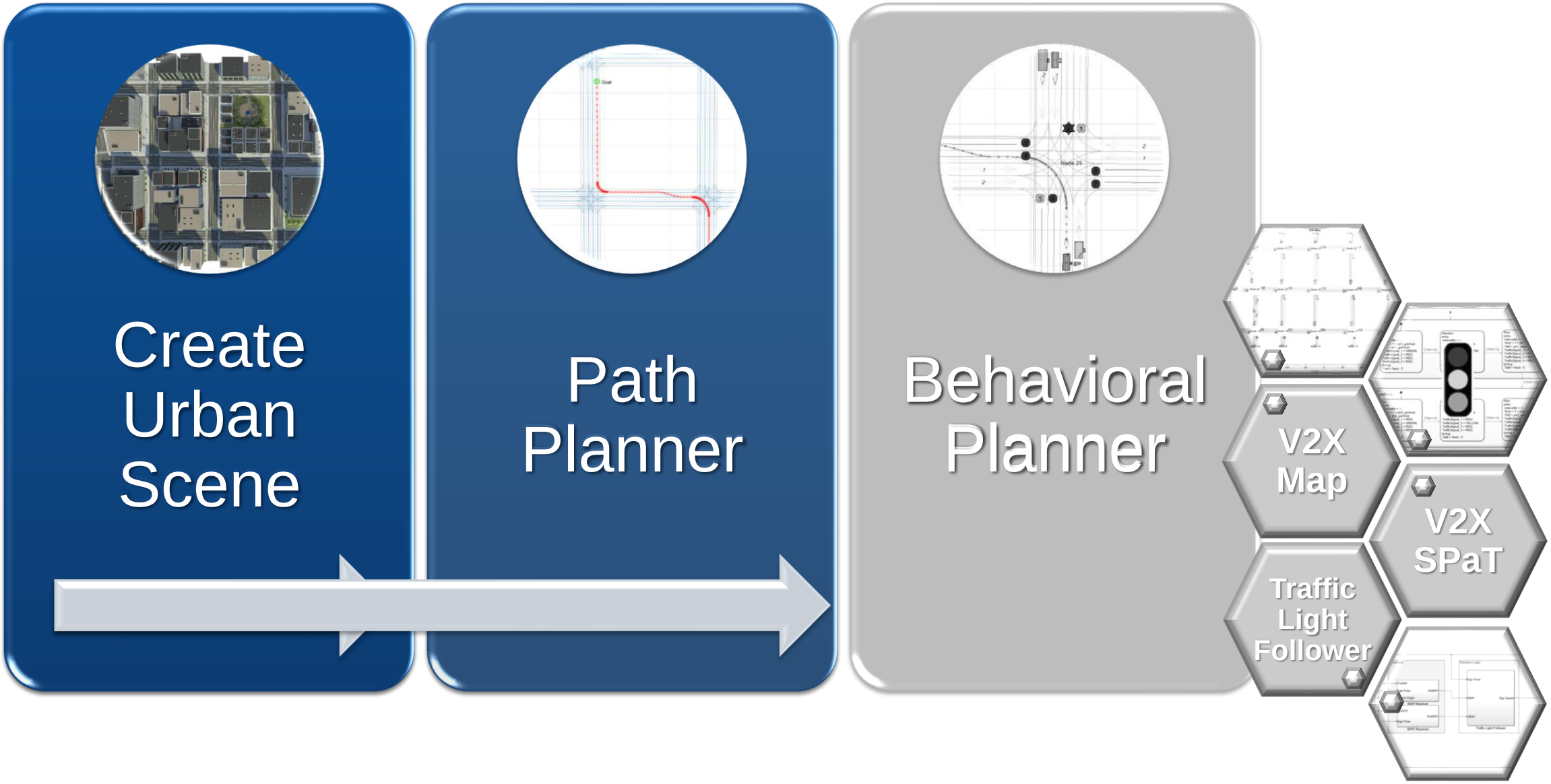
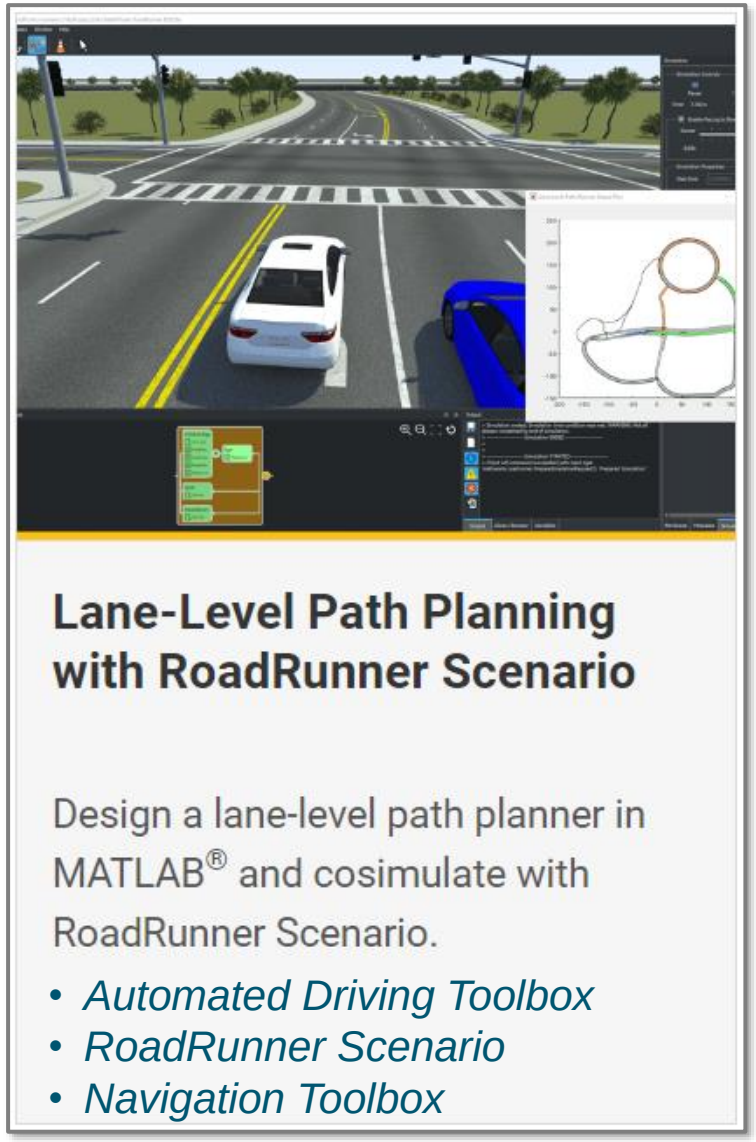


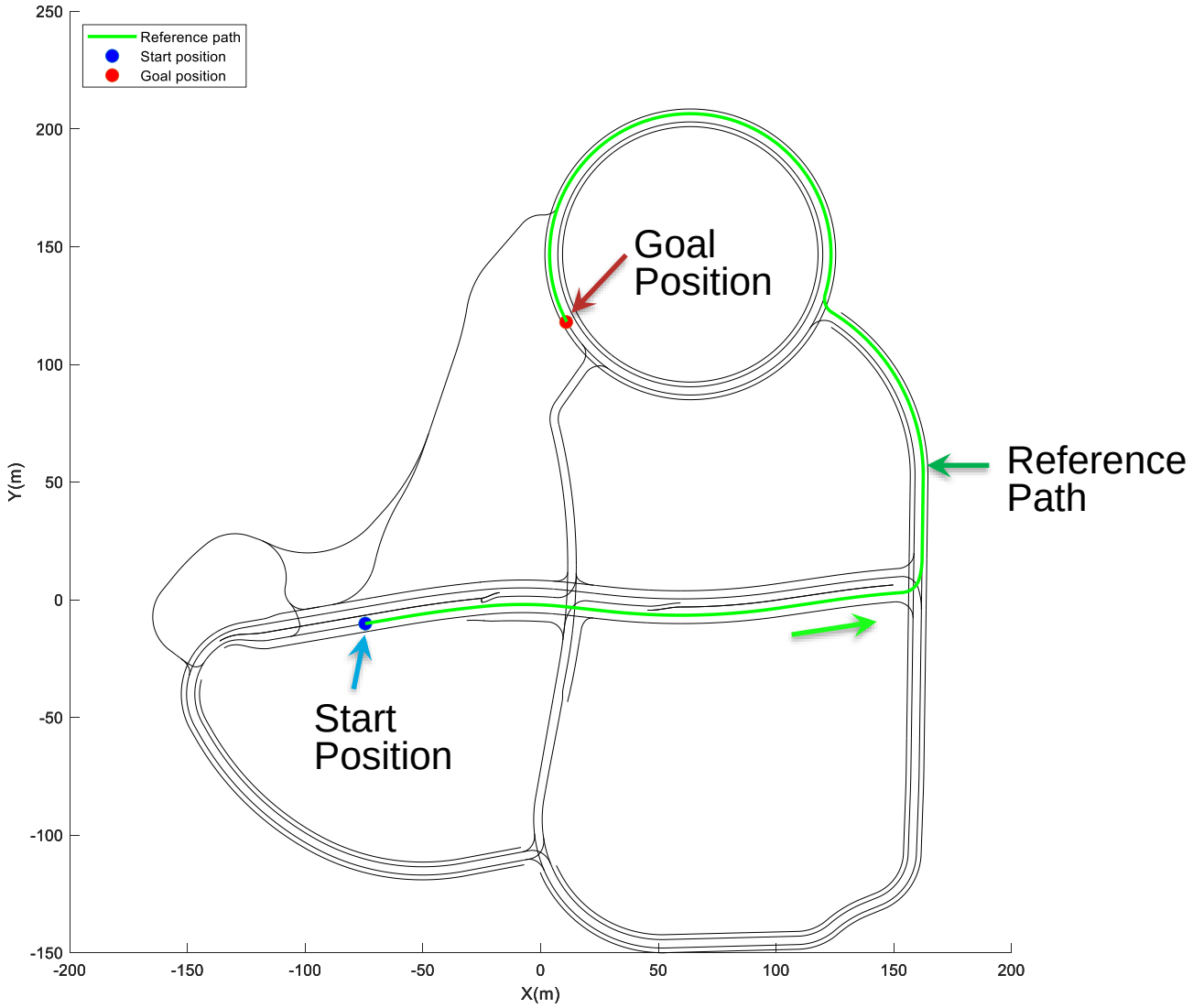
Workflow


Create Urban Scene
Path Planner
Behavioral Planner
V2X Map
V2X SPaT
Traffic Light Follower

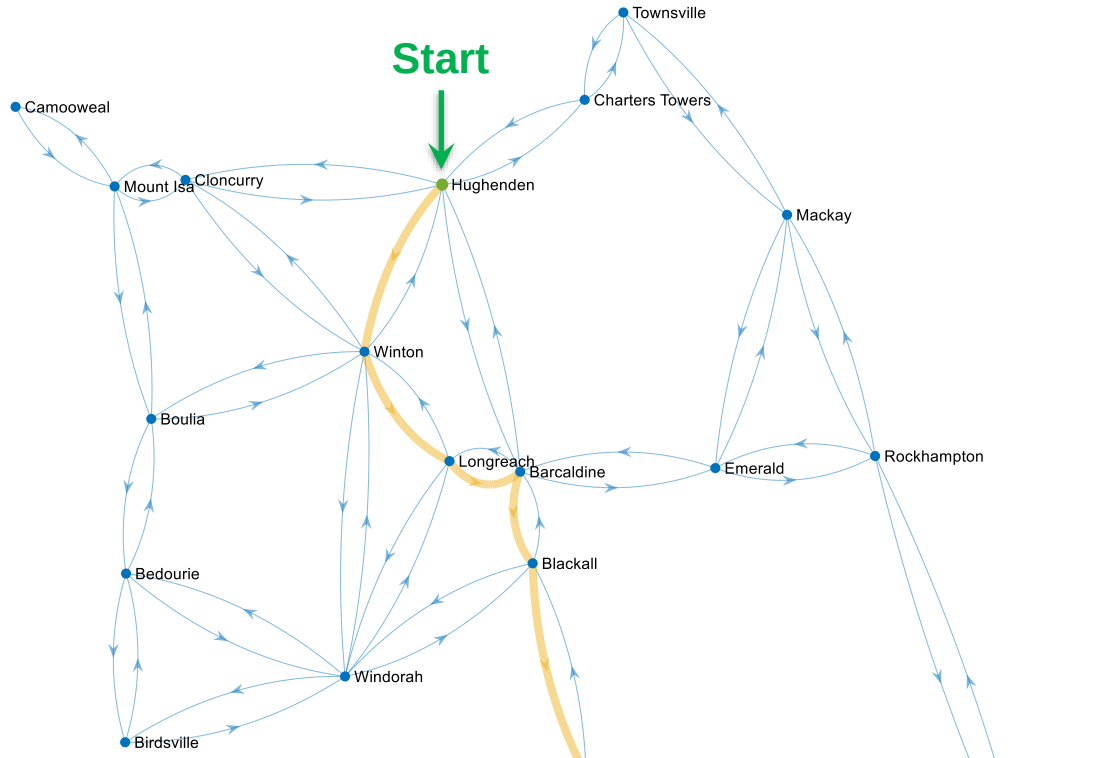
Path Planner



- Finds the shortest path between the start position and the goal position.



Path Planner



A graph is a collection of *nodes* and *edges*

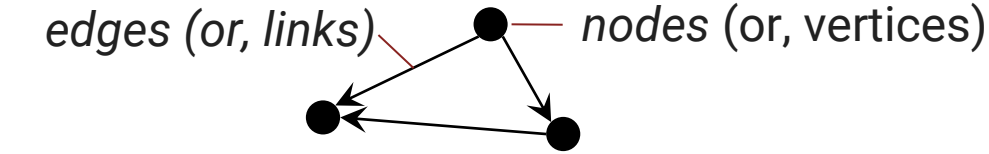
Graph

```
planner = plannerAStar(graph);
```

Goal

- Finds the shortest path between the start position and the goal position.

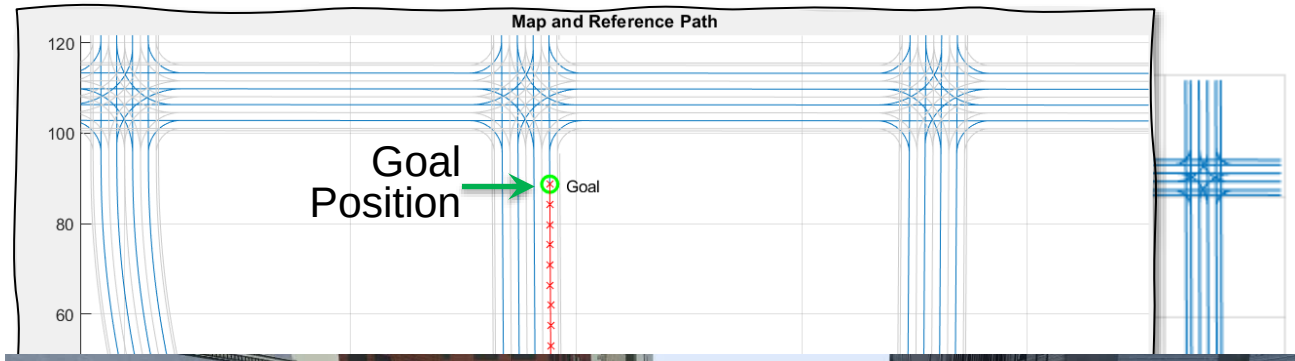
1. Create the nodes and edges table from RoadRunnerHD map

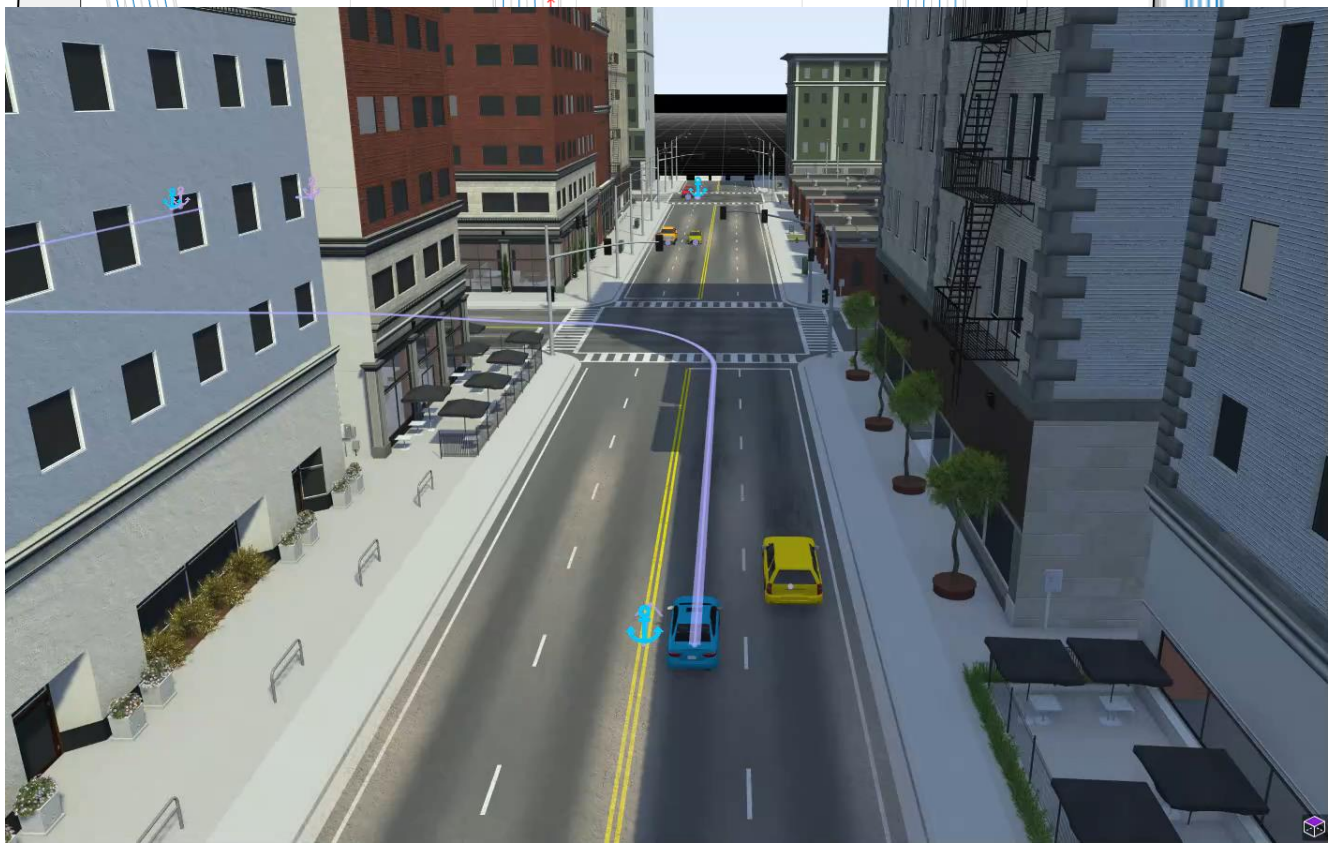


2. Create a graph data structure using navGraph from *Navigation Toolbox*
3. Create an A* planner from the navGraph object
4. Use the planPath method to find the shortest path between the start position and the goal position

```
refPath = planPath(planner,graph,Start,Goal);
```

Path Planner





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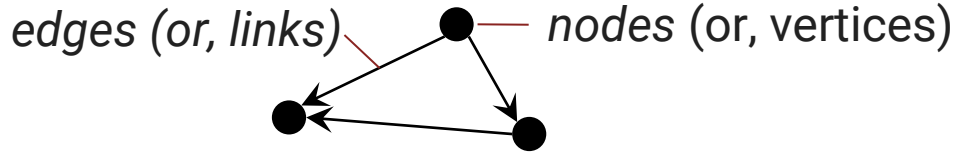
1. Create the nodes and edges table from RoadRunnerHD map



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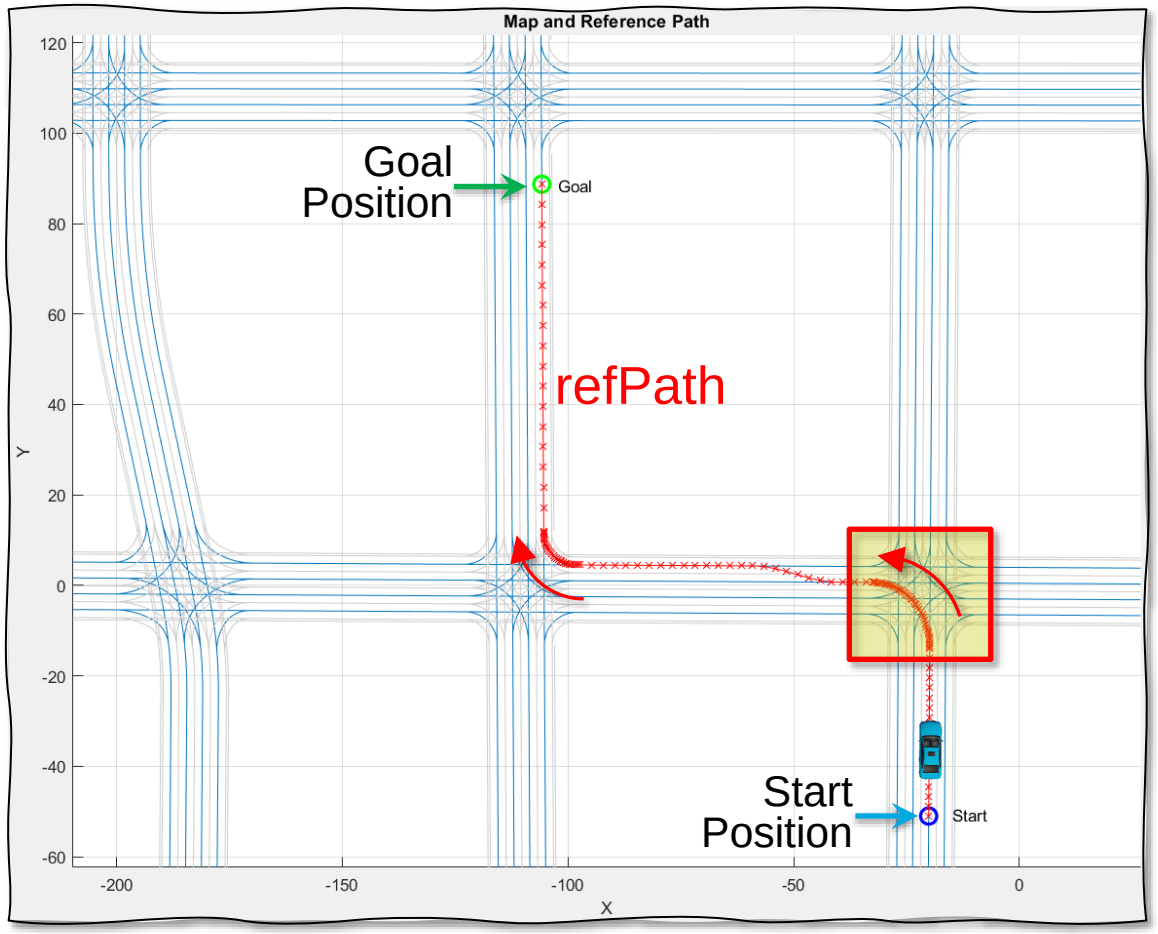
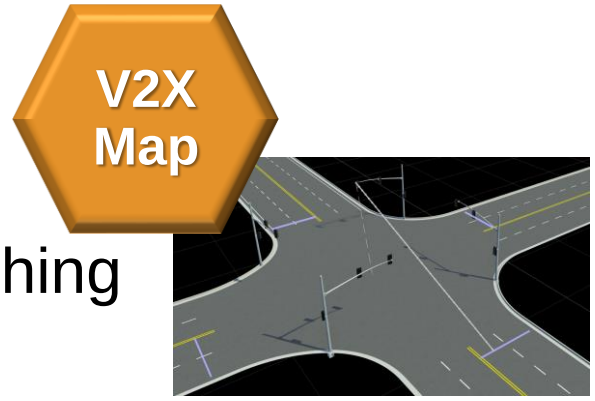
```

Workflow

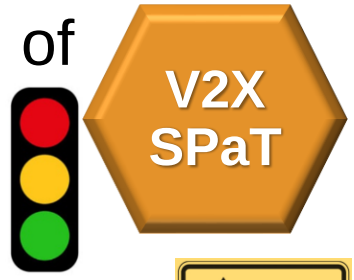

Create Urban Scene
Path Planner
Behavioral Planner
V2X Map
V2X SPaT
Traffic Light Follower

Behavioral Planer at intersections





- How to detect an approaching intersection?
- How to get current state and timing of the associated traffic light?



- How to identify a maneuver at the intersection to follow the reference path – proceed straight, turn left, or turn right?

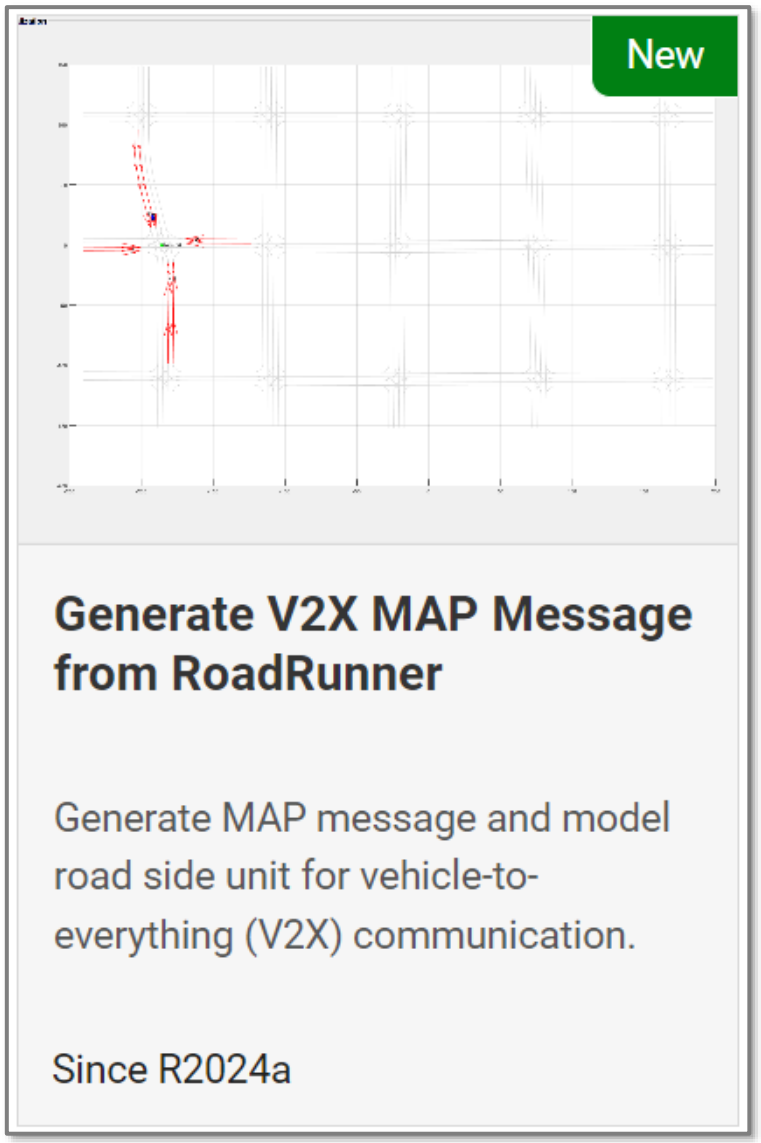
- How to decide to “go” or “stop” at the intersection, based on the traffic light’s state and timing?

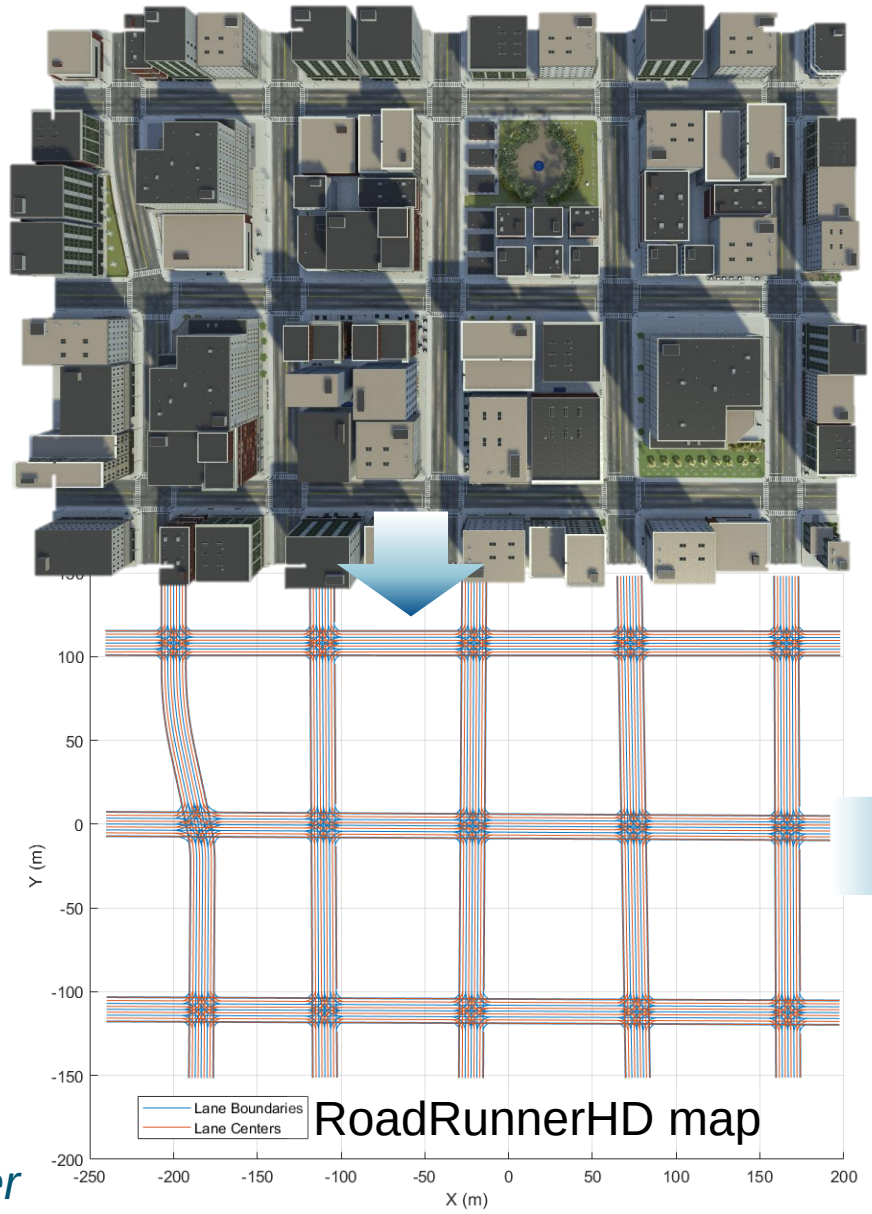
Note) V2X: Vehicle-To-Everything, SPaT: Signal Phase and Timing

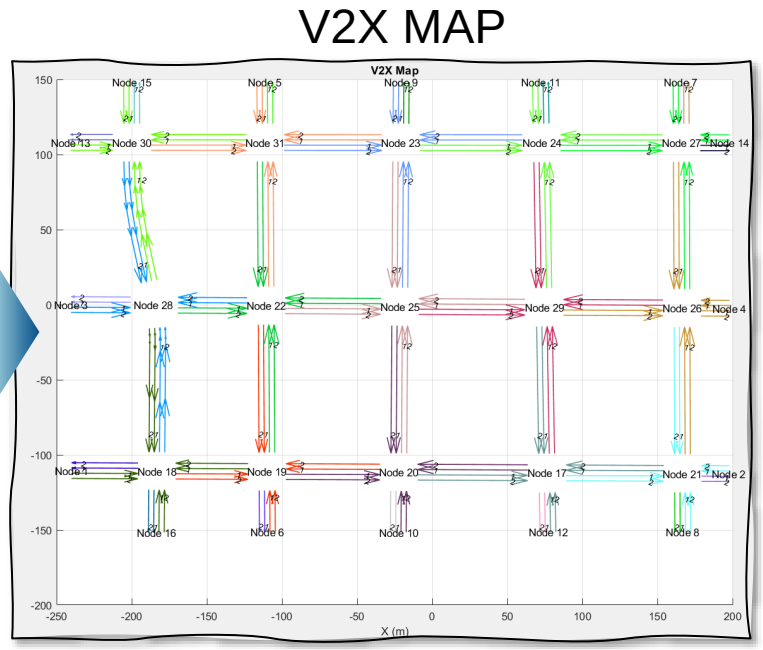
Workflow

Note) V2X: Vehicle-To-Everything, SPaT: Signal Phase and Timing

Generate V2X MAP from RoadRunner

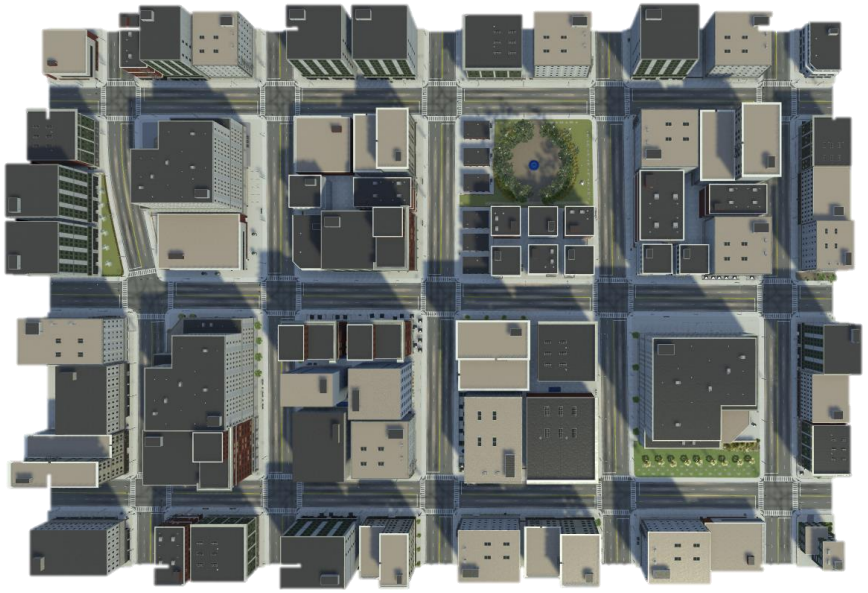






Automated Driving Toolbox, RoadRunner

Get RoadRunnerHD map for the scene used in scenario simulation



USCityBlockBidirectional.rrscene
GenerateMapMessage.rrscenario

`get("Map")`

Road data model for representing high-definition (HD) map data in a RoadRunner scene.

rrHDMap

1x1 roadrunnerHDMap

Property	Value
Author	""
GeoReference	[0,0]
GeographicBoundary	[-240.8043,-152.9707,-6.8775;198.9754,148.3578,54.5400]
Lanes	*2350x1 Lane*
LaneBoundaries	*2947x1 LaneBoundary*
LaneGroups	*538x1 LaneGroup*
LaneMarkings	*3x1 LaneMarking*
Junctions	*15x1 Junction*
BarrierTypes	*5x1 BarrierType*
Barriers	*56x1 Barrier*
SignTypes	*0x1 SignType*
Signs	*0x1 Sign*
StaticObjectTypes	*69x1 StaticObjectType*
StaticObjects	*2888x1 StaticObject*

```
% Open Scene and Scenario
rrApp = roadrunner(rrProjectPath);

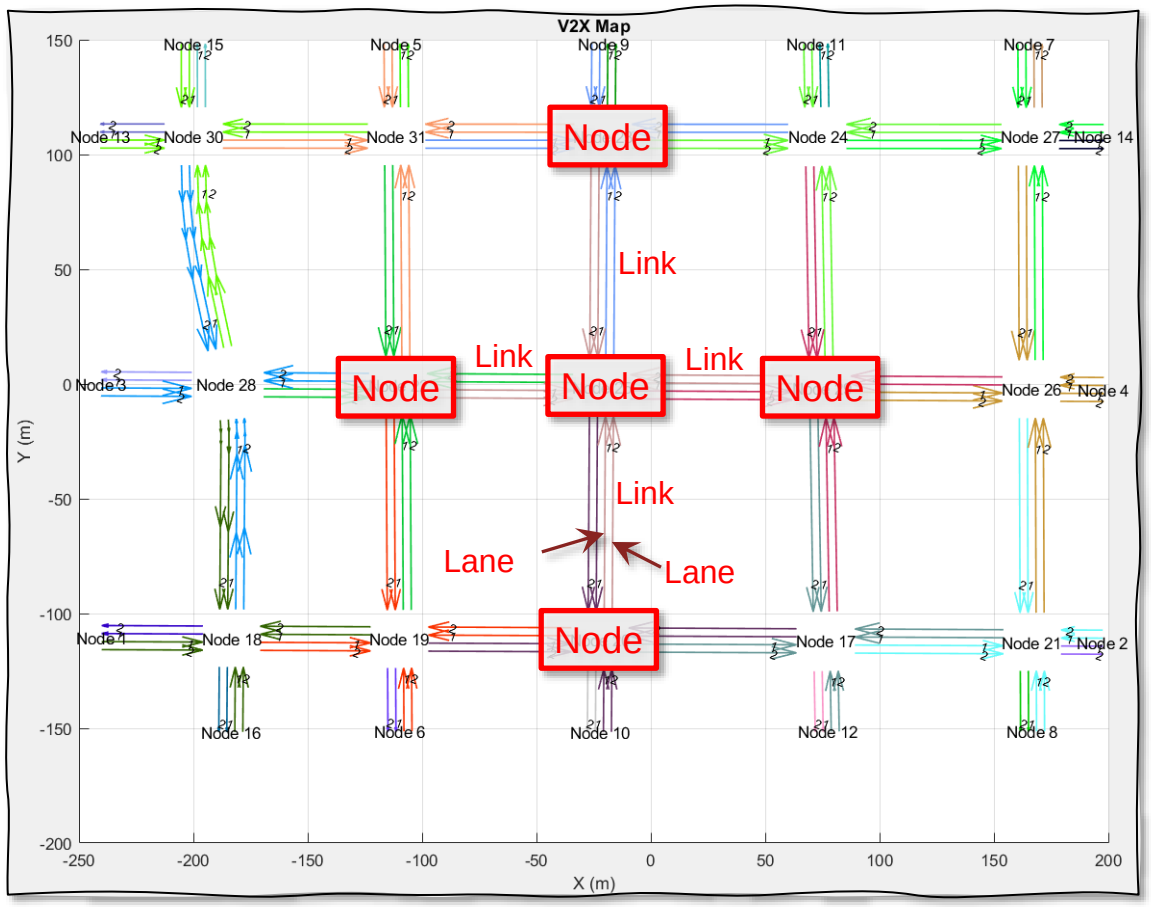
% Open Scene
openScene(rrApp,"USCityBlockBidirectional.rrscene");
% Open the scenario
openScenario(rrApp,"GenerateMapMessage.rrscenario");
```

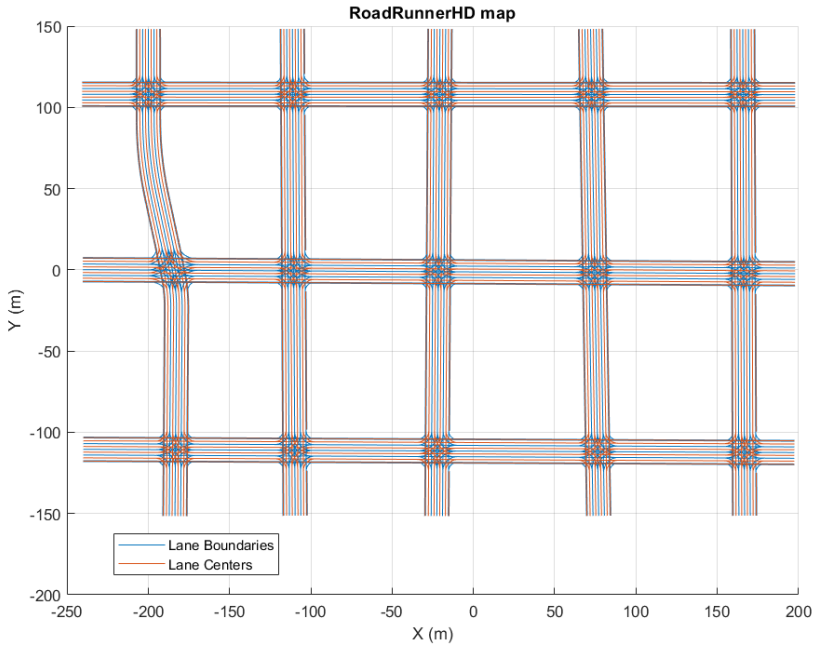
```
% Create Simulation object
rrSim = createSimulation(rrApp);

% Get RoadRunnerHD map for the scene used
in scenario simulation.
rrHDMap = get(rrSim,"Map");
```

```
% Plot RoadRunner HD Map
plot(rrHDMap,'ShowLineMarkers',false);
```

Generate V2X map message from RoadRunnerHD map data



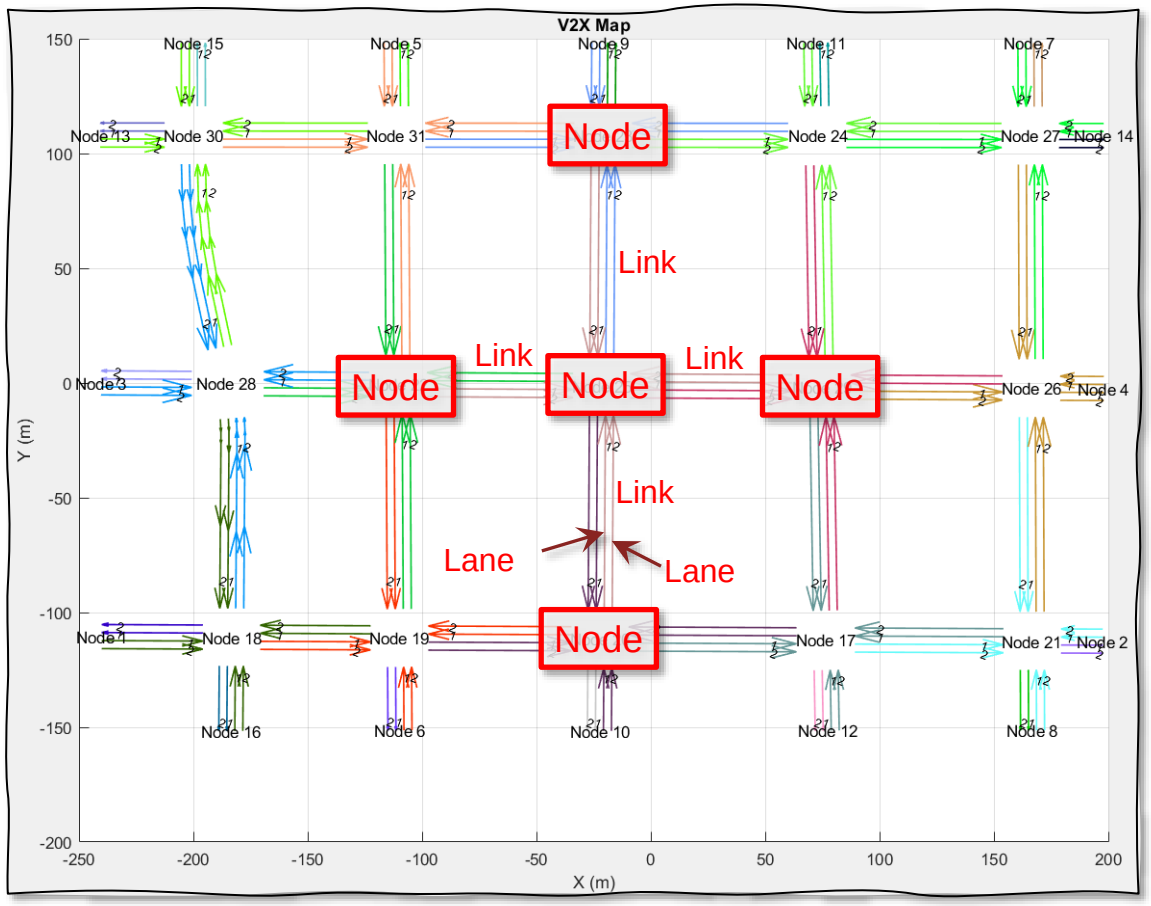


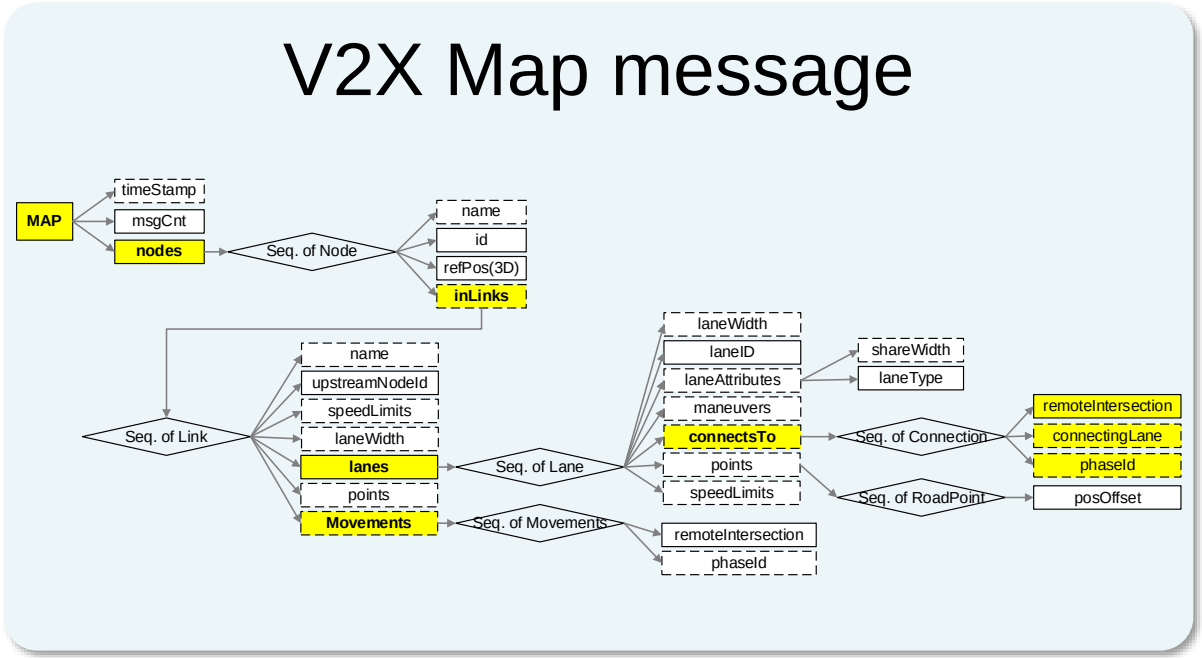
1) Finds all **nodes** (intersections or junctions)
2) Find **links** connecting all nodes.
3) Find connections between all **lanes**.

```
%% Generate MAP messgage
sceneOrigin = [42.3648, -71.0214, 10.0];
v2xMapMsg = helperGenerateV2XMap(rrHDMap,sceneOrigin);

% Visualize MAP message
helperPlotV2XMap(v2xMapMsg);
```

Generate V2X map message from RoadRunnerHD map data

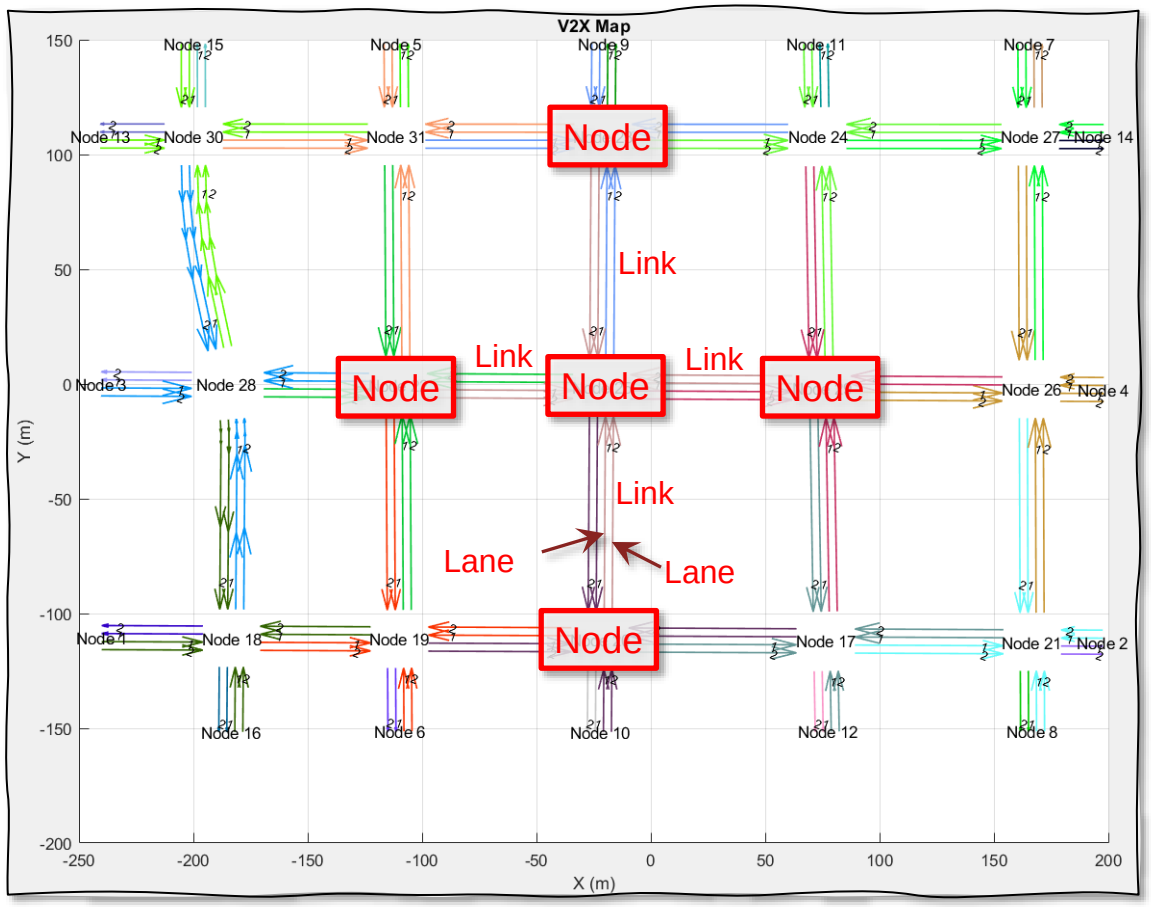


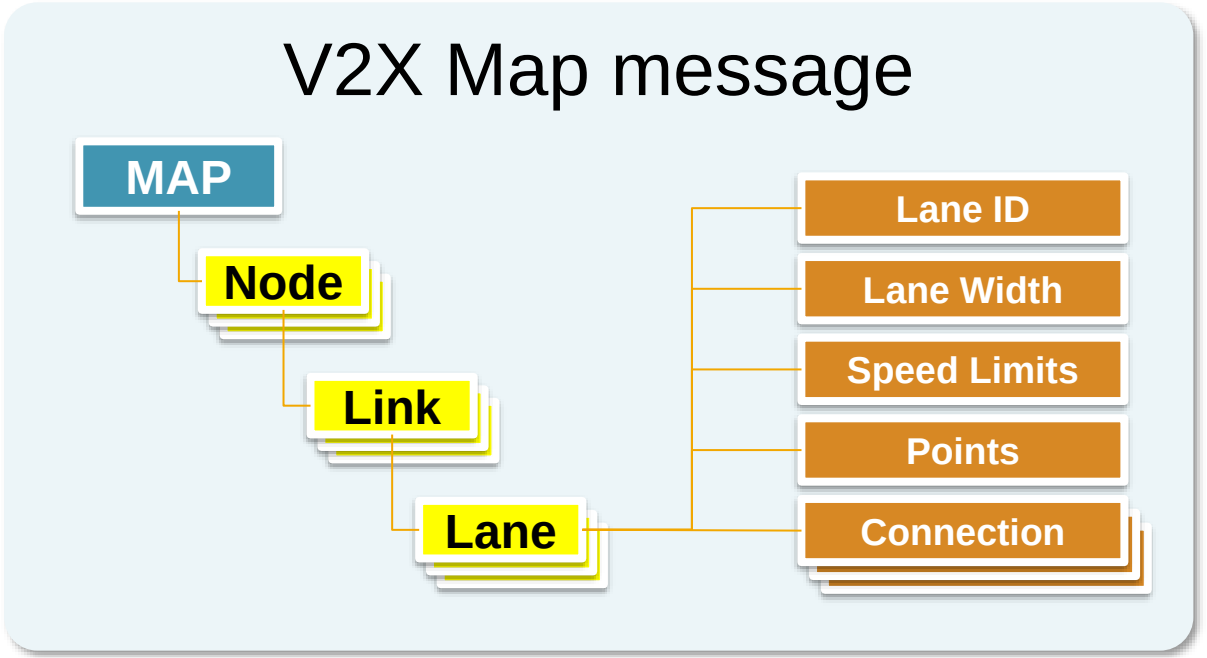


- T/CSAE 53-2020, *Cooperative Intelligent Transportation System — Vehicular Communication Application Layer Specification and Data Exchange Standard (Phase I)*. China Society of Automotive Engineers, 2020.
- ~ SAE J2735, V2X Communications Message Set Dictionary

1) Finds all **nodes** (intersections or junctions)
2) Find **links** connecting all nodes.
3) Find connections between all **lanes**.
4) Encapsulate the nodes, links, and lane connections within **V2X map messages**.

Generate V2X map message from RoadRunnerHD map data

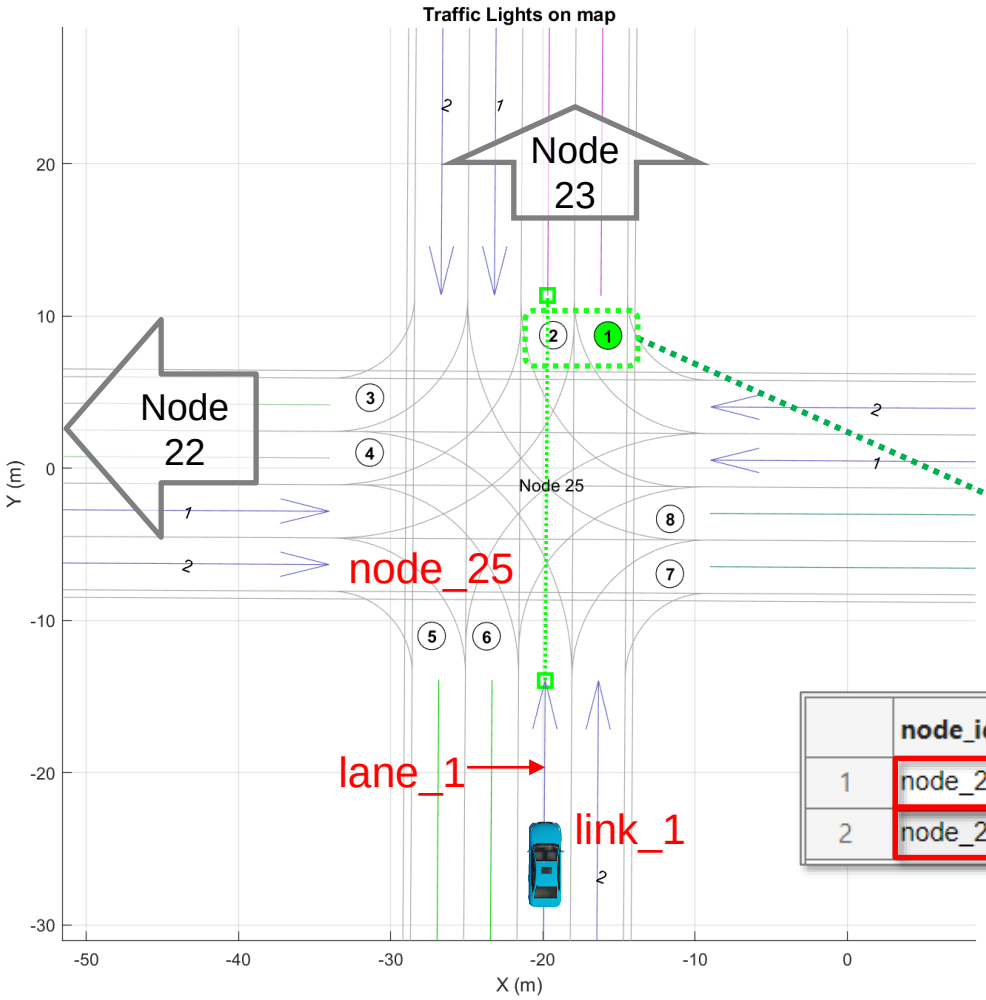


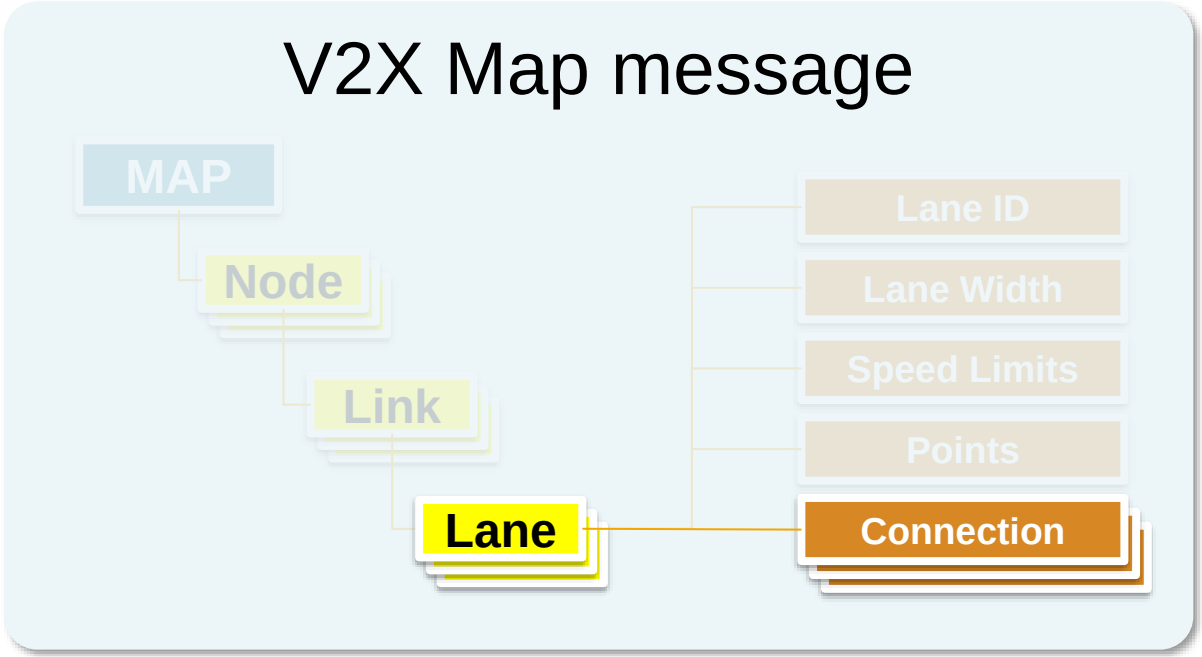


1) Finds all **nodes** (intersections or junctions)
2) Find **links** connecting all nodes.
3) Find connections between all **lanes**.
4) Pack the nodes, links, and lane connections with **V2X map messages**.

- T/CSAE 53-2020, *Cooperative Intelligent Transportation System — Vehicular Communication Application Layer Specification and Data Exchange Standard (Phase I)*. China Society of Automotive Engineers, 2020.
- ~ SAE J2735, V2X Communications Message Set Dictionary

V2X map message: Lane Connection to downstream nodes and traffic signal id



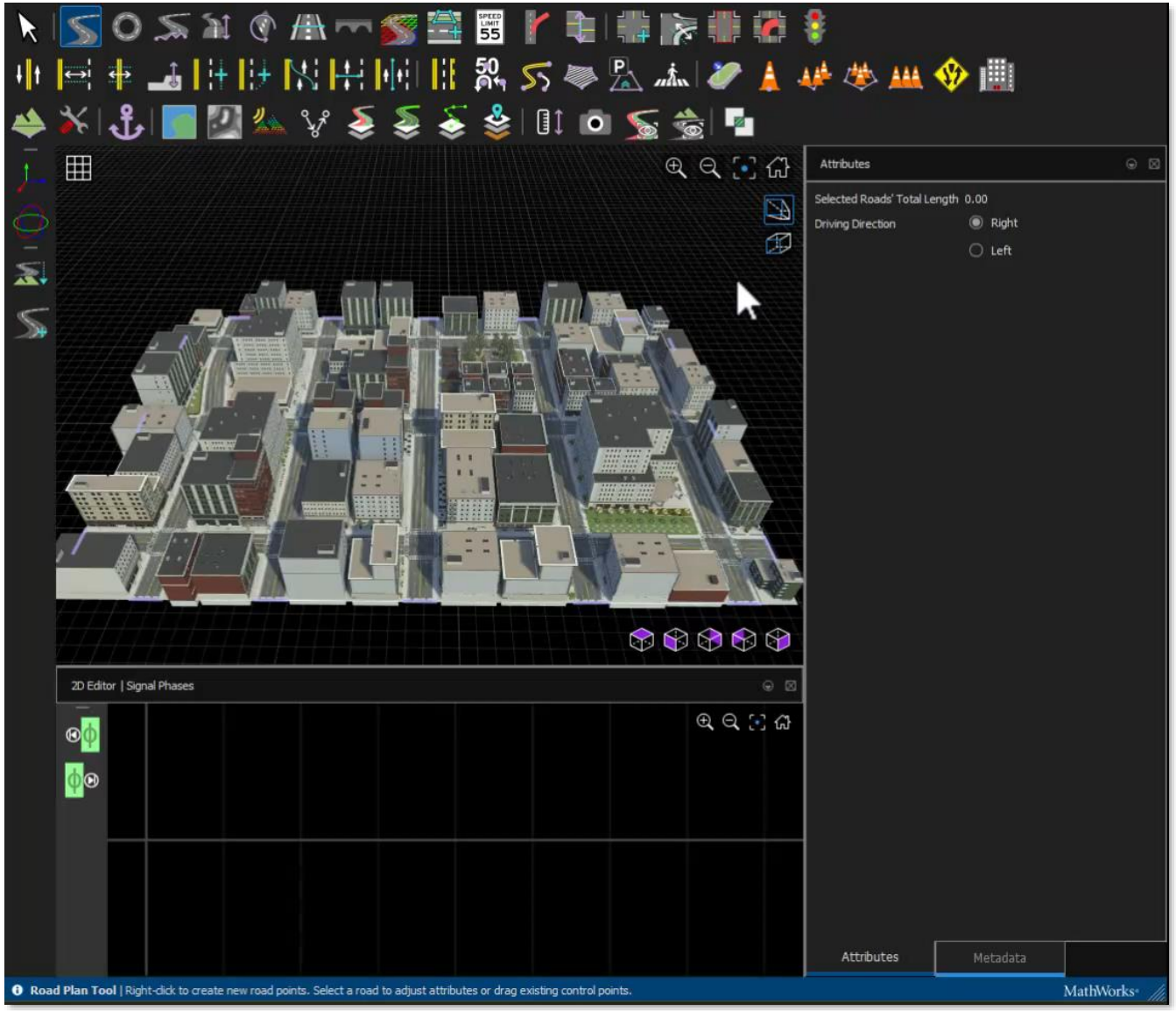


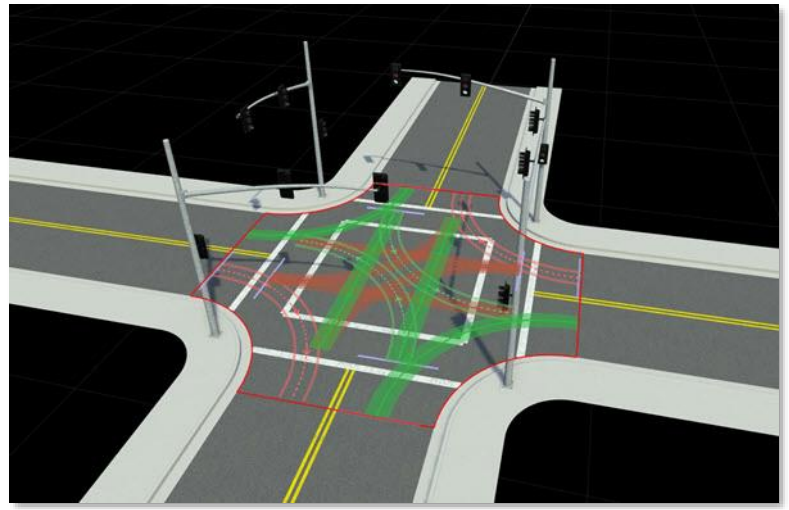
	node_id	link_id	lane_id	signal_id	remote_node	connecting _lane	maneuver	description
1	node_25	link_1	1	2	22	1	0002	Turn Left
2	node_25	link_1	1	1	23	1	0001	Move Straight

Workflow

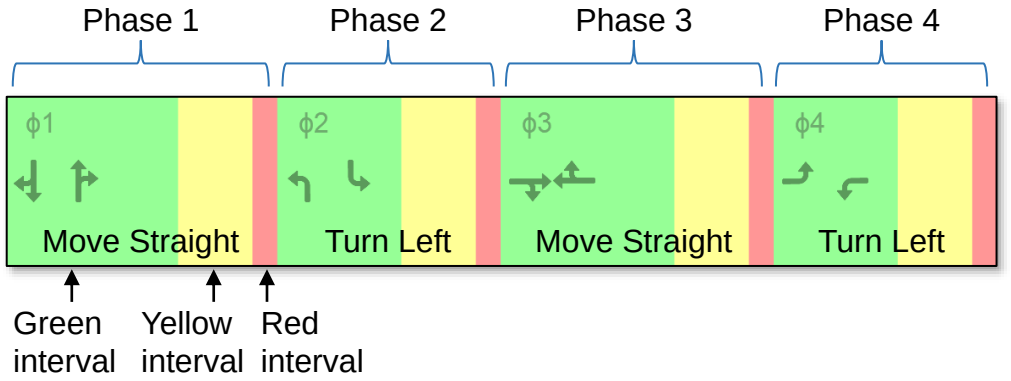
Note) V2X: Vehicle-To-Everything, SPaT: Signal Phase and Timing

“Signal Tool” of RoadRunner

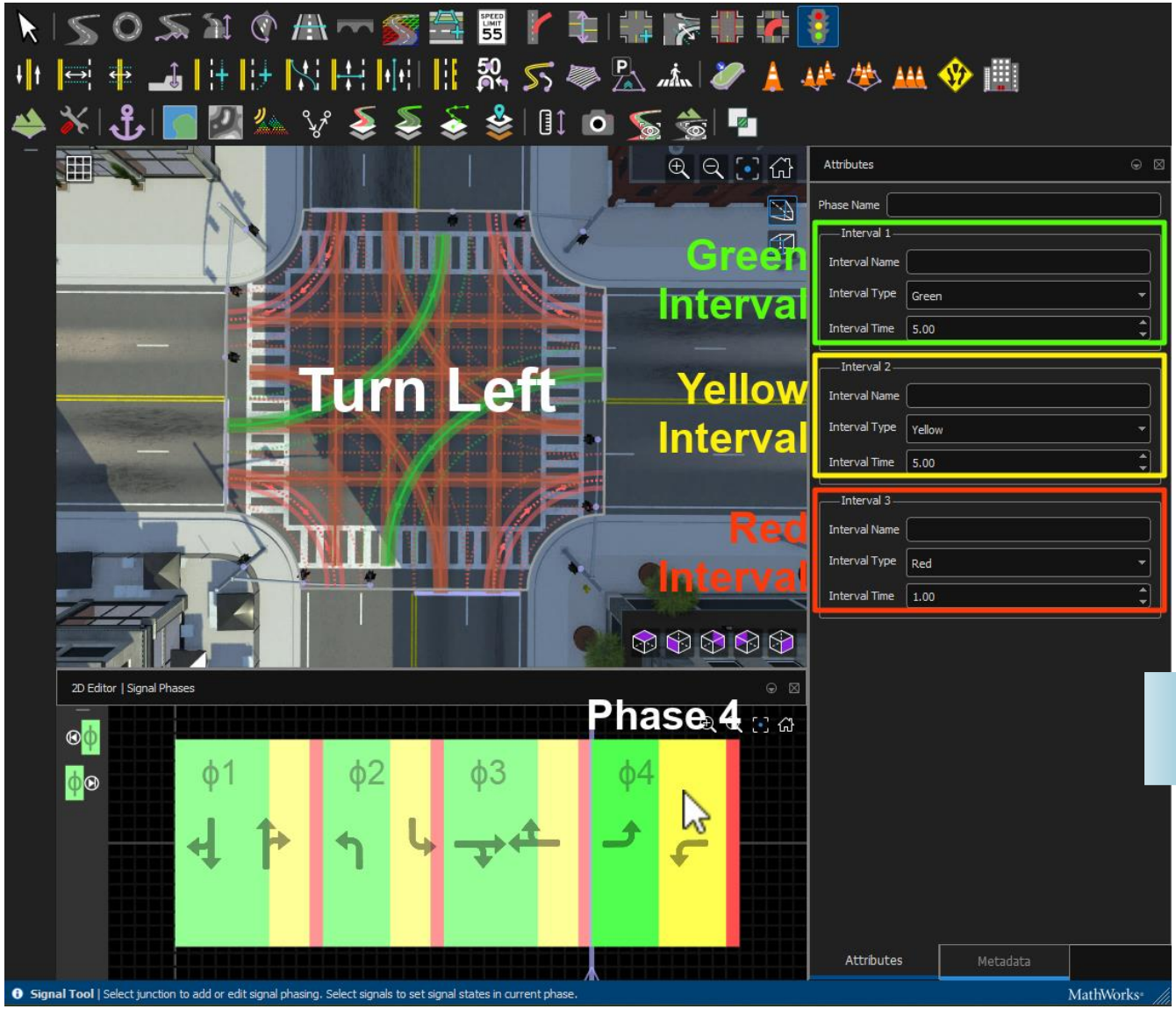


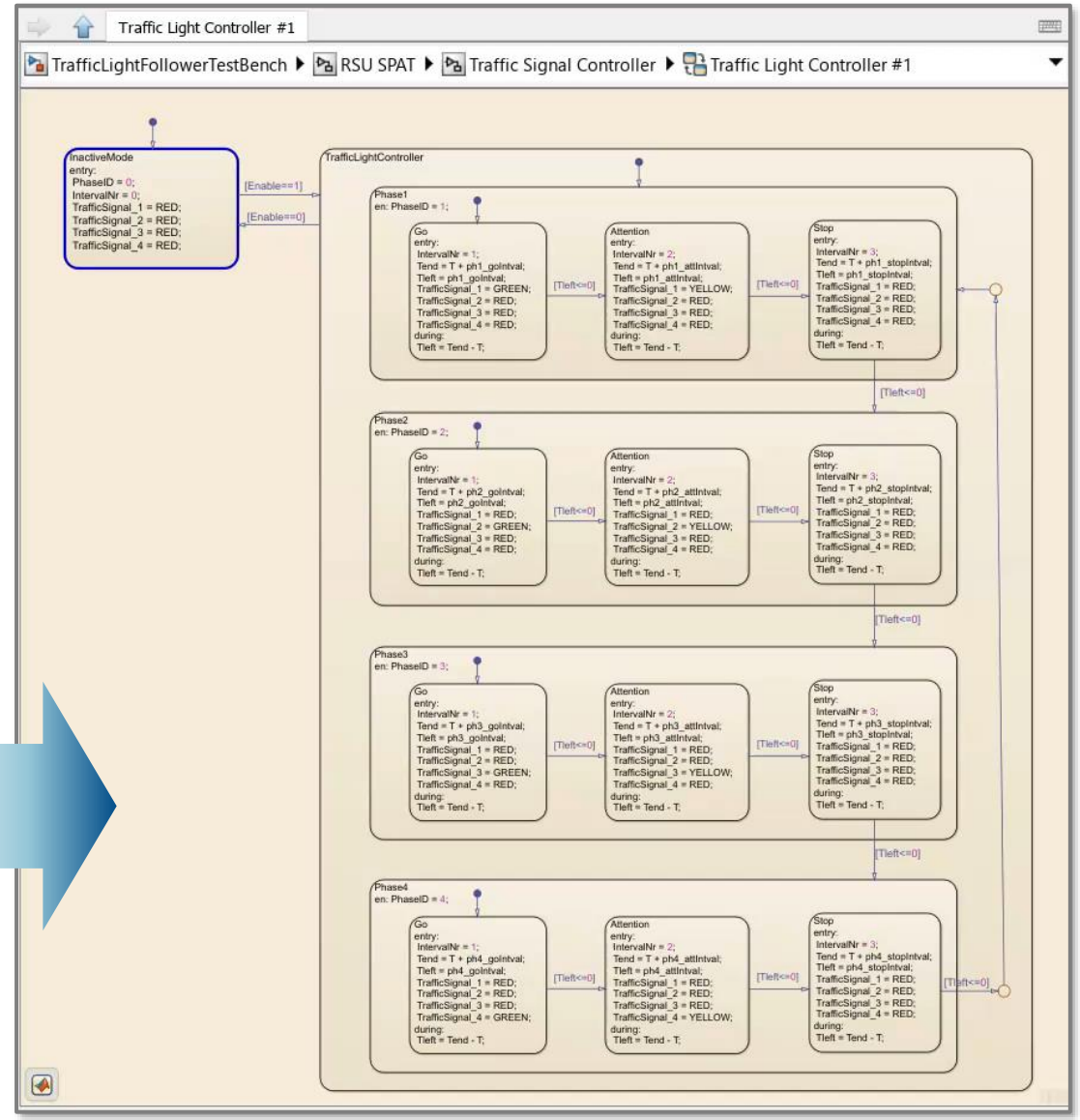


- The Signal Tool is used to configure
  - Junction Signalization
  - Signal Traffic Phases



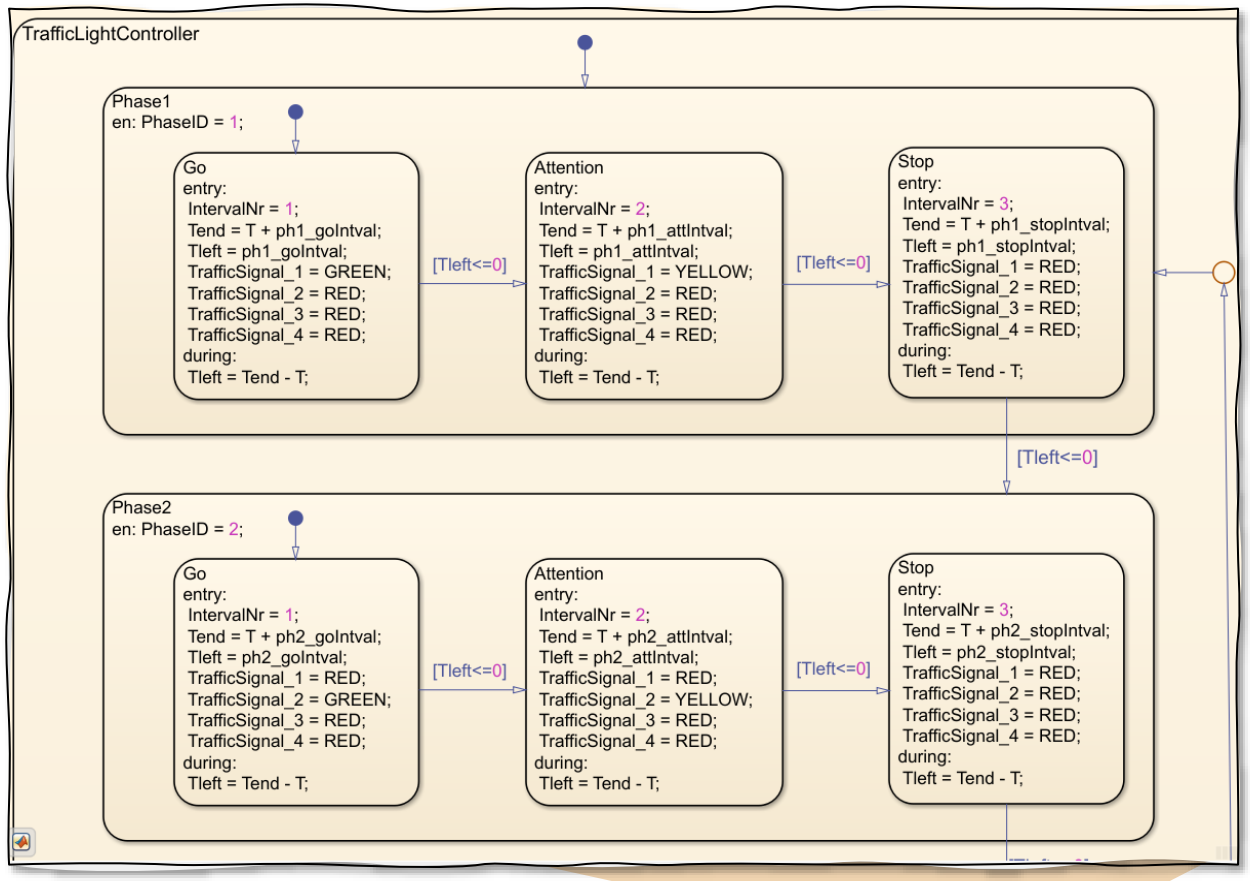
Implement traffic light controller using Stateflow®

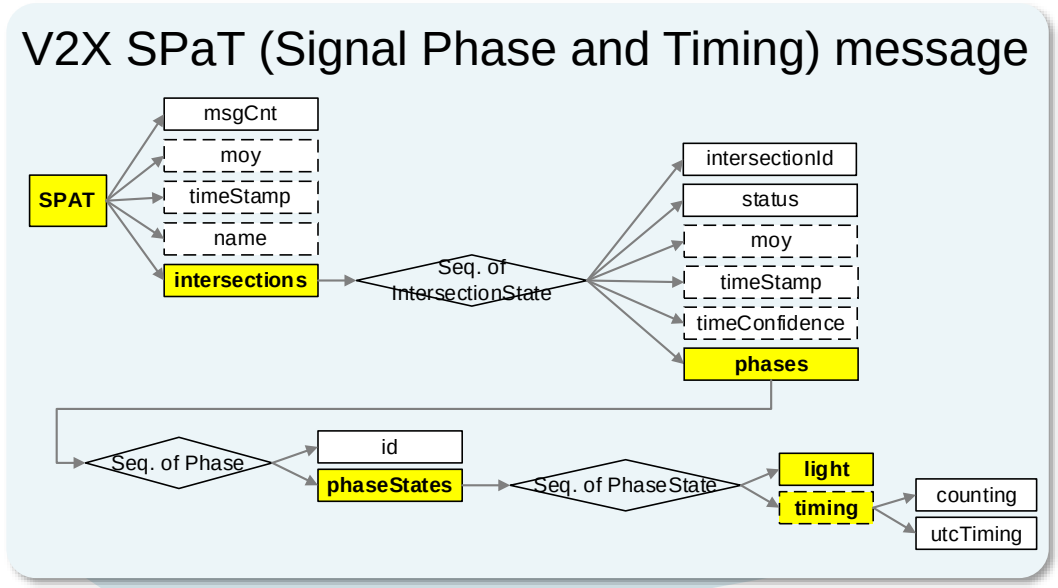


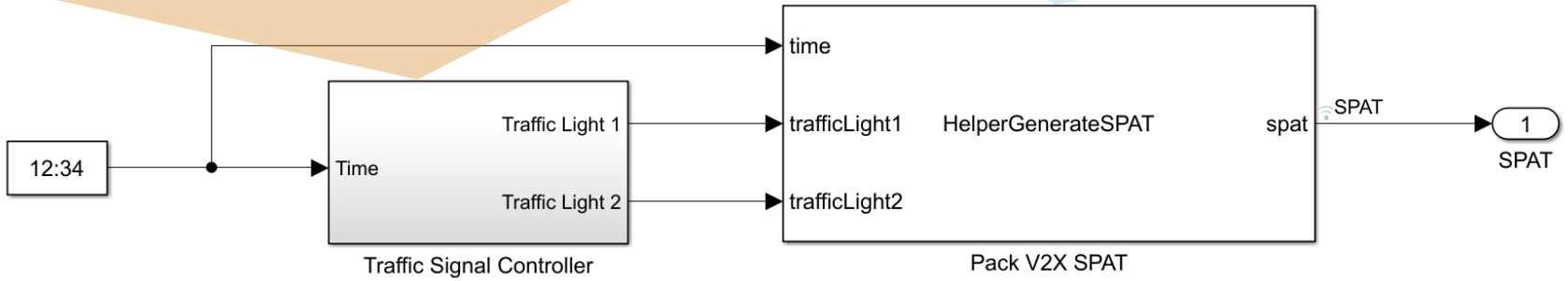


Generate V2X SPaT (Signal Phase and Timing) message

T/CSAE 53-2020



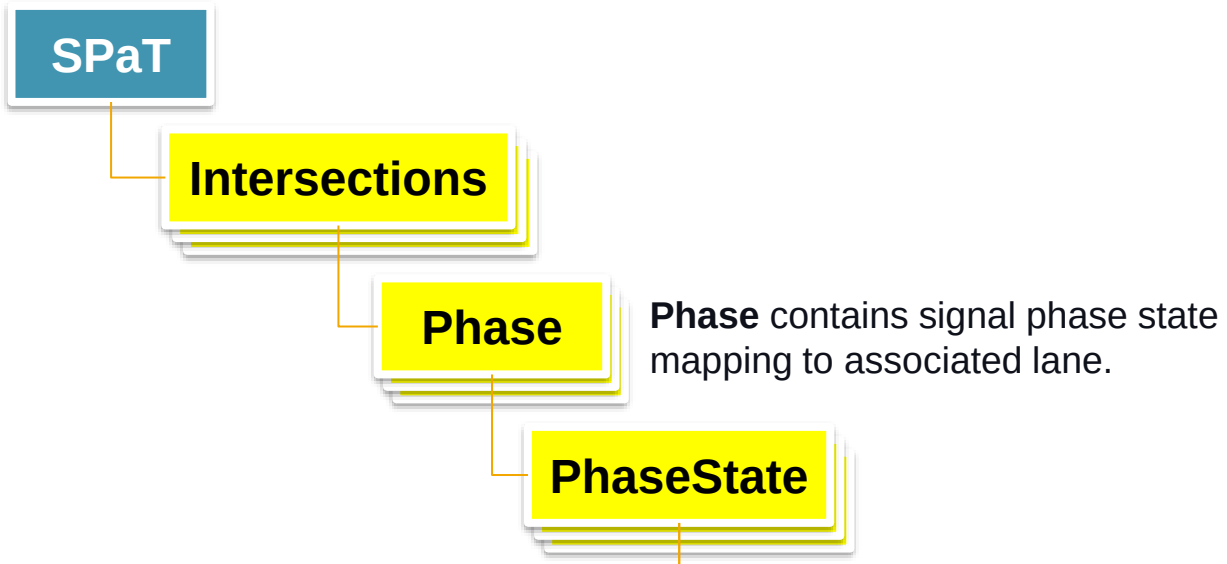




Generate V2X SPaT (Signal Phase and Timing) message

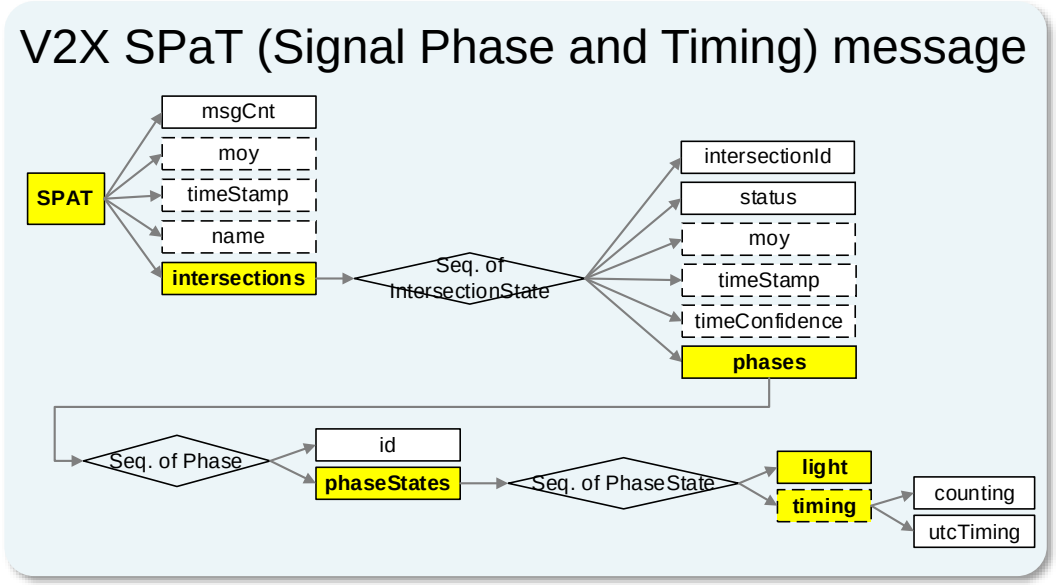
T/CSAE 53-2020

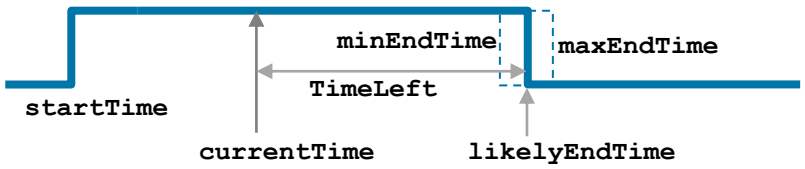
- SPaT message describes the current state of a signal system and its phases and relates this to the specific lanes in the intersection.



Phase contains signal phase state mapping to associated lane.

Phase state provides a signal phase ID map to an associated lane and current signal light state and timing information.

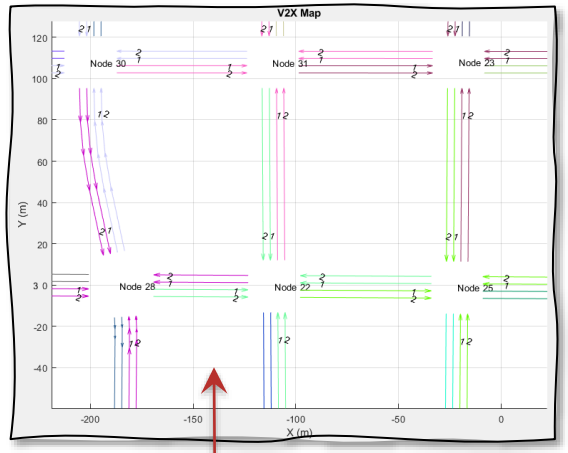


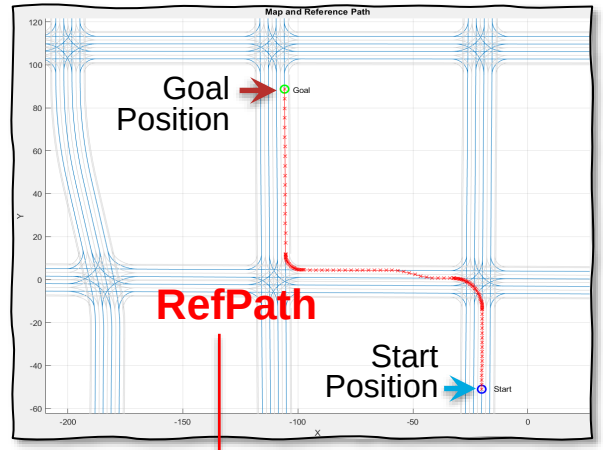


Workflow

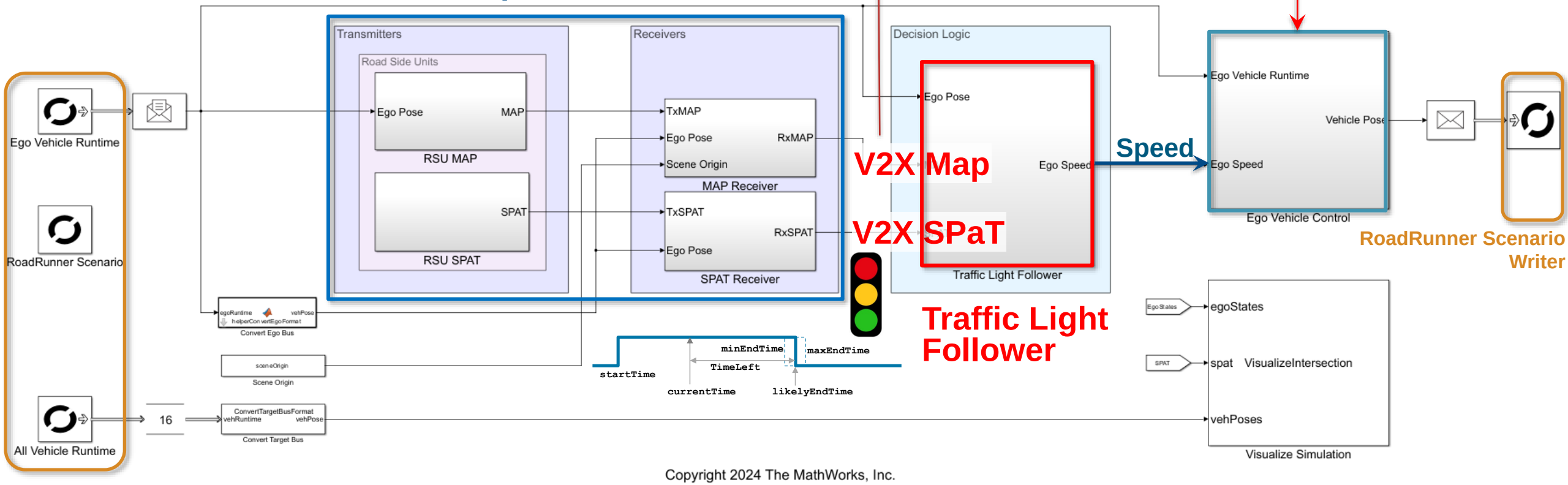
Note) V2X: Vehicle-To-Everything, SPaT: Signal Phase and Timing

Traffic Light Follower



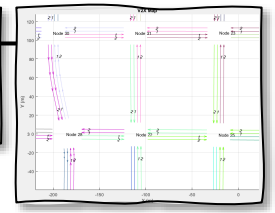


Road Side Unit for V2X map & SPaT

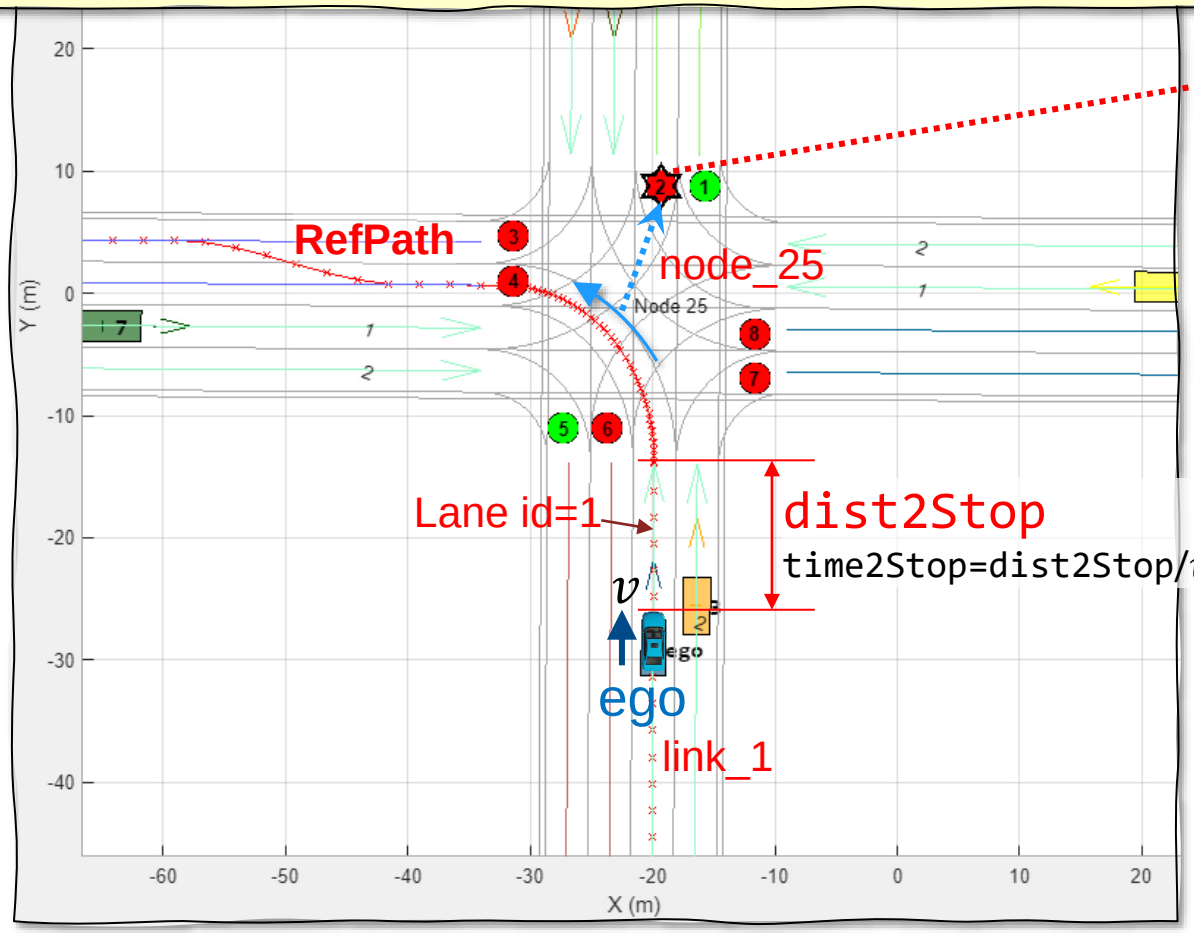


Query V2X Map & SPaT

```
% v2xMapQuery: get map query API object
obj.MapQuery = v2xMapQuery(obj.V2XMap,obj.origin);
```



```
% getConnection: get matching traffic light signal_id and maneuver
% at intersection based on ego current states and reference path
[signal_id_ego, maneuver_ego] =
  obj.MapQuery.getConnection(lane_ego,obj.RefPath,obj.SearchDist);
```



Ego current state

Ego V2X Map info

Maneuver at Junction	TURN_LEFT

Traffic Signal Runtime associated with ego	
SignalId	
2	

Ego States	
Position (x,y)	-19.9, -29.0
Speed (m/s)	10.0
Yaw (deg)	89.6

Node Name	node_25
Link Name	link_1
Lane Id	1

Dist2StopLine (m)	12.28
Time2StopLine (sec)	1.51

Action	Apply brake to stop

```
% locateVehicleOnMap: get v2x map information
% associated with the current ego position
[node_ego,link_ego,lane_ego,dist2stop,info] =
    obj.MapQuery.locateVehicleOnMap(Ego.Position);
```

Stop or Go at the intersection?

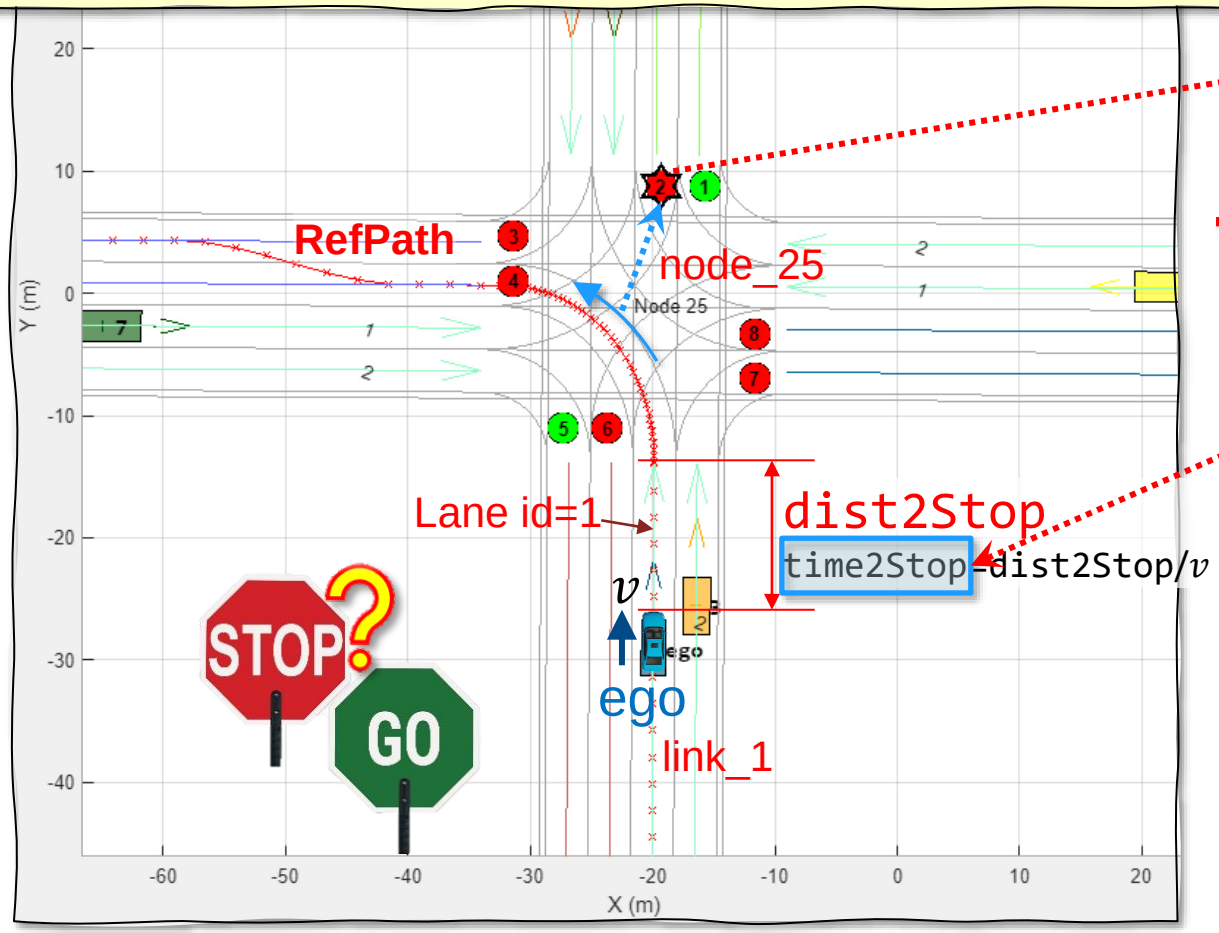
```
% getConnection: get matching traffic light signal_id and maneu
% at intersection based on ego current states and reference path
[signal_id_ego, maneuver_ego] =
  obj.MapQuery.getConnection(lane_ego,obj.RefPath,obj.SearchDist);
```

```
% getCurrentSPAT: get traffic light state and timing
% associated with ego car
[Light, Tleft, Tdur] = getCurrentSPAT(NodeId, SignalId,SPAT);
```

Maneuver at Junction	TURN_LEFT

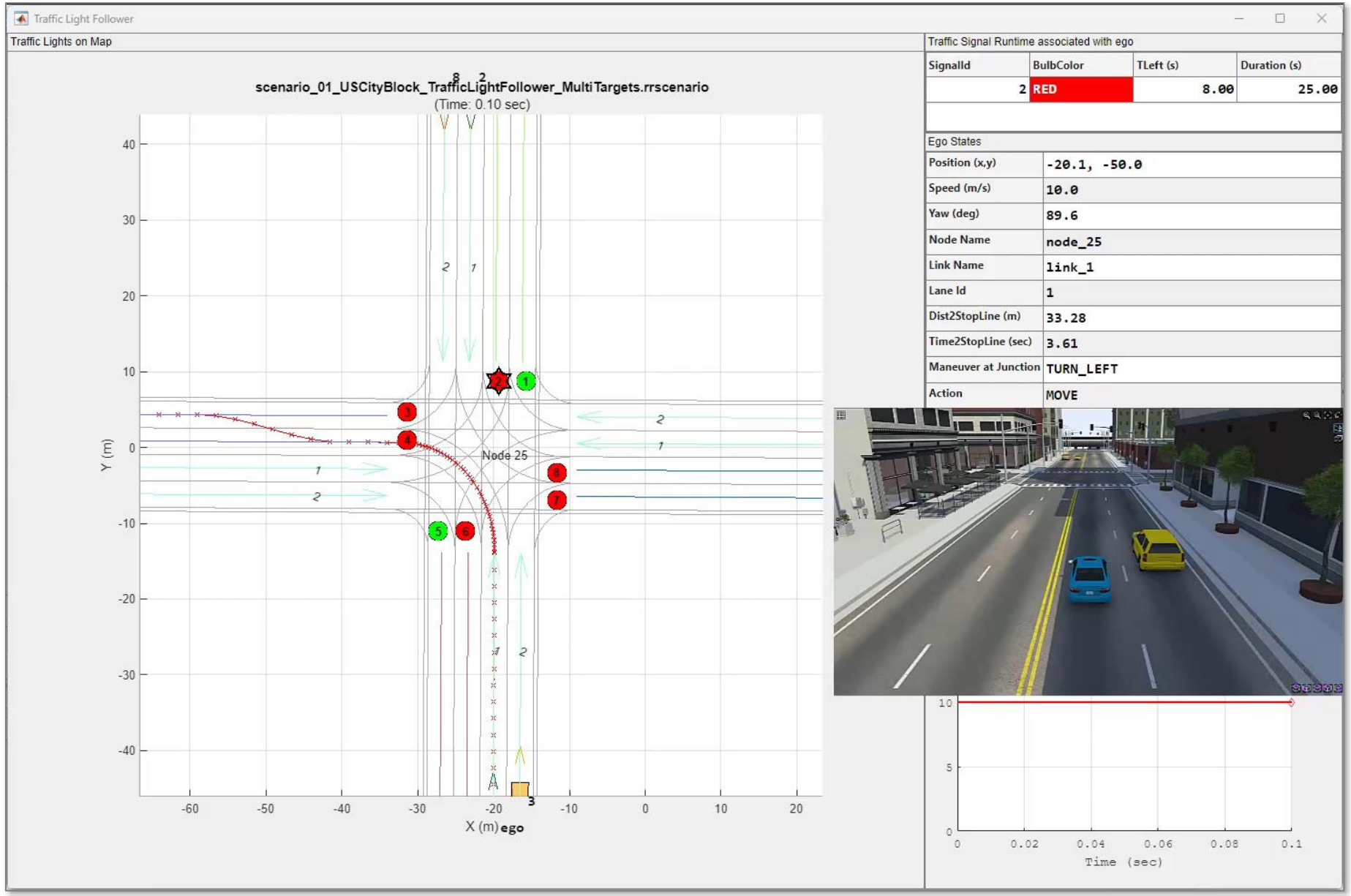
Traffic Signal Runtime associated with ego

SignalId	BulbColor	TLeft (s)	Duration (s)
2	RED	5.90	25.00




```
switch Light % traffic bulb color associated with ego
    case BulbColor.RED
        if Tleft > Time2Stop
            % red light stays when ego vehicle reaches the stop line
            StopAction = true; % then, stop in advance
        end
    case {BulbColor.GREEN, BulbColor.YELLOW}
        if Tleft < Time2Stop
            % green or yellow light will be expired when ego vehicle
            reaches the stop line
                StopAction = true; % then, stop in advance
        end
end
```

Traffic light follower with co-simulating RoadRunner Scenario

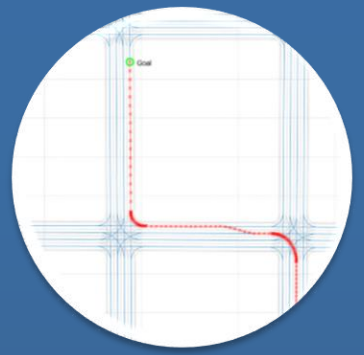


Key Takeaways:

Automated Driving in the Urban Environment with RoadRunner Scenario

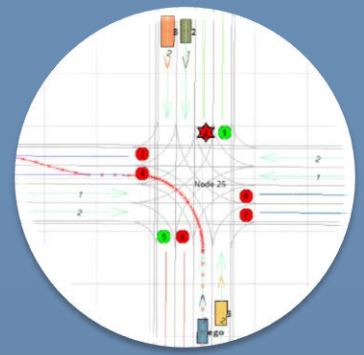
Create a complex **Urban Scene** consisting of Intersections with Traffic Lights.

- *RoadRunner*
- *RoadRunner Asset Library*

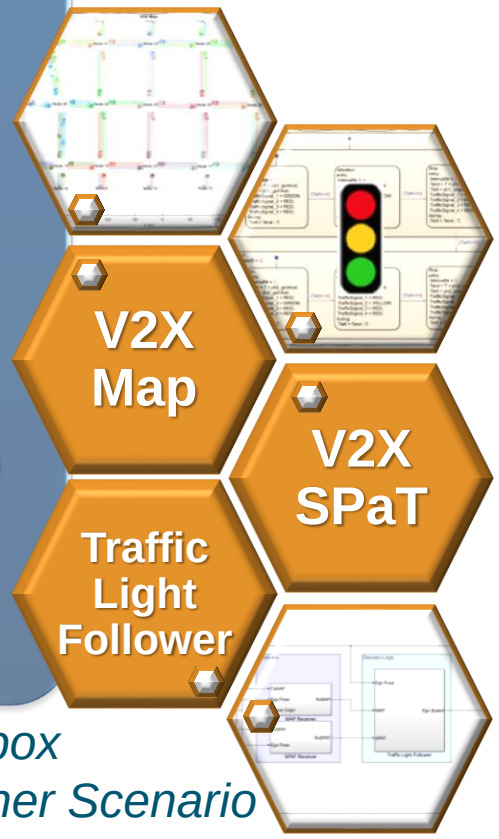


Design **Path Planner** using **A-star Planner**.

- *Navigation Toolbox*



Develop **Behavioral Planner** using **V2X Map and SPaT**.



- *Automated Driving Toolbox*
- *RoadRunner, RoadRunner Scenario*
- *Simulink, Stateflow*

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Thank you

Please contact me at spark@mathworks.com
with questions