# Agent-Based Modeling and Simulation of CAVs Using Game Engine: A Cooperative Freeway On-Ramp Merging Study

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# Agent-Based Modeling and Simulation

Focuses on microscale models that simulate the simultaneous operations and interactions of multiple agents, where "agents" are defined as:

- *Identifiable*, with rules governing their decision-making capabilities

- *Interactive*, with the ability to recognize and distinguish the traits of other agents

- *Goal-directed*, with goals to achieve with respect to their behaviors

- *Autonomous*, with the capability to function independently in their environment

- *Flexible*, with the ability to learn and adapt their behaviors over time based on experience

**CAVs satisfy all the agent requirements to some degrees**

# Freeway On-Ramp Merging

Drawbacks of <u>traditional</u> on-ramp merging systems

- Not safe: Collisions are caused by human error while merging

- Not sustainable: perturbations are caused by late merging

- Not efficient: Congestions are caused by speed perturbations of highway vehicles

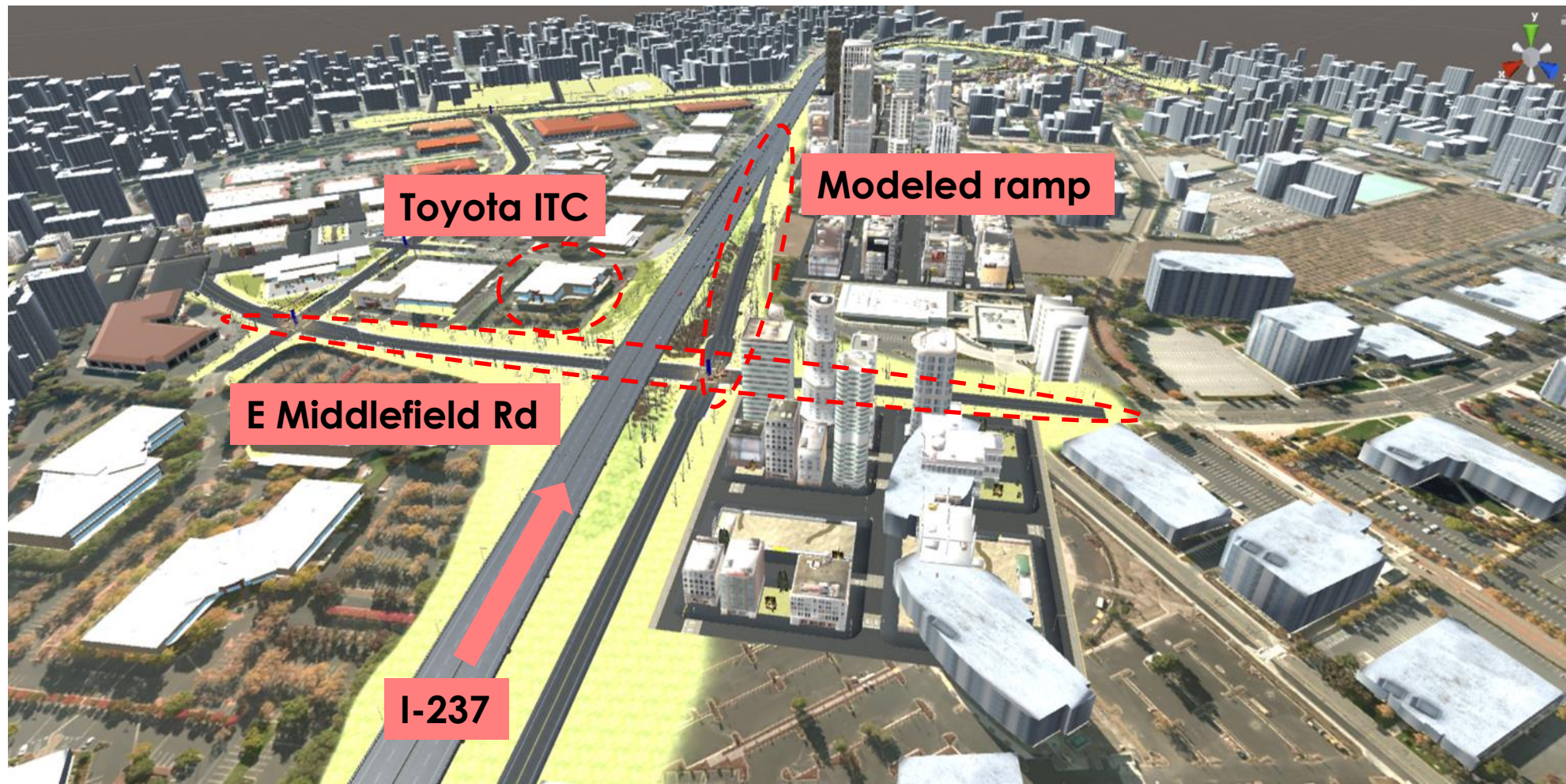<u>V2X-based</u> cooperative freeway on-ramp merging system
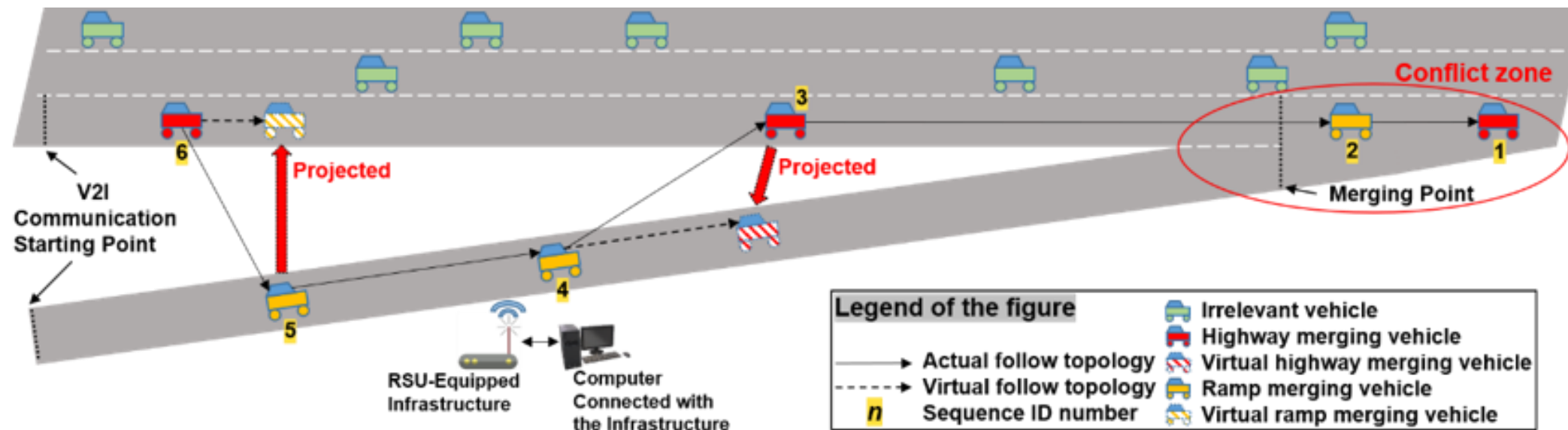
# Workflow of the proposed system
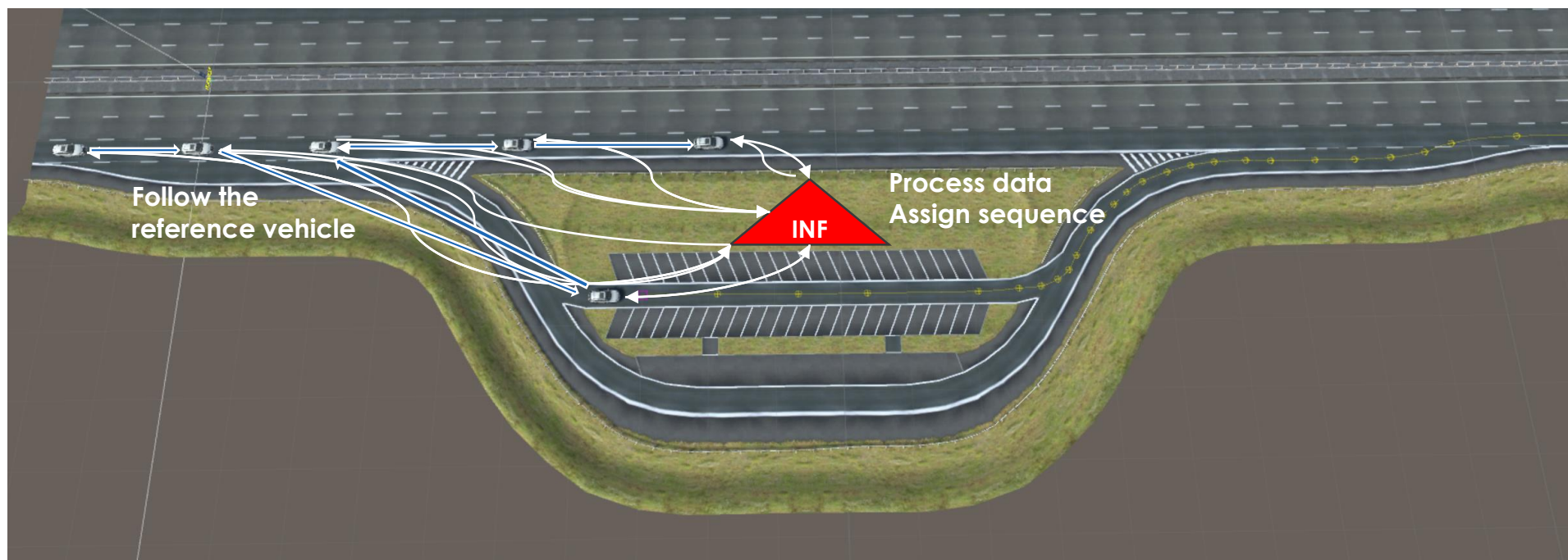


- **Process data: estimated arrival time protocol**

- **Assign sequence: vehicle sequencing protocol**

- **Follow the reference vehicle: online feedforward/feedback longitudinal control algorithm**
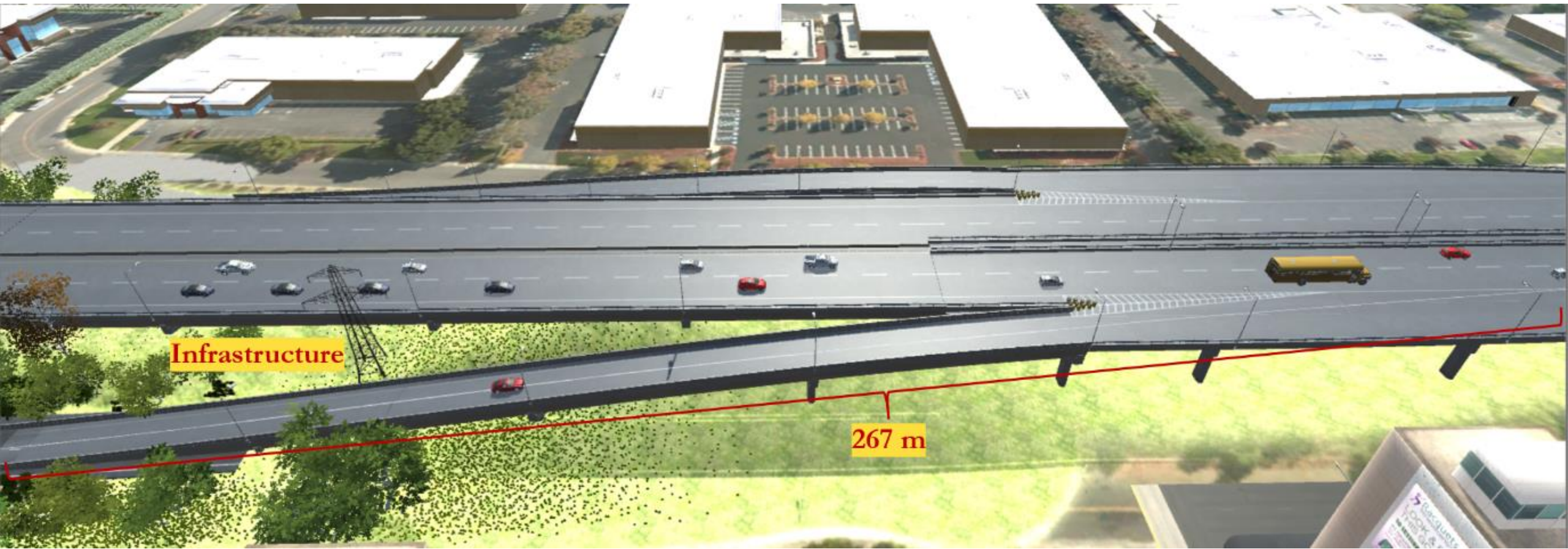
# Simulation Environment in Unity3D

**Mountain View, CA modeled in Unity3D environment**
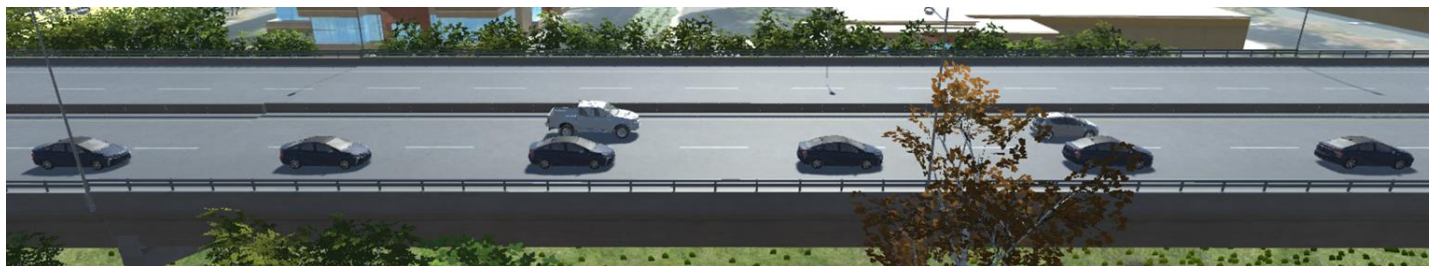
# Simulation Environment in Unity3D

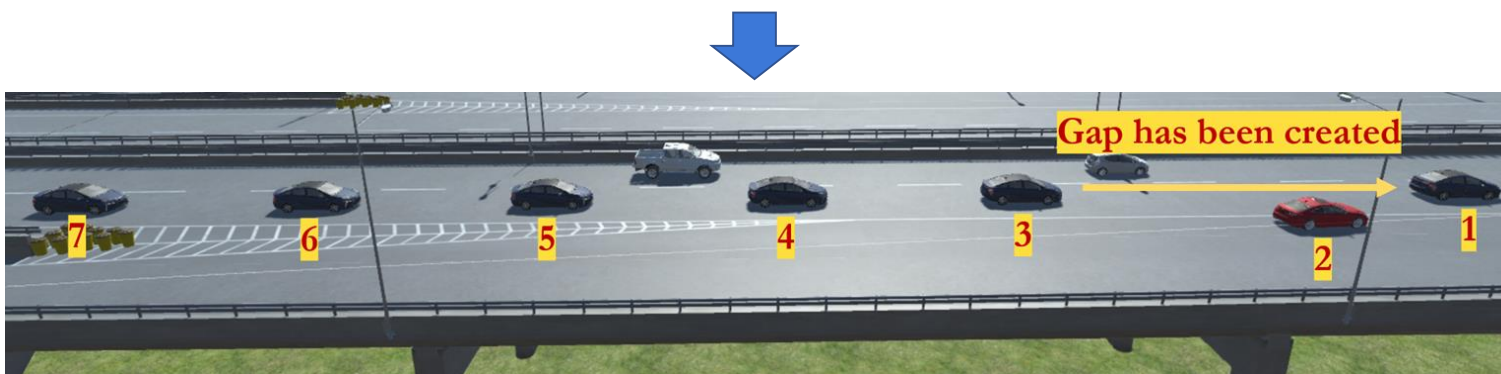**Ramp modeled in Unity3D to conduct simulation**

# Cooperative On-Ramp Merging Simulation

# Cooperative On-Ramp Merging Simulation



Simulation setting:
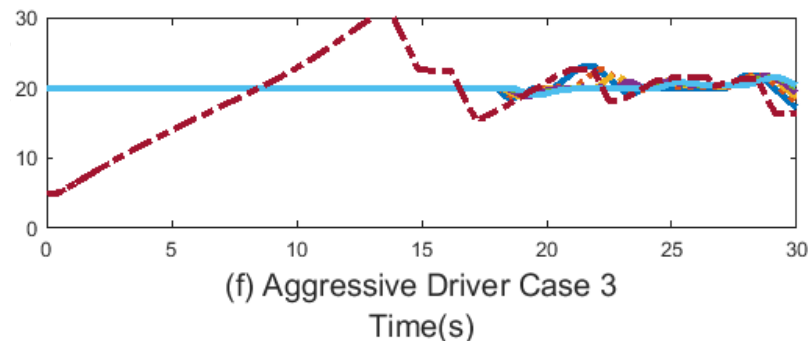1 ramp vehicle, 6 highway vehicles
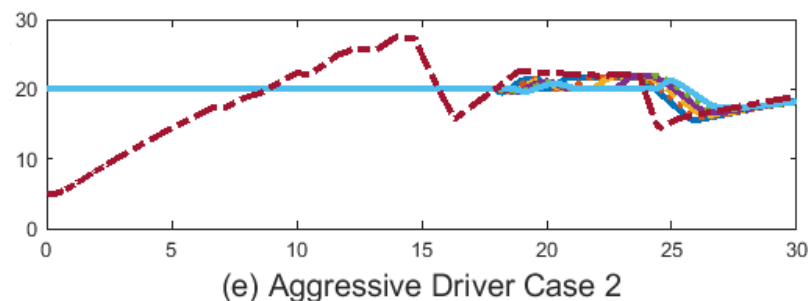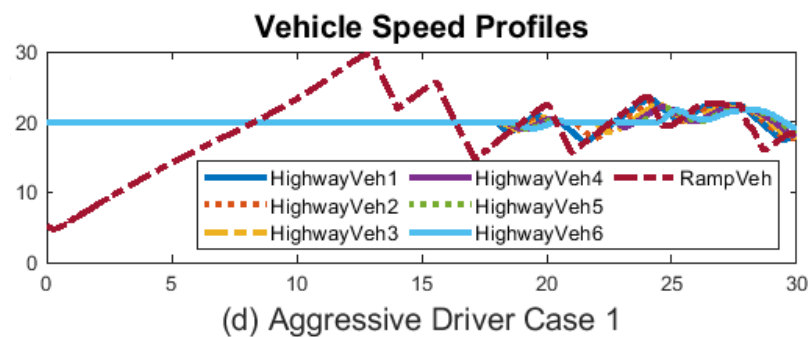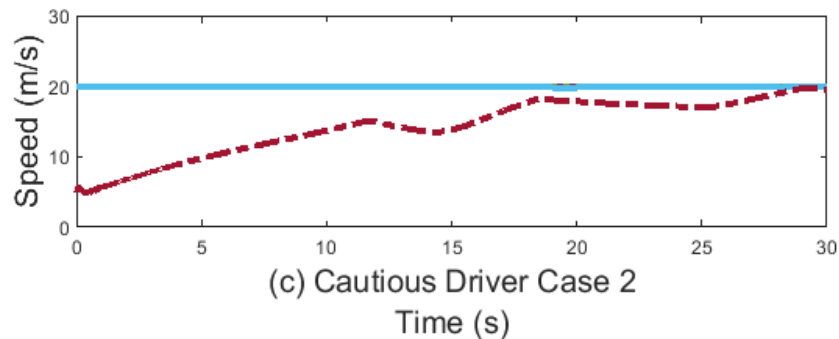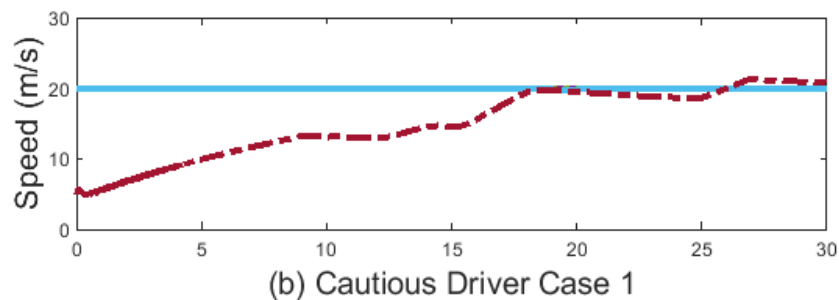(already formed vehicle string)

# Baseline: Human-in-the-Loop Simulation



**Simulation setting:**
- **Control the merging vehicle**
- **4 different drivers**
- **20 simulation runs**

# Simulation Results-Speed Profiles



Vehicle Speed Profiles

(a) Cooperative Merging
(b) Cautious Driver Case 1
(c) Cautious Driver Case 2
(d) Aggressive Driver Case 1
(e) Aggressive Driver Case 2
(f) Aggressive Driver Case 3
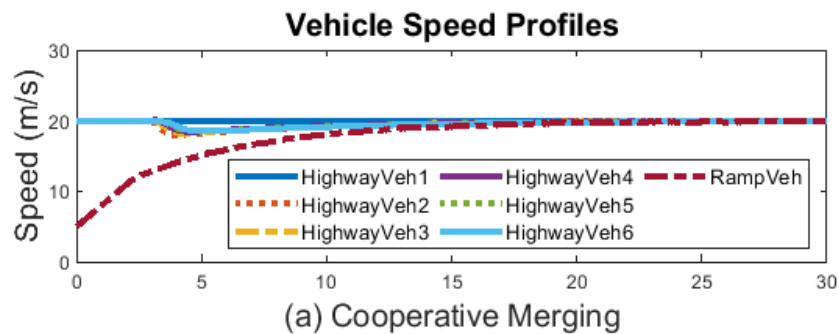
**20 HIL simulations are categorized into:**
- **Aggressive driver cases**
- **Cautious driver cases**

# Simulation Results-Energy and Emissions

- Vehicles in different simulations traveled through the same distance (600m per vehicle)
- HIL results are the average of all 20 simulation runs
- USEPA's MOVES model is adopted to calculate the energy and emissions results

|  | Travel Time | Energy | HC | CO | CO2 | NOx |
|---|---|---|---|---|---|---|
| Cooperative Merging | 218.14 s | 9153.97 KJ | 0.0094 g | 1.1737 g | 651.287 g | 0.0440 g |
| Human-in-the-loop | 233.58 s | 9930.56 KJ | 0.0200 g | 2.8192 g | 706.5392 g | 0.0759 g |
| Reduction Percentage | 6.61 % | 7.82 % | 53.00 % | 58.37 % | 7.82 % | 42.03 % |

# Team Members

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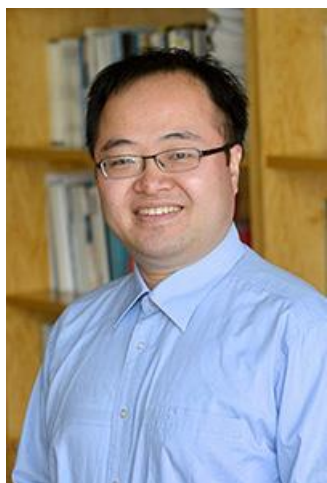
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Welcome to our poster session @B388 Tuesday 10:15-12:00pm!

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