UCR College of Engineering- Center for Environmental Research & Technology

Developing Agent-Based Distributed Cooperative Vehicle-Infrastructure Systems in the Connected and Automated Vehicle Environment

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Mechanical Engineering, UC Riverside
May 29th, 2019

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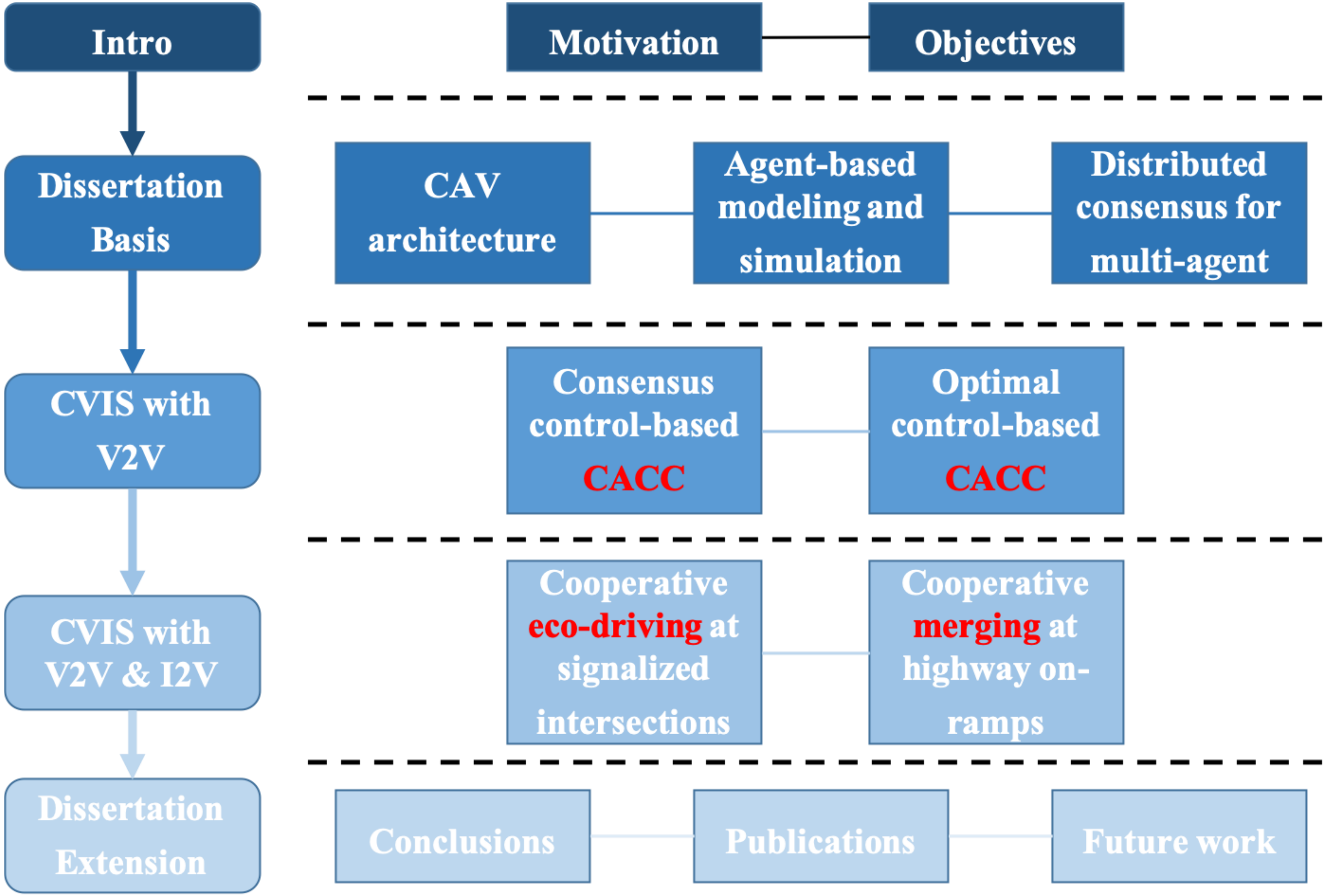
Roadmap of the Dissertation



Intro

Motivation — Objectives

Dissertation Basis

CAV architecture — Agent-based modeling and simulation — Distributed consensus for multi-agent

CVIS with V2V

Consensus control-based **CACC** — Optimal control-based **CACC**

CVIS with V2V & I2V

Cooperative **eco-driving** at signalized intersections — Cooperative **merging** at highway on-ramps

Dissertation Extension

Conclusions — Publications — Future work

INTRODUCTION AND BACKGROUND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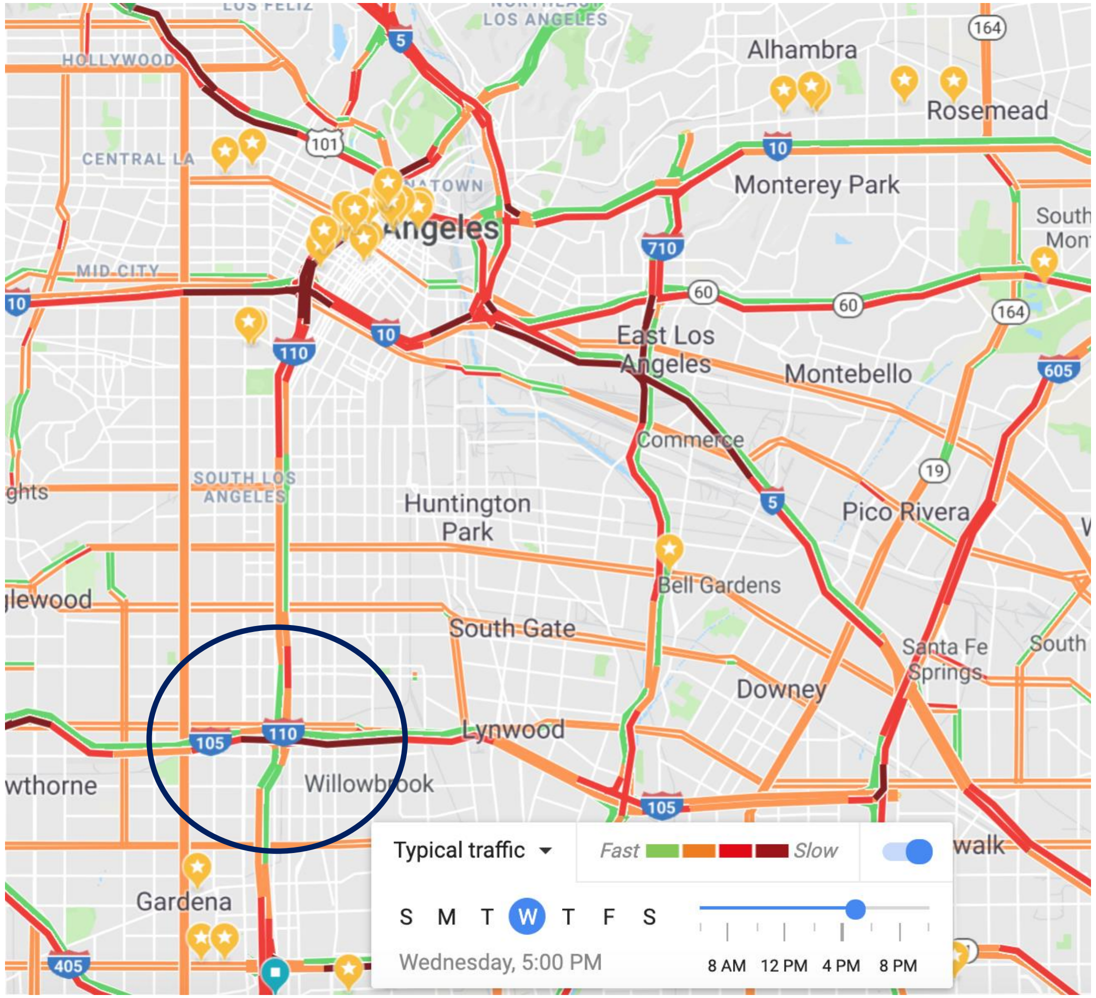
Introduction



105/110 freeway interchange, Los Angeles, CA

Source: Google Map

Introduction

Issues of current transportation systems:

- **Safety 37,461 people perished in traffic accidents in the U.S. in 2016**
- **Mobility 41 hrs/yr/driver are spent by U.S. drivers in traffic during peak hours in 2017, costing nearly $305 billion in total**
- **Environmental sustainability 11.7 billion gallons of fuel were wasted worldwide due to traffic congestion in 2015**

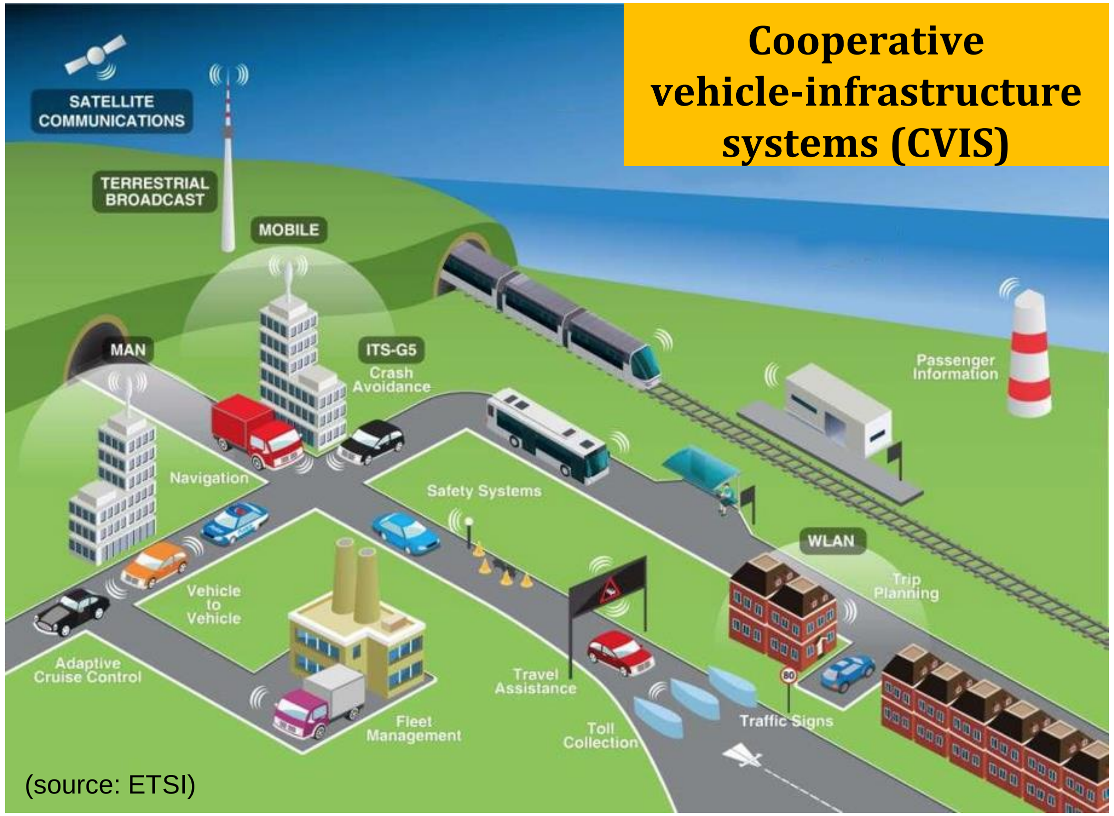
Car crash in Moscow, Russia

Haze in Los Angeles, CA

Traffic jam in Chongqing, China

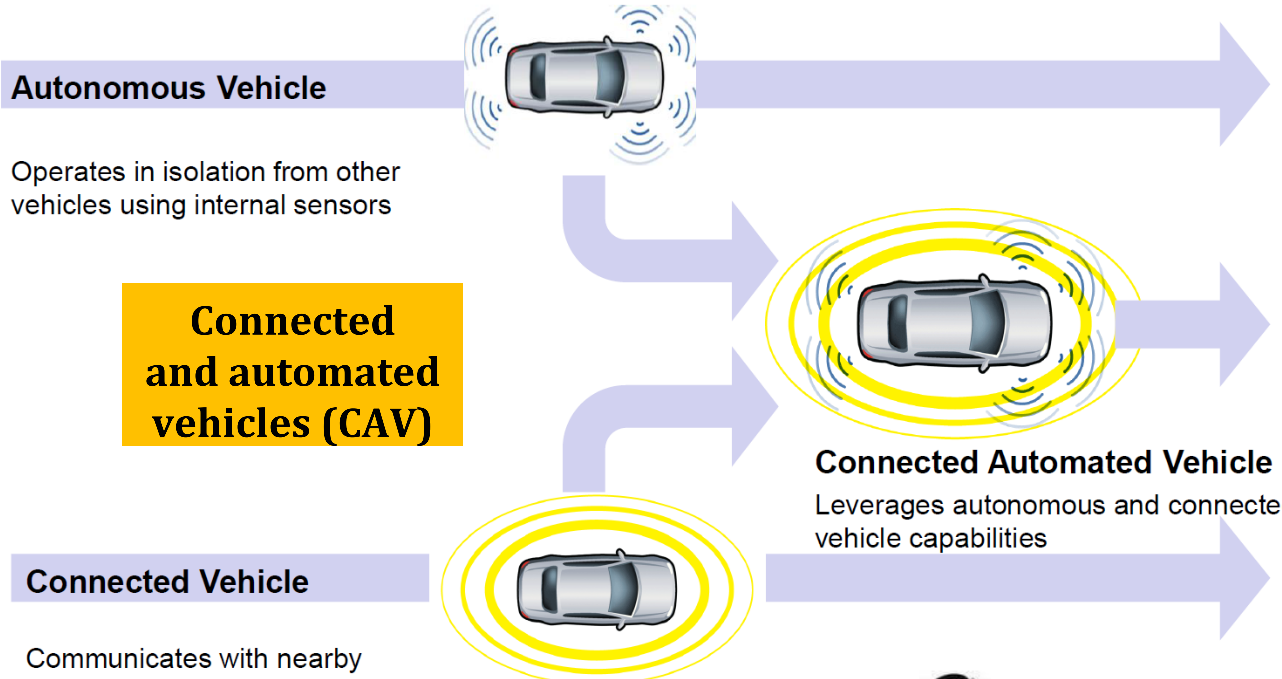
Introduction

Helping solve the issues by cooperative vehicle-infrastructure systems with connected and automated vehicles



Cooperative vehicle-infrastructure systems (CVIS)

(source: ETSI)



Autonomous Vehicle

Operates in isolation from other vehicles using internal sensors

Connected and automated vehicles (CAV)

Connected Automated Vehicle

Leverages autonomous and connected vehicle capabilities

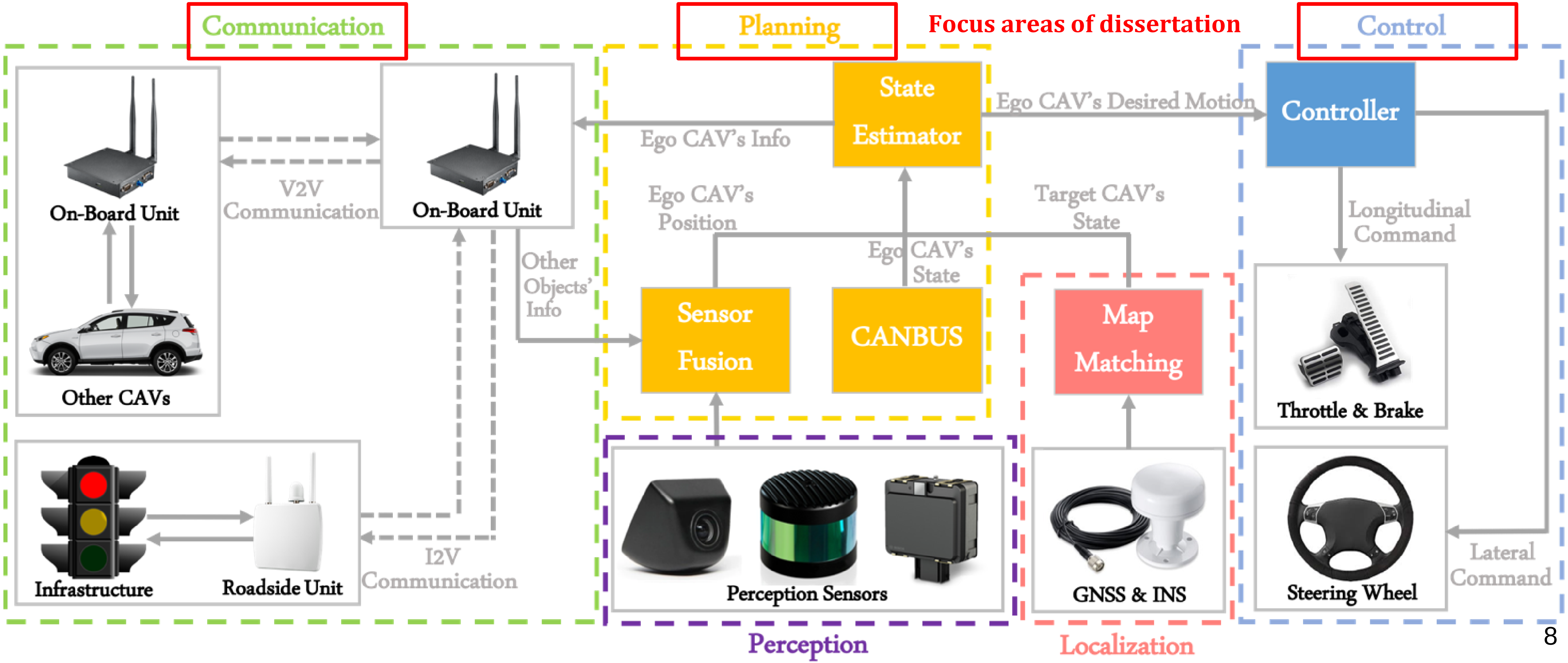
Connected Vehicle

Communicates with nearby vehicles and infrastructure

U.S. Department of Transportation
ITS Joint Program Office

Research Background

- **Generalized connected and automated vehicle (CAV) system**



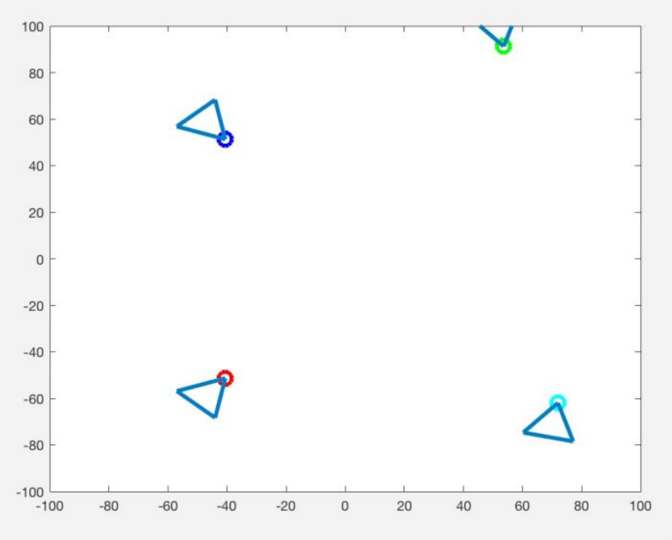
Research Background

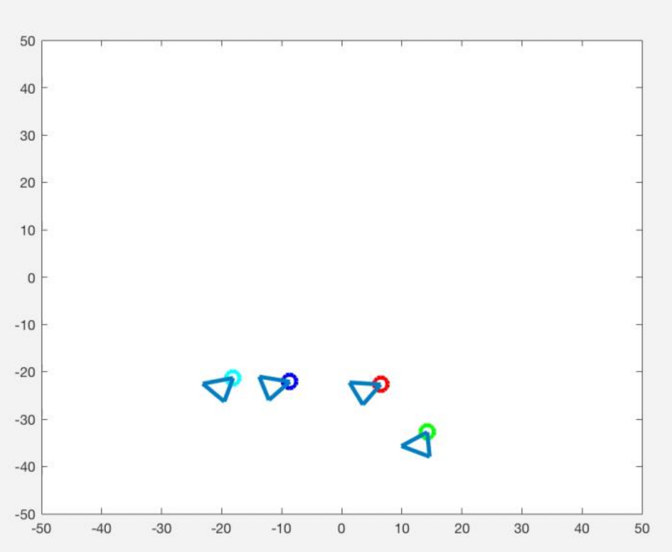
- **Longitudinal cooperative automation of CAVs using V2X communication**

	Extent of Work using CAVs		Potential Benefit to Transportation Systems		
	Theoretical Work	**Experimental Work**	**Safety Benefit**	**Mobility Benefit**	**Environment Benefit**
A. Cooperative adaptive cruise control and platooning	✦✦✦	✦✦	★	★★★	★★
B. Cooperative merging at highway on-ramps	✦✦	✦	★★	★★★	★
C. Speed harmonization on highways	✦✦	✦	★★	★⯨	★
D. Cooperative eco-driving at signalized intersections	✦	⯨	★	★★	★★⯨
E. Automated coordination at non-signalized intersections	✦⯨			★★	★

Number of stars denotes the extent of work conducted, and the extent of the benefits to current transportation systems

DISTRIBUTED CONSENSUS FOR MULTI-AGENT SYSTEMS





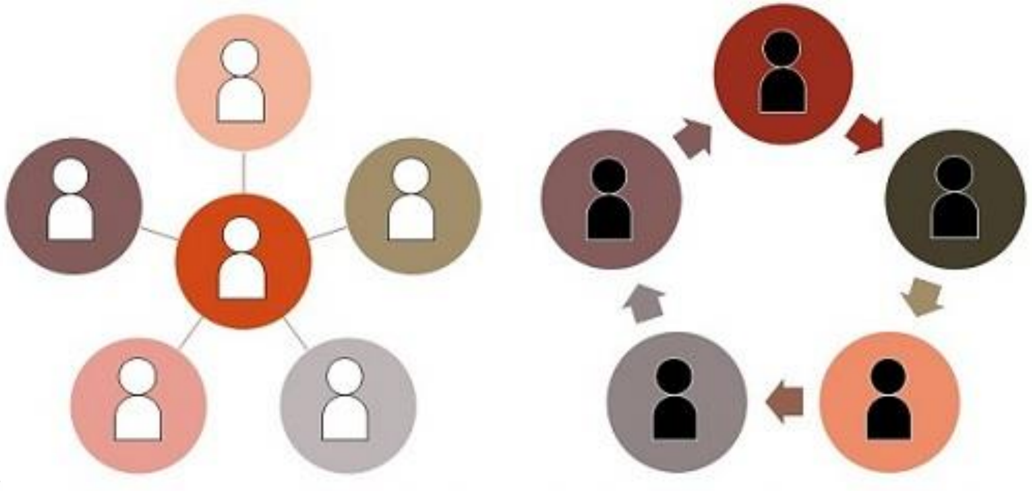
Centralized and Distributed Approaches

Centralized Approaches

- Assumptions: availability of global team knowledge, centralized planning and coordination, fully connected network
- Practical Issues: limited communication/sensing range, environmental factors

Distributed Approaches

- Features: local neighbor-to-neighbor interaction, evolve in a parallel manner
- Strengths: reduced communication/sensing requirement, improved scalability, flexibility, reliability, and robustness

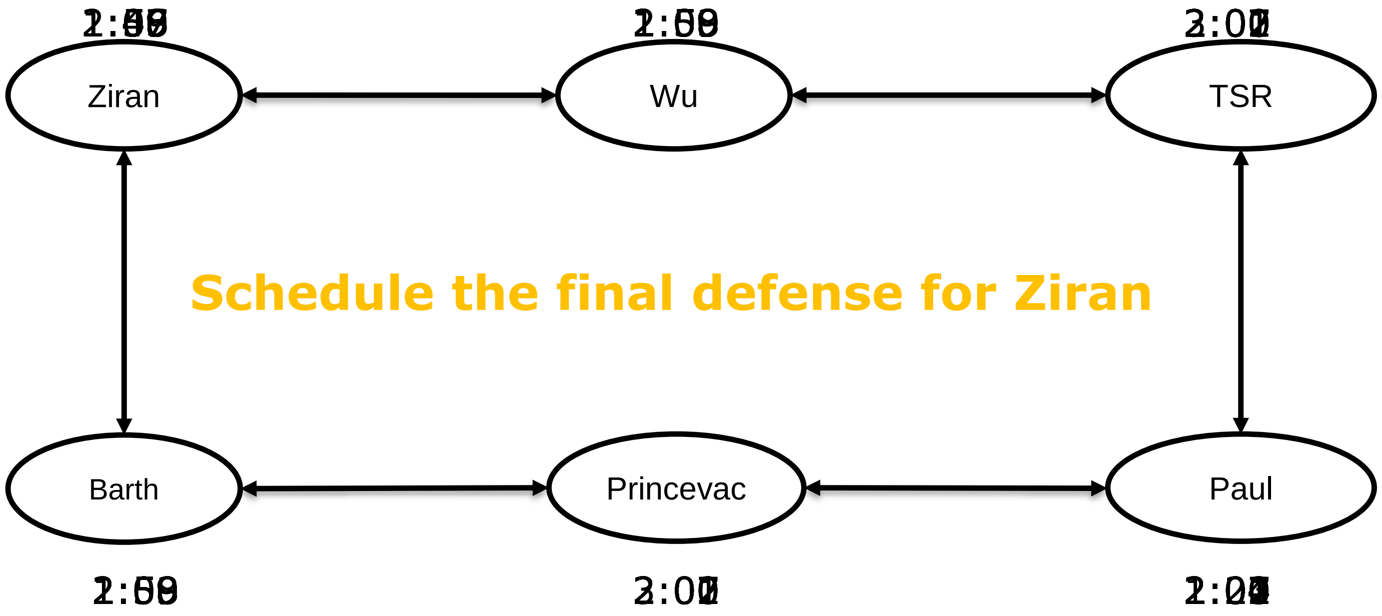


CENTRALIZED V.S. DISTRIBUTED

Distributed Consensus for Multi-Agent Systems

Reach global/centralized agreement or consensus

by distributed/decentralized cooperation among multiple agents



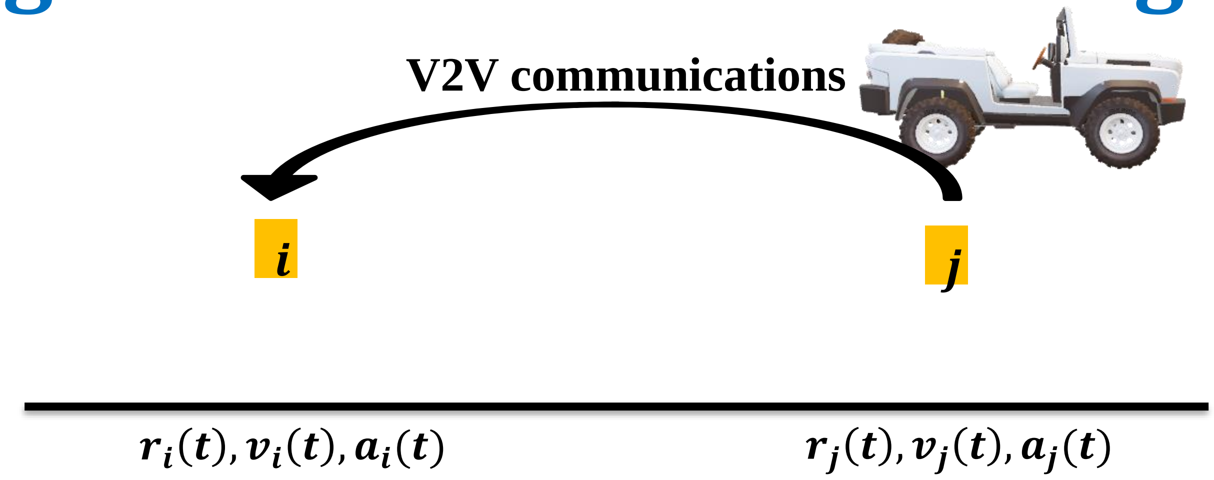
Schedule the final defense for Ziran

$$x_i[k+1] = \sum_{j=1}^{n} a_{ij}[k]\, x_j[k], \qquad i, j = 1, \dots, n$$

where j is the neighbor agent of i

$$\frac{1:00 + 1:00 + 2:00 + 2:00 + 3:00 + 3:00}{6} = 2:00$$

Distributed Consensus Algorithms for Car Following



Dynamics of a connected vehicle

$$\dot{r}_i(t) = v_i(t)$$
$$\dot{v}_i(t) = a_i(t)$$

- **First-order consensus algorithm**

$$v_i(t) = -\sum_{j=1}^{n-1} a_{ij} k_{ij} \left(r_i(t) - r_j(t) \right), \qquad i = 2, \dots, n, j = i - 1$$

- **Second-order consensus algorithm**

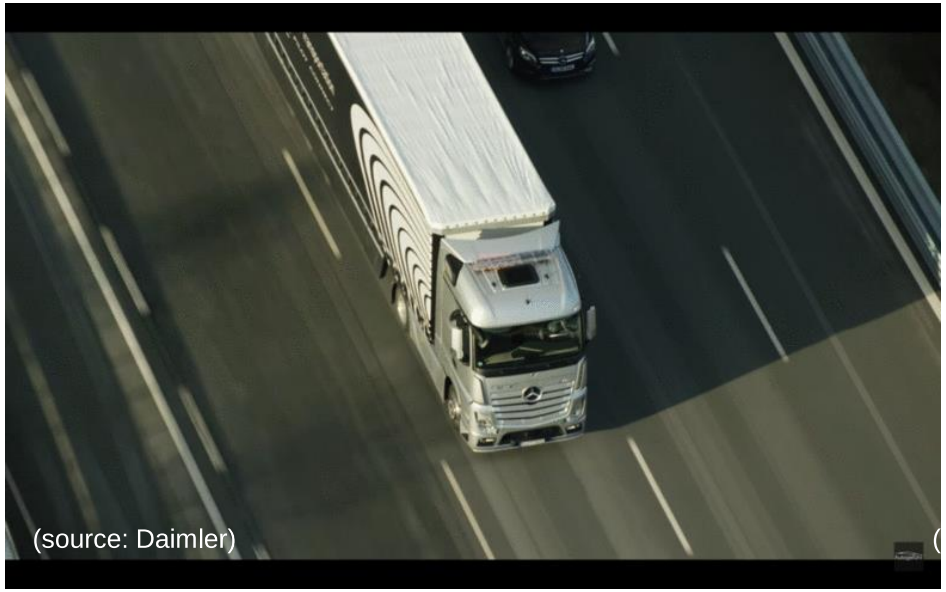
$$a_i(t) = -\sum_{j=1}^{n-1} a_{ij} k_{ij} \left[\left(r_i(t) - r_j(t) \right) + \gamma \left(v_i(t) - v_j(t) \right) \right], \qquad i = 2, \dots, n, j = i - 1$$

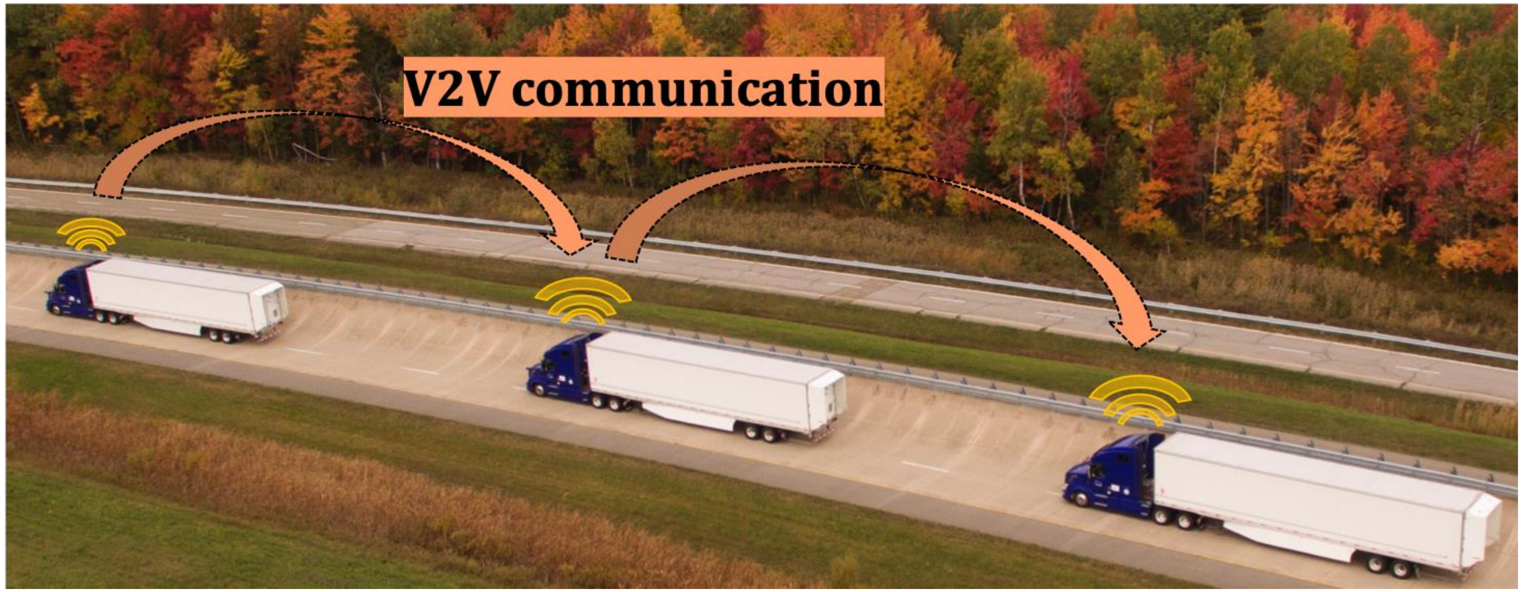
where a_{ij} is the adjacency matrix of the associated communication graph, k_{ij} and γ are control gains

COOPERATIVE ADAPTIVE CRUISE CONTROL
→ MOBILITY BENEFIT

Cooperative Adaptive Cruise Control

- Safer than human driving by taking a lot of danger out of the equation
- Roadway capacity is increased due to the reduction of inter-vehicle time gap
- Fuel consumption and pollutant emissions are reduced due to the mitigation of unnecessary stop and go, and aerodynamic drag of following vehicles


(source: Daimler)



Cooperative Adaptive Cruise Control

Distributed consensus-based CACC algorithms for heterogeneous CAVs with predecessor-following

$$\begin{cases} \dot{r}_i(t) = v_i(t) \\ \dot{v}_i(t) = -a_{ij}k_{ij}\left[r_i(t) - r_j\left(t - \tau_{ij}(t)\right) + l_{if} + l_{jr} + v_j\left(t - \tau_{ij}(t)\right)\left(t_{ij}^{g} + \tau_{ij}(t)\right) b_i\right] \\ \qquad\qquad - \gamma a_{ij}k_{ij}\left[v_i(t) - v_j\left(t - \tau_{ij}(t)\right)\right] \end{cases}$$

$$i = 2, \ldots, n, j = i - 1$$

$r_i(t)$	Longitudinal position of vehicle i at time t	t_{ij}^{g}	Inter-vehicle time gap
$v_i(t)$	Longitudinal speed of vehicle ***i*** at time ***t***	l_{if}	Length between GPS antenna to front bumper
$\dot{v}_i(t)$	Longitudinal acceleration of vehicle ***i*** at time ***t***	l_{jr}	Length between GPS antenna to rear bumper
a_{ij}	(i, j)th entry of the adjacency matrix	b_i	Braking factor of vehicle ***i***
$\tau_{ij}(t)$	Communication delay at time ***t***	γ, k_{ij}	Tuning parameter

(Reference: Wang et al, Developing a distributed consensus-based CACC for heterogenous vehicles with predecessor-following topology, Journal of Advanced Transportation, 2017)

Cooperative Adaptive Cruise Control

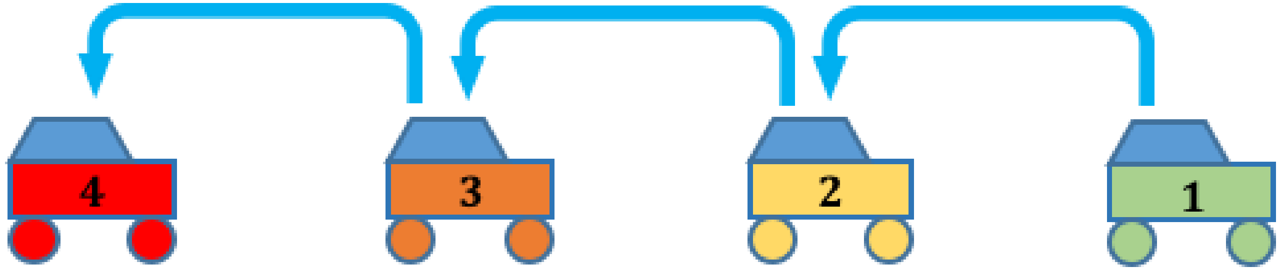
$$\begin{cases} \dot{r}_i(t) = v_i(t) \\ \dot{v}_i(t) = -a_{ij}k_{ij}\boxed{\left[r_i(t) - r_j\left(t - \tau_{ij}(t)\right) + l_{if} + l_{jr} + v_j\left(t - \tau_{ij}(t)\right)\left(t_{ij}^{g} + \tau_{ij}(t)\right)b_i\right]} \\ \qquad - \gamma a_{ij}k_{ij}\boxed{\left[v_i(t) - v_j\left(t - \tau_{ij}(t)\right)\right]} \end{cases}$$

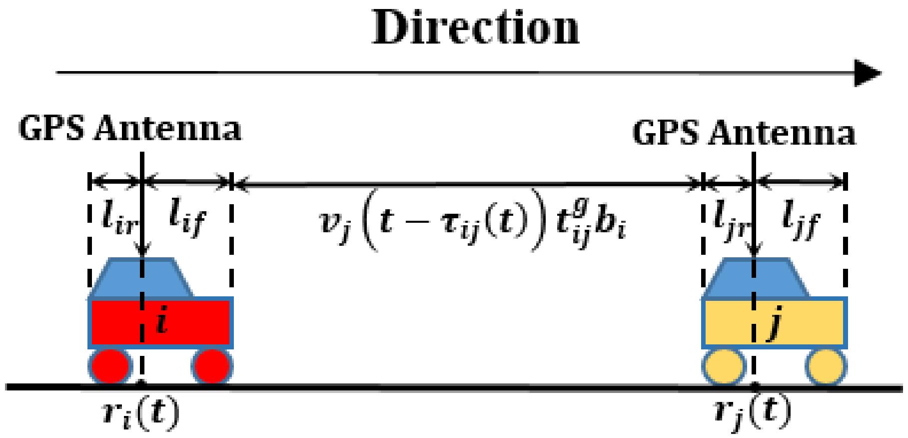
position consensus

$i = 2, \dots, n, j = i - 1$

velocity consensus

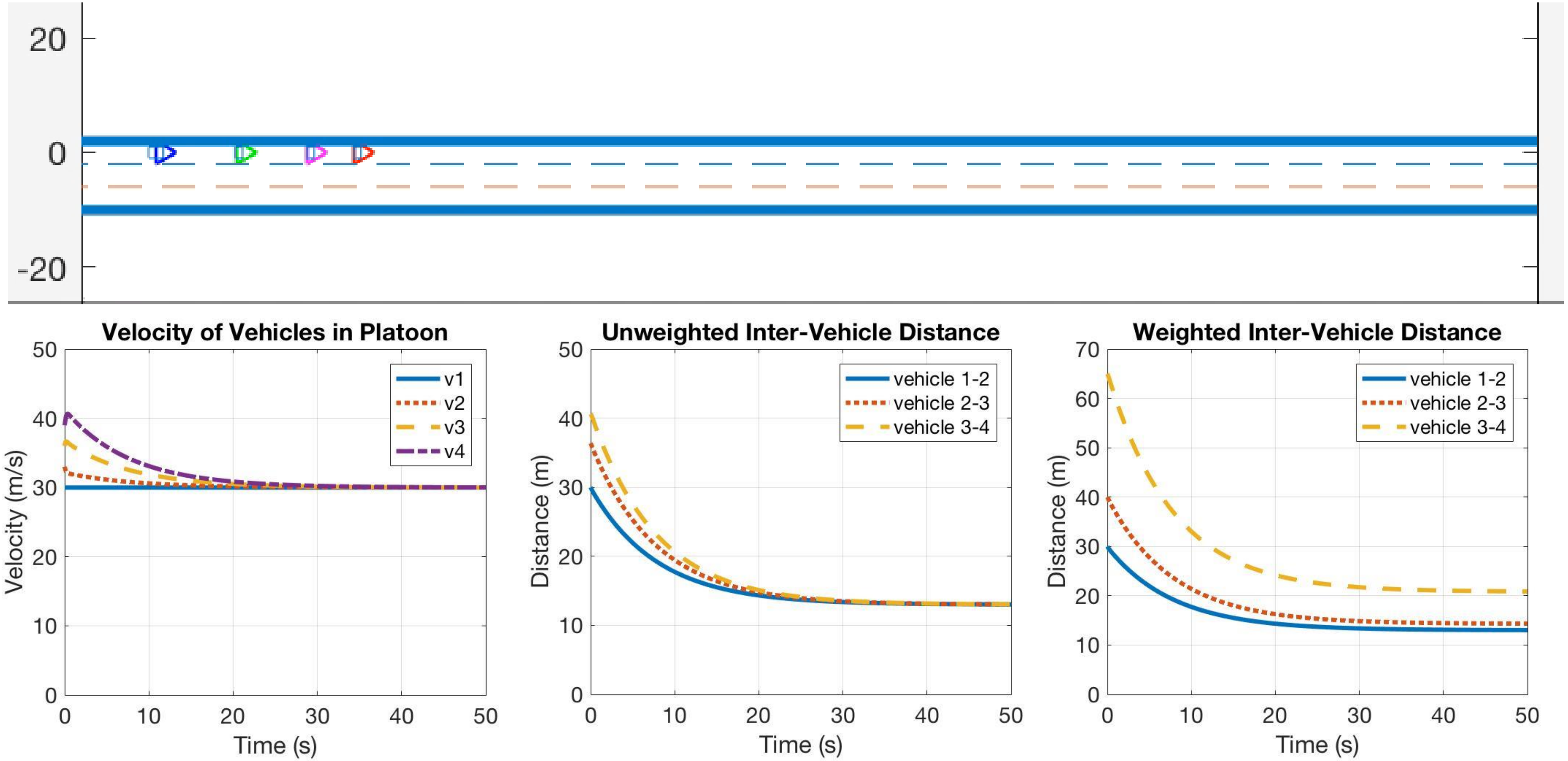
Predecessor following topology





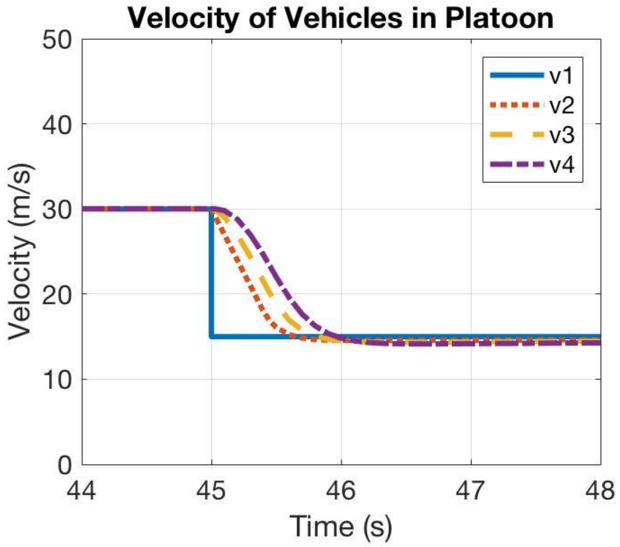
Cooperative Adaptive Cruise Control

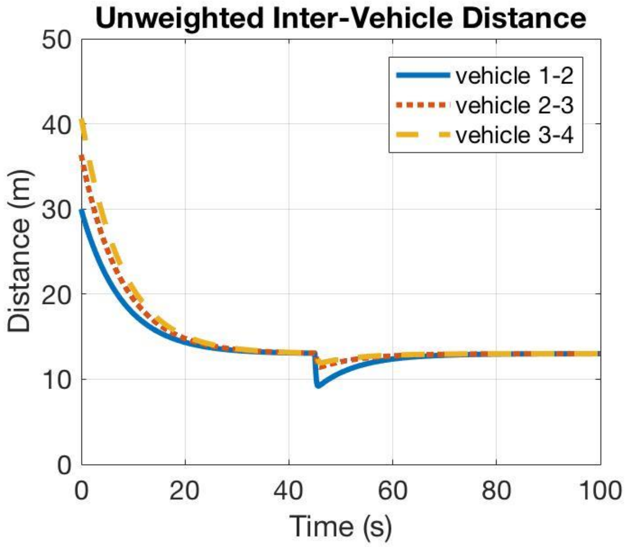
- **Scenario 1: Normal platoon formation**

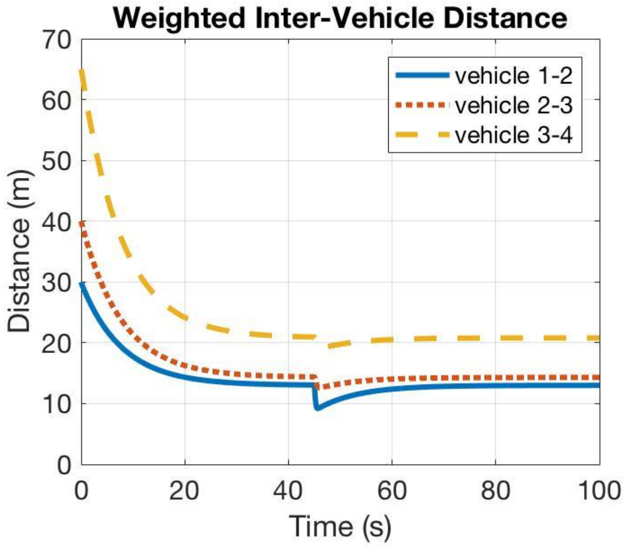


Cooperative Adaptive Cruise Control

- **Scenario 2: Platoon restoration from disturbances**
  - ❖ **A step change is applied to the velocity of the leading vehicle**
  - ❖ **All following vehicles are capable to take immediate responses**

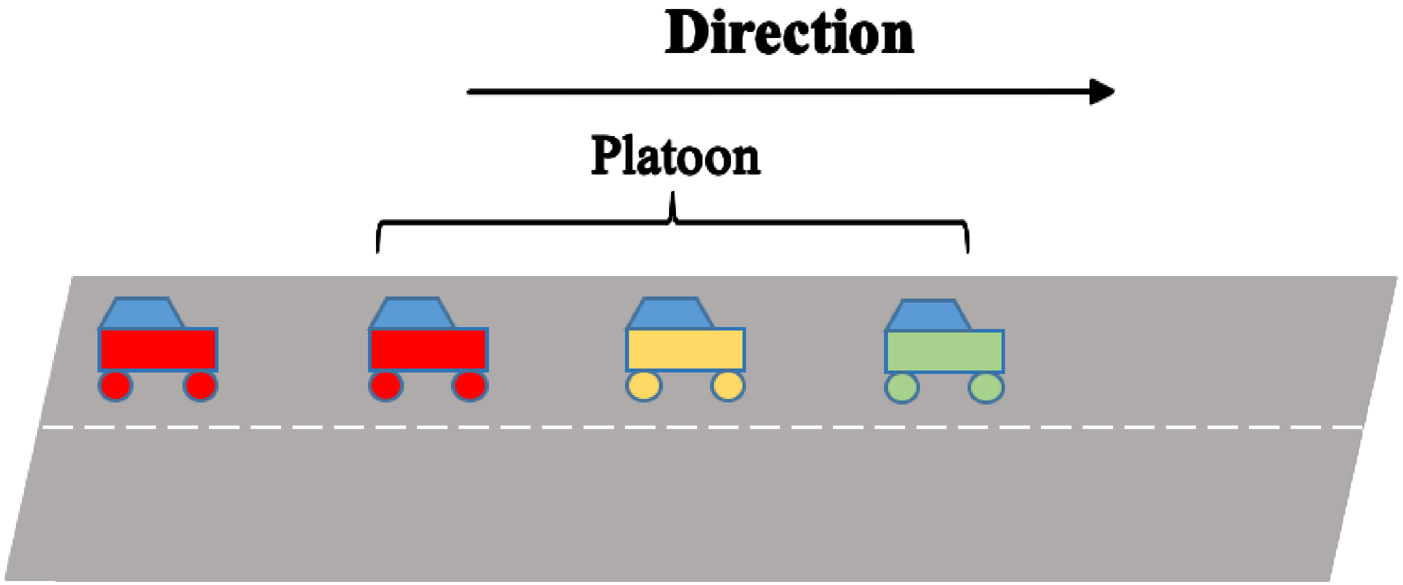






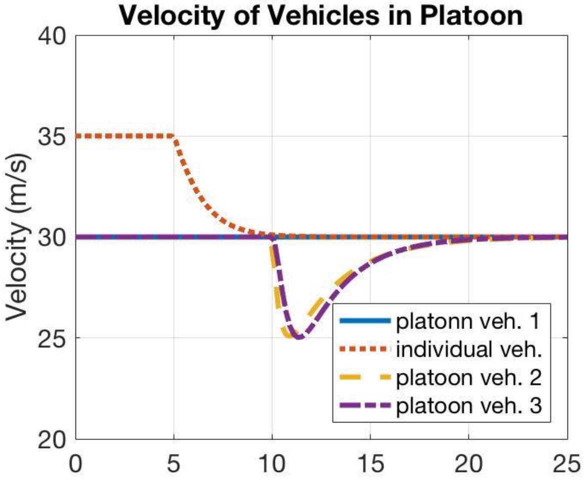
Cooperative Adaptive Cruise Control

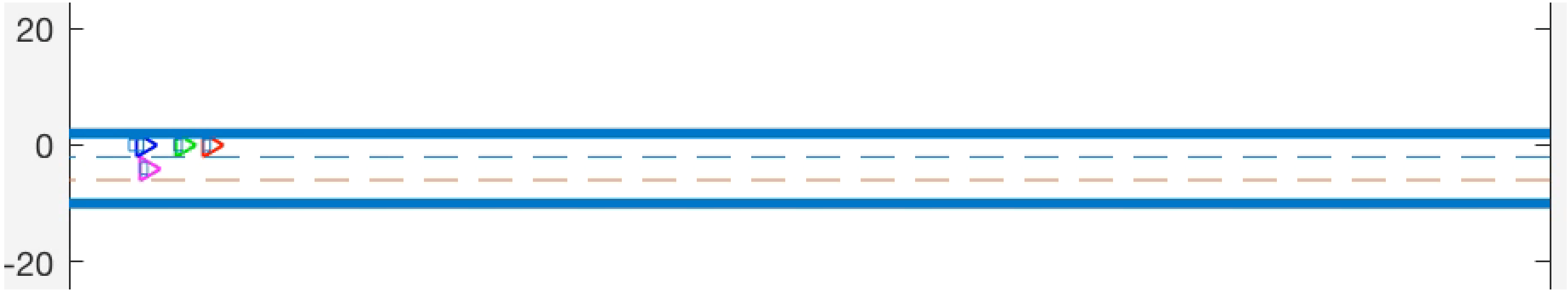
- **Merging protocol**

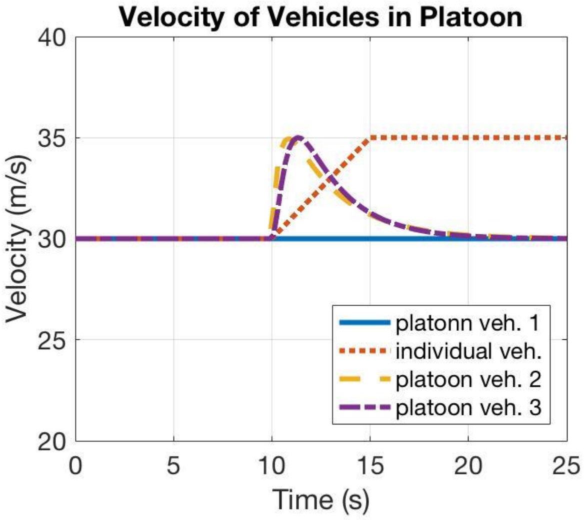


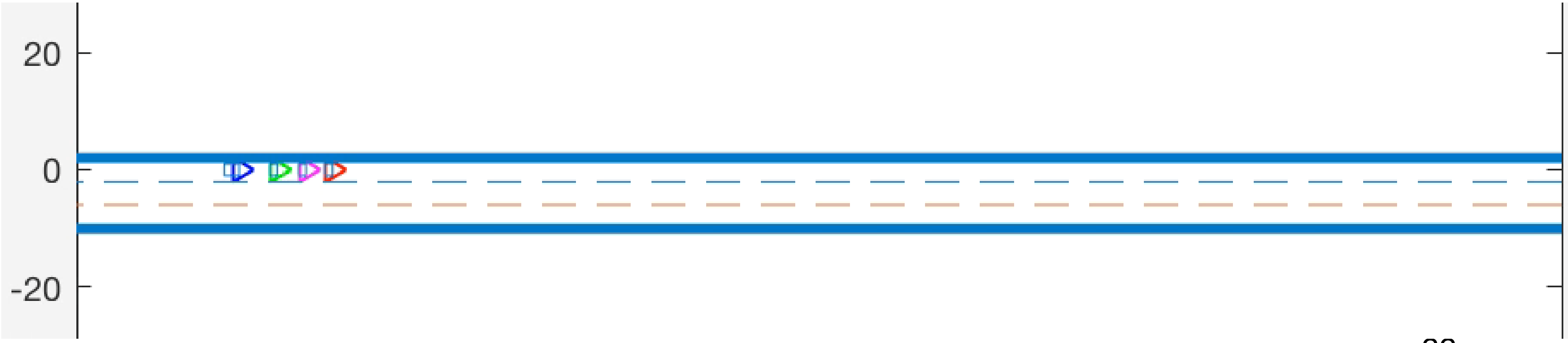
Cooperative Adaptive Cruise Control

- **Scenario 3: Merging and splitting maneuvers**









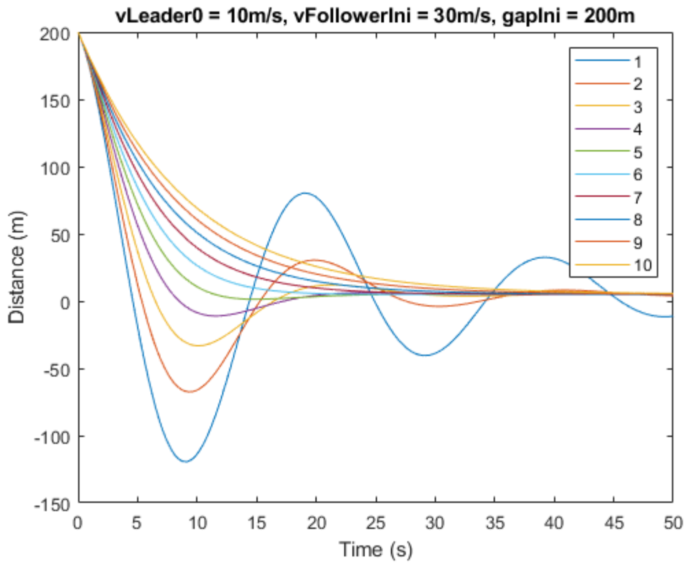
Cooperative Adaptive Cruise Control

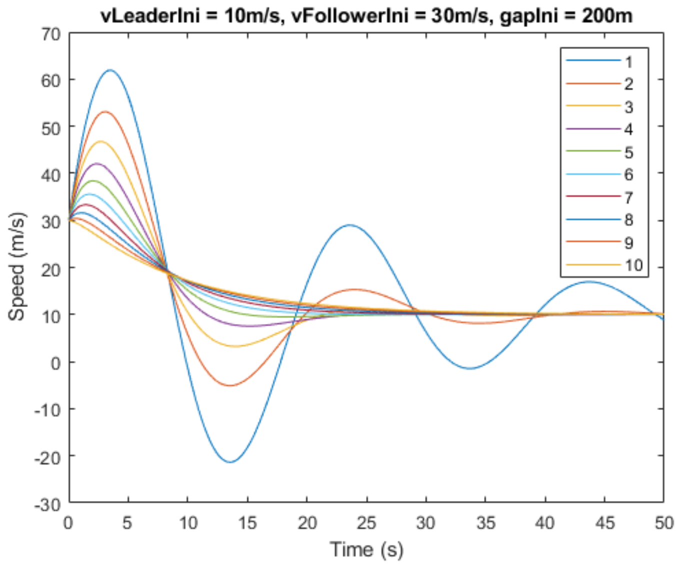
- **Feedforward control: Lookup table for control gain**

Initial states $\left(\Delta r_{ij}(t_0), v_i(t_0), v_j\left(t_0 - \tau_{ij}(t_0)\right)\right)$ **varies every time the algorithm is switched on by vehicles**

Initial states of vehicles highly affect the convergence of the consensus algorithm

Build up a lookup table to find the optimal value of control gains with respect to different initial conditions





Cooperative Adaptive Cruise Control

Safety Constraint (1st priority)

Evaluated by headway overshoot

$$r_j\left(t-\tau_{ij}(t)\right)-r_i(t)>l_j, t\in[t_0,t_{consensus}]$$

Efficiency Constraint (2nd priority)

Evaluated by convergence time

$$\left|r_j\left(t_{consensus}-\tau_{ij}(t_{consensus})\right)-r_i(t_{consensus})\right|\le\eta_r\cdot\left[l_j+v_i(t_{consensus})\cdot\left(t_{ij}^{g}(t_{consensus})+\tau_{ij}(t_{consensus})\right)\right]$$

$$\left|v_j\left(t_{consensus}-\tau_{ij}(t_{consensus})\right)-v_i(t_{consensus})\right|\le\eta_v\cdot v_j\left(t_{consensus}-\tau_{ij}(t_{consensus})\right)$$

$$|a_i(t_{consensus})|\le\delta_a$$

$$|jerk_i(t_{consensus})|\le\delta_{jerk}$$

Comfort Constraint (3rd priority)

Evaluated by maximum acceleration/deceleration and maximum jerk

$$\Omega_i=\omega_1\cdot\max_{t\in[t_0,t_{consensus}]}\left(|a_i^{\max}(t)|,|d_i^{\max}(t)|\right)+\omega_2\cdot\max_{t\in[t_0,t_{consensus}]}\left(|jerk_i^{\max}(t)|,\left|jerk_i^{\min}(t)\right|\right), t\in[t_0,t_{consensus}]$$

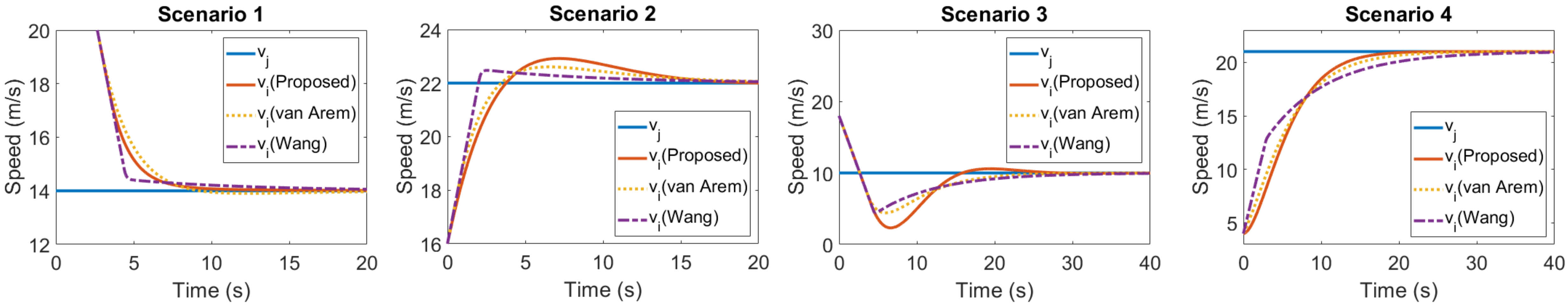
Cooperative Adaptive Cruise Control

TABLE I. Settings of Simulation Scenarios

	$\Delta r_{ij}(t_0)$ (m)	$v_i(t_0)$ (m/s)	$v_j\left(t_0 - \tau_{ij}(t_0)\right)$ (m/s)
Scenario 1	50	28	14
Scenario 2	20	16	22
Scenario 3	-30	18	10
Scenario 4	-80	4	21

TABLE II. SIMULATION RESULTS

	Convergence time (s)				Maximum jerk (m/s^3)			
Scenario	1	2	3	4	1	2	3	4
Wang	35.9	35.0	56.5	57.6	21.2	20.7	25.7	13.4
van Arem	29.3	32.1	41.8	40.1	1.5	1.6	2.3	0.7
Proposed	24.9	22.9	32.1	28.3	2.3	0.8	1.6	1.6

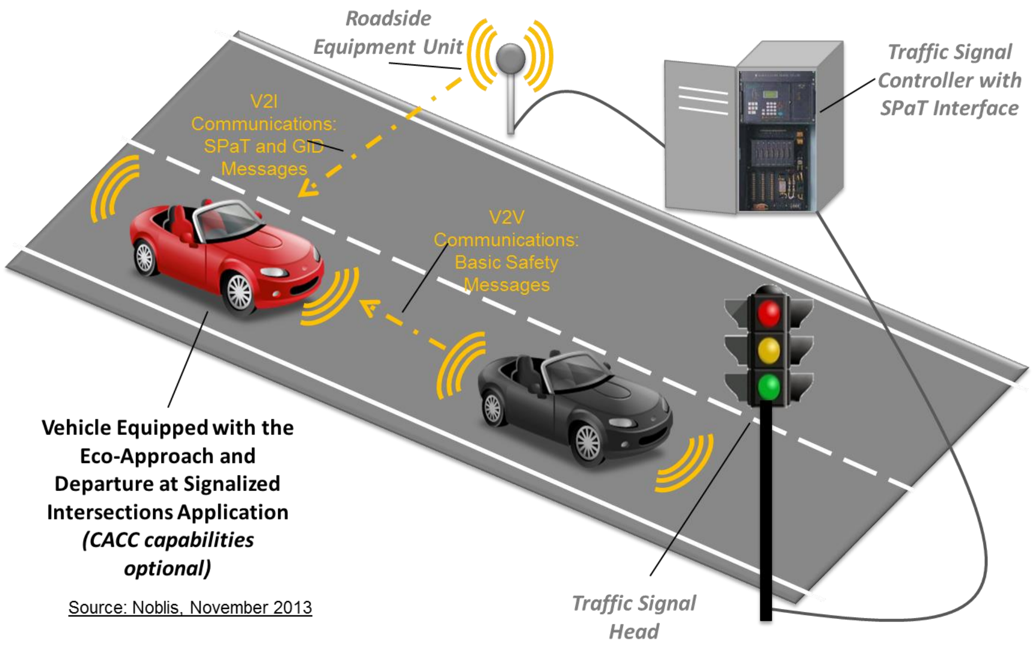


COOPERATIVE ECO-DRIVING AT SIGNALIZED INTERSECTIONS

→ ENVIRONMENTAL SUSTAINABILITY BENEFIT

Eco-Approach and Departure

- **Utilizes traffic signal phase and timing (SPaT) data to provide driver recommendations that encourage "green" approaches to signalized intersections**

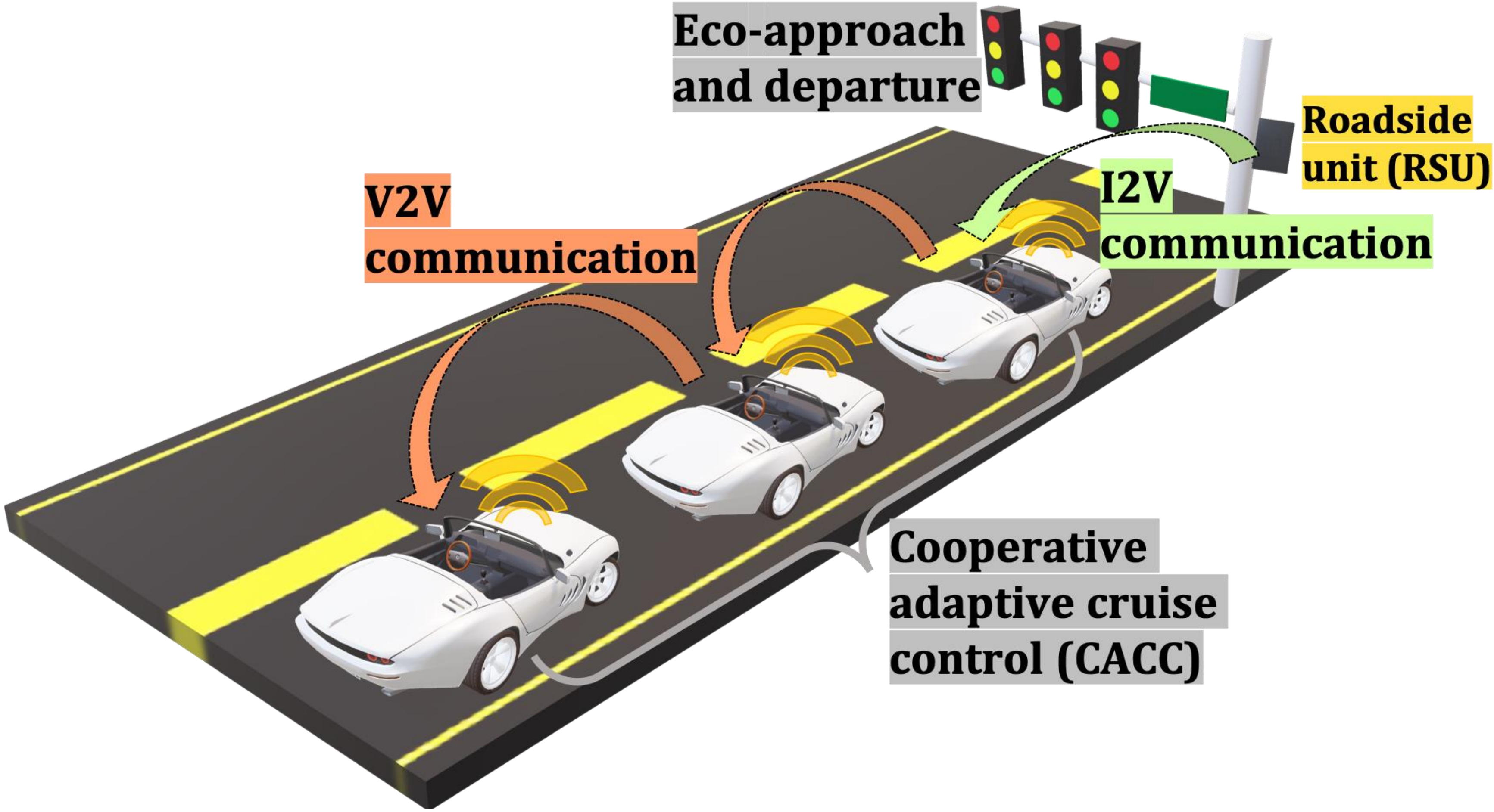


Source: Noblis, November 2013

Volvo truck demo @ Carson, CA, Mar. 6, 2019

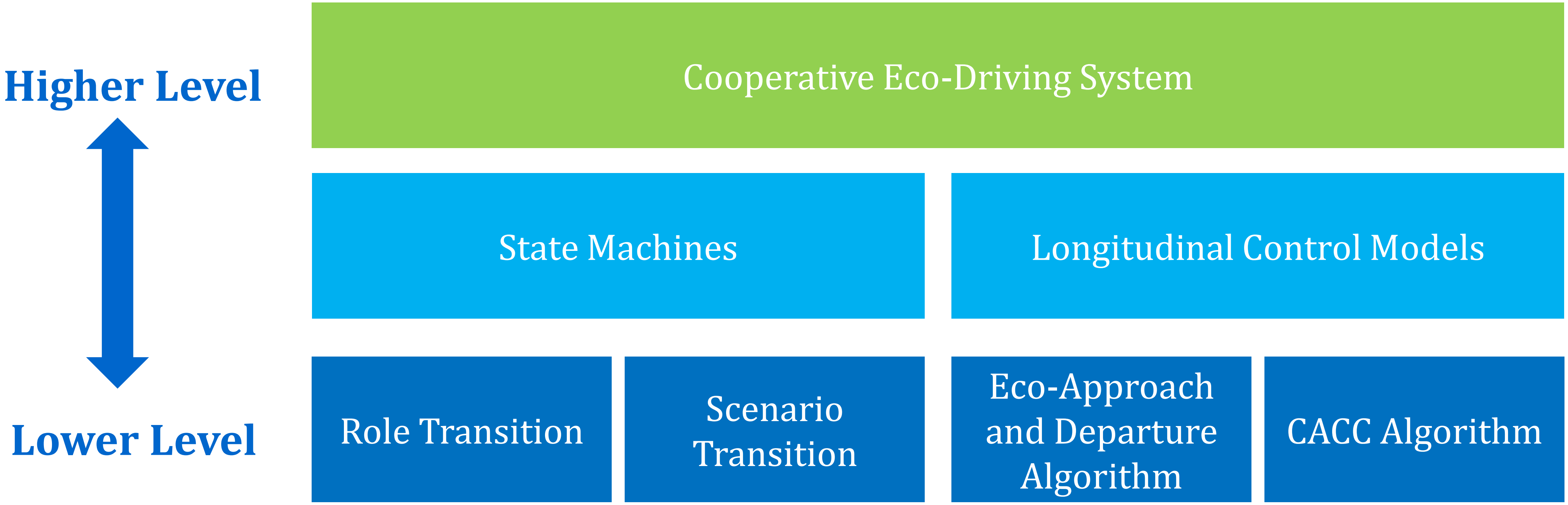
Cooperative Eco-Driving

- **Taking advantages of both eco-approach and departure, as well as CACC**



Cooperative Eco-Driving

- **System Architecture**



Higher Level

Lower Level

Cooperative Eco-Driving System

State Machines

Longitudinal Control Models

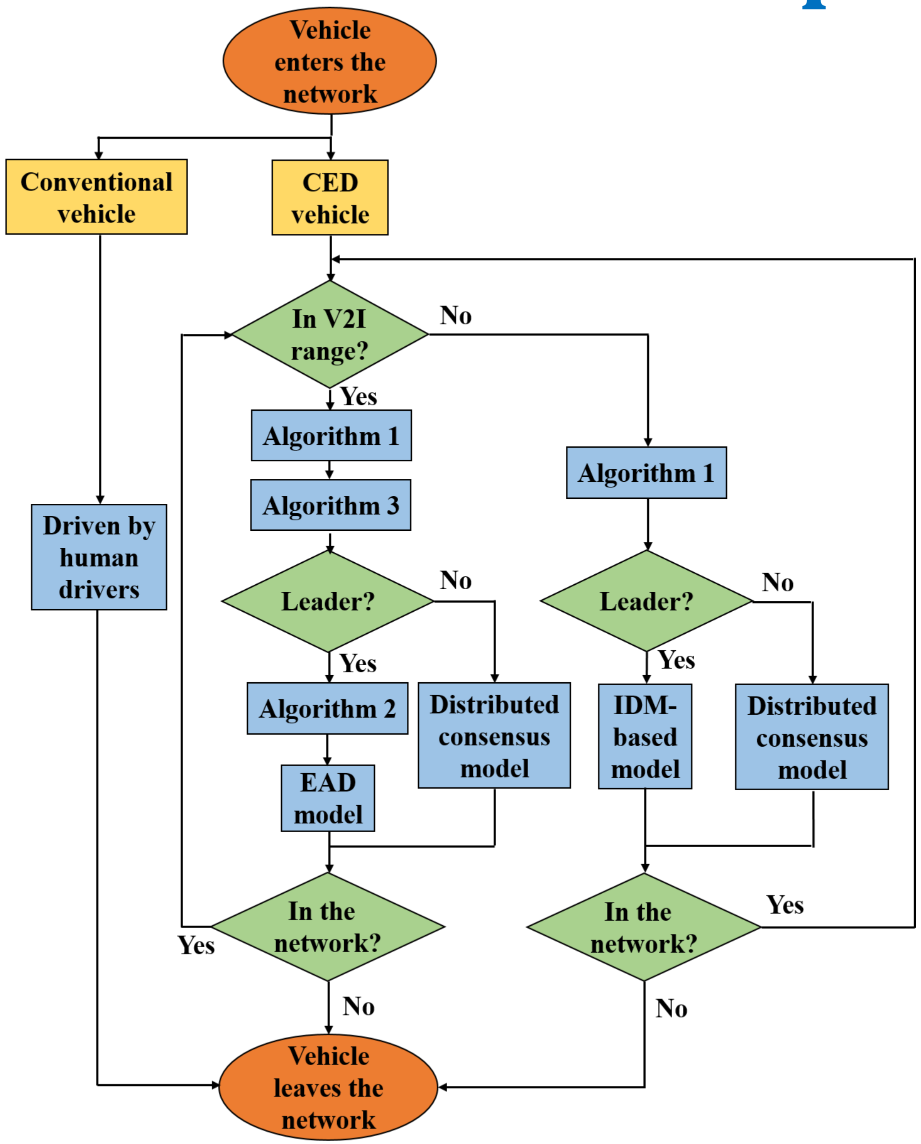
Role Transition

Scenario Transition

Eco-Approach and Departure Algorithm

CACC Algorithm

Cooperative Eco-Driving



Vehicle enters the network

Conventional vehicle

CED vehicle

Driven by human drivers

In V2I range?

Yes

No

Algorithm 1

Algorithm 3

Leader?

Yes

No

Algorithm 2

EAD model

Distributed consensus model

In the network?

Yes

No

Algorithm 1

Leader?

Yes

No

IDM-based model

Distributed consensus model

In the network?

Yes

No

Vehicle leaves the network

- Two vehicle types:

  Conventional vehicle and CED vehicles

- Two vehicle roles:

  Leader and follower

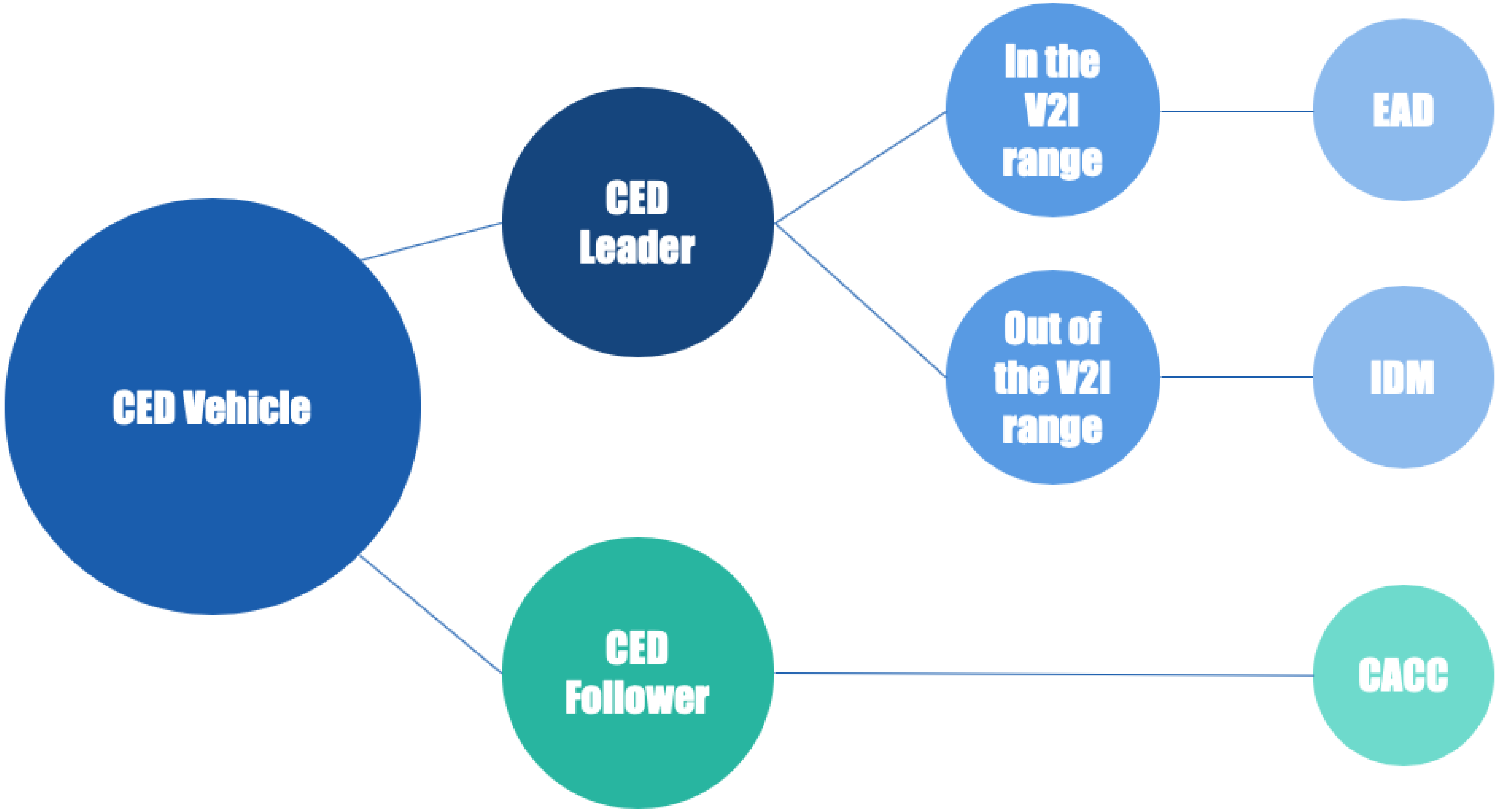
- Four longitudinal controllers:

  Human driver model, EAD model, IDM model, and distributed consensus model

(Reference: Wang et al, Cooperative eco-driving at signalized intersections in a partially connected and automated vehicle environment, IEEE Transactions on Intelligent Transportation Systems, 2019)

Cooperative Eco-Driving

- **Role and control models of CED vehicles**



Cooperative Eco-Driving

- **How cooperative eco-driving system works?**

1. Calculate cruising, earliest and latest time-to-arrival value

$$t_c = \frac{d_1}{v_1}$$

$$t_e = \frac{d_1 - v_1 \cdot \frac{\pi}{2\alpha}}{v_{lim}} + \frac{\pi}{2\alpha}, \alpha = \min\left\{\frac{2 \cdot a_{max}}{v_{lim} - v_1}, \sqrt{\frac{2 \cdot jerk_{max}}{v_{lim} - v_1}}\right\}$$

$$t_l = \frac{d_1 - v_1 \cdot \frac{\pi}{2\beta}}{v_{coast}} + \frac{\pi}{2\beta}, \beta = \min\left\{\frac{2 \cdot a_{max}}{v_1 - v_{coast}}, \sqrt{\frac{2 \cdot jerk_{max}}{v_1 - v_{coast}}}\right\}$$

Parameter	Definition
d_1	current distance to the intersection
v_1	current speed of vehicle
a_{max}	maximum changing rate of speed
$jerk_{max}$	maximum changing rate of acceleration or deceleration
v_{lim}	the speed limit of the current roadway
v_{coast}	coasting speed

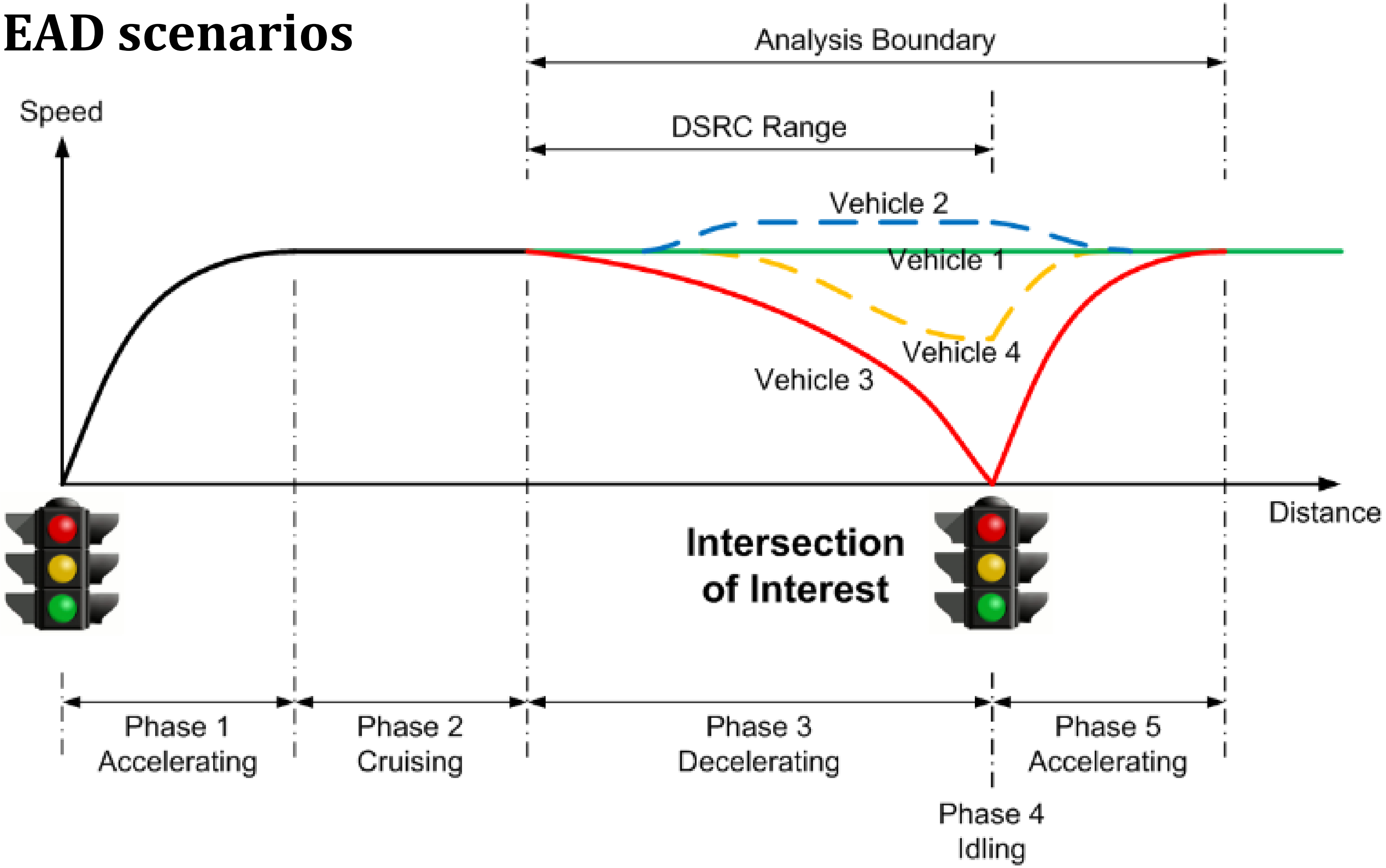
2. Run the scenario transition state machine to decide the scenario

3. Assign the time-to-arrival value t_{arr} to one of t_c, t_e, t_l based on the selected scenario

4. Propose EAD algorithm for the CED leader with respect to different scenarios

Cooperative Eco-Driving

- **EAD scenarios**



Scenario of vehicles:

- **Vehicle 1 – Cruise**
- **Vehicle 2 – Accelerate**
- **Vehicle 3 – Stop**
- **Vehicle 4 – Decelerate**

Cooperative Eco-Driving

- **Algorithms for eco-approach and eco-departure, different scenarios**

$$\textbf{Approach}\begin{cases} a_{ref} = v_{d1}\cdot j_1\cdot \sin(j_1 t), t\in\left[0,\frac{\pi}{2j_1}\right) \\ a_{ref} = v_{d1}\cdot j_1\cdot \sin\left[k_1\cdot\left(t+\frac{\pi}{k_1}-t_1\right)\right], t\in\left[\frac{\pi}{2j_1},\frac{\pi}{2j_1}+\frac{\pi}{2k_1}\right) \end{cases}$$

$$\textbf{Departure}\begin{cases} a_{ref} = v_{d2}\cdot j_2\cdot \sin\left[k_2\cdot\left(t+\frac{\pi}{k_2}-t_{depart}\right)\right], t\in\left[t_{depart},t_{depart}+\frac{\pi}{2k_2}\right) \\ a_{ref} = v_{d2}\cdot j_2\cdot \sin\left[j_2\cdot\left(t-t_{depart}-\frac{\pi}{2j_2}-\frac{\pi}{2k_2}\right)\right], t\in\left[t_{depart}+\frac{\pi}{2k_2},t_{depart}+\frac{\pi}{2j_2}+\frac{\pi}{2k_2}\right) \end{cases}$$

1. Accelerate or decelerate scenario

$v_h = \frac{d_1}{t_{arr}}, v_{d1} = v_h - v_1, v_{d2} = v_h - v_{tar}$, and $t_{depart} = \frac{d_2}{v_h}$

$\max\limits_{i=1,2} k_i$ subject to

$$\begin{aligned} |k_i\cdot v_{di}| &\le a_{max} \\ |{k_i}^2\cdot v_{di}| &\le jerk_{max}, j_i = \frac{-\frac{\pi}{2}k_i-\sqrt{\left(\frac{\pi}{2}k_i\right)^2-4{k_i}^2\cdot\left[\left(\frac{\pi}{2}-1\right)-\frac{d_i}{v_h}\cdot k_i\right]}}{2\left[\left(\frac{\pi}{2}-1\right)-\frac{d_i}{v_h}\cdot k_i\right]}, (i=1,2) \\ k_i &\ge \left(\frac{\pi}{2}-1\right)\cdot\frac{v_h}{d_i} \end{aligned}$$

2. Stop scenario

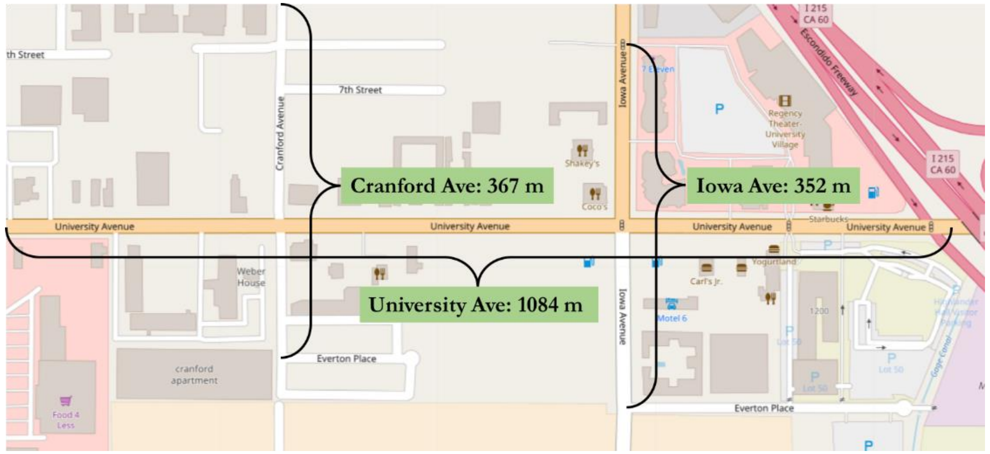
$v_h = \frac{v_1}{2}, k_i = j_i = \frac{v_h}{d_i}\cdot\pi$, and $t_{depart} = t_{next\_s}$

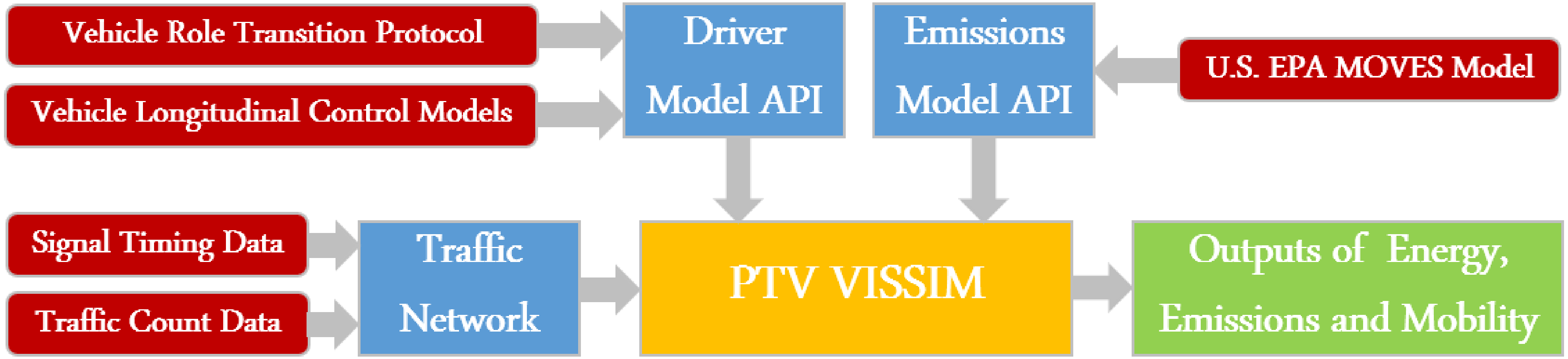
Cooperative Eco-Driving

- **Microscopic traffic simulation in pure CAV environment**

Cooperative Eco-Driving

Microscopic traffic simulation study is conducted based on the University Avenue corridor in Riverside, CA, with realistic traffic data provided by City of Riverside





Vehicle Role Transition Protocol

Vehicle Longitudinal Control Models

Driver Model API

Emissions Model API

U.S. EPA MOVES Model

Signal Timing Data

Traffic Count Data

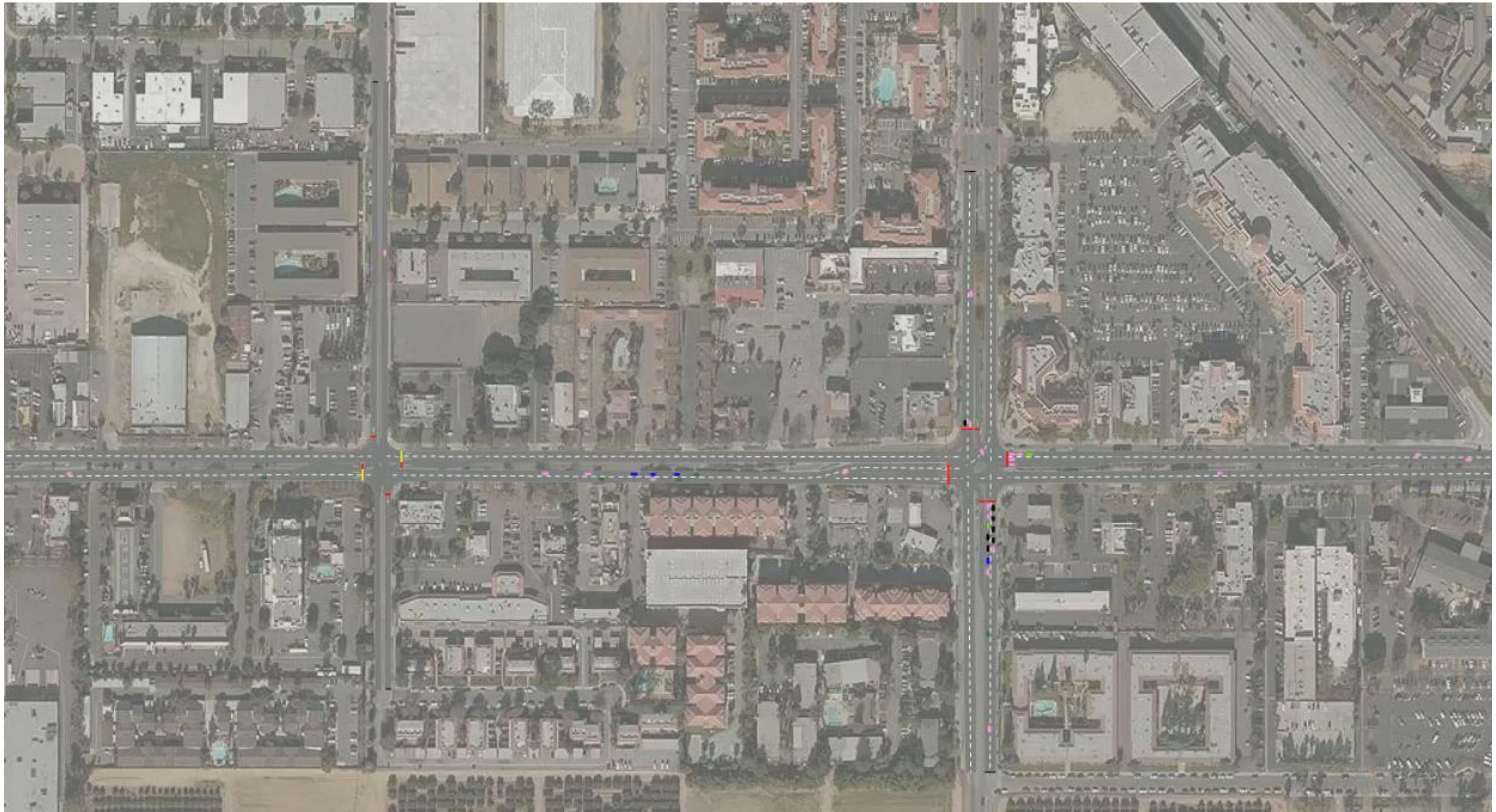
Traffic Network

PTV VISSIM

Outputs of Energy, Emissions and Mobility

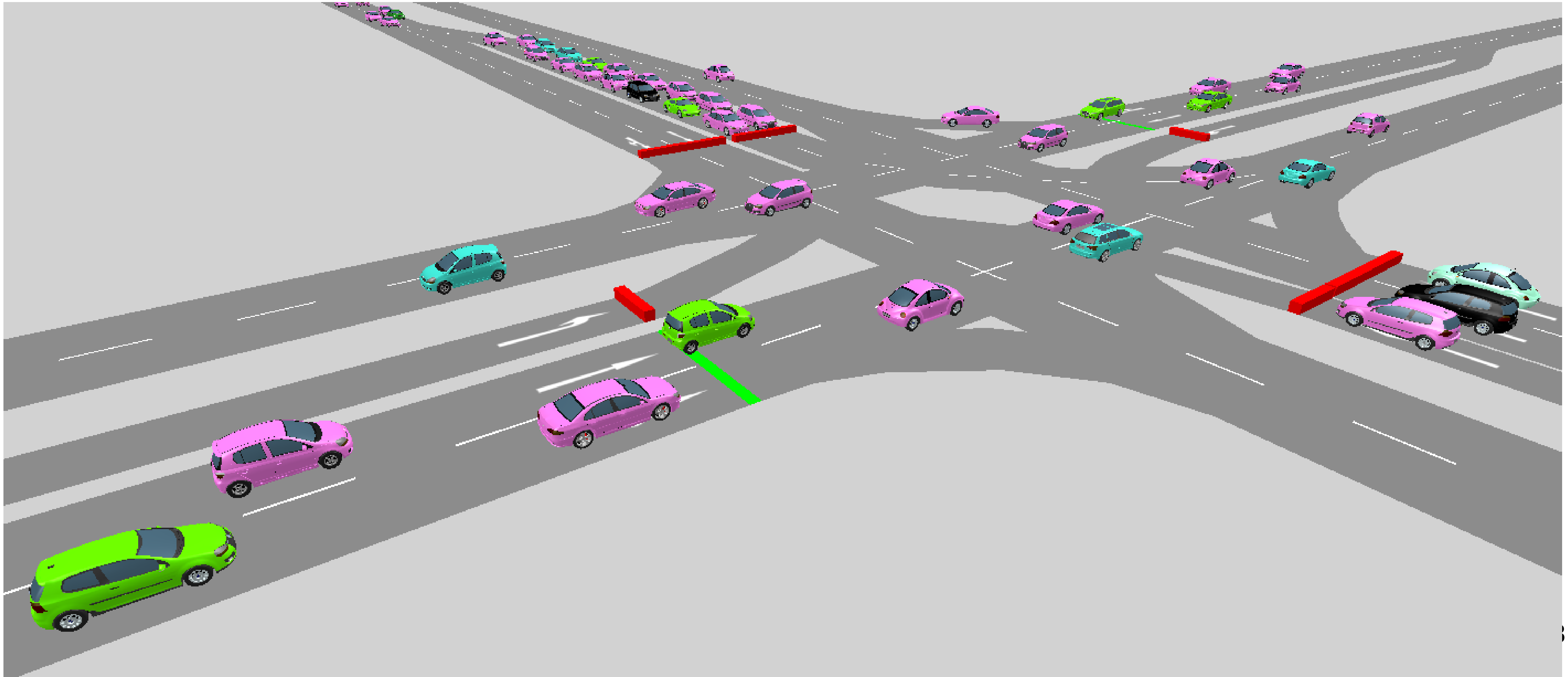
Cooperative Eco-Driving

- **Microscopic traffic simulation in mixed traffic environment**



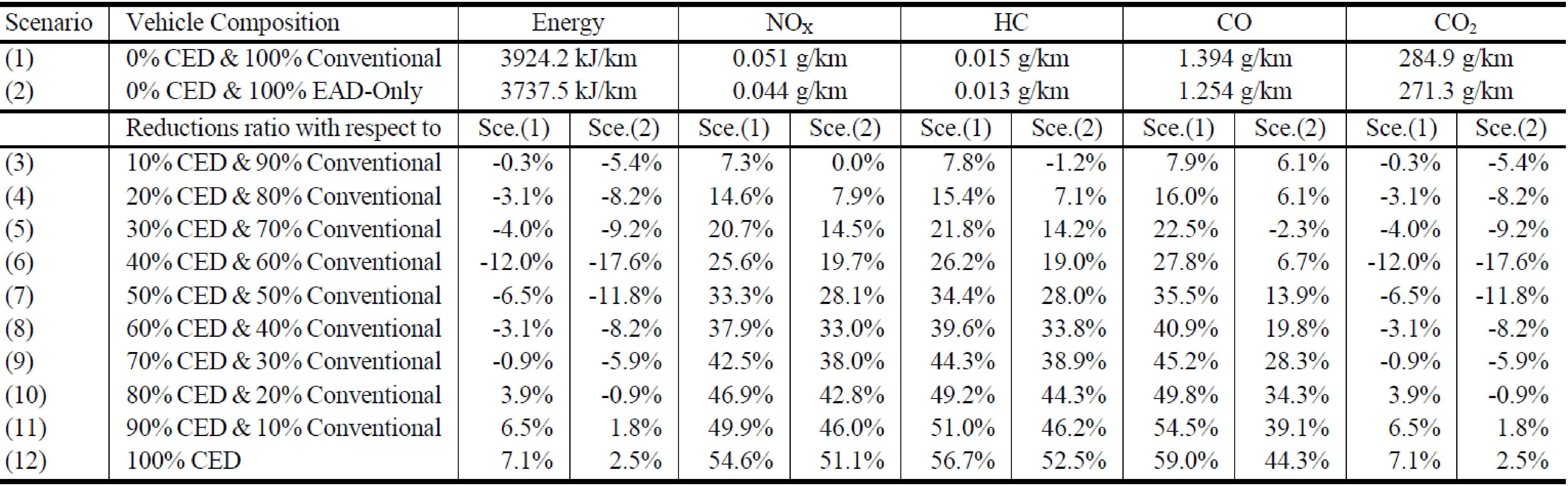
Cooperative Eco-Driving

- **Microscopic traffic simulation running in PTV VISSIM (3D mode)**



Cooperative Eco-Driving

- **Simulation results**



Scenario	Vehicle Composition	Energy		NO_X		HC		CO		CO_2	
(1)	0% CED & 100% Conventional	3924.2 kJ/km		0.051 g/km		0.015 g/km		1.394 g/km		284.9 g/km	
(2)	0% CED & 100% EAD-Only	3737.5 kJ/km		0.044 g/km		0.013 g/km		1.254 g/km		271.3 g/km	
	Reductions ratio with respect to	Sce.(1)	Sce.(2)	Sce.(1)	Sce.(2)	Sce.(1)	Sce.(2)	Sce.(1)	Sce.(2)	Sce.(1)	Sce.(2)
(3)	10% CED & 90% Conventional	-0.3%	-5.4%	7.3%	0.0%	7.8%	-1.2%	7.9%	6.1%	-0.3%	-5.4%
(4)	20% CED & 80% Conventional	-3.1%	-8.2%	14.6%	7.9%	15.4%	7.1%	16.0%	6.1%	-3.1%	-8.2%
(5)	30% CED & 70% Conventional	-4.0%	-9.2%	20.7%	14.5%	21.8%	14.2%	22.5%	-2.3%	-4.0%	-9.2%
(6)	40% CED & 60% Conventional	-12.0%	-17.6%	25.6%	19.7%	26.2%	19.0%	27.8%	6.7%	-12.0%	-17.6%
(7)	50% CED & 50% Conventional	-6.5%	-11.8%	33.3%	28.1%	34.4%	28.0%	35.5%	13.9%	-6.5%	-11.8%
(8)	60% CED & 40% Conventional	-3.1%	-8.2%	37.9%	33.0%	39.6%	33.8%	40.9%	19.8%	-3.1%	-8.2%
(9)	70% CED & 30% Conventional	-0.9%	-5.9%	42.5%	38.0%	44.3%	38.9%	45.2%	28.3%	-0.9%	-5.9%
(10)	80% CED & 20% Conventional	3.9%	-0.9%	46.9%	42.8%	49.2%	44.3%	49.8%	34.3%	3.9%	-0.9%
(11)	90% CED & 10% Conventional	6.5%	1.8%	49.9%	46.0%	51.0%	46.2%	54.5%	39.1%	6.5%	1.8%
(12)	100% CED	7.1%	2.5%	54.6%	51.1%	56.7%	52.5%	59.0%	44.3%	7.1%	2.5%

COOPERATIVE MERGING AT HIGHWAY ON-RAMPS → SAFETY BENEFIT

Cooperative Merging at Highway On-Ramps

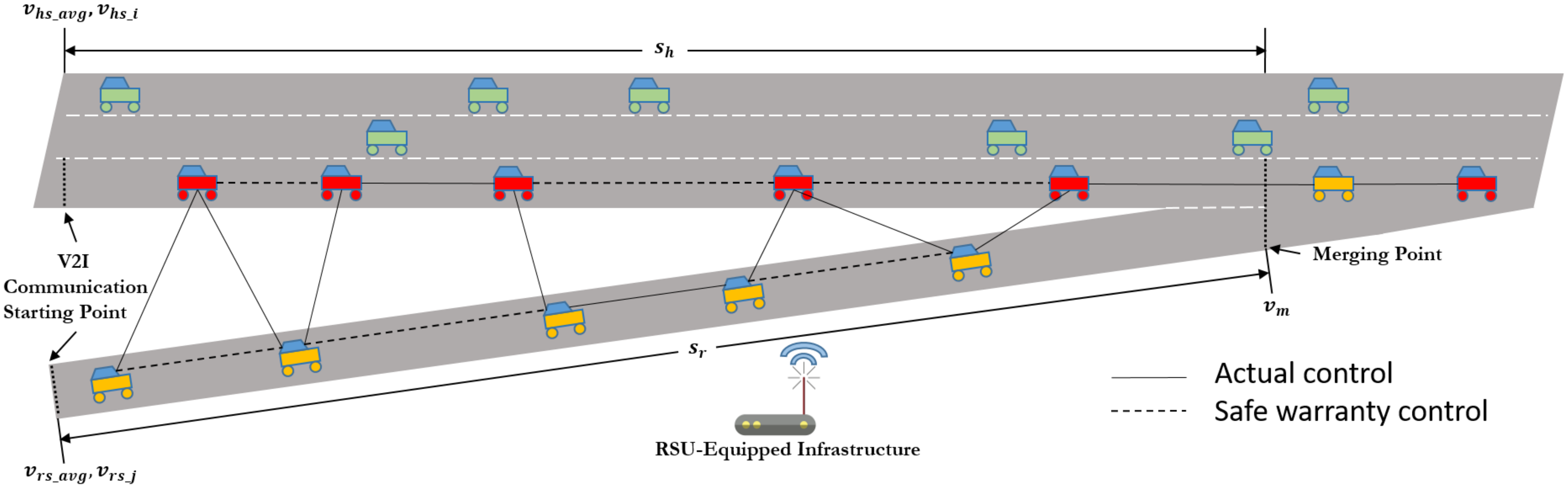
- **Drawbacks of traditional on-ramp merging systems**
  - Obstructed vision of drivers
  - Late merging decision
  - Extreme speed changes

(source: Google Map)

(CA-60 WB, Main St. On-Ramp, Riverside, CA)

Cooperative Merging at Highway On-Ramps

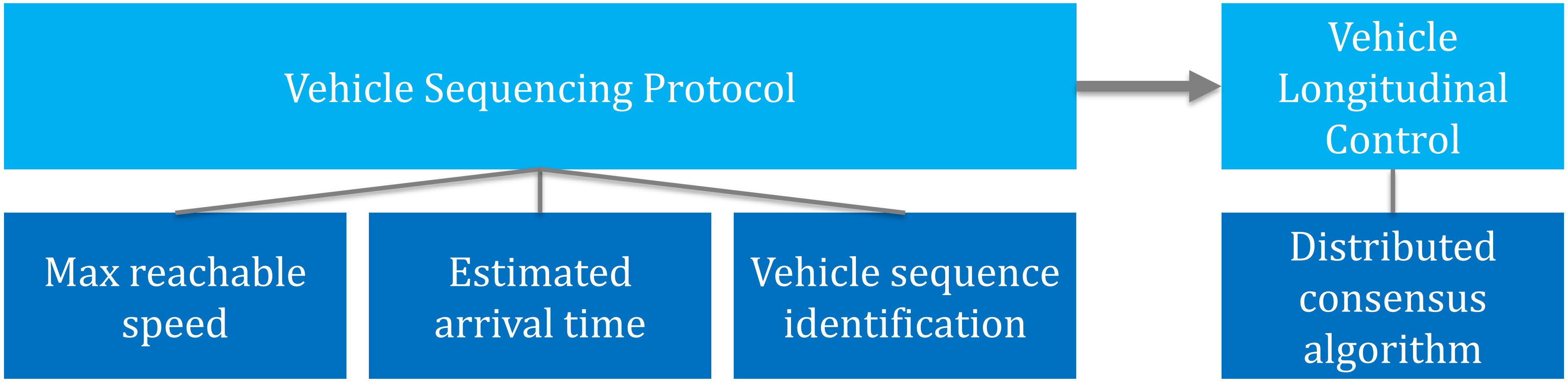
- Cooperative merging at highway on-ramps
  - Take advantage of V2V and I2V communication
  - Adopt “ghost vehicle” concept
  - Complete longitudinal formation before merging



(Reference: Wang et al, Cooperative ramp merging system: Agent-based modeling and simulation using game engine, SAE International Journal of Connected and Automated Vehicles, 2019)

Cooperative Merging at Highway On-Ramps

- **System Architecture**



Vehicle Sequencing Protocol

Vehicle Longitudinal Control

Max reachable speed

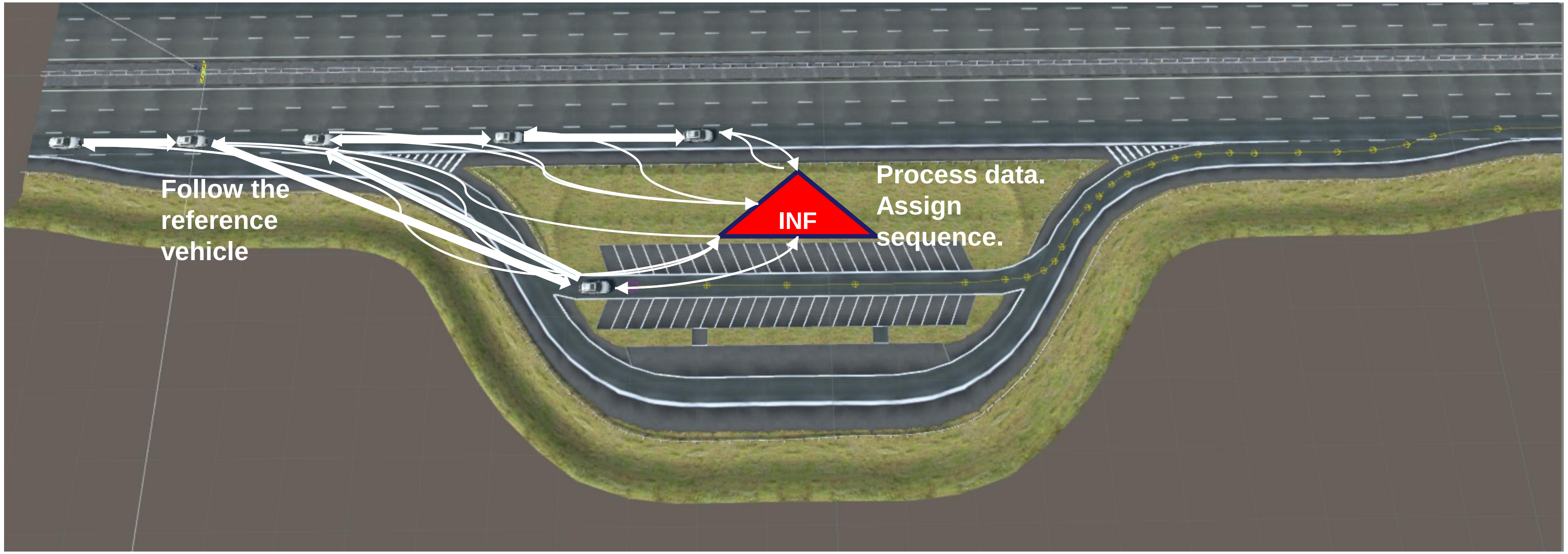
Estimated arrival time

Vehicle sequence identification

Distributed consensus algorithm

Cooperative Merging at Highway On-Ramps

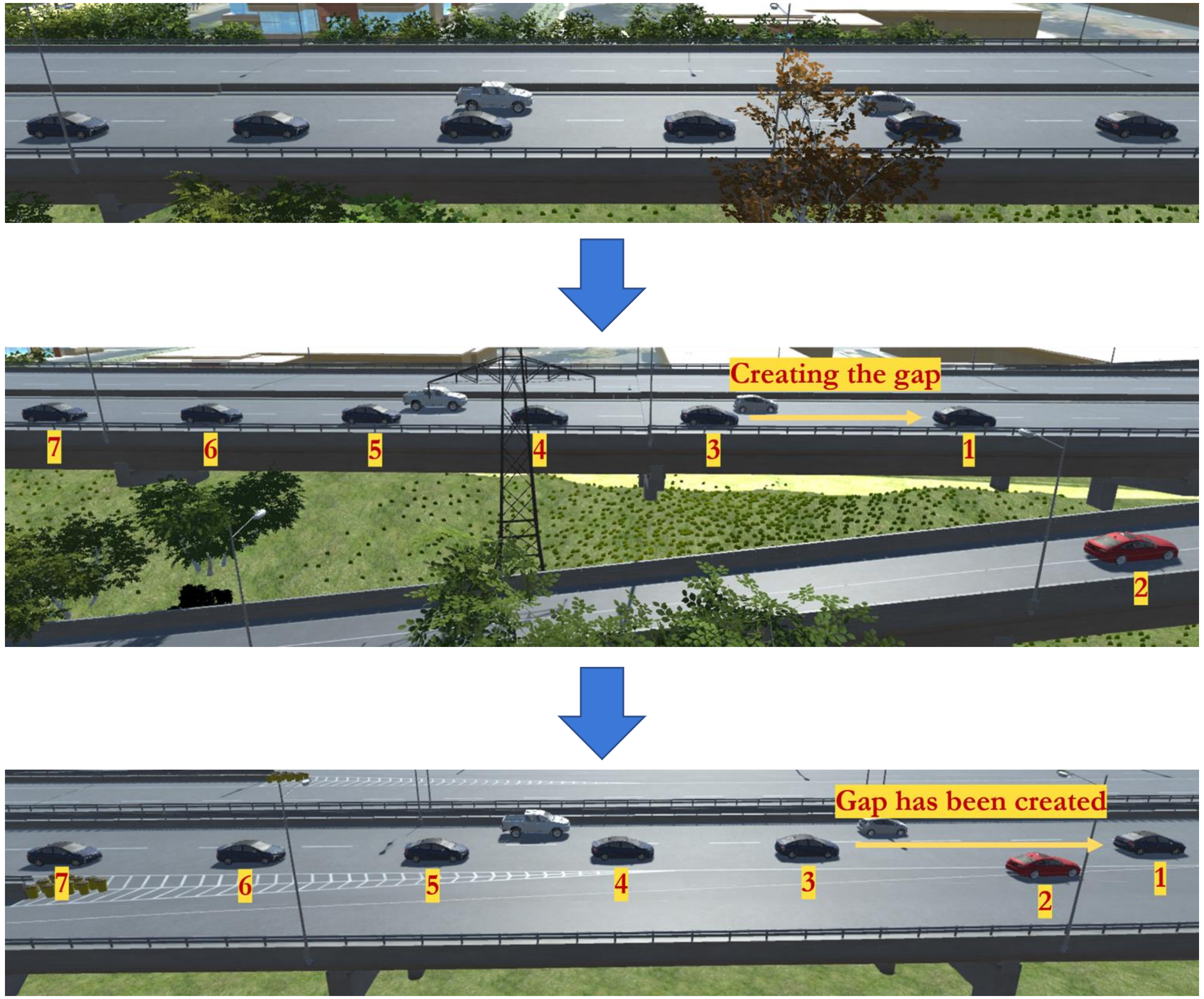
- **System Workflow**



Cooperative Merging at Highway On-Ramps

- **Simulation in game engine Unity**

Video captured during simulation

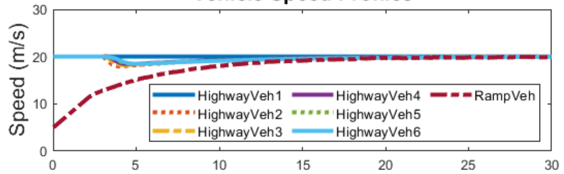


Key steps during the simulation

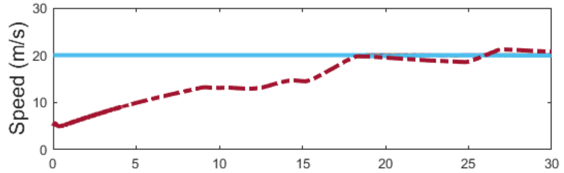
Cooperative Merging at Highway On-Ramps

- Compare with human-in-the-loop simulation
- 4 different drivers contribute 20 simulation runs on the driving simulator

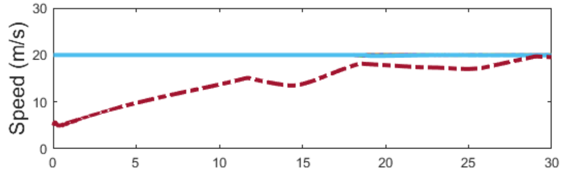
Vehicle Speed Profiles



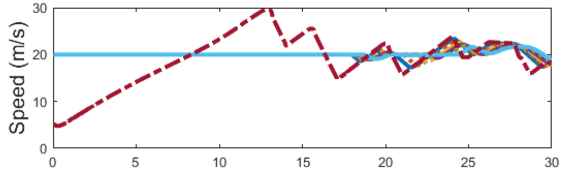
(a) Cooperative Merging



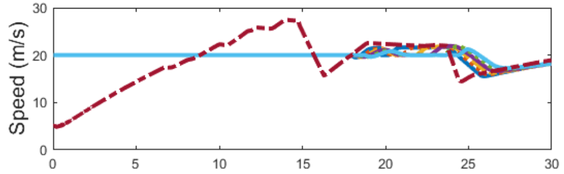
(b) Cautious Driver Case 1



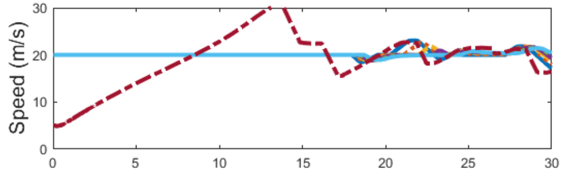
(c) Cautious Driver Case 2



(d) Aggressive Driver Case 1

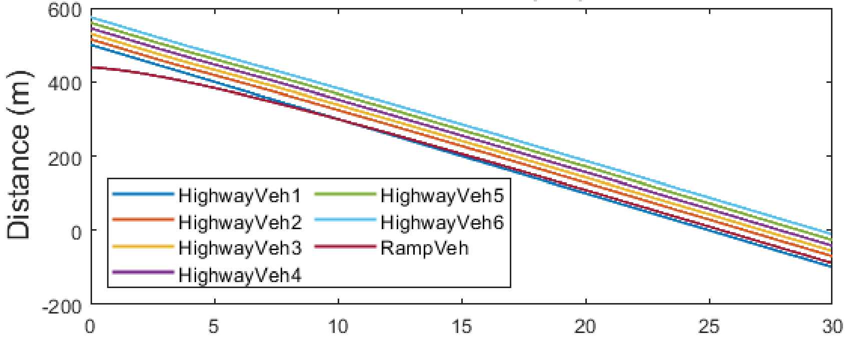


(e) Aggressive Driver Case 2

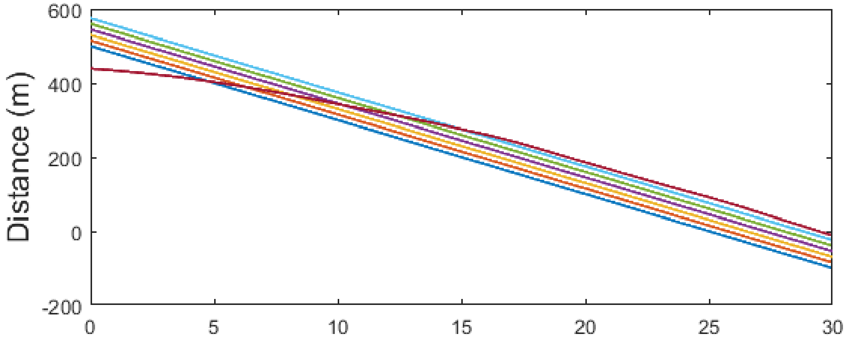


(f) Aggressive Driver Case 3
Time(s)

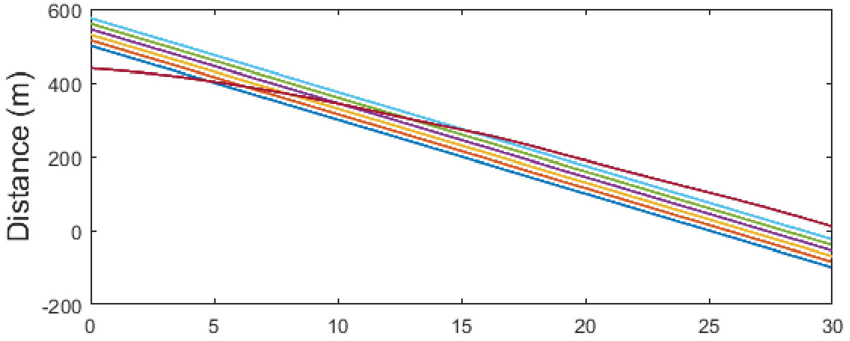
Distance to the Merging Point



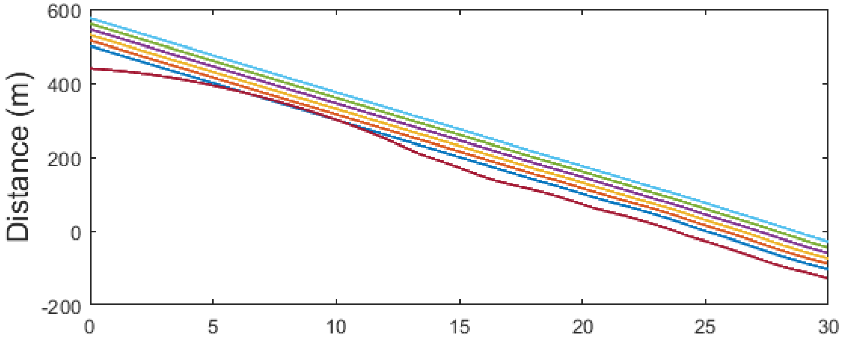
(a) Cooperative Merging



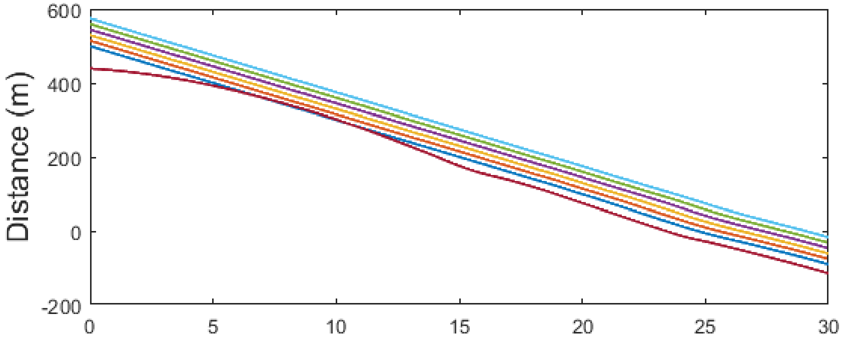
(b) Cautious Driver Case 1



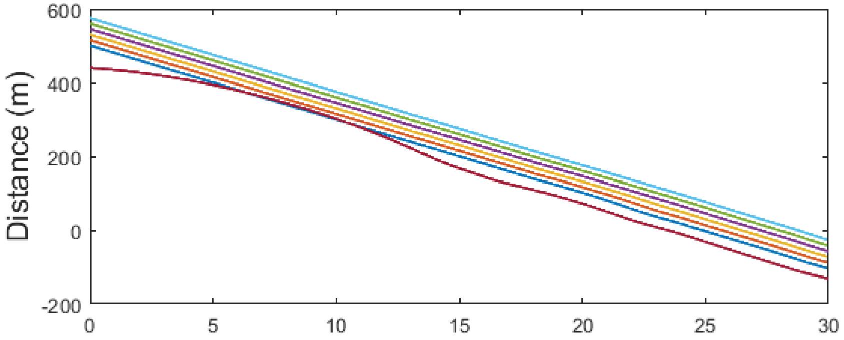
(c) Cautious Driver Case 2



(d) Aggressive Driver Case 1



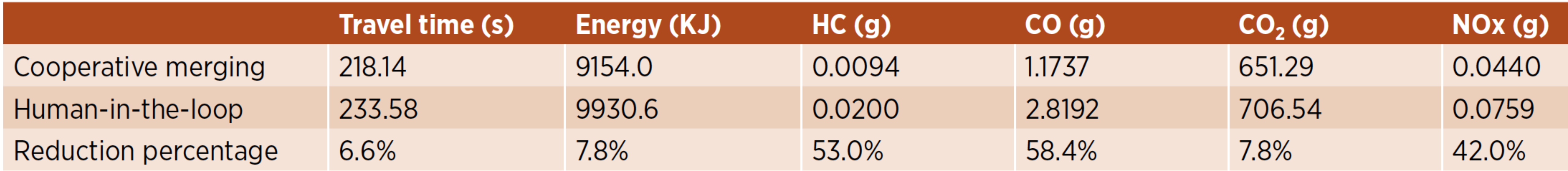
(e) Aggressive Driver Case 2



(f) Aggressive Driver Case 3
Time(s)

Cooperative Merging at Highway On-Ramps

- **Savings in terms of travel time, energy consumption, and pollutant emissions**
- **Calculated for all 7 vehicles in the network**



	Travel time (s)	Energy (KJ)	HC (g)	CO (g)	CO_2 (g)	NOx (g)
Cooperative merging	218.14	9154.0	0.0094	1.1737	651.29	0.0440
Human-in-the-loop	233.58	9930.6	0.0200	2.8192	706.54	0.0759
Reduction percentage	6.6%	7.8%	53.0%	58.4%	7.8%	42.0%

Cooperative Merging at Highway On-Ramps

- Conducting field implementation using real vehicles

CONCLUSIONS AND FUTURE WORK

Main Contributions of the Dissertation

- **Developed a high-level architecture for agent-based distributed cooperative vehicle-infrastructure systems (CVIS)**

- **Proposed cooperative automation applications in the CAV environment under V2V and/or I2V communication, with each of them bringing one or more benefits to the transportation system**

- **Developed motion control algorithms to realize the desired movements of CAVs in the proposed CAV applications, where algorithms were analyzed qualitatively and quantitatively by various simulation approaches**

Future Work Based on the Dissertation

- **Build a more reliable architecture for CVIS**
    - **Conduct fault detection/isolation regarding communication impairments or cyberattacks**
    - **Temporarily/smoothly switch to degraded modes of control, depending less on communication**
    - **Maintain string stability under special occasions**

- **Identify and close the gap between research and implementation**
    - **Theoretical research results need to be tested under various realistic conditions to identify this gap**
    - **Could be both labor-intensive and time-consuming**

- **Develop more ready-to-market CVIS with mixed traffic environment**
    - **CVIS that work for a pure CAV environment do not necessarily work for a mixed traffic environment, given the uncertainties introduced by other vehicle types in the environment**
    - **Future development of CVIS may take advantages of advanced sensing & communication technology**

Publications Related to the Dissertation

[1] “Cooperative Ramp Merging System: Agent-Based Modeling and Simulation Using Game Engine”, *SAE International Journal of Connected and Automated Vehicles*, vol. 2, no. 2, May 2019

[2] “Cooperative Eco-Driving along Multiple Signalized Intersections in a Partially Connected and Automated Vehicle Environment”, *IEEE Transactions on Intelligent Transportation Systems*, Early Access

[3] “Cluster-Wise Cooperative Eco-Approach and Departure Application for Connected and Automated Vehicles along Signalized Arterials,” *IEEE Transactions on Intelligent Vehicles*, vol. 3, no. 4, Dec. 2018, pp. 404–413

[4] “Developing a Distributed Consensus-Based Cooperative Adaptive Cruise Control (CACC) System for Heterogeneous Vehicles with Predecessor Following Topology,” *Journal of Advanced Transportation*, vol. 2017, Article ID 1023654, Aug. 2017

[5] “Lookup Table-Based Consensus Algorithm for Real-Time Longitudinal Motion Control of Connected and Automated Vehicles,” *2019 American Control Conference,* Philadelphia, PA, Jul. 2019

[6] “Agent-Based Modeling and Simulation of Connected and Automated Vehicles Using Game Engine: A Cooperative On-Ramp Merging Study,” *Transportation Research Board 98th Annual Meeting*, Washington D.C., Jan. 2019

[7] “Eco-Approach and Departure along Signalized Corridors,” *Transportation Research Board 98th Annual Meeting*, Washington D.C., Jan. 2019

[8] “A Review on Cooperative Adaptive Cruise Control (CACC) Systems: Architectures, Controls, and Applications,” *IEEE 21st International Conference on Intelligent Transportation Systems*, Maui, Hawaii, Nov. 2018

[9] “Distributed Consensus-Based Cooperative Highway On-Ramp Merging Using V2X Communications,” *SAE Technical Paper,* 2018-01-1177, Apr. 2018

Publications Related to the Dissertation

[10] “Cluster-Wise Cooperative Eco-Approach and Departure Application along Signalized Arterials,” *IEEE 20th International Conference on Intelligent Transportation Systems*, Yokohama, Japan, Oct. 2017

[11] “Intra-Platoon Vehicle Sequence Optimization for Eco-Cooperative Adaptive Cruise Control,” *IEEE 20th International Conference on Intelligent Transportation Systems*, Yokohama, Japan, Oct. 2017

[12] “Developing a Platoon-Wide Eco-Cooperative Adaptive Cruise Control (CACC) System,” *2017 IEEE Intelligent Vehicles Symposium*, Redondo Beach, CA, Jun. 2017

[13] “Developing a Distributed Consensus-Based Cooperative Adaptive Cruise Control (CACC) System,” *Transportation Research Board 96th Annual Meeting*, Washington D.C., Jan. 2017

[14] “A Survey on Cooperative Longitudinal Motion Control of Multiple Connected Automated Vehicles,” IEEE Intelligent Transportation Systems Magazine, under review

[15] “Human Factor Modeling of Driver Speed Assistance using Game Engine: A Learning-Based Approach,” IEEE Transactions on Intelligent Vehicles, under review

[16] “Recent Field Implementation Results of a Heavy-Duty Truck Connected Eco-Driving System ,” *IEEE 22nd International Conference on Intelligent Transportation Systems*, Auckland, New Zealand, Oct. 2019, under review

[17] “The State-of-the-Art of Coordinated Ramp Control with Mixed Traffic Conditions ,” *IEEE 22nd International Conference on Intelligent Transportation Systems*, Auckland, New Zealand, Oct. 2019, under review

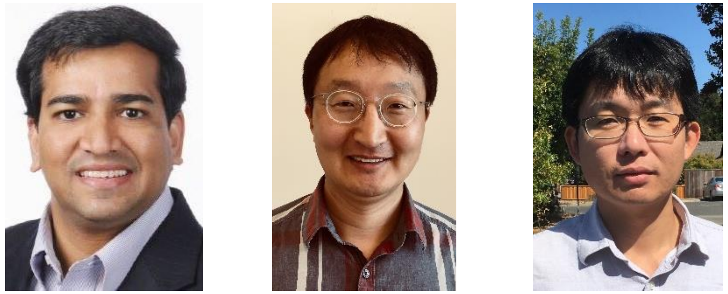
Publications Related to the Dissertation

- Published: 4 journal articles, 9 conference proceedings (11/13 as the first author)
- Under review: 2 journal articles, 2 conference proceedings, 4 U.S. patents
- Reviewed more than 50 journal articles and conference proceedings as a reviewer
- Thanks for the hard work from all the co-authors:

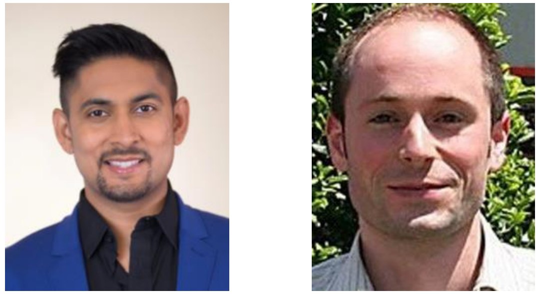
UC Riverside

UC Berkeley

Tsinghua University



Toyota Motor North America



Volvo Group North America

Acknowledgement

- **Thanks for the support from all members of TSR at CE-CERT**

Thank you all! QUESTIONS?