Cooperative Adaptive Cruise Control: Assessing Challenges and Solutions

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Why CACC?

- Cooperative Adaptive Cruise Control (i.e., automated vehicle platooning – cars move like “train”
- Mobility improvement
  - CACC with 0.6 sec headways
  - Human driven vehicles with 1.8 sec headways
- Fuel savings
  - ~ 20% for following trucks

What are Major Challenges?

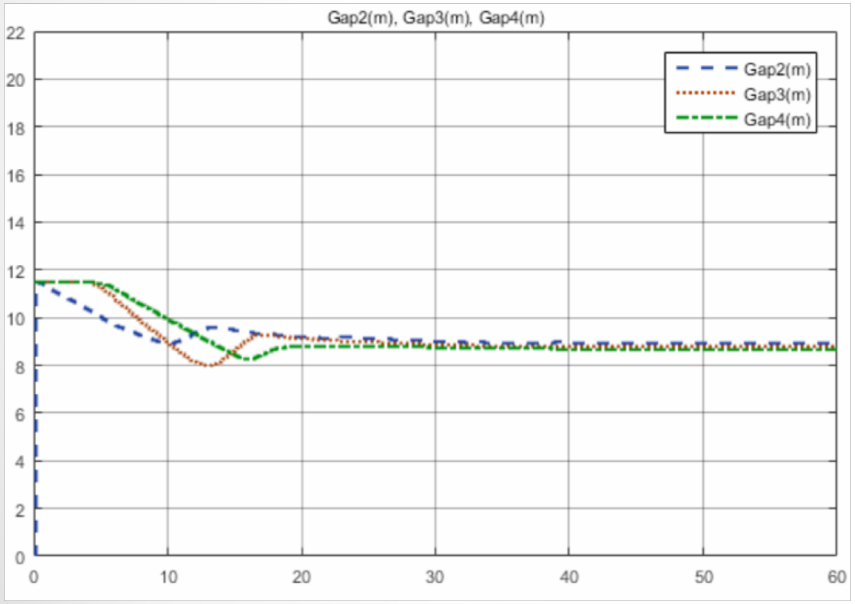
- Simulation platform for CACC algorithm development and evaluation
  - Proper vehicle dynamics model
  - Sensor errors & Communications
- Mixed traffic interacting with human driven vehicles
  - Not likely to have 100% Connected-and-Automated vehicles in a near future
- Robust control
- Cyber security

CACC Demonstration

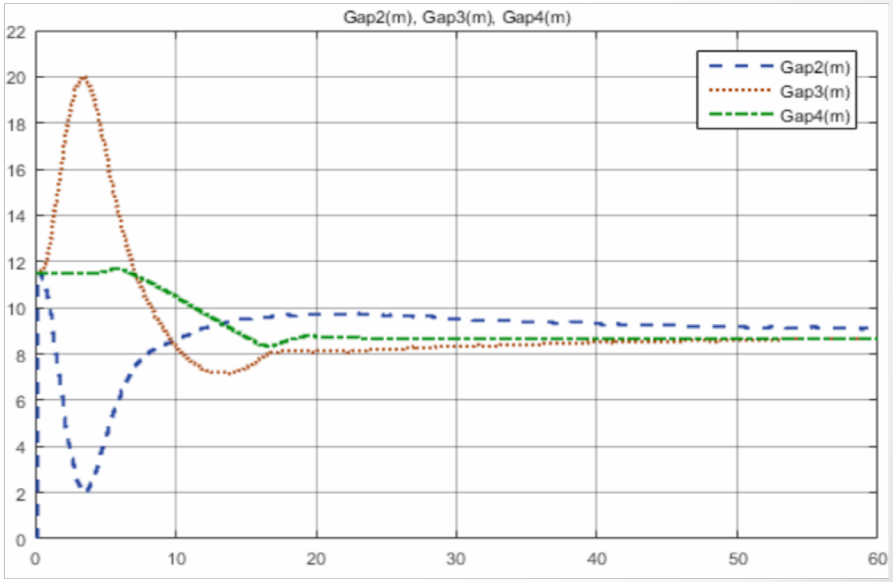
These are all Cadillac vehicles!

Why Vehicle Dynamics?

Same Vehicles

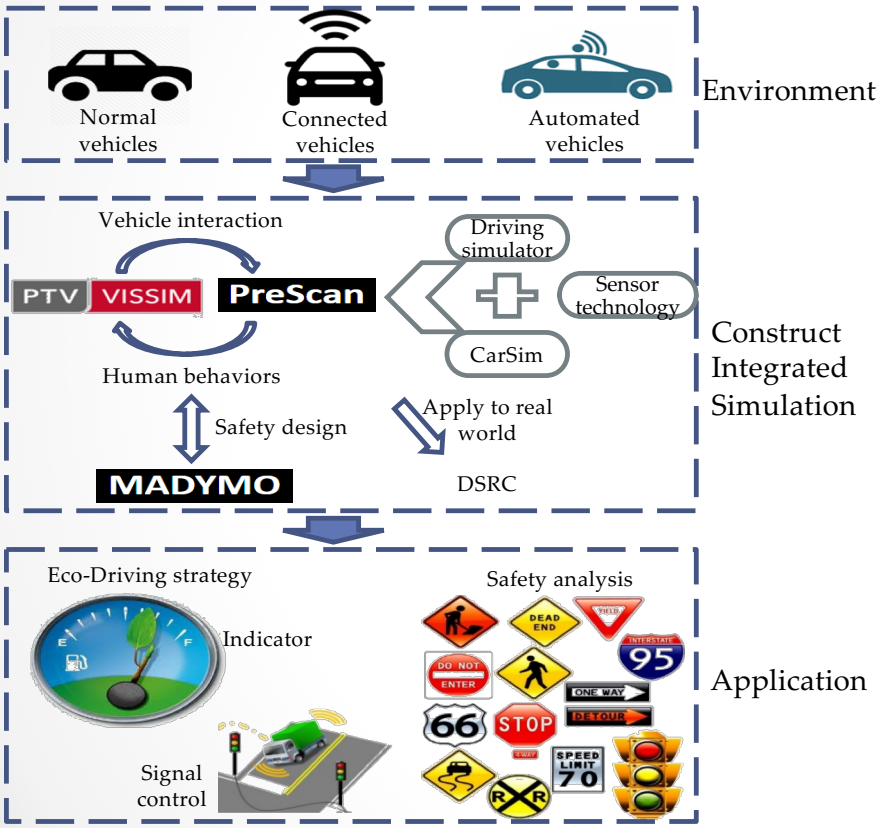


Different Vehicles



CACC Platoon with Four Connected-and-Automated Vehicles

Integrated Framework for CACC Simulation



- **VISSIM** for drivers and traffic control devices
- **PreScan** to explicitly consider **vehicle dynamics**, sensors & communications
- **MADYMO** for crash severity estimation
- **Driving Simulator** for a human driver interacting with CACC

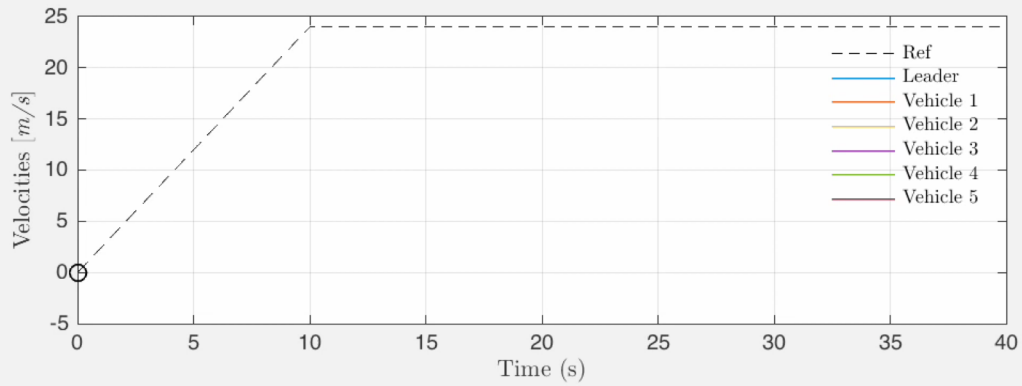
CACC Evaluation under Cyber-Attack

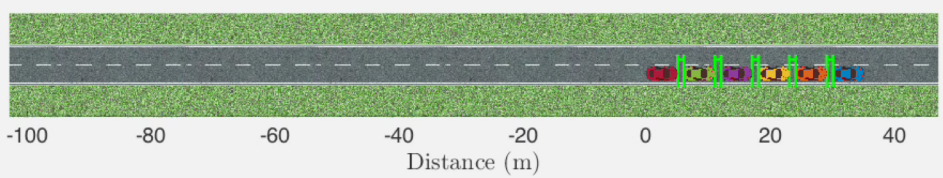
- Set a constant target speed of 24 m/s

$$v_T(t) = 24\, m/s, \qquad \forall\, t \in [0, T]$$

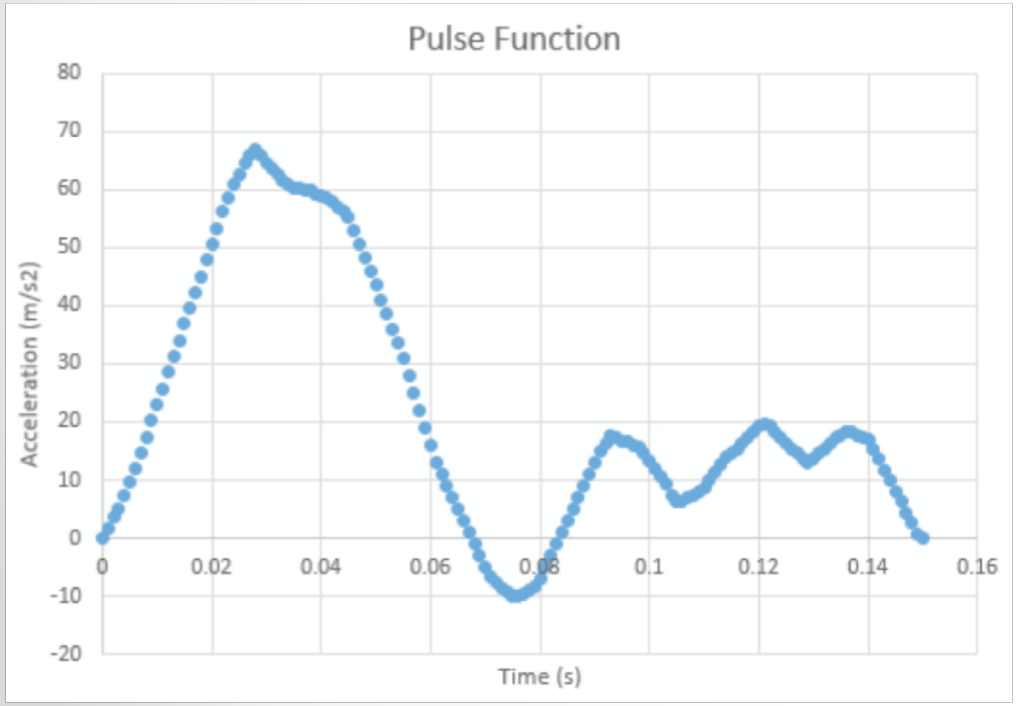
- Platoon accelerated to target speed for 15 seconds and then became stabilized
- To mimic a cyber-attack in radar or DSRC, false data were given to 3rd vehicle around 20 seconds

Case Study: CACC Cyber Attack





Crash Severity Evaluation



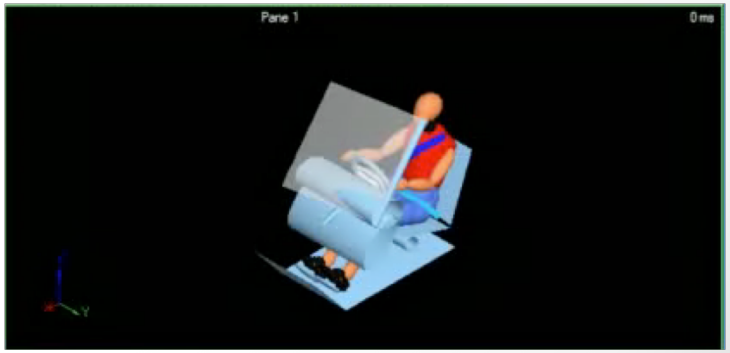
Frontal - Driver Stars

Relative Risk Score **0.78**

Injury Probability			Relative Risk Score			Star Rating
	P	< 0.100		RRS	< 0.67	5 stars
0.100 ≤	P	< 0.150	0.67 ≤	RRS	< 1.00	4 stars
0.150 ≤	P	< 0.200	1.00 ≤	RRS	< 1.33	3 stars
0.200 ≤	P	< 0.400	1.33 ≤	RRS	< 2.67	2 stars
	P	≥ 0.400		RRS	≥ 2.67	1 star

Driver Summary

Body region	Injury probability
Head Assessment	0.0035
Neck Assessment	0.0534
Chest Assessment	0.0493
Femur Assessment	0.0151
Frontal - injury probability	**0.116**

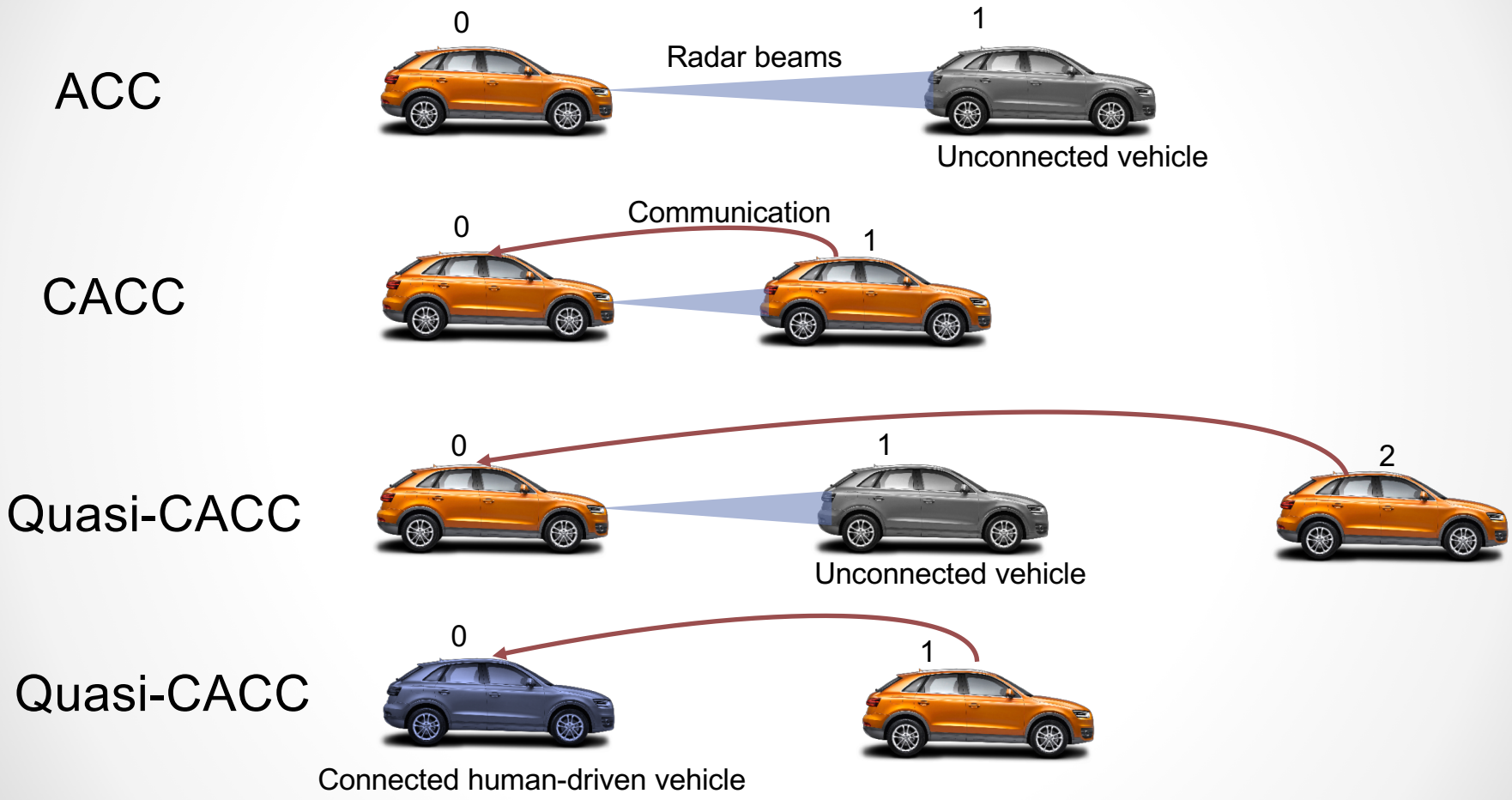


CACC under Mixed Traffic

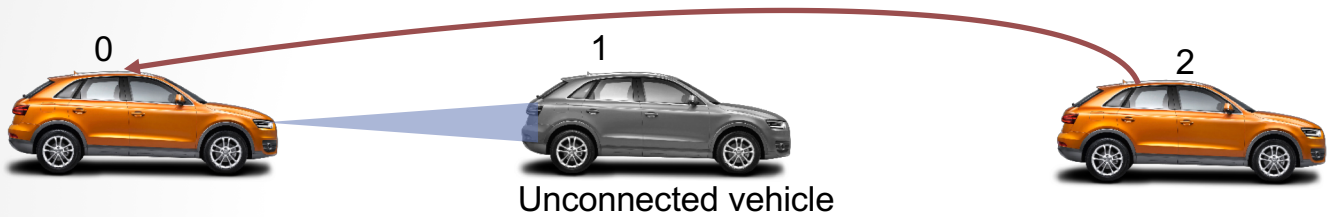
- CACC with 100% connected-and-automated vehicles is not likely (except for dedicated lanes) in a near future

- When CACC vehicles run into a human driven vehicle, they fall back to Adaptive Cruise Control (ACC)
  - String stability issue
  - Major issue with multiple ACC vehicles

ACC vs CACC vs quasi-CACC



CACCu (CACC w/ unconnected vehicle)

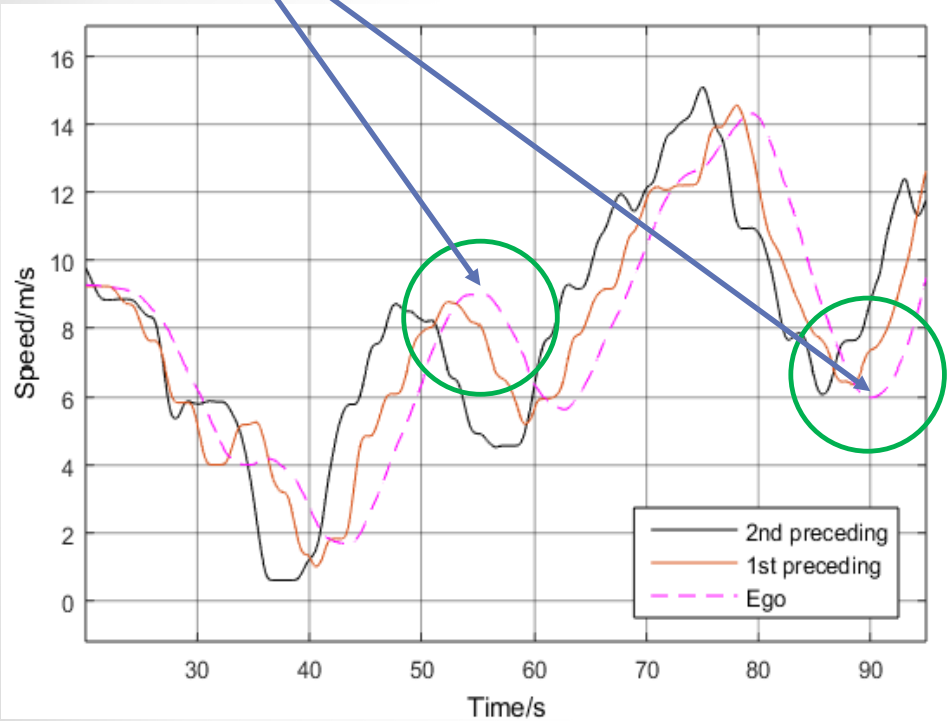


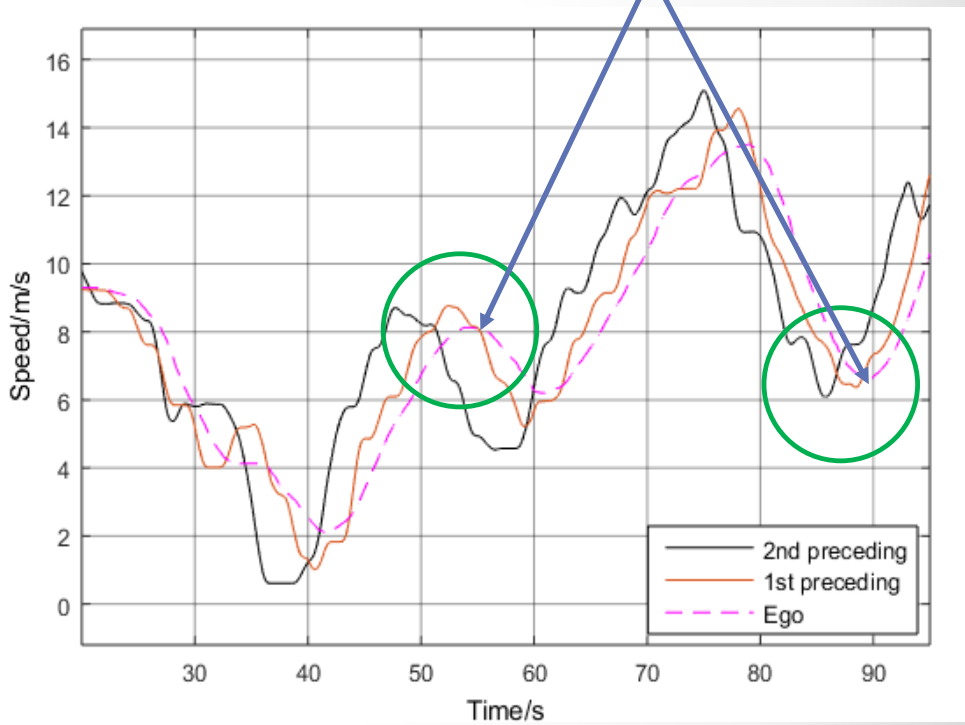
- CACC capable (i.e., CAV) vehicle runs into unconnected human driven vehicle but vehicle #2 is connected and possibly automated
- Goal – design control policy of ego-vehicle to outperform ACC based on the information from vehicle #2 and radar measurement of vehicle #1

ACC vs CACCu

Ego vehicle overshoots the speed - string unstable

Ego vehicle no overshooting - string stable





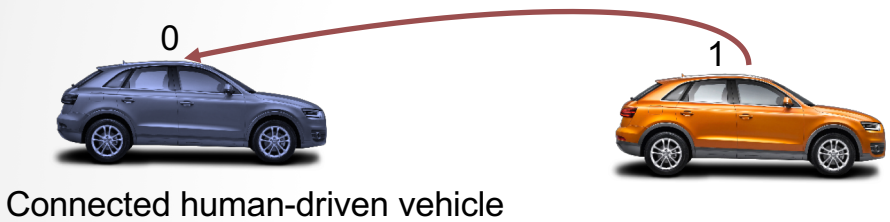
1st and 2nd preceding vehicles' trajectories are from NGSIM data

ACC vs CACCu

Entering time	Control type	# of speed overshootings	Acceleration peak (m/s^2)	Acceleration RMS (m/s^2)	Spacing error peak (m)	Spacing error RMS (m)
0 min	CACCu	0	1.05	0.43	1.58	0.88
	ACC	1	1.10	0.48	3.62	1.85
10min	CACCu	0	1.12	0.46	2.47	1.23
	ACC	1	1.60	0.51	4.18	2.10
20min	CACCu	0	1.62	0.35	2.10	0.91
	ACC	0	1.70	0.38	4.20	1.73
30min	CACCu	0	1.59	0.54	3.69	1.79
	ACC	2	1.90	0.66	5.52	2.77
40min	CACCu	0	1.40	0.34	4.14	1.29
	ACC	2	1.48	0.36	4.50	1.90

In average, CACCu show 100% less speed over shootings, 10.4% less acceleration RMS, and 41.7% less spacing errors

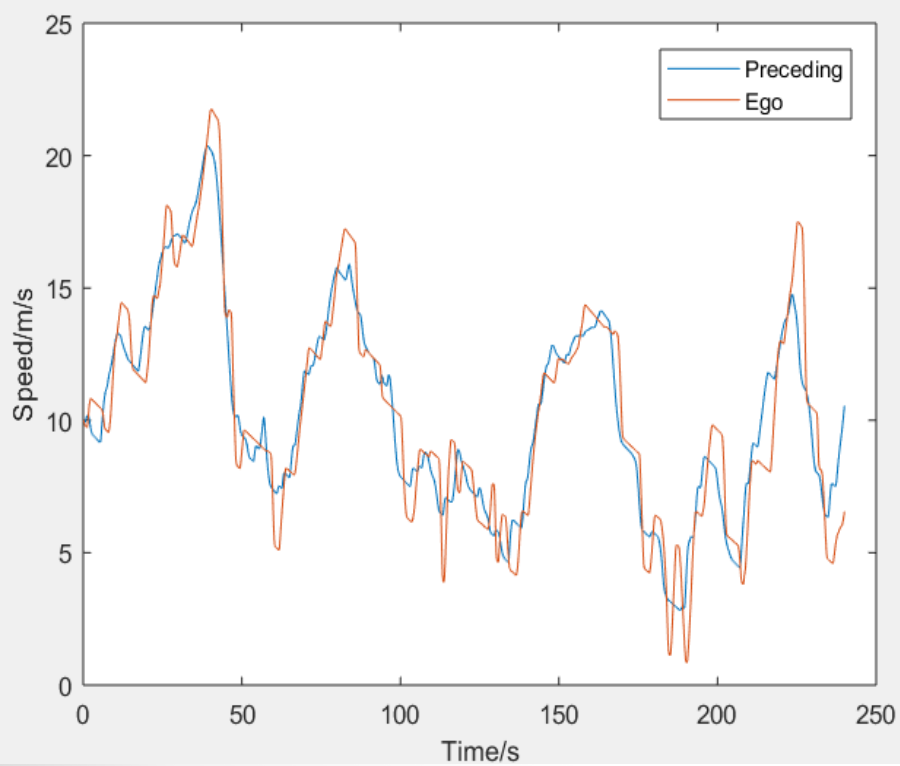
hCACC (CACC for human driven vehicle)

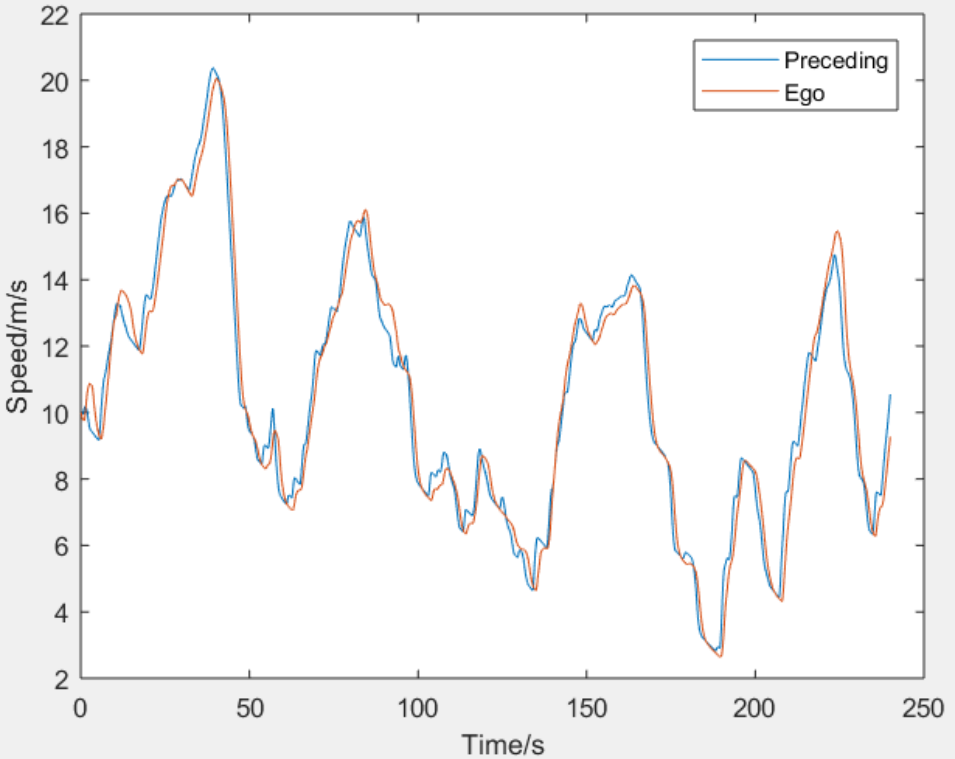


hCACC: string stable at human-chosen headway

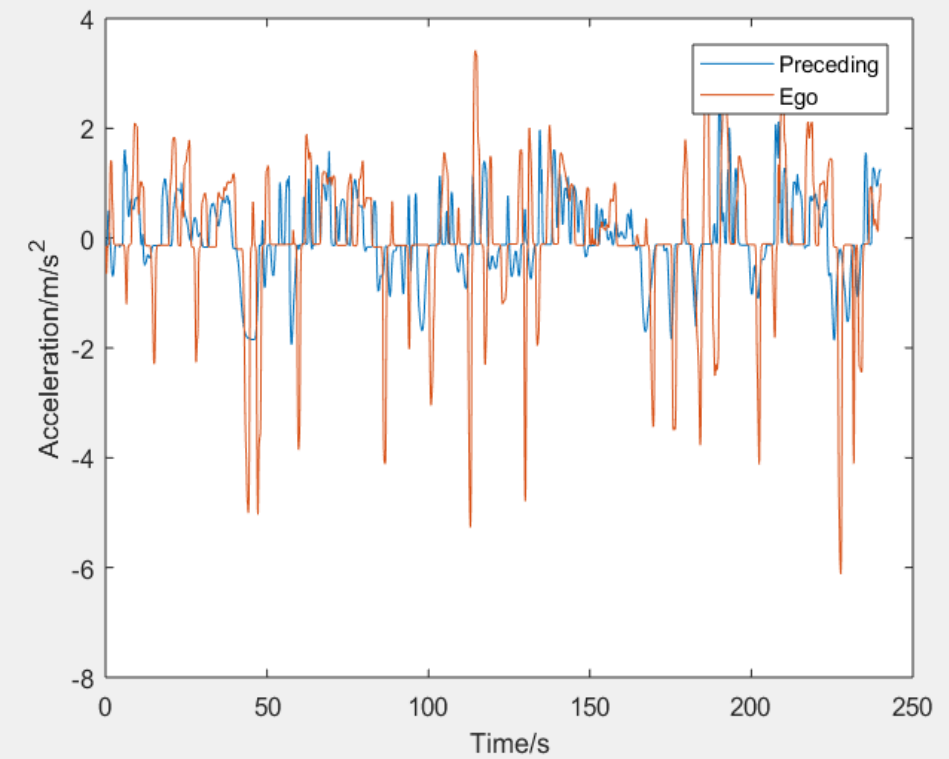
- A human driven vehicle (connected but no sensors) follows a connected or connected-and-automated vehicle
- Goal – help human driver achieve string-stability on speed and acceleration, that is, human driver determines comfortable spacing

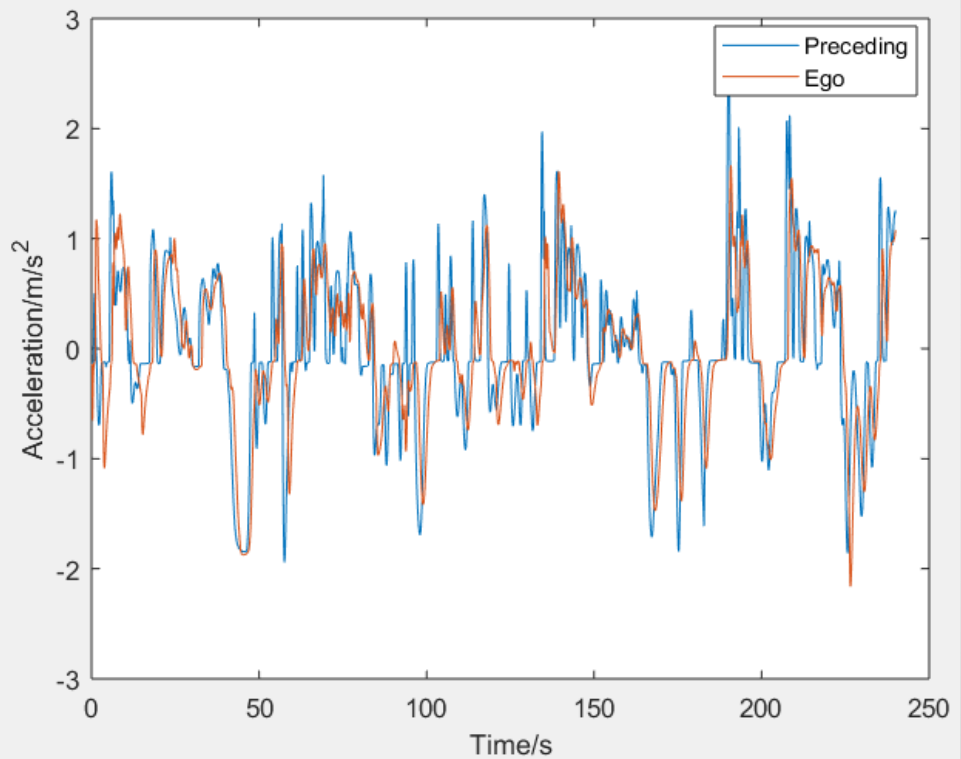
ACC vs hCACC – Speed Profile



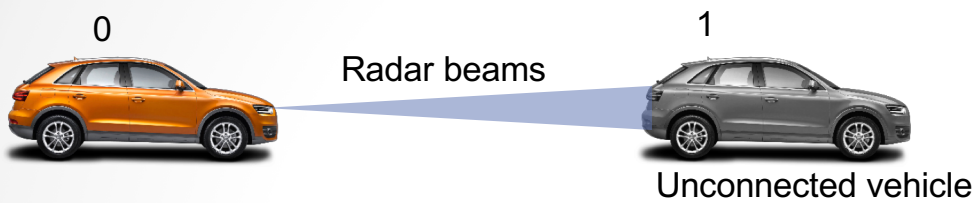


ACC vs hCACC – Acceleration Profile

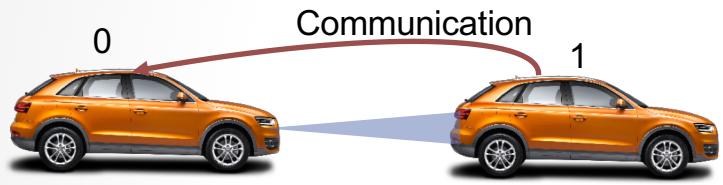




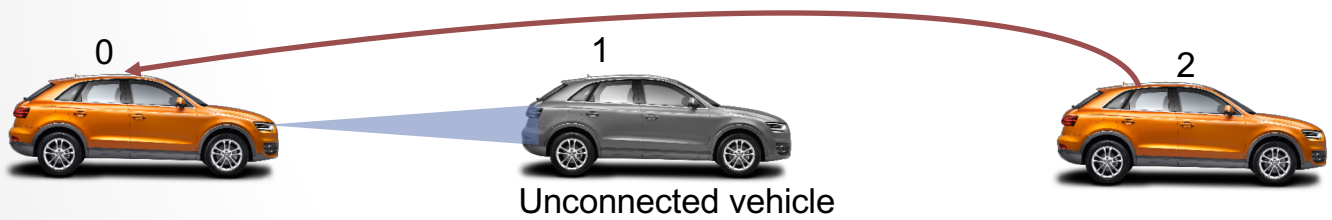
ACC, CACC, CACCu and hCACC



ACC: string stable at headway > 2.5s



CACC: string stable at headway of 0.6s



CACCu: 0.9~1.4s

hCACC: string stable at human-chosen headway

Connected human-driven vehicle

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