Clustering Strategies of Cooperative Adaptive Cruise Control: Impacts on Human-driven Vehicles

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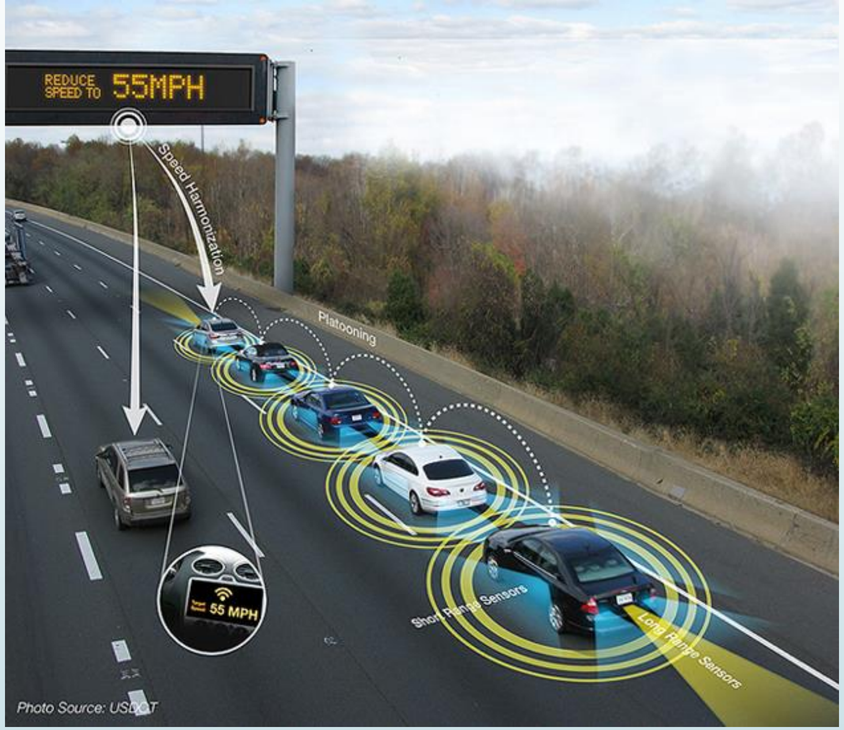
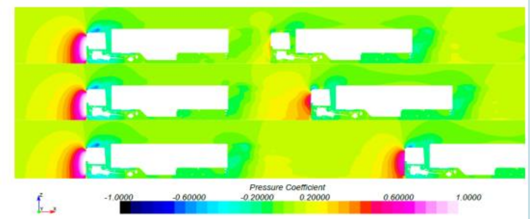
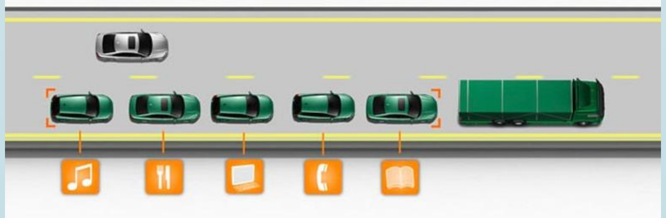
*the presented work was conducted at the University of Delaware

Background

- Cooperative adaptive cruise control (CACC) is expected to drastically increase mobility, decrease emission, while providing a safer and more convenient ride for occupants.
- CACC enables closely coupled vehicular platoon by extra layers of communication and automation.
- CACC-equipped vehicles are expected to deployed in the public road in the near term alongside with conventional vehicles.

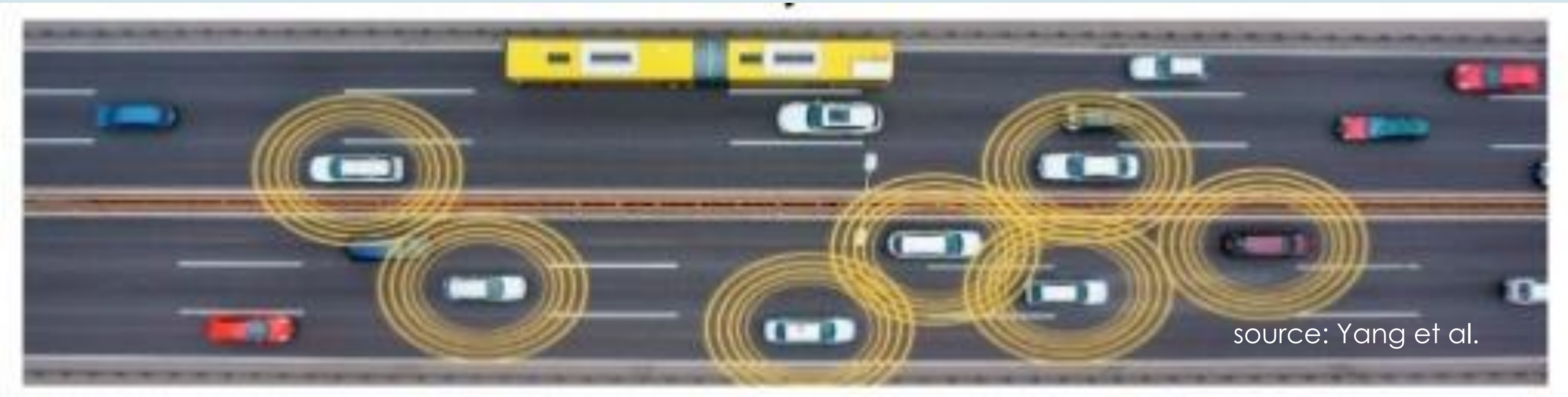






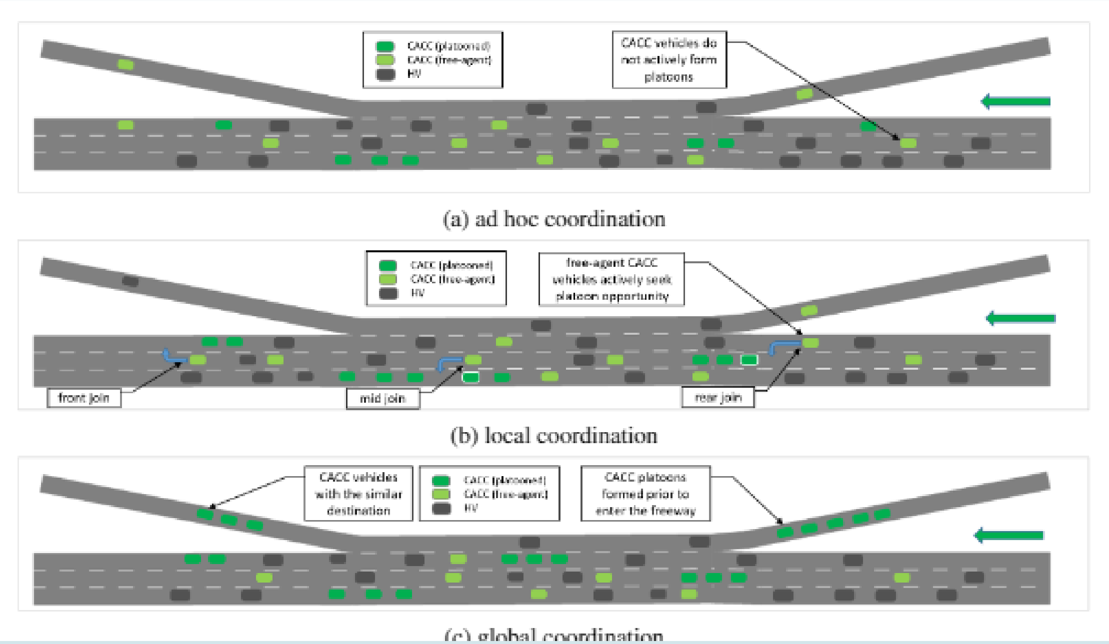
Motivation

- Near-term deployment in mixed traffic condition is likely to be an reality
- The potential impact on non-equipped vehicles (i.e. Human-driven vehicles(HVs)) has rarely been investigated, given consensus of CAV's potential benefits.
- The majority of the studies focused on longitudinal movement of CACC, with less attentions of the lateral movement, especially when it comes to platoon formation.



CAV Platoon Organization

- **Ad hoc coordination:** no coordination among CAVs. CAV distribution based on arrival pattern.
- **Local coordination:** free-agent CAV actively seeks and form platoons
- **Global coordination:** coordination at origin-designation (OD) level prior to entering the highway

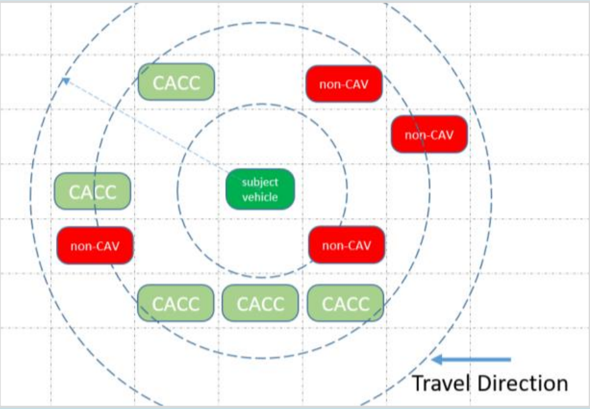


Potential Negative Impact

i. **The induced weaving during platoon formation**

ii. **Induced lane changing for HVs due to weaving**

iii. **Lane blockage for HVs by platoons**



Study Method

- Various mixed traffic flow scenarios and CAV models act as the stimuli
- The calibrated Wiedemann behavior model acts as a black box
- Measure the resultant traffic flow characteristics at individual vehicle level

Simulation Framework

- The network was calibrated with field traffic data (video, traffic sensor, INRIX travel time)
- The I-66 network has been used in multiple studies
- 8-km stretch 4-lane highway with 2 interchanges
- A 30% growth of current traffic demand is assumed.

Zone ID	Description	Demand, vph	HOV Demand, vph
Z1	I-66 East	5456	2451
Z2	Exit 62 Nutley St.	926	436
Z3	Exit 60 SR 123	1834	1483
Z4	I-66 West	-	-

CAV Behavior

Case	Longitudinal Control	Lateral Control
Base (no CAVs)	Calibrated Wiedemann	Vissim calibrated
Ad hoc coordination	E-IDM	Vissim calibrated
Local coordination	E-IDM	Gap acceptance-based (Lee et al, 2013)

$$\ddot{x} = \begin{cases} a[1 - (\frac{\dot{x}}{\dot{x}_{des}})^{\delta} - (\frac{s^*(\dot{x},\dot{x}_{lead})}{s_0})] \\ \text{ if } x = \ddot{x}_{IDM} \geq \ddot{x}_{CAH} \\ (1-c)\ddot{x}_{IDM} + c[\ddot{x}_{CAH} + b \cdot tanh(\frac{\ddot{x}_{IDM} - \ddot{x}_{CAH}}{b})] \\ \text{otherwise} \end{cases}$$

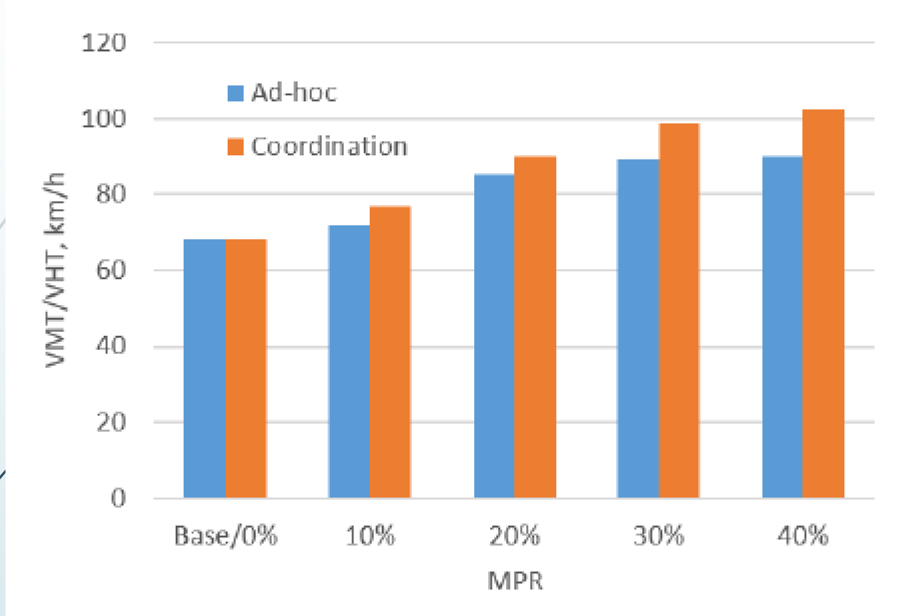
$$s^*(\dot{x}, \dot{x}_{lead}) = s_0 + \dot{x}T + \frac{\dot{x}(\dot{x} - \dot{x}_{lead})}{2\sqrt{ab}}$$

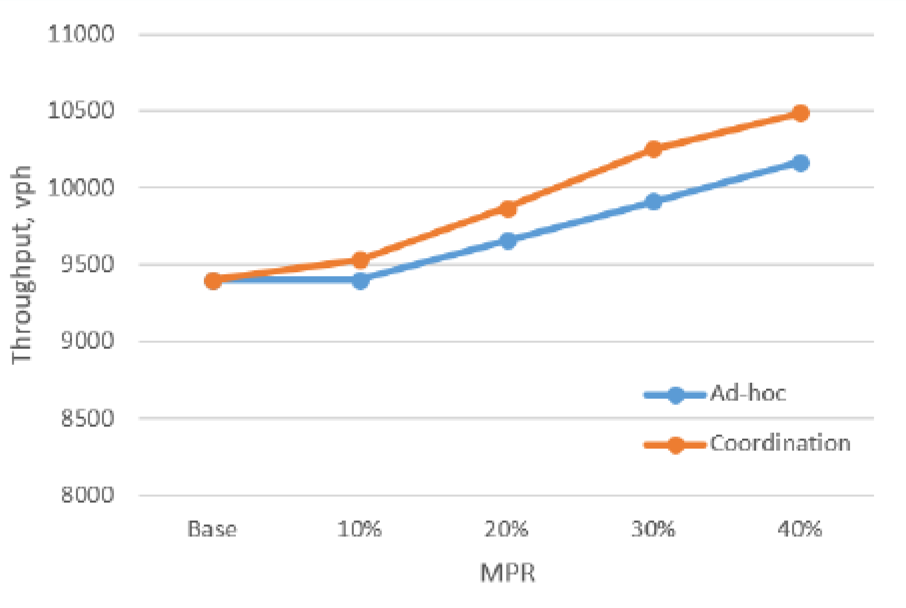
$$\ddot{x}_{CAH} = \begin{cases} \frac{\dot{x}^2 \cdot \min(\ddot{x}_{lead}, \ddot{x})}{\dot{x}_{lead}^2 - 2x \cdot \min(\ddot{x}_{lead}, \ddot{x})} \\ \text{ if } \dot{x}_{lead}(\dot{x} - \dot{x}_{lead}) \leq -2x \min(\ddot{x}_{lead}, \ddot{x}) \\ \min(\ddot{x}_{lead}, \ddot{x}) - \frac{(\dot{x} - \dot{x}_{lead})^2 \Theta(\dot{x} - \dot{x}_{lead})}{2x} \\ \text{otherwise} \end{cases}$$

x- position of a vehicle
a-max. acceleration
b- desired deceleration
c- coolness factor
T- desired time gap
δ- free acceleration exponent
Θ- Heaviside function

- Inter-platoon headway: 0.9 s
- Intra-platoon headway: 0.6 s
- other parameters as in (Kesting et al. 2010)
- SAE Lv. 2 automation is assumed

Result- Network Performance

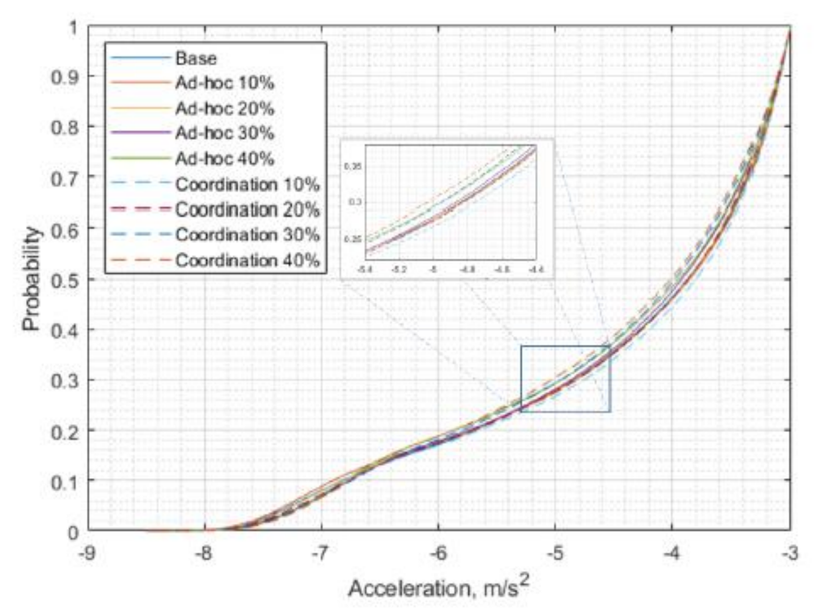




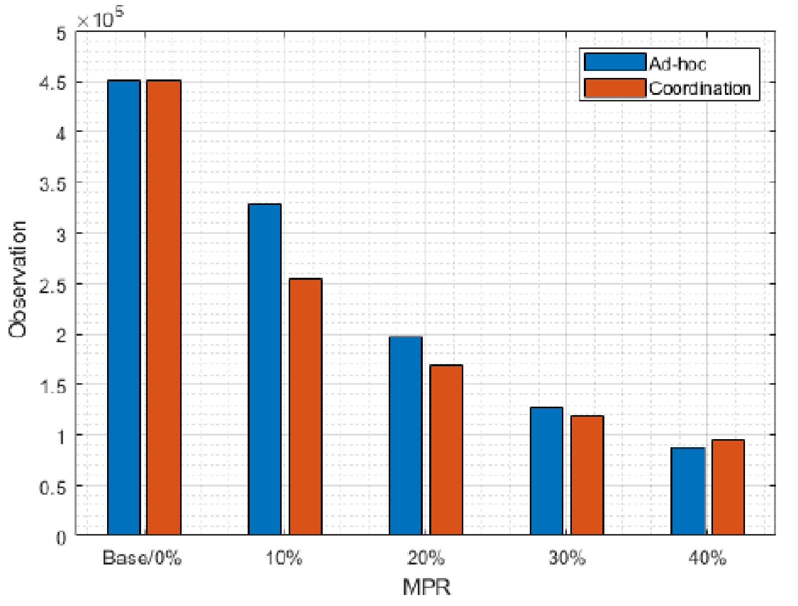
- Ratio of VMT and VHT presents the productivity of a transportation system
- the benefits gained by ad hoc coordination show taper off after 30% MPR.

- Increase trend corresponding to MPR, expect for 10% at ad hoc coordination
- The throughput reaches the highest 10,167 vph at 40% for Coordination

Result- Hard Braking Events (HV-HV)



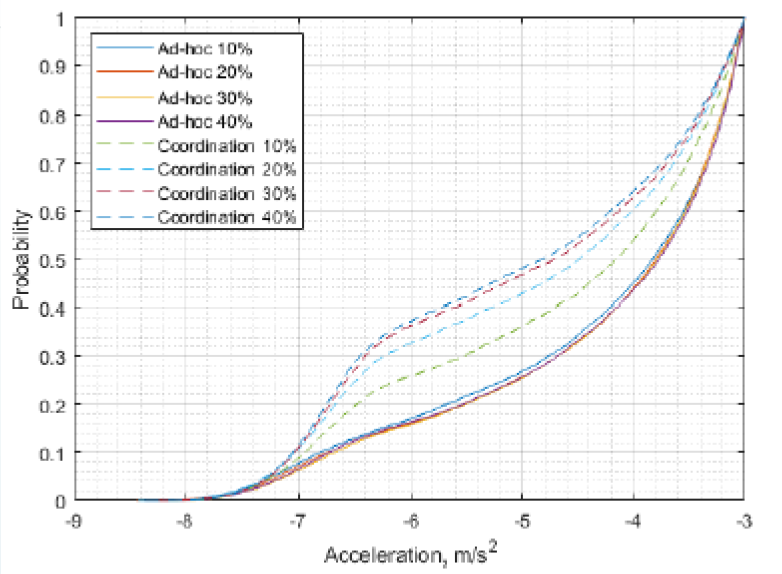
(a) hard braking observation CDF



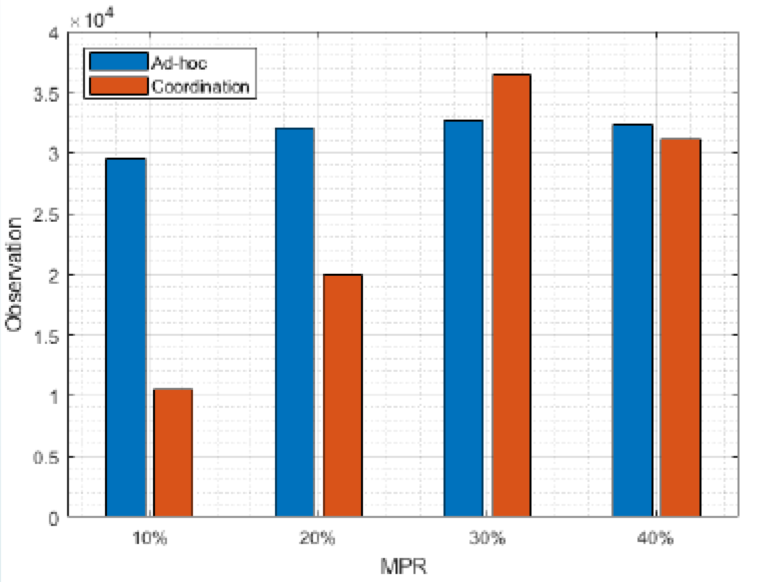
(b) hard braking observation

- Hard braking observations were recorded when the acceleration of a vehicle is less than -3 m/s/s
- Only breaking for HVs when reacting to other HVs is shown
- The breaking decrease is due to decrease in the HV pool. The linear trend infers that the hard braking remains at the same level

Result- Hard Braking Events (HV-CAV)



(a) hard braking event CDF

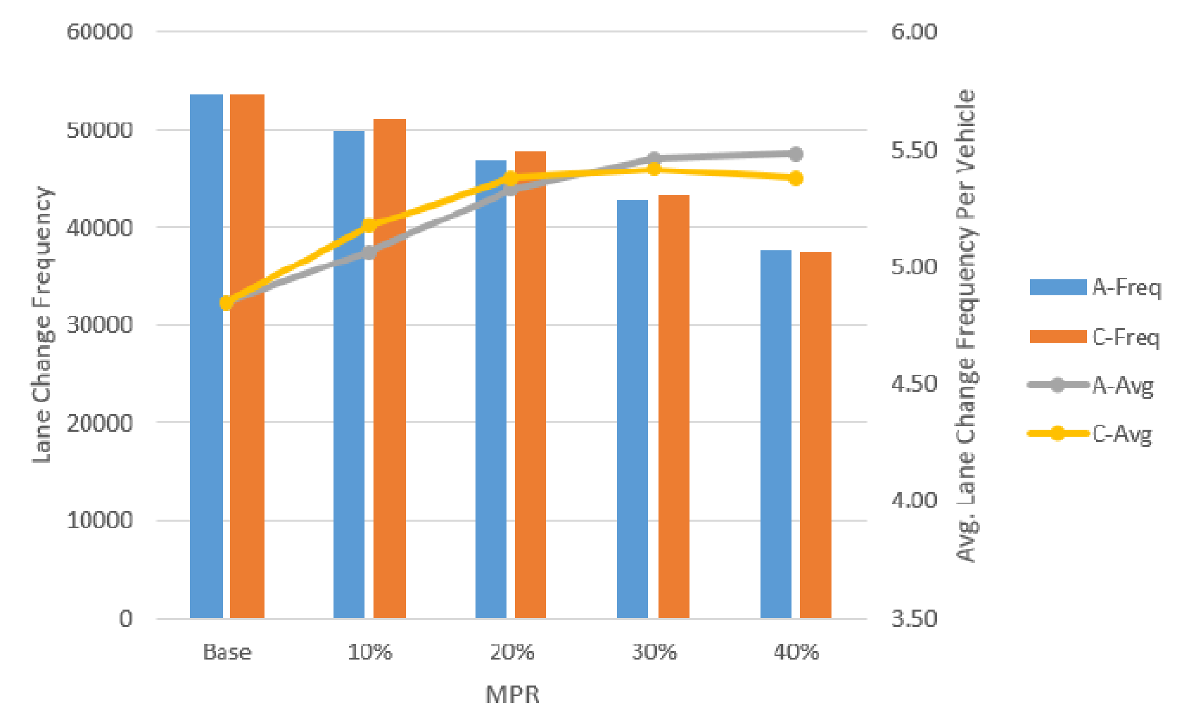


(b) hard braking event sample size

- The CDF curves show two distinct patterns for HVs when interacting to CAVs. CDF curves of the local coordination are more sensitive to MPR
- The occurrence of hard braking event keeps at the same level in ad hoc coordination; whereas the occurrence of coordination strategy shows an increasing trend until 30% MPR where the value peaks.
- 30% MPR is a turning point for frequency of the hard breaking event

Lane Change Activity (HVs)

- Only lane change activity for HVs are shown
- At 10% and 20% MPR, local coordination strategy shows a higher average lane change frequency.
- The average lane change frequency peaks at 30% for Coordination and at 40% for Ad hoc
- At 40% MPR, two strategies have the same level of total lane change activity.

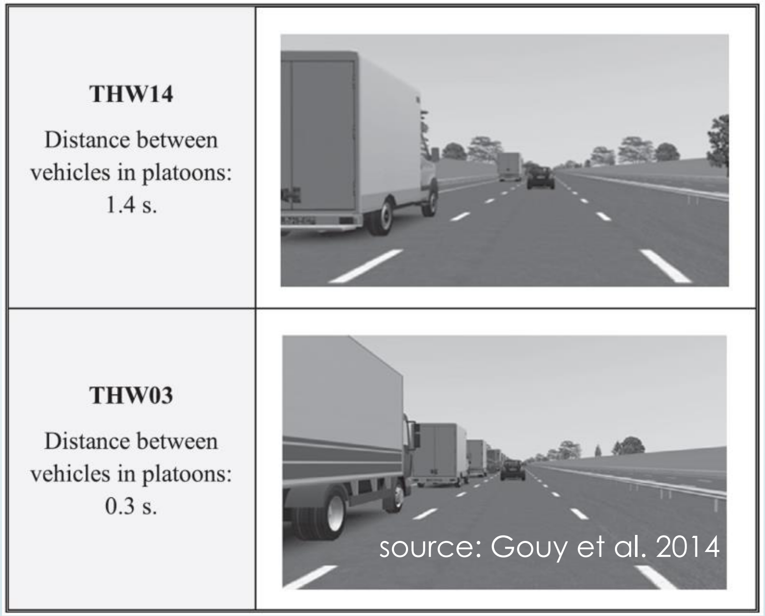


Conclusions

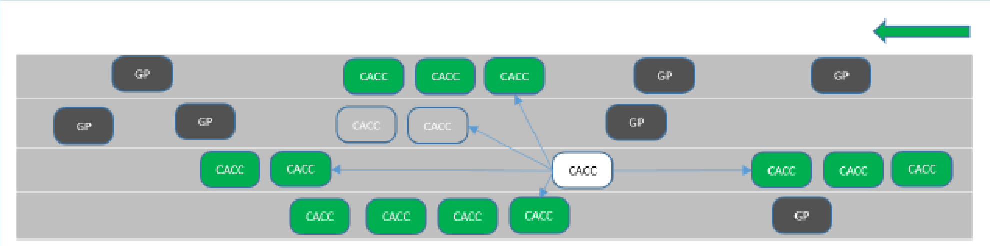
- While re-affirming the benefits of CAV, adapting local coordination can further increase the benefits.
- The distribution of the hard-braking observation for HVs, when interacting with CAVs, change substantially with local coordination strategy for platoon formation
- The average lane change for HVs increases with the presence of CAVs until 30% MPR in local coordination case. Such trend was not observed in the ad hoc coordination case.
- Incorporation of human factor when designing a CAV clustering algorithm is highly recommended.

Future Research

- Evaluate platoon formation in mixed traffic (vehicle-vehicle, vehicle-platoon, platoon-platoon)
- Heterogeneous platoon formation (e.g. HV-CAV platoon)
- Quantify the aggressiveness of the lane change for CAVs when forming a platoon
- Improve modeling on HV behavior when next to CAV platoons

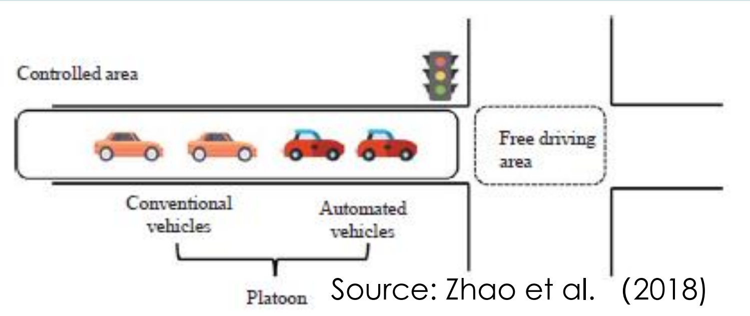


Driving next to platoons



A free-agent CACC vehicle join an existing or form a new platoon

Platoon formation in mixed traffic condition



Heterogeneous platoon

Thank you for your time!

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