Empirical Testing of Advanced Driver Assistance Systems in Recent Market Vehicles:

Implications for Mobility, Safety, and Energy

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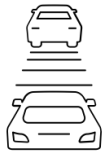
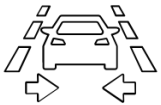
Outline

- Adaptive Cruise Control (ACC)



- Lane Keeping Assist (LKA)



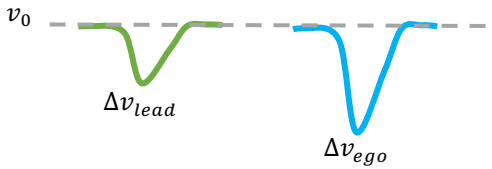
- EV’s opportunities and challenges

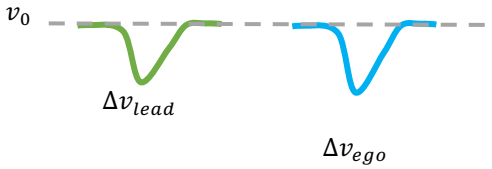
ACC’s impact on mobility & safety

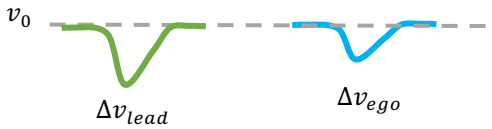
- Does it help smooth traffic congestion?
- Does it contribute to rear-end collisions?
- Other safety limitations

Why does ACC/car-following affect mobility? String stability!

Car following







String stability

String **unstable**

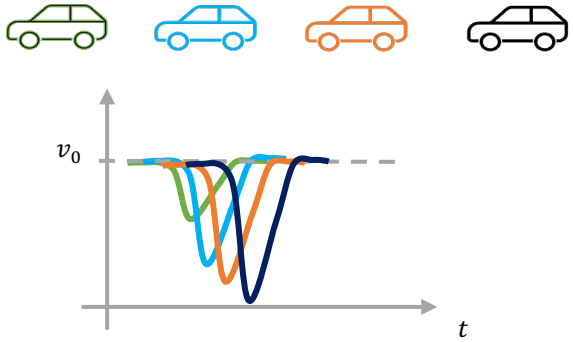
$\Delta v_{ego} > \Delta v_{lead}$

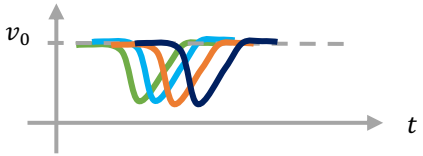
Marginal string stable

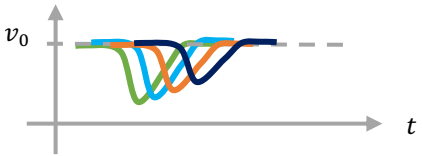
$\Delta v_{ego} = \Delta v_{lead}$

Strict string stable

$\Delta v_{ego} < \Delta v_{lead}$







Our experiments on ACC's empirical features

Boston, MA. Feb 2020

GPS on ACC cars

Speed, position data

Atlanta, GA, Nov 2021

worldwide experiments have reported the same finding:

Georgia Tech

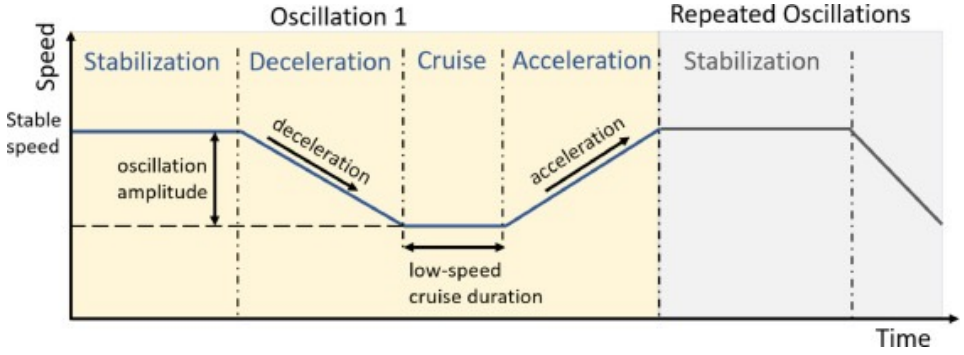
USF

UMASS LOWELL

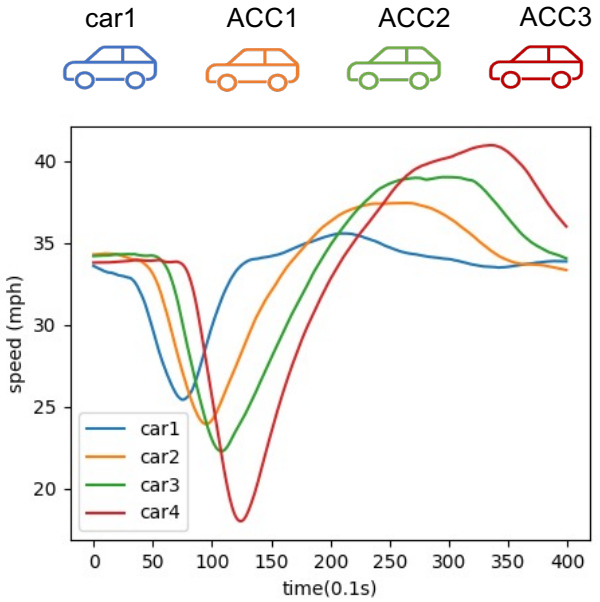
European Commission

Empirical finding: ACC can be even worse than human

Recent worldwide experiments (Gunter 2020, Makridis 2020, Shi 2021, Li 2021..) have shown market ACC systems are **string unstable** in most cases, which can be **even worse than human drivers**.

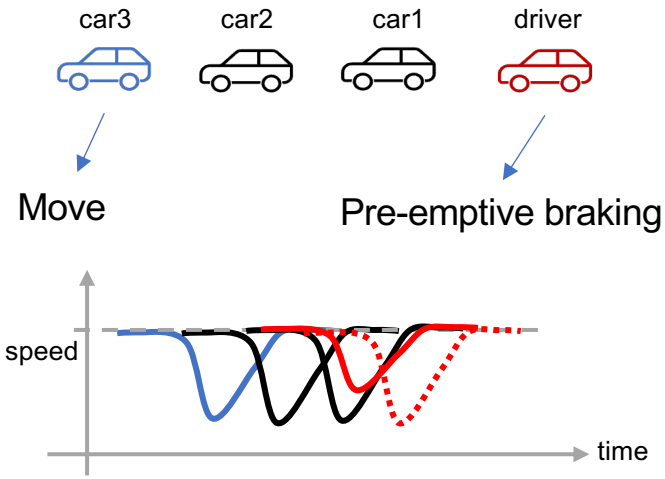


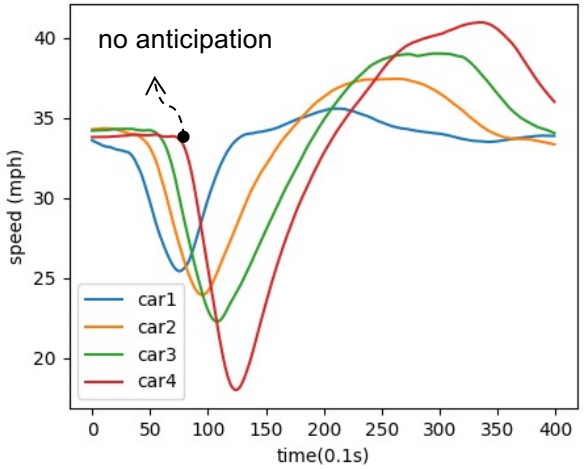
Speed profile used in MA and GA experiments

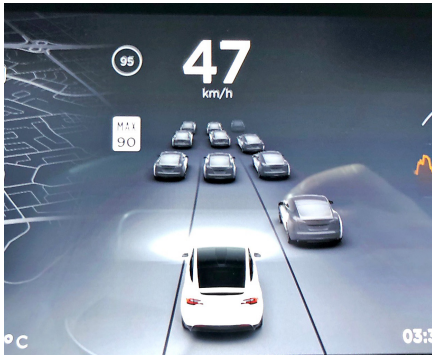


Tesla Autopilot: string unstable trajectories

ACC does not have pre-emption



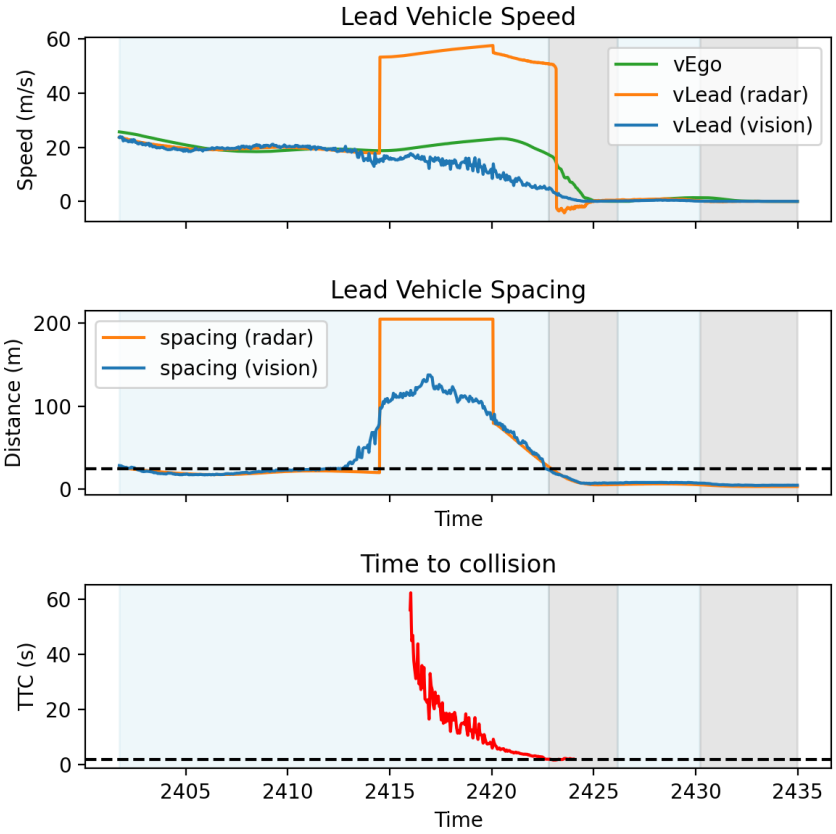




Platoon test of Tesla ACC

Anticipative/pre-emptive driving can smooth traffic congestion and improve safety by seeing further and reacting earlier

Safety: near-collision approaching to stopped cars



Radar cannot detect stopped object (car)
The ttc drops to below 2 seconds when taken over

Quick summary: ACC's impact

ACC can cause more congestion by amplifying traffic oscillations

While causing more congestion, it also increases risks of rear-head collision on highway, especially for vehicles at the back of a long platoon

ACC needs connectivity to enhance pre-emptive driving, which has the potential to increase mobility, safety and energy

Current radar technology is not ready, safety issues exist.

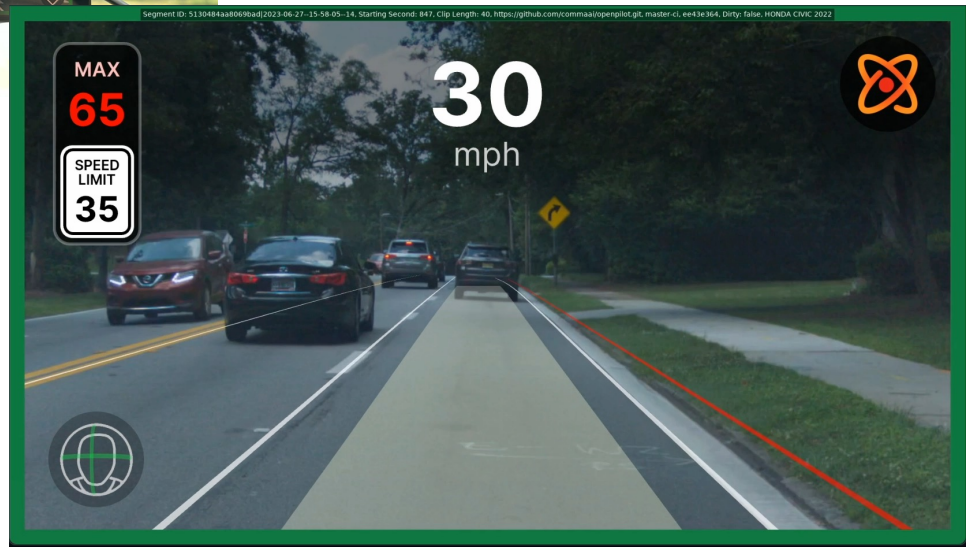
Lateral: LKA's safety

- Does it center in the lane?
- Are current lane markings ready?
- Does weather/lighting affect?
- Implications for geometry design and road maintenance

Our LKA road experiment:

- A camera device that detects lane lines and vehicles
- Vehicle CAN-bus message, variables in stock LKAS
- Rental vehicles, in Tampa and Orlando

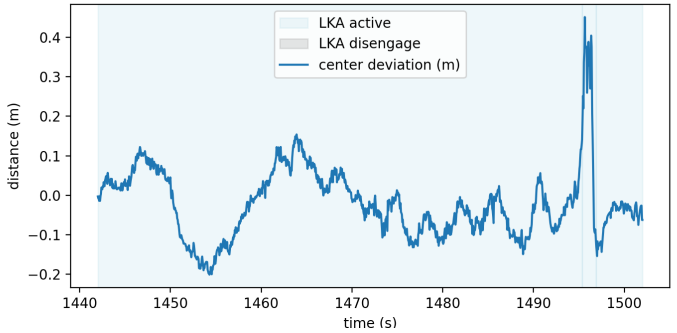
Testing device and what we get

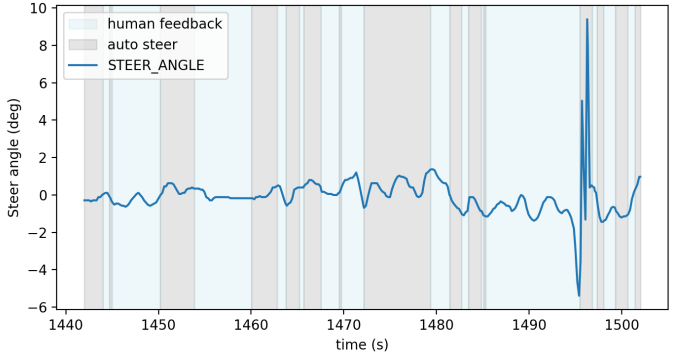


- Left and right lane line position
- Lead vehicle distance and speed

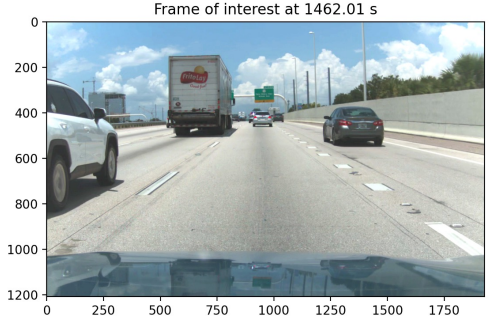
Does LKA system really center the car?

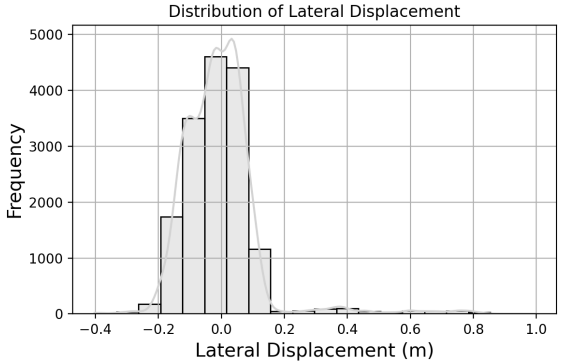
- Metric include center deviation from vision estimation
- The steering angle can be derived from vehicle CAN messages
- It turns out, the centering performance mainly depends on road infrastructure, weather and lightning and vehicle speeds.

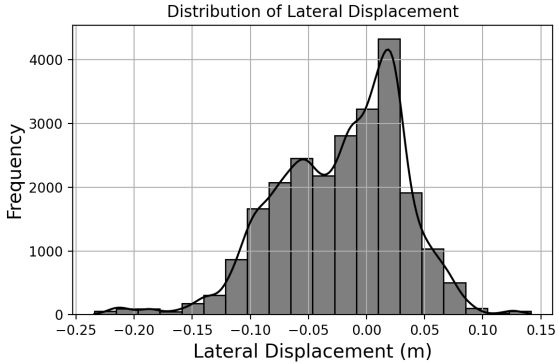




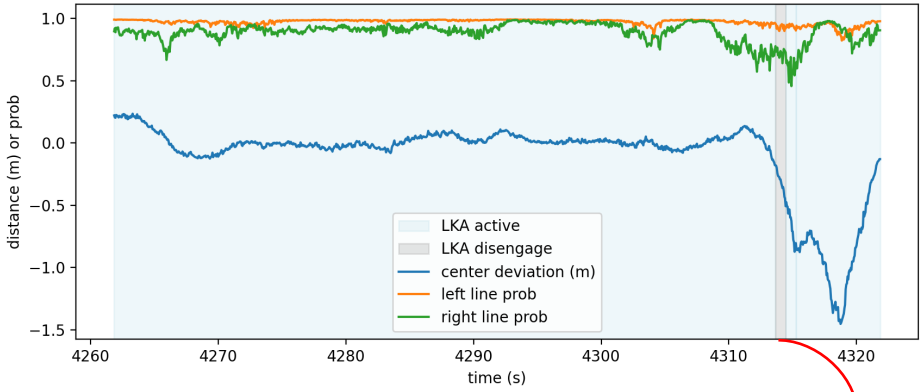
Comparing centering error on concrete/asphalt pavement

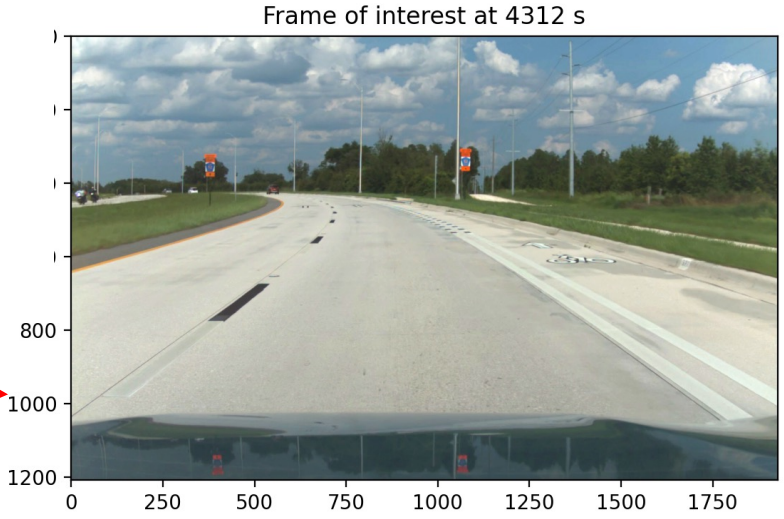






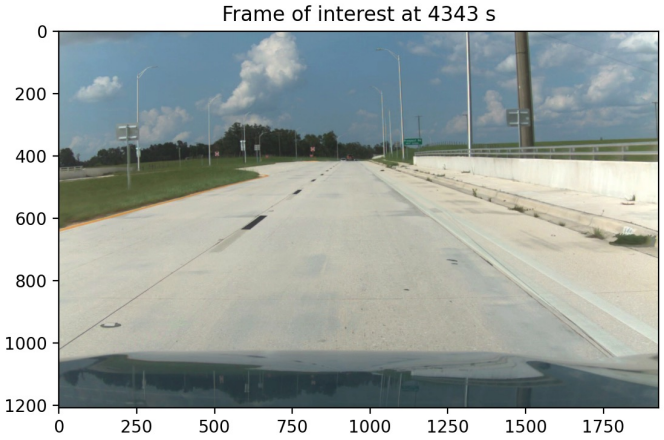
Lane marking not detectable: probability

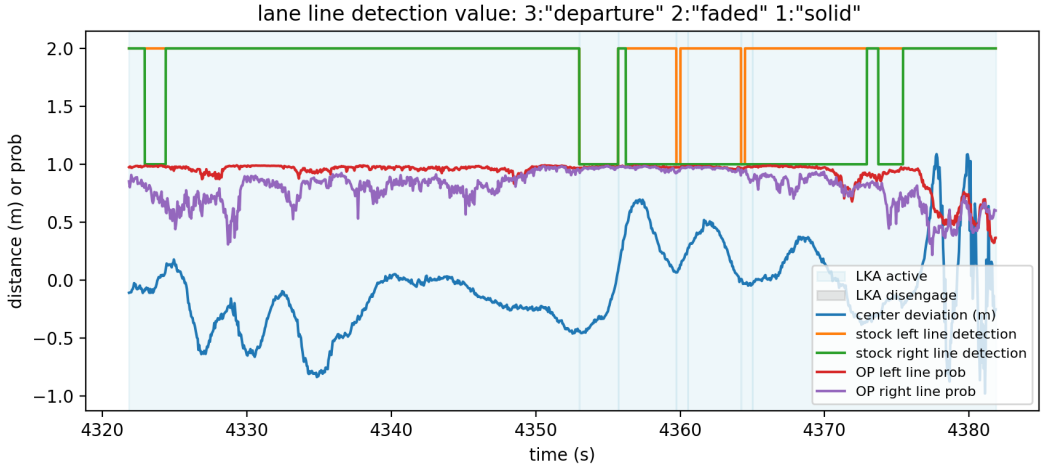




- Contrast due to sunlight
- Discontinuity/lane line change

Lane markings not detectable

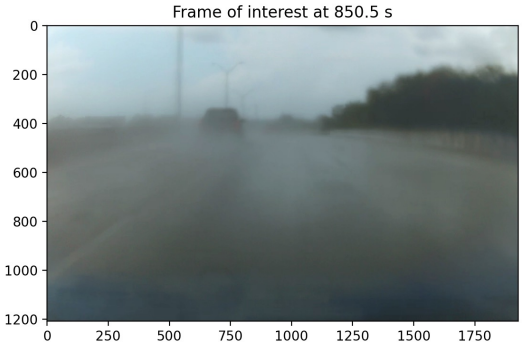


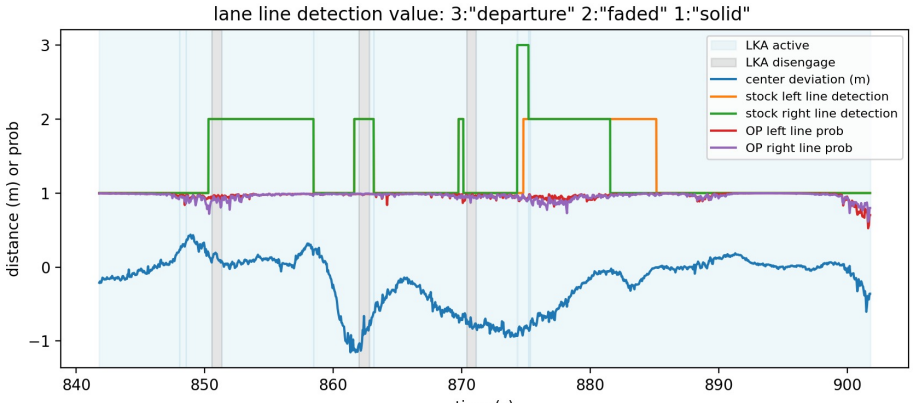


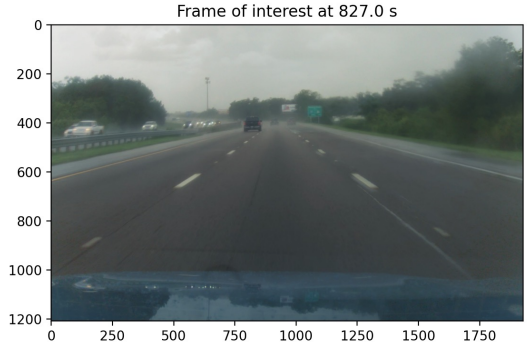
- White pavement, strong light
- White lane line
- Black dashed line

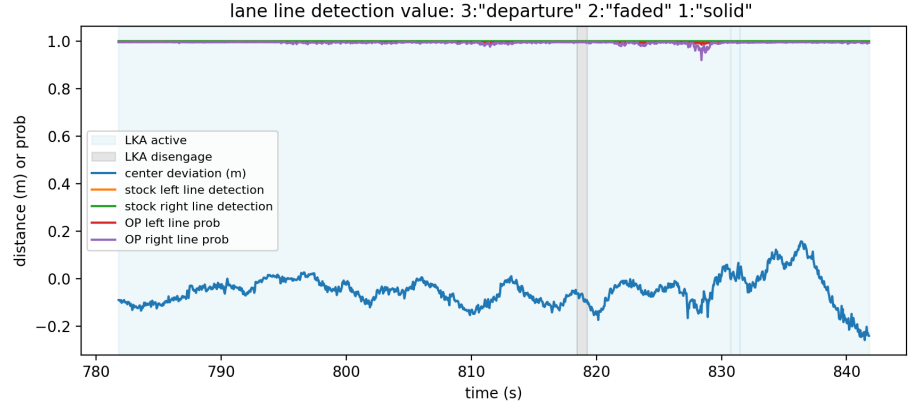
OP has better detection capabilities than stock LKA

Weather: heavy rain that obscures visibility

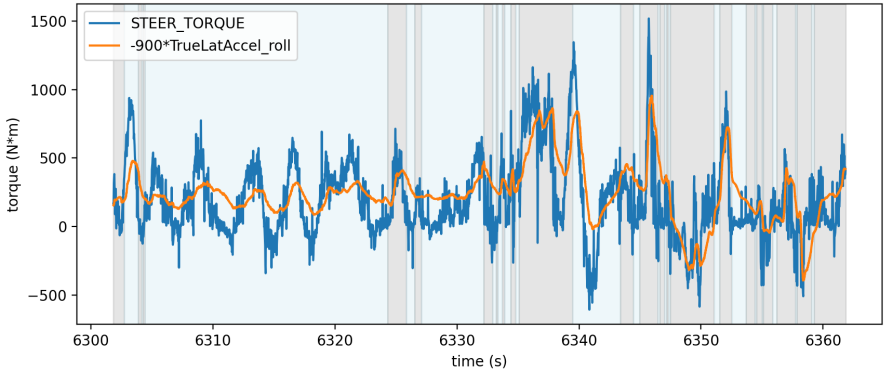




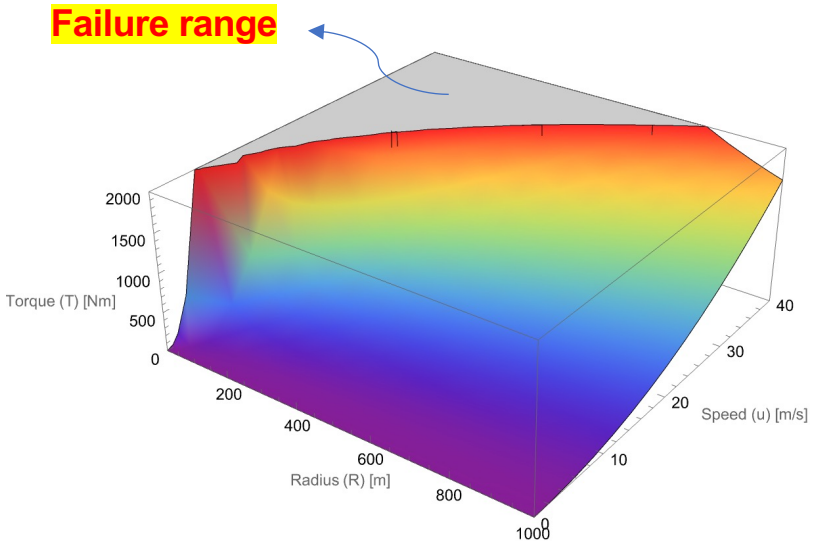




Implications for speed limits & geometry design



- LKA has a torque limit
- Then we get speed and R domain



$$a_{lat} = v(x)^2 \cdot 1/R(x) - \text{roll}(x) \cdot g$$

The steer torque is linearly proportional to the lateral acceleration

$$T(x) = K_a \left(\frac{v(x)^2}{R(x)} - \text{roll}(x) \cdot g \right)$$

Implications for design of the transition curve

On the transition segment to a curve, where the radius changes with position, we have

$$\frac{dT}{dt} = u \cdot K_a \left(\frac{2a(x)}{R(x)} - \frac{u(x)^2 R'(x)}{R^2(x)} - g \cdot \text{roll}'(x) \right) \tag{5}$$

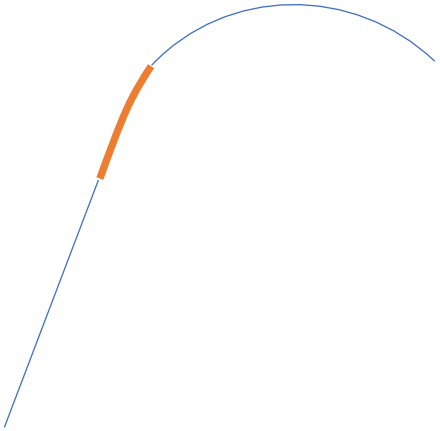
$$\tag{6}$$

Note that here the radius is decreasing, where $R'(x) < 0$. It means that when the transition is more rapid, the required torque rate gets larger. We can also see that deceleration would help reduce the increase of torque.

Let's ignore acceleration and roll, we have some design principle that can be applied to the transition curve before a circular curve with radius R.

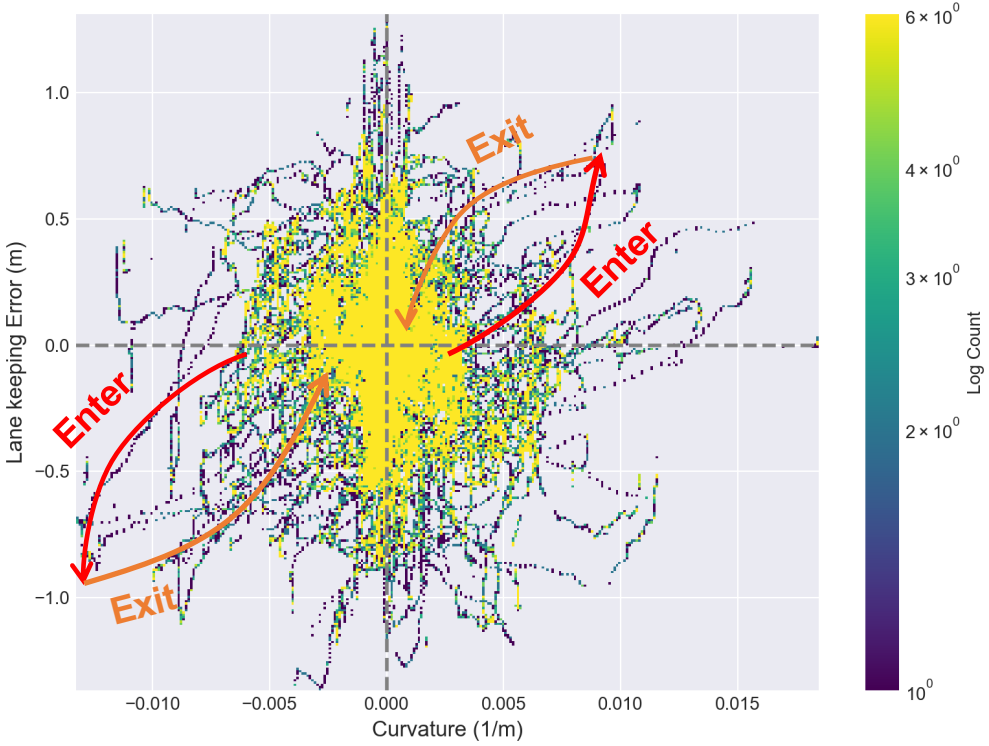
$$\frac{dT}{dt} = u(x)^3 K_a / R^2(x) \cdot (-R'(x)) \tag{7}$$

$$= u(x)^3 K_a / R^2(x) \cdot (-\frac{R_c - \inf}{L}) \tag{8}$$



- Make sure the transition curve geometry does not require a torque rate exceeding its limit

Relationship between center error and curvature

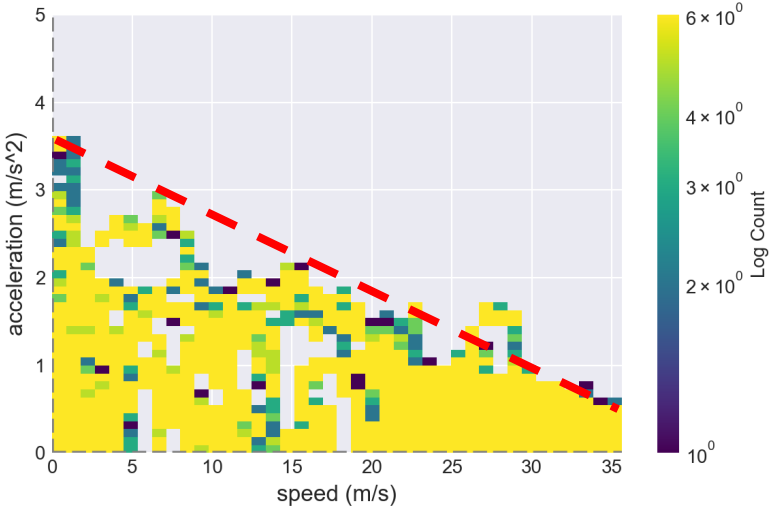


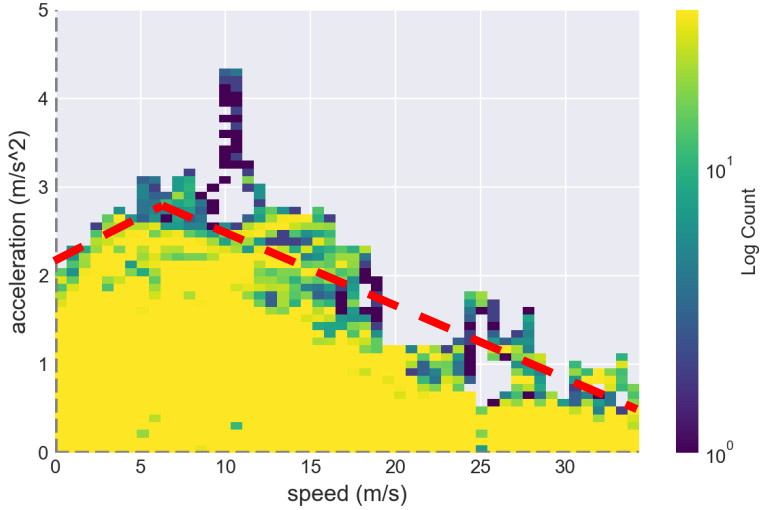
- Positive curvature (right)
- Error increases when entering a curve, decreases when exiting the curve
- But they are not symmetric
- A direct relationship is not clear, since the error can be influenced by many other factors
- Need more experiments on curves

Uncertain Future of EVs: New Perspectives

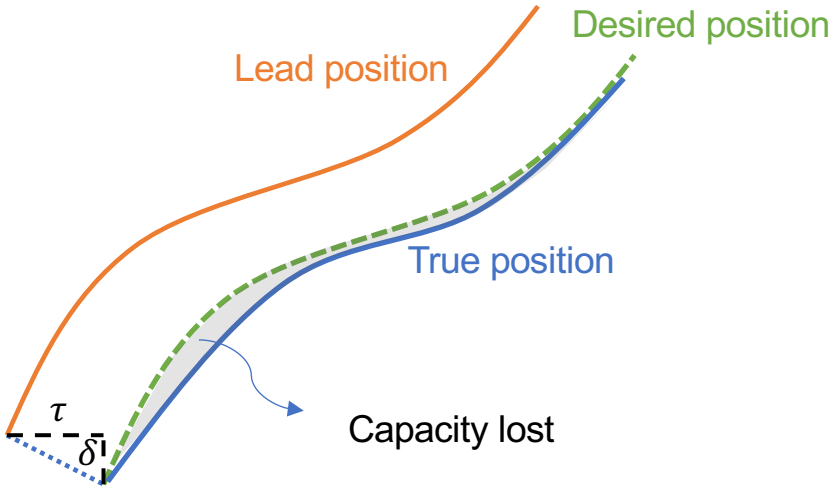
- Opportunities: EVs' potential to improve traffic capacity
- Challenges: energy saving (regen braking) can do more harm than good

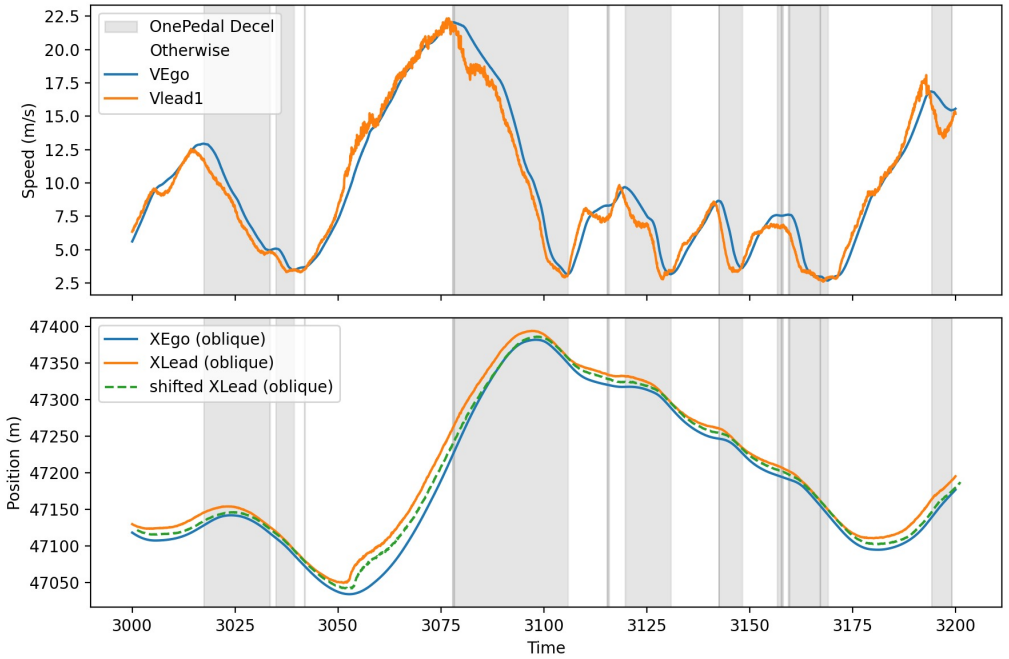
EV has stronger accelerations than ICE





One-pedal driving can deteriorate traffic

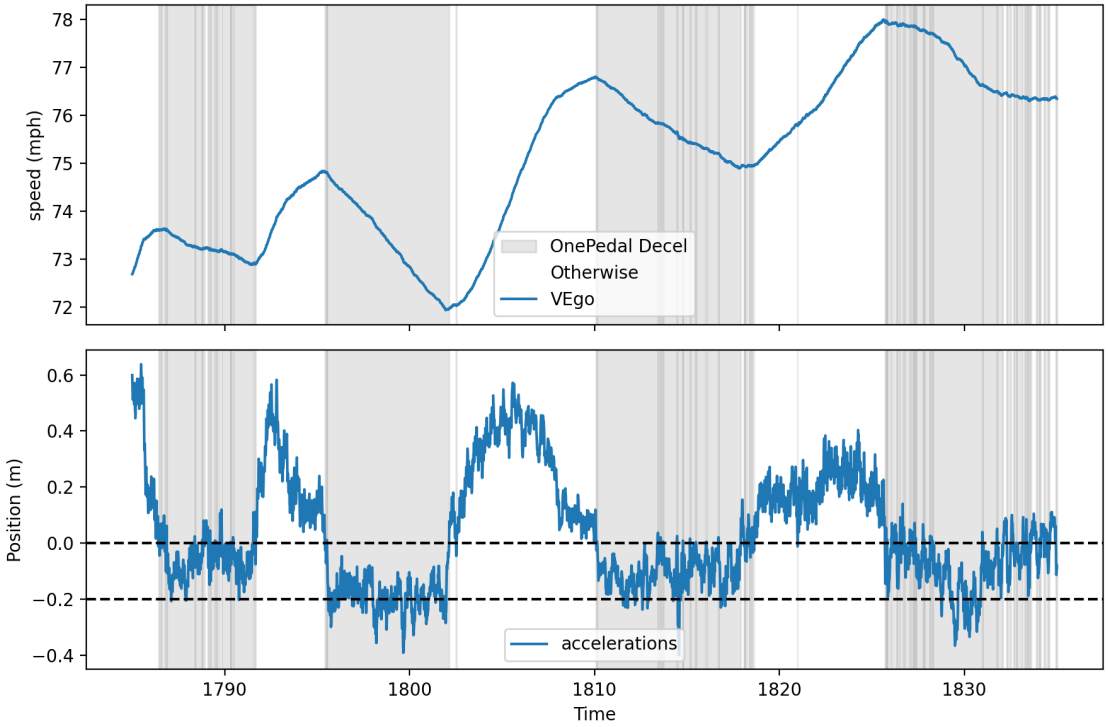




Cons: EV drivers prioritize mileage over …

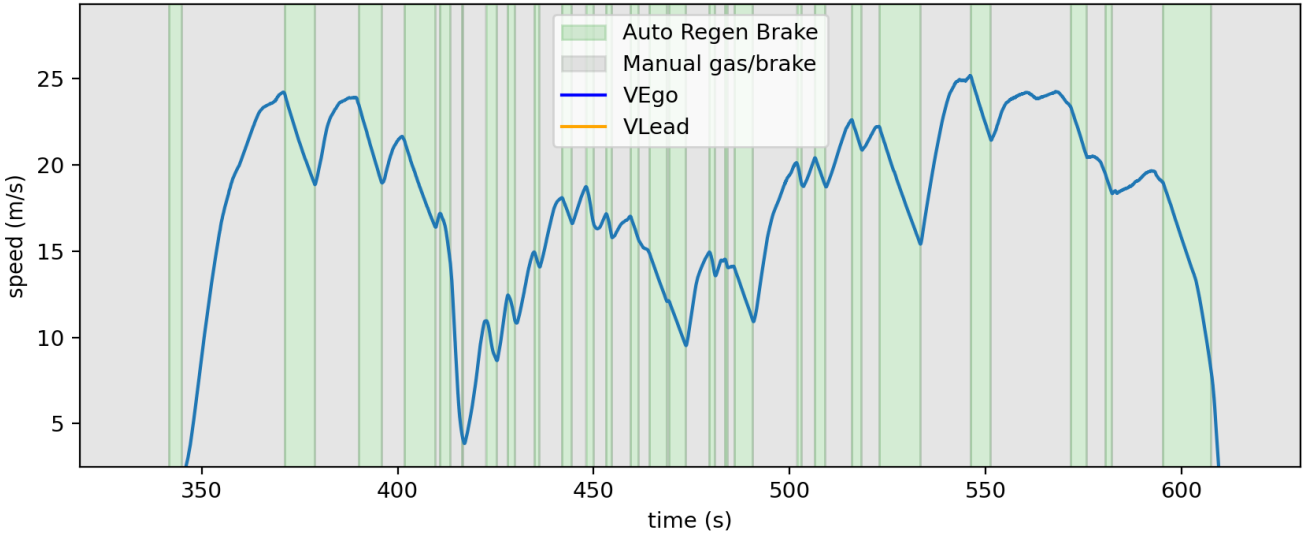
- One-pedal driving
- Auto regen
- The oscillation it may cause
- Sacrifice traffic (system) mobility for a car's (individual) energy

EV does not cruise, causing more oscillations



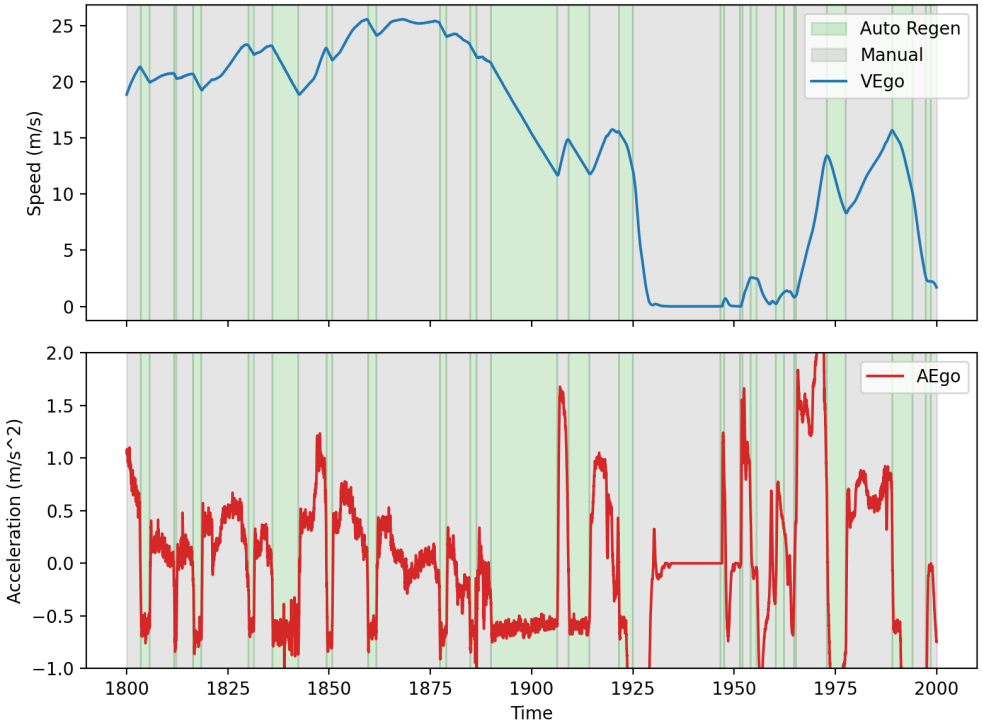
- One pedal driving means that, as soon as the driver lifts his foot for rest, a significant speed reduction will occur.
- Cause more disruptions to the traffic

A glimpse into auto-regen bahaviors



- Strong regen braking causes spikes in speed profiles
- Actually, the regen selects fixed deceleration values

Regen braking is not naturalistic as human drivers



- Regen braking has different levels from weak to strong
- Intriguingly, those pre-defined regen braking levels use certain fixed decelerations, not naturalistic.

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