Regulations on Automated Driving Systems: The current state and some important challenges

Konstantinos Mattas EC - JRC

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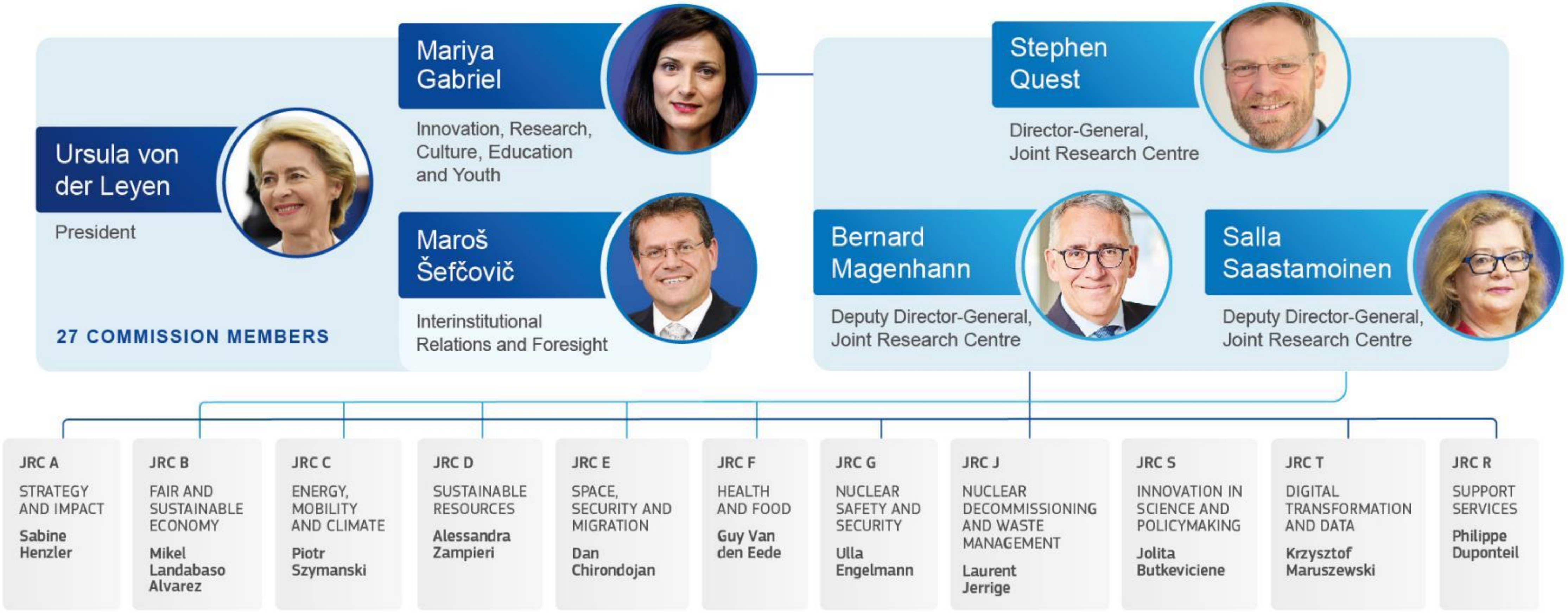
European Commission

The Joint Research Centre within the Commission



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Current state of ADS

Situation for different levels of automation

Level		Deployment	Example Regulations	Notes
1	Driver Assistance	Widely Available		
2	Partial Automation	Available	UN Reg. 79	Restricting (e.g. no system initiated maneuvers). Upcoming new regulation this year will be more general
3	Conditional Automation	Limited Cases	UN Reg. 157	ALKS, **highway** up to 130 km/h with lane changing
4	High Automation	Mostly pilots and small-scale applications	EU 1426/2022	**Limited series** and cases (hub-to-hub, AVP, shuttles, robotaxis)
5	Full Automation			

Existing Regulations

Regulation 157

EU ADS Regulation

The new EU type approval framework for connected and automated vehicles

AUTOMATED VEHICLES
UN R157

KEY CHARACTERISTICS:

- Driver present
- Automated driving mode limited to motorways up to 60 km/h, up to 130km/h from January 2023
- No limitation to size of vehicle series
- Cybersecurity measures

FULLY DRIVERLESS VEHICLES
EU ADS Reg

KEY CHARACTERISTICS:

- No driver present
- Automated driving permitted in defined areas
- Limit on size of vehicle series to max.1500 vehicles per model per year (review of limit 2025)
- Allowed from September 2022

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I) Automated Vehicles: UN Regulation 157 (2020, amended 2022)

- In June 2020 UNECE WP.29 adopted the **Regulation on Automated Lane Keeping Systems (ALKS) for low-speed highway applications** (“*traffic-jam pilot*”), the first regulation setting technical requirements for Level 3 vehicle automation*
- In force since January 2021, it applies to passenger cars and vans. From June 2022 it applies also to trucks, buses and coaches
- **First amendment** adopted in June 2022 for scope extension to high speed and lane change (“*highway chauffer*”)
- World’s first internationally valid ALKS approvals granted by Germany and Japan in 2021

* https://unece.org/transport/press/un-regulation-automated-lane-keeping-systems-milestone-safe-introduction-automated

II) Driverless vehicles: the new EU ADS Regulation (1426/2022)

Commission Implementing Regulation laying down rules for the application of Regulation (EU) 2019/2144 of the European Parliament and of the Council as regards uniform procedures and technical specifications for the type-approval of motor vehicles with regard to their automated driving system (ADS)

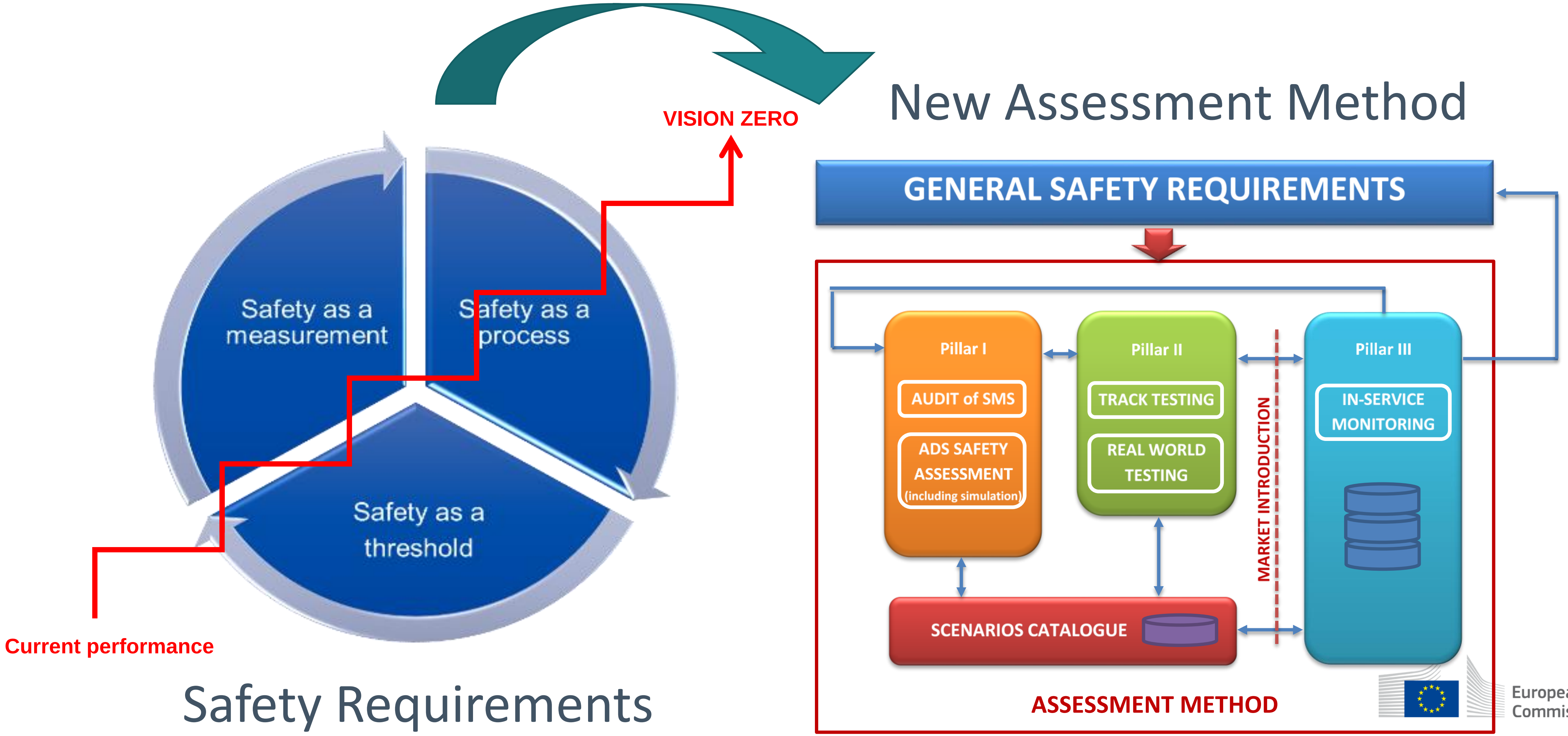
ANNEXES to the Commission Implementing Regulation

1) Information Document
2) Performance Requirements
3) Compliance Assessment

   PART 1 Traffic Scenarios
   PART 2 Audit of SMS and safety assessment
   PART 3 Tests
   PART 4 Guidelines for the credibility assessment
   PART 5 In-service reporting

4) EU Type approval certificate

Innovative approach



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Annex III – Compliance Assessment

Audit of the SMS and Safety Assessment

AUDIT

The Manufacturer shall demonstrate that effective processes, methodologies, training and tools are in place, up to date and being followed within the organization to manage the safety and continued compliance throughout the ADS lifecycle.

SAFETY ASSESSMENT

The manufacturer shall provide a documentation package which gives access to the design and validation of the ADS.

Annex III – Compliance Assessment

Physical Testing

- These tests shall confirm the minimum performance requirements
- Tests scenarios to assess the performance of the ADS **on a test track** (e.g. lane keeping and changing, response to road infrastructure, collision avoidance, cut-in, etc…)
- The ADS shall also be tested **on-road** in accordance with the applicable law of the Member State granting the type-approval and provided that tests can be carried out safely and without any risk to other road users.

Annex III – Compliance Assessment

IN-SERVICE REPORTING

The manufacturer shall report relevant occurrences during ADS operation:

- within one month: short-term report, on occurrences which needs to be remedied by the manufacturer ➔ to the type-approval authorities, market surveillance authorities and the Commission
- every year: periodic report, to provide evidence of the ADS performance on safety relevant occurrences in the field ➔ to the type-approval authority that granted the approval

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Safety Requirements

Some general requirements

Reg 157:
“The activated system shall not cause any collisions that are reasonably foreseeable and preventable.”

“…the performance of the system shall be ensured at least to the level at which a competent and careful human driver could minimize the risks .”

“ "Unreasonable risk" means the overall level of risk for the driver, vehicle occupants and other road users which is increased compared to a competently and carefully driven manual vehicle.”

Minimum Following Distance

Also, in Reg 157 we see minimum distance requirements for speeds up to 60 km/h.

There is conceptual difference in this requirement and the previously presented ones.

- Is that distance always safe?
- Are smaller distances always unsafe?
- Platooning?

The minimum following distance shall be calculated using the formula:

$$d_{min} = v_{ALKS} * t_{front}$$

Where:

d_{min} = the minimum following distance

v_{ALKS} = the present speed of the ALKS vehicle in m/s

t_{front} = minimum time gap in seconds between the ALKS vehicle and a leading vehicle in front as per the table below:

Present speed of the ALKS vehicle		*Minimum time gap*	*Minimum following distance*
(km/h)	(m/s)	(s)	(m)
7.2	2.0	1.0	2.0
10	2.78	1.1	3.1
20	5.56	1.2	6.7
30	8.33	1.3	10.8
40	11.11	1.4	15.6
50	13.89	1.5	20.8
60	16.67	1.6	26.7

For speed values not mentioned in the table, linear interpolation shall be applied.

Notwithstanding the result of the formula above for present speeds below 2 m/s the minimum following distance shall never be less than 2 m.

Operational and performance requirements

Operational Requirements:
Easy to explain, implement and check, possibly restrictive, valid as much as their assumptions
"the system shall adapt the speed to adjust the distance to a vehicle in front in the same lane to be equal or greater than the minimum following distance"

Performance Requirements:
Requirements on the end result, the designer is free to select the way of achieving it, harder to implement and check
"The activated system shall not cause any collisions that are reasonably foreseeable and preventable."

Preventable cut-in scenarios

What is a preventable accident?

Simulation models have been developed to classify between preventable/unpreventable cases

Simple kinematics have been used based on **reaction time** and **maximum deceleration.**

Based on previous research for active safety systems, the last point **reaction** is used.

However, most drivers manage to be safe, avoiding such emergency reactions, by driving in a **defensive**, **anticipatory** fashion.

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Emergency reaction models

The ADS shall react as soon as the other vehicle has started entering into its lane, using the maximum deceleration

We argue that a normal driver can start a reaction in advance, but not with a maximum deceleration (too conservative)

We developed a Fuzzy Safety Model that was included in the first amendment Regulation 157

Preventable cut-in scenarios

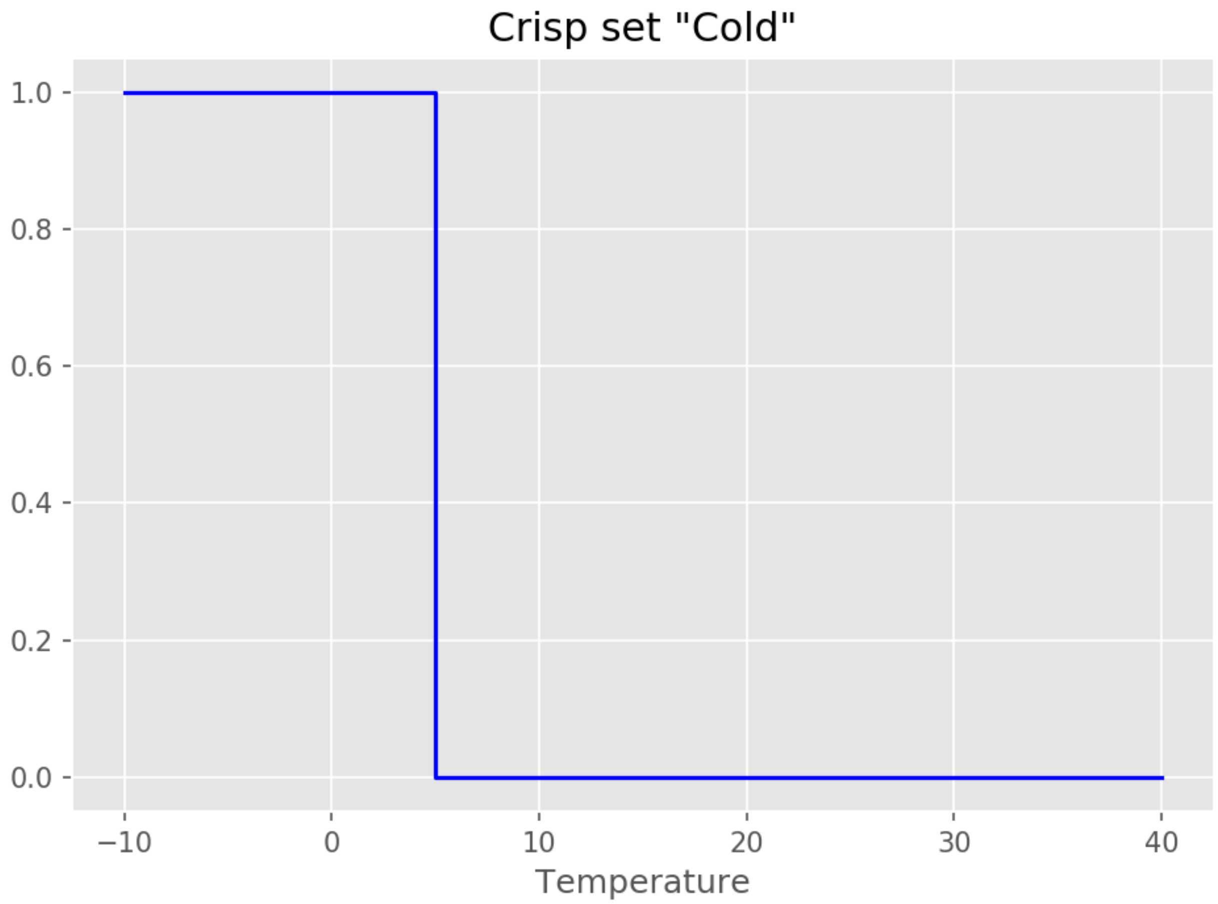
The model

What is Fuzzy Logic? Crisp sets

Classical set is a collection of distinct objects. Any element is either in a set or not.

We can describe a set by its characteristic function. It takes the value 1 for elements that are in the set and the value 0 for elements that are not in the set

The sets are ‘Crisp’

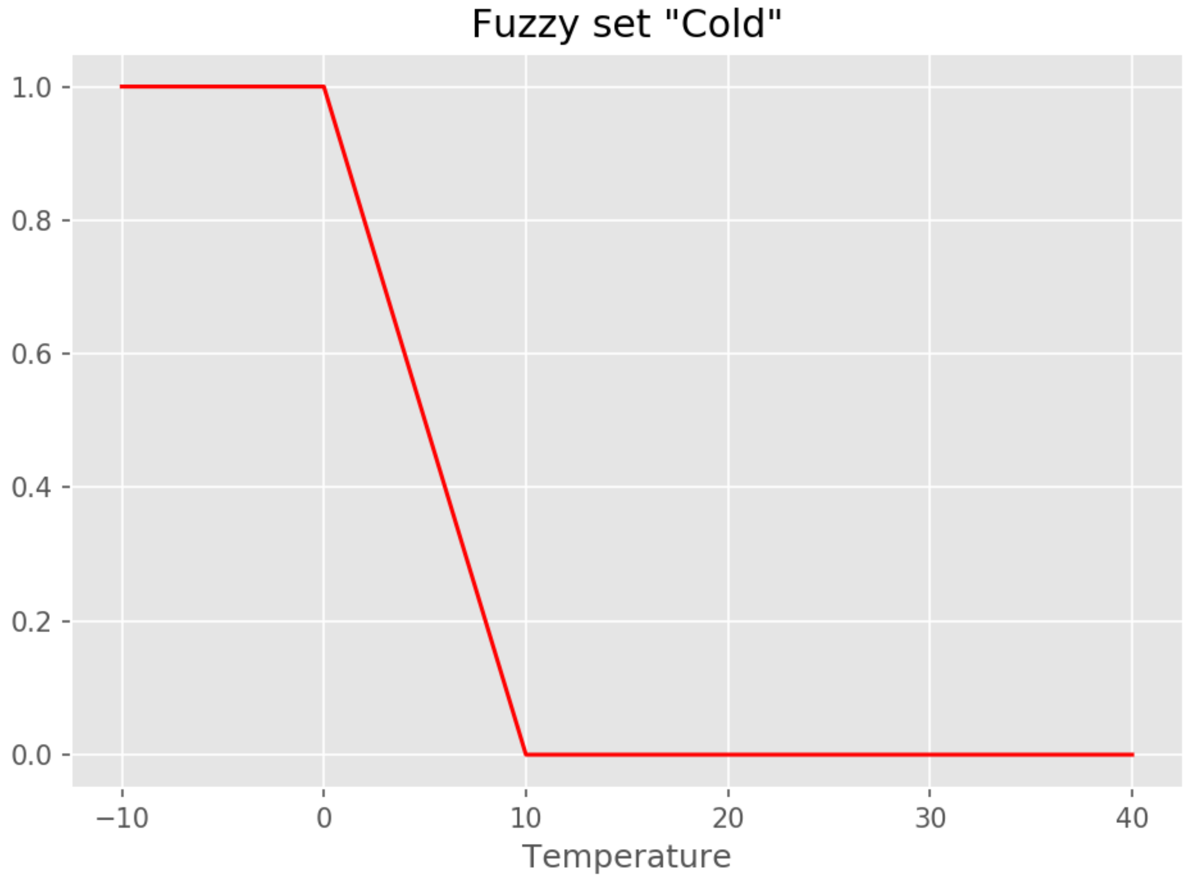


What is Fuzzy Logic? Fuzzy sets

Characteristic functions of Fuzzy sets can take all values from 0 to 1

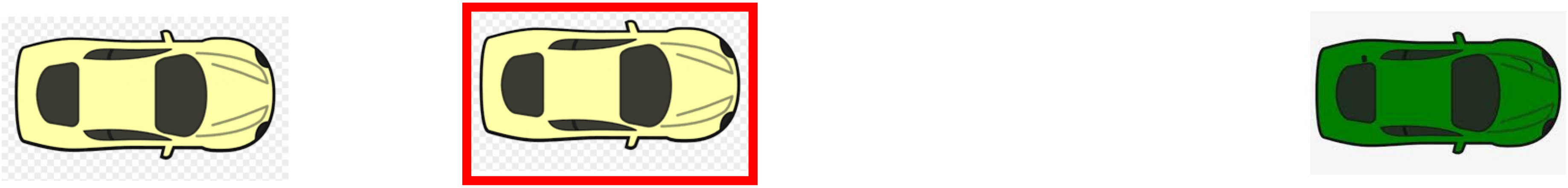
This can be helpful in many cases to better describe a situation

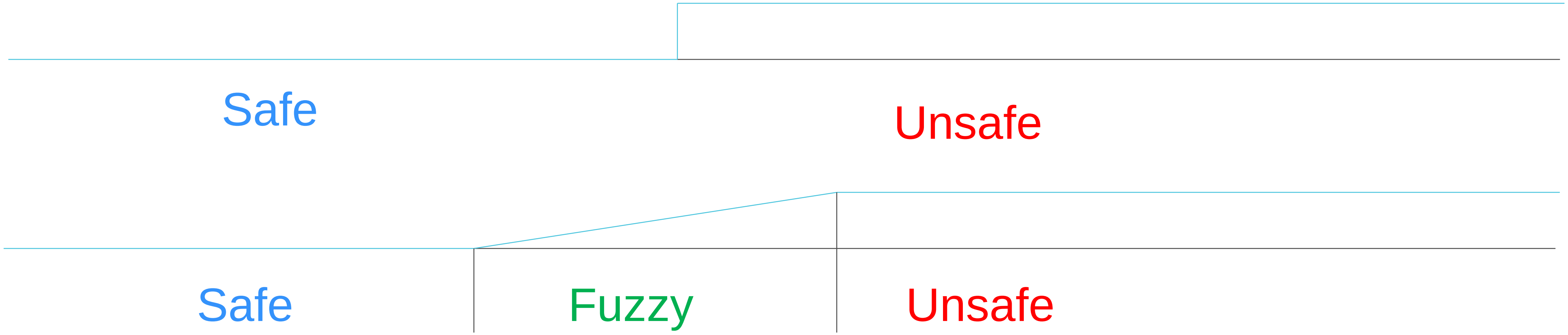
Based on those we can create fuzzy rules



Why Fuzzy logic

Two vehicles with known speeds. What is a safe distance?





The more unsafe, the harder the vehicle must decelerate

Different calculation of lateral safe distance

1. The cutting in vehicle has to be in front of the ego vehicle
2. The cutting in vehicle has lateral speed towards the ego vehicle
3. The lateral net time headway < The longitudinal gross TTC + 0.1 sec

If all three restrictions apply, then we have to check the situation for the longitudinal safe distance

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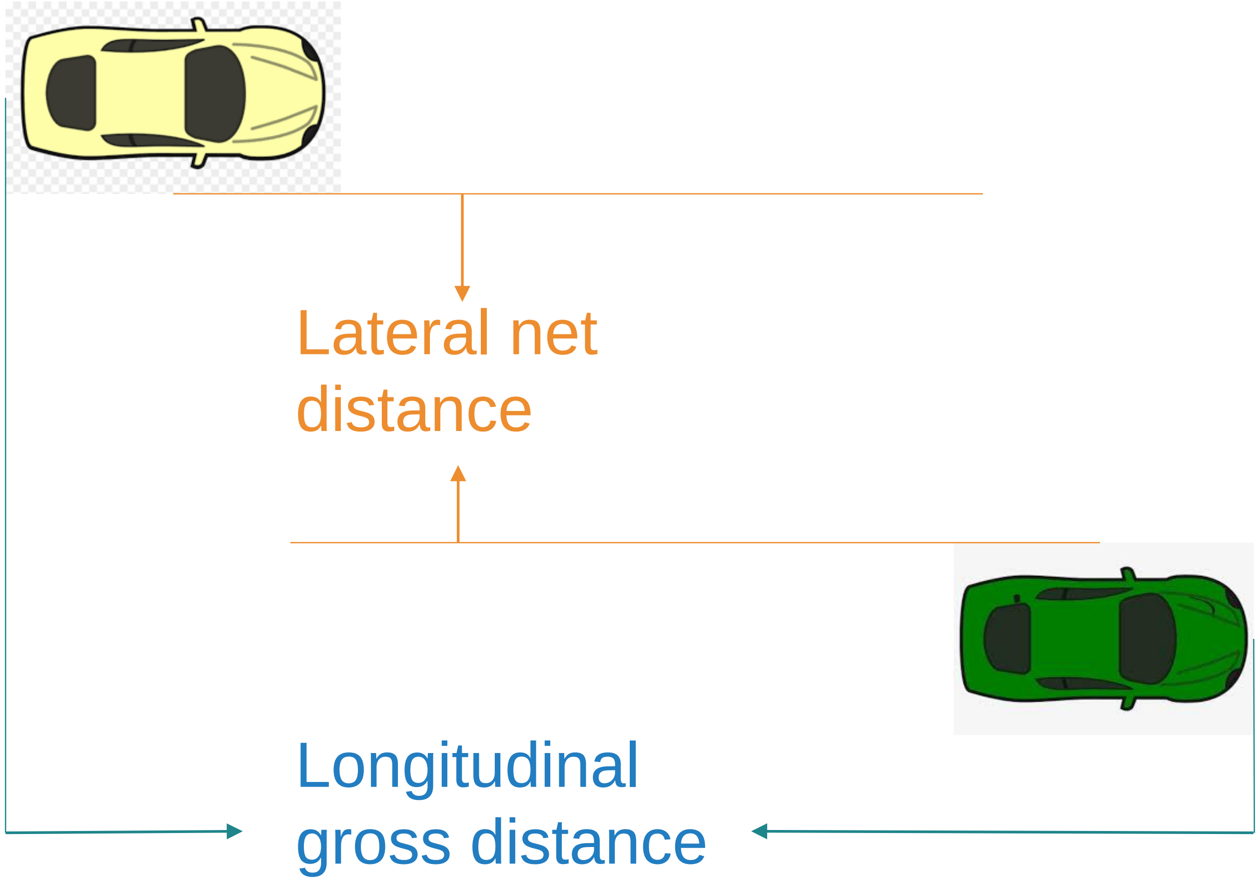
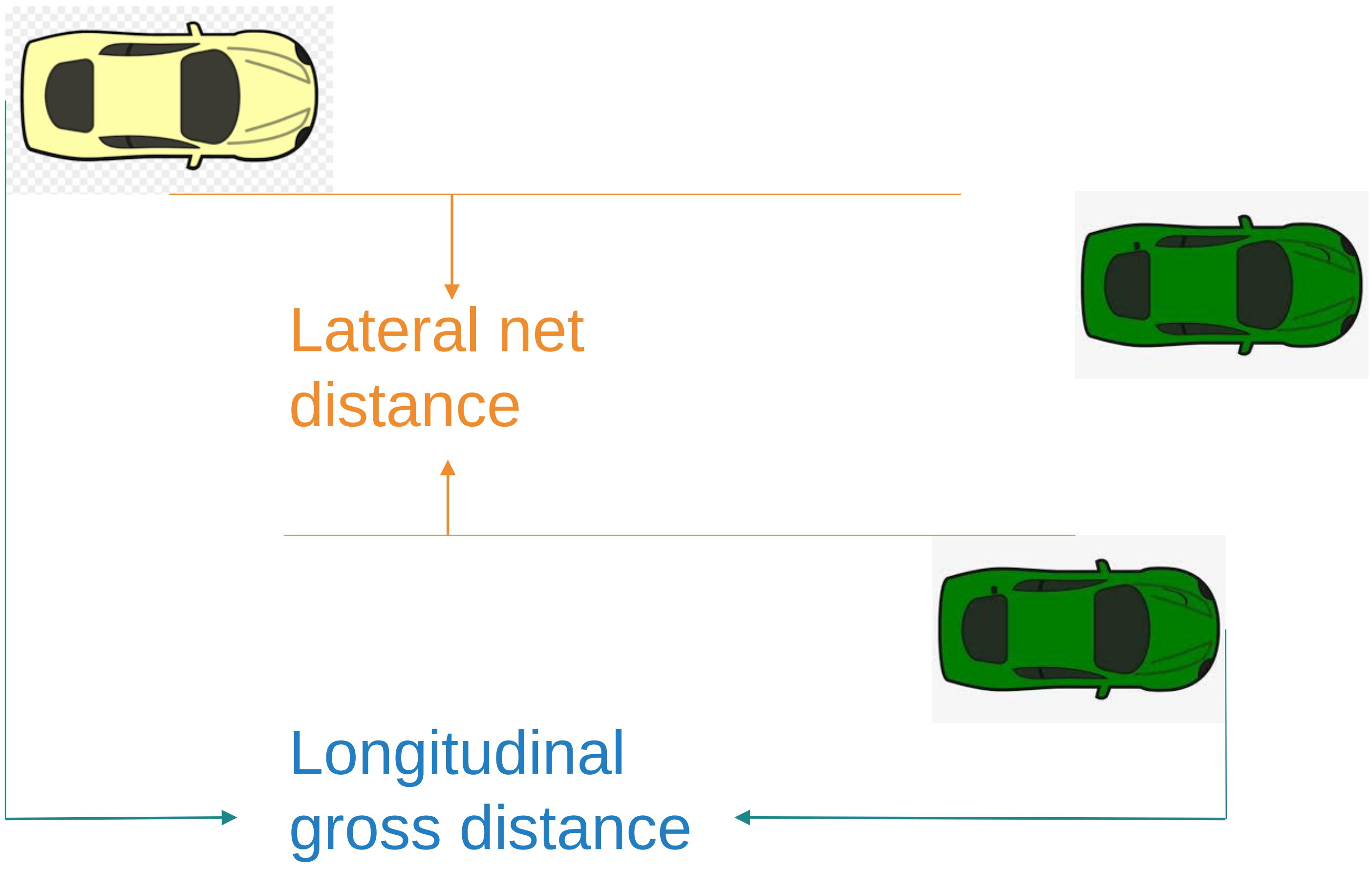
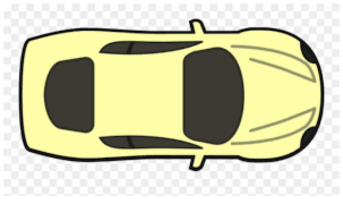
Different calculation of lateral safe distance



- The lateral net distance the space between the vehicles laterally
- The longitudinal gross distance is the longitudinal space from the rear of the ego vehicle to the front of the cutting in vehicle
- To calculate headway, they have to be divided to the cutting in vehicle lateral speed and the approaching speed respectively

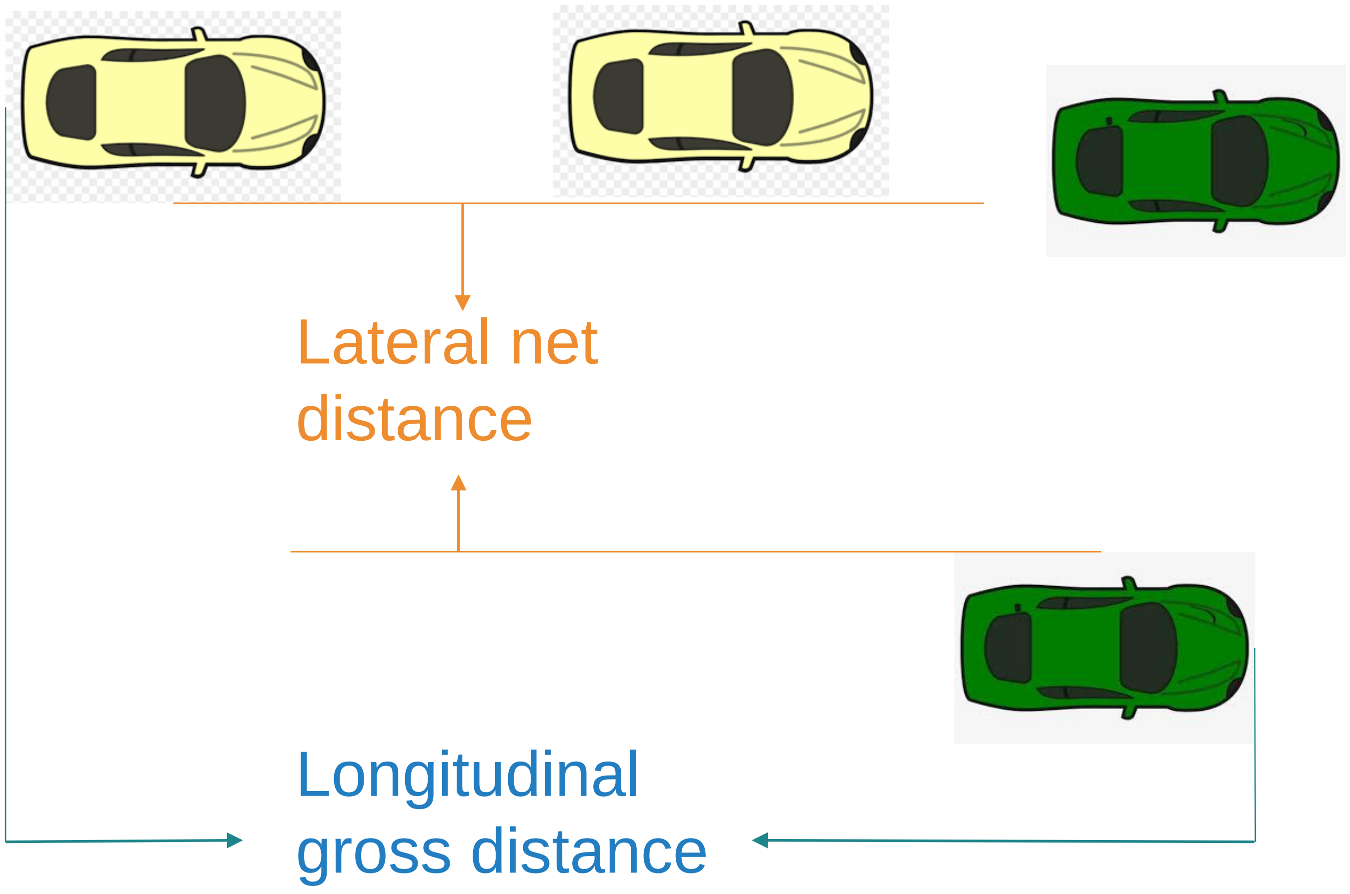
Different calculation of lateral safe distance





If the lateral net time headway > The longitudinal gross TTC+ 0.1 sec, the cut-in is very slow and the ego vehicle will not have to decelerate

Different calculation of lateral safe distance



Else, if the longitudinal distance is long and the cut-in speed is slow, it goes to the longitudinal safety part and may be considered safe at the end

Different calculation of lateral safe distance

Advantages

- Less parameters needed
- Less information that may induce errors (lane markings)
- Cases when the vehicles deceleration causes an accident are avoided
- Slow lane changes for vehicles in a distance are also considered

Longitudinal safe distance according to Fuzzy SSMs

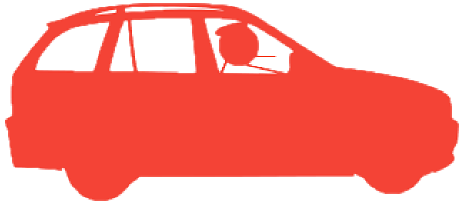
Two different definitions of unsafe:

- If the leader vehicle decelerates, the follower vehicle cannot avoid an accident (Vienna Convention on Road Traffic)
- If nothing changes, there will be a collision in x sec (TTC)

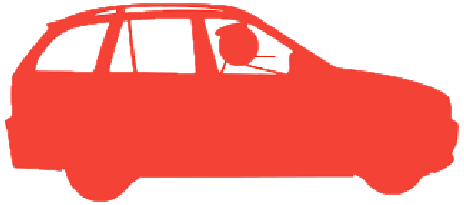
We calculated the Proactive Fuzzy SSM (PFS) and the Critical Fuzzy SSM (CFS)

Longitudinal safe distance according to Fuzzy SSMs

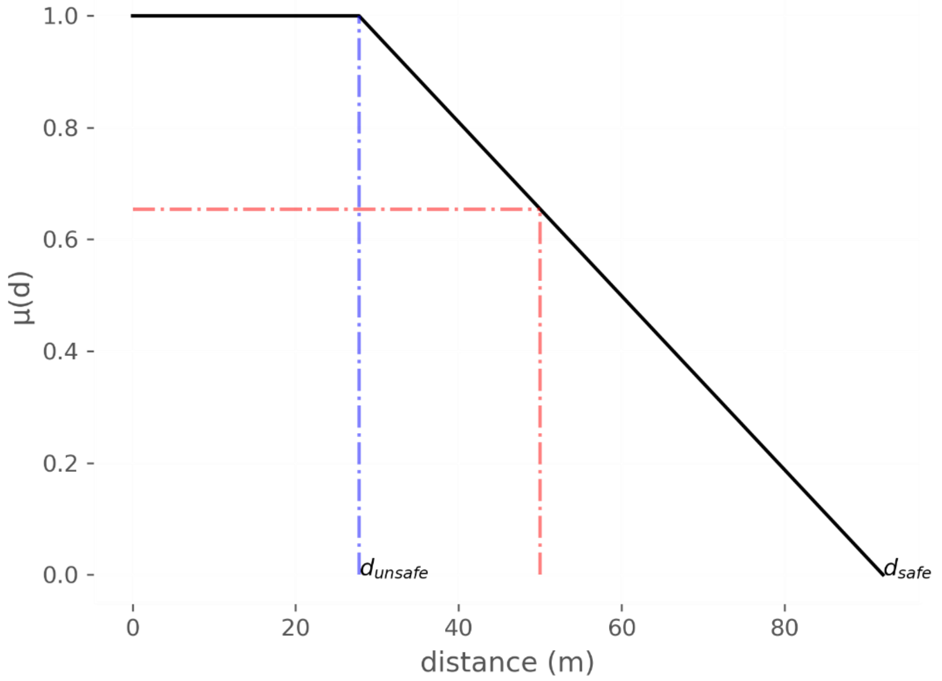
Maximum
Unsafe
distance



Minimum
Safe
distance



$$\mu_A(d) = \begin{cases} 1, & 0 < d < d_{unsafe} \\ 0, & d > d_{safe} \\ \dfrac{d - d_{safe}}{d_{unsafe} - d_{safe}}, & d_{unsafe} < d < d_{safe} \end{cases}$$



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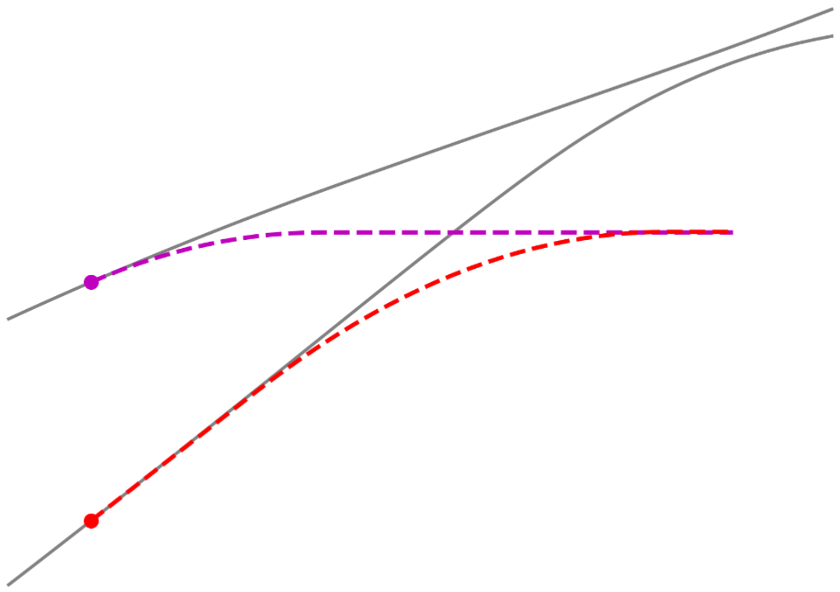
Longitudinal safe distance according to Fuzzy SSMs

PFS: If the leader vehicle decelerates, the follower vehicle cannot avoid an accident

$$d_{safe}(t) = u_2(t)\tau + \frac{u_2^2(t)}{2b_{2comf}} - \frac{u_1^2(t)}{2b_{1max}}$$

$$d_{unsafe}(t) = u_2(t)\tau + \frac{u_2^2(t)}{2b_{2max}} - \frac{u_1^2(t)}{2b_{1max}}$$



Longitudinal safe distance according to Fuzzy SSMs

CFS: If nothing changes, there will be a collision

$$a'_2(t) = \max(a_2(t), -b_{2comf})$$

$$u_2(t+\tau) = u_2\ a'_2(t)$$

If $u_2(t+\tau) \leq u_1(t)$:

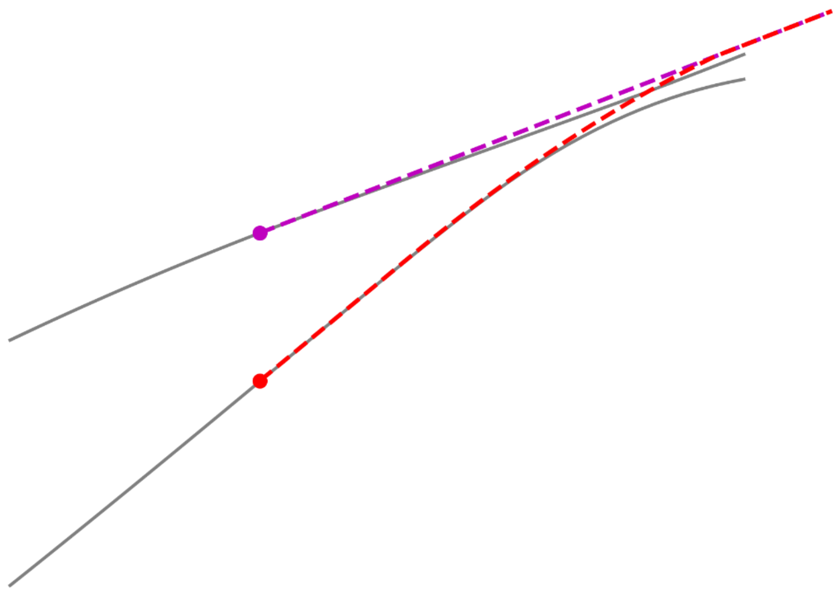
$$d_{safe}(t) = d_{unsafe}(t) = \frac{\left(u_2(t) - u_1(t)\right)^2}{2a'_2(t)}$$

Else if $u_2(t+\tau) > u_1(t)$:

$$d_{new} = \left(\frac{(u_2(t)+u_2(t+\tau))}{2} - u_1(t)\right)\tau$$

$$d_{safe}(t) = d_{new} + \frac{\left(u_2(t)+a'_2(t)\tau-u_1(t)\right)^2}{2b_{2comf}}$$

$$d_{unsafe}(t) = d_{new} + \frac{\left(u_2(t)+a'_2(t)\tau-u_1(t)\right)^2}{2b_{2max}}$$



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Capacity for calm proactive reaction

The deceleration is relative to the values of PFS and CFS

PFS value of 1 induces full comfortable deceleration (e.g. 3 m/s^2)

CFS value of 1 induces full deceleration (e.g. 6 m/s^2)

PFS value of 0.2 induces 20% of comfortable deceleration (e.g. 0.6 m/s^2)

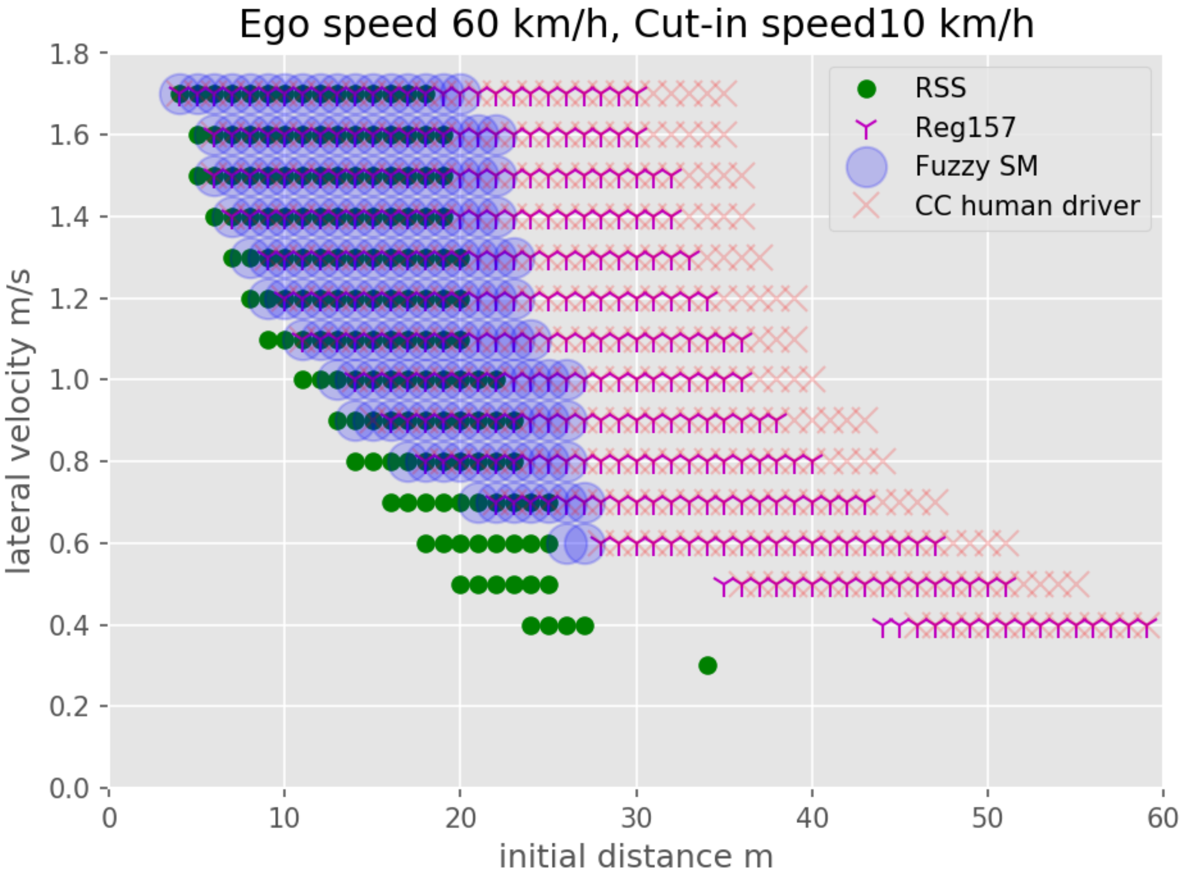
- The suggested model has the ability to apply a calm deceleration proactively, to avoid getting into a more serious (and possibly unavoidable) conflict

Preventable cut-in scenarios

Results

Results low speed (ego speed $\leq 60\ \mathrm{km/h}$)

	CASES SIMULATED	UNPREVENTABLE CASES	PERCENTAGE
Reg157	15930	2417	15.17%
CC human driver	15930	2956	18.56%
RSS	15930	944	5.93%
FSM	15930	974	6.11%



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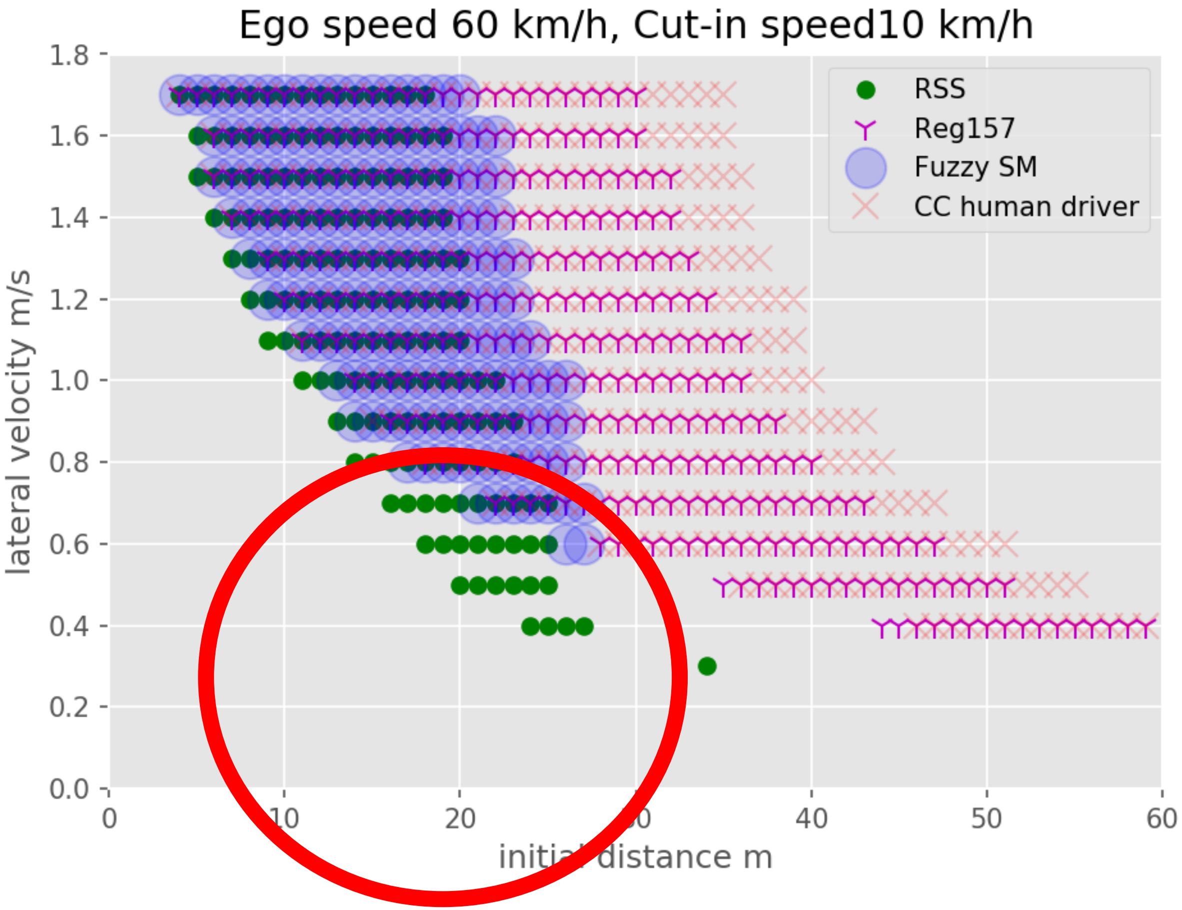
Results

Two areas of interest

The first is about cases when the deceleration of RSS vehicles causes an accident

Other models do not decelerate and avoid the accident



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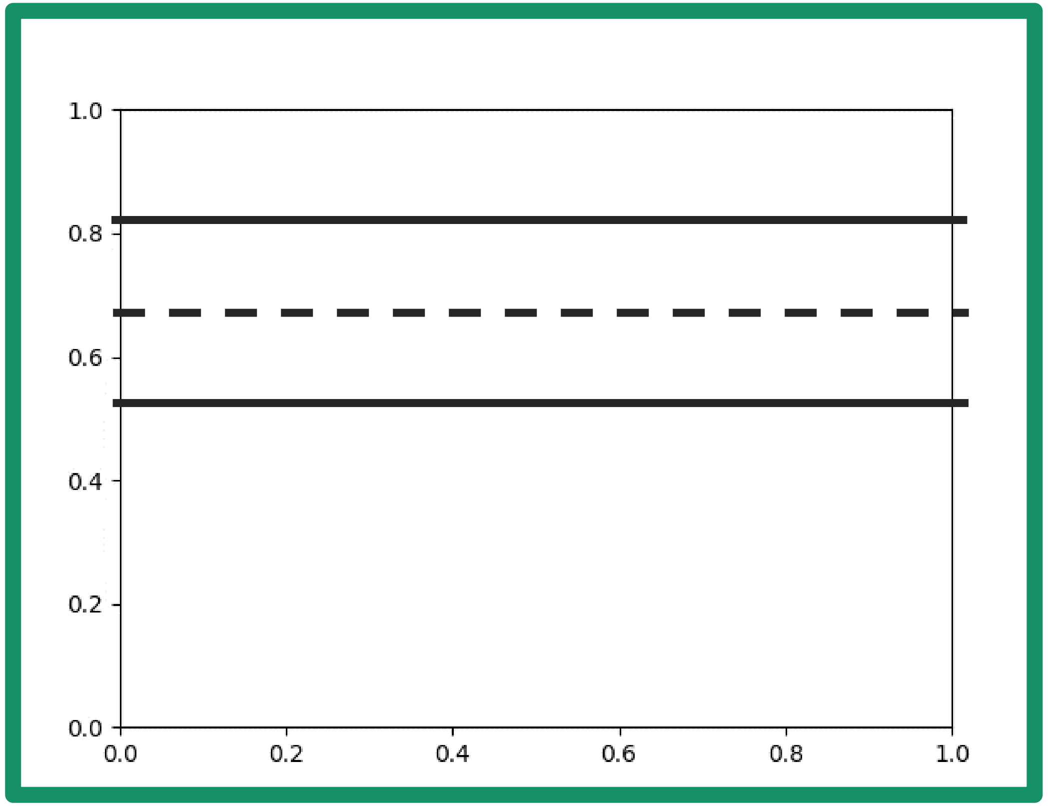
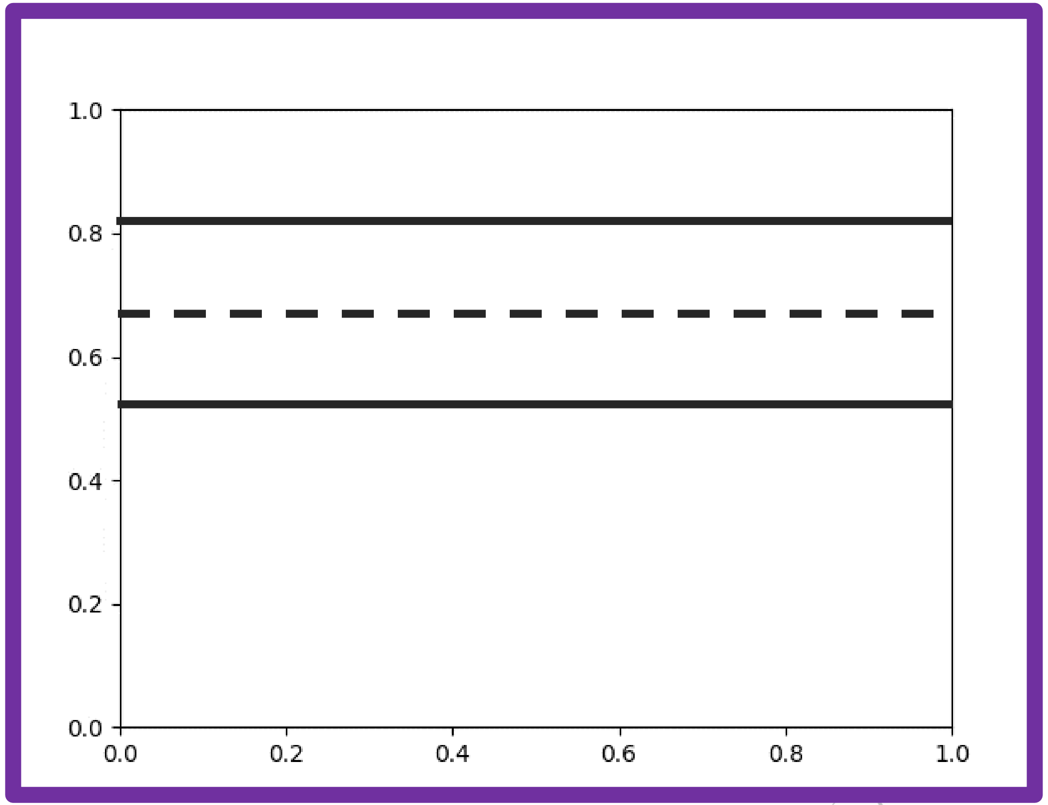
Results

RSS



Reg157

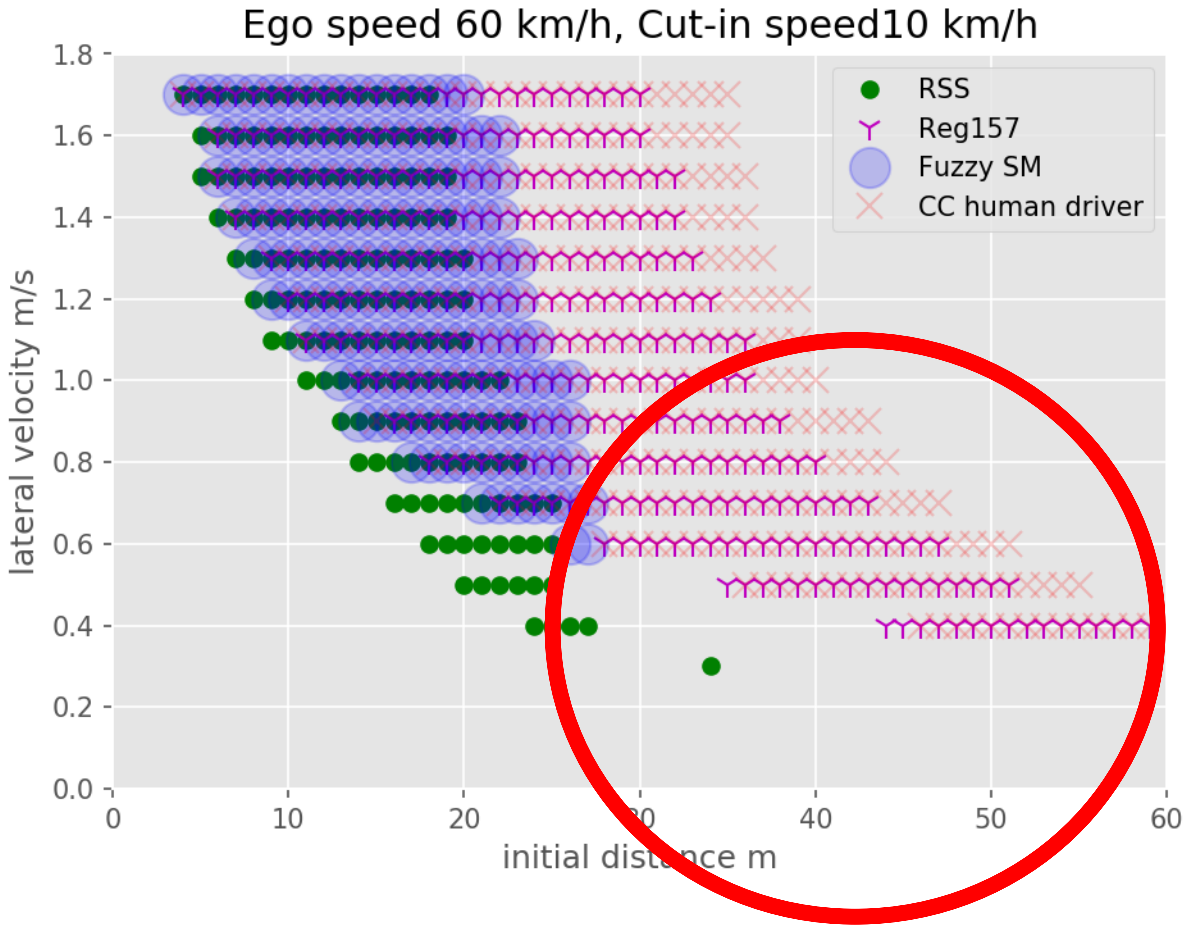


Results

Two areas of interest

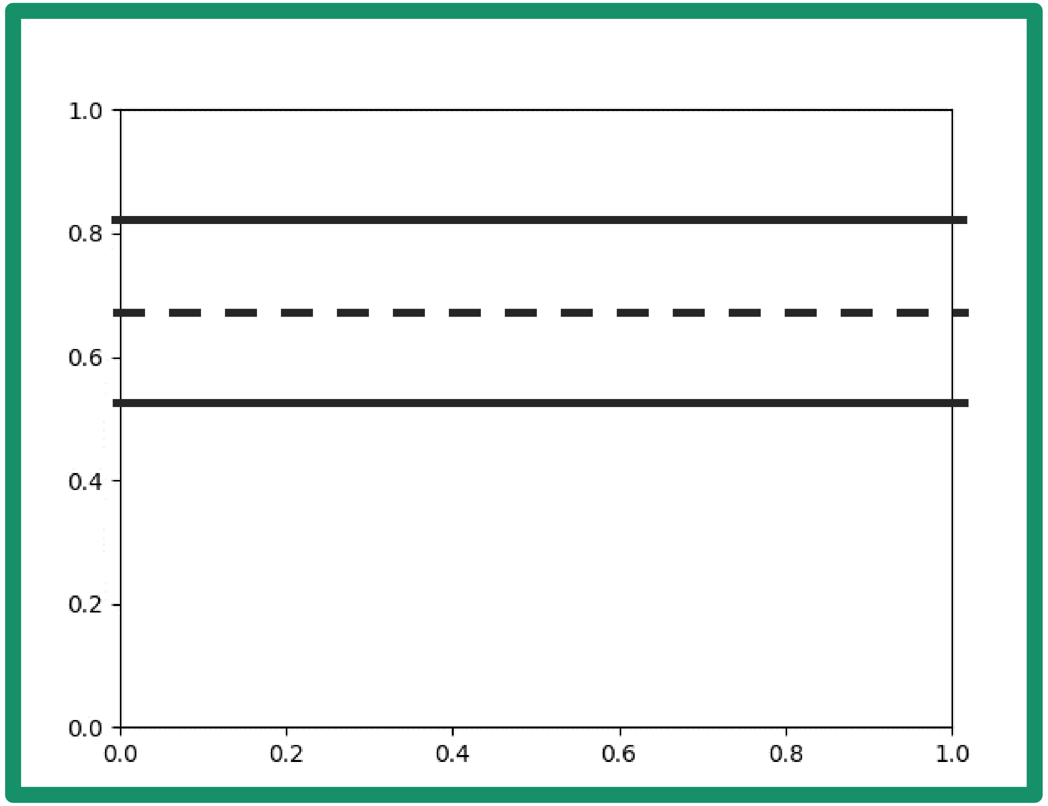
The second is for vehicles in large distance and small lateral speed

Those cases are avoidable by decelerating in a proactive manner

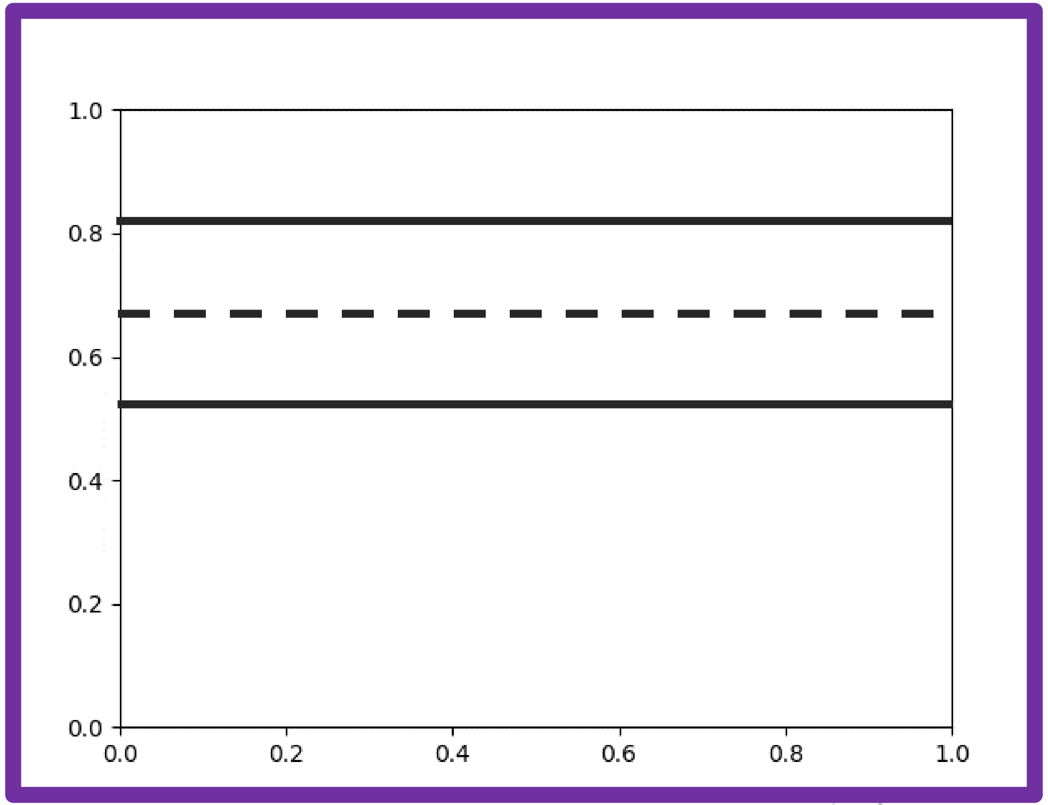


Results

RSS



Reg157

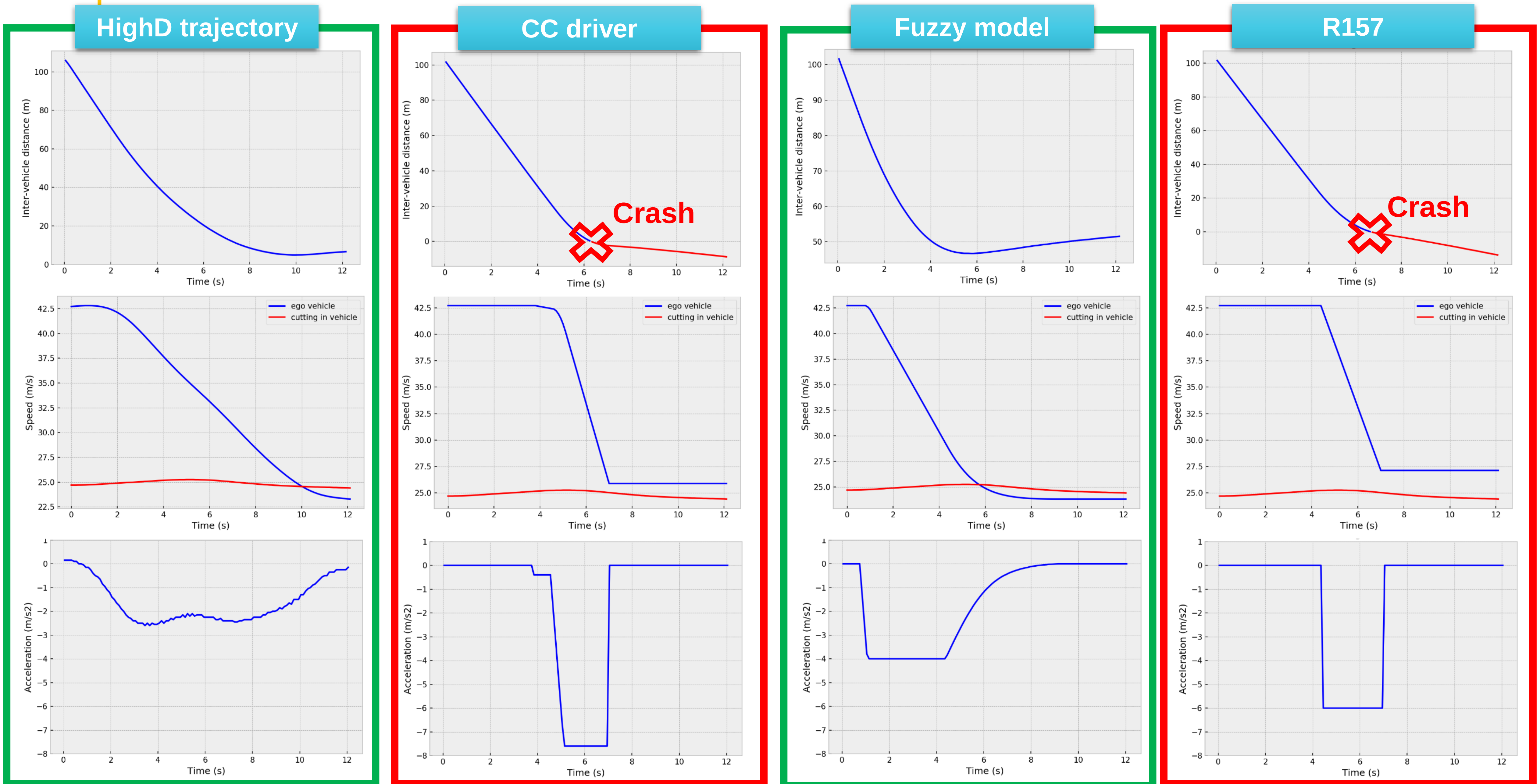


Initial validation activities

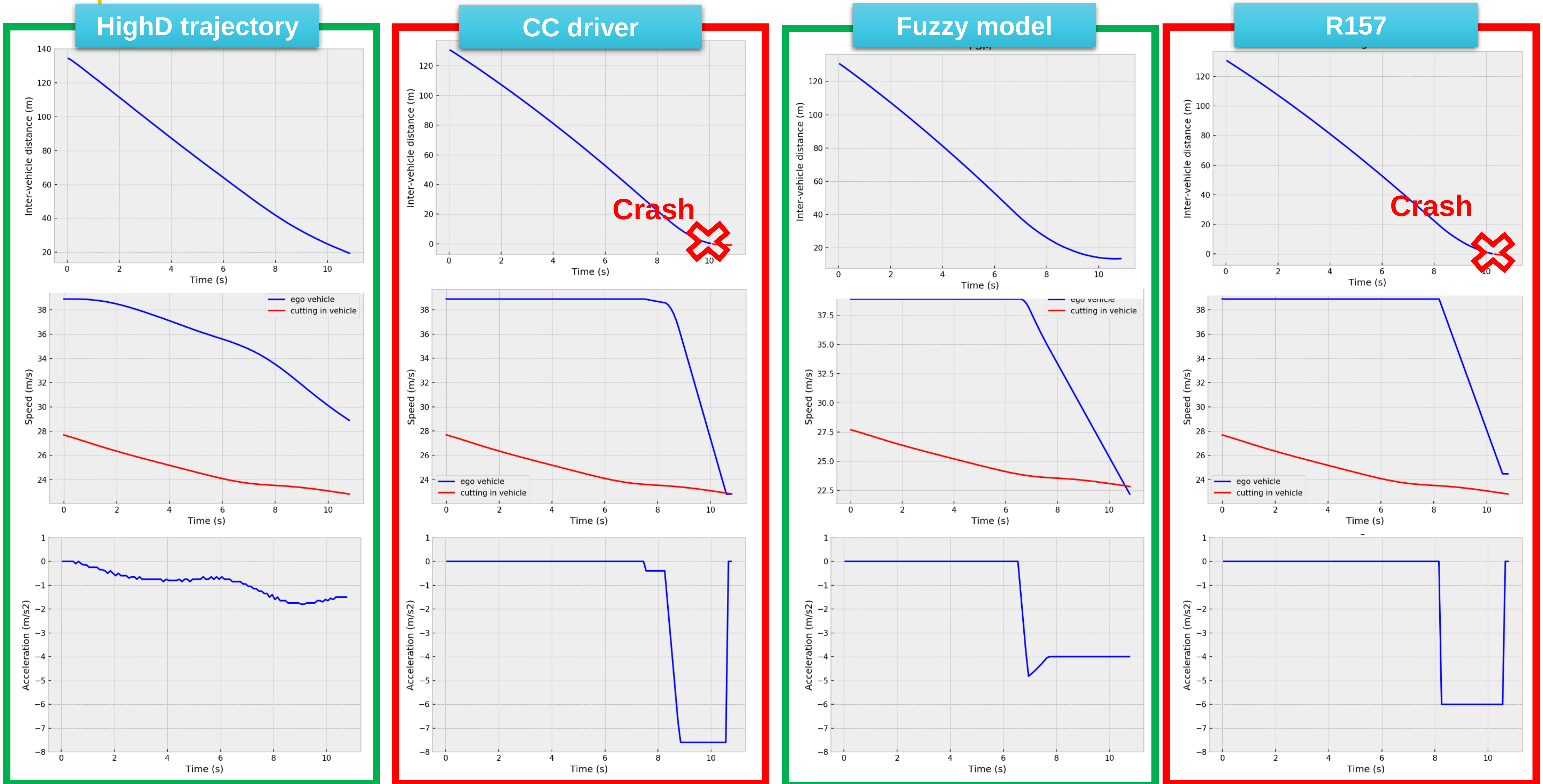
- In the spirit of the proposal, the first validation activity focused on the capability of the model to **correctly classify preventable scenarios**

- 110,500 vehicle trajectories
- 3,000 cut-in scenarios
- 99 cut-ins with minimum TTC < 5”
- No accidents (all preventable scenarios)
- In all cases the Fuzzy Safety Model was able to classify the cut-in as preventable

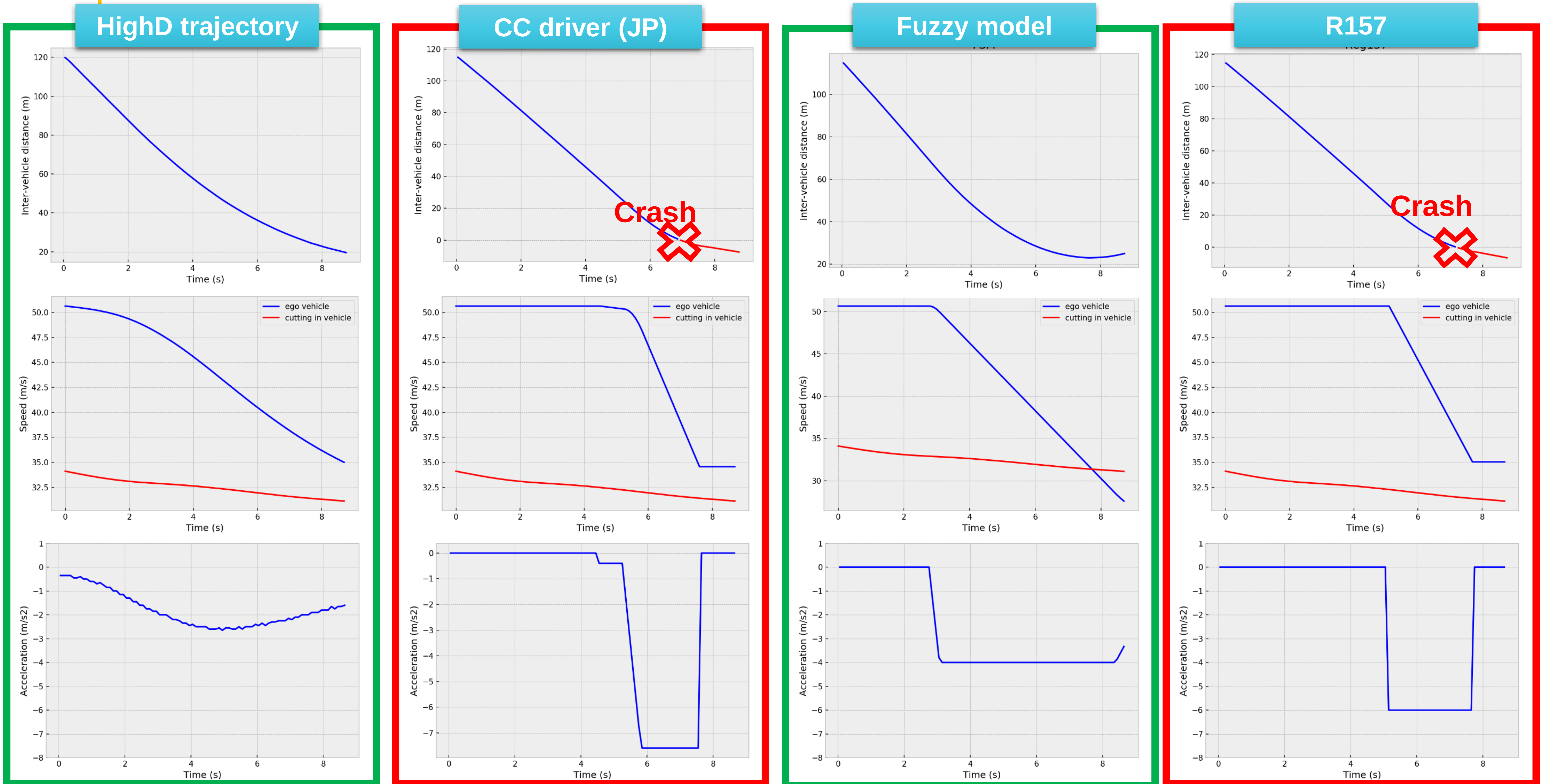
Results of cut-in scenarios: Case A



Results of cut-in scenarios: Case B



Results of cut-in scenarios: Case C

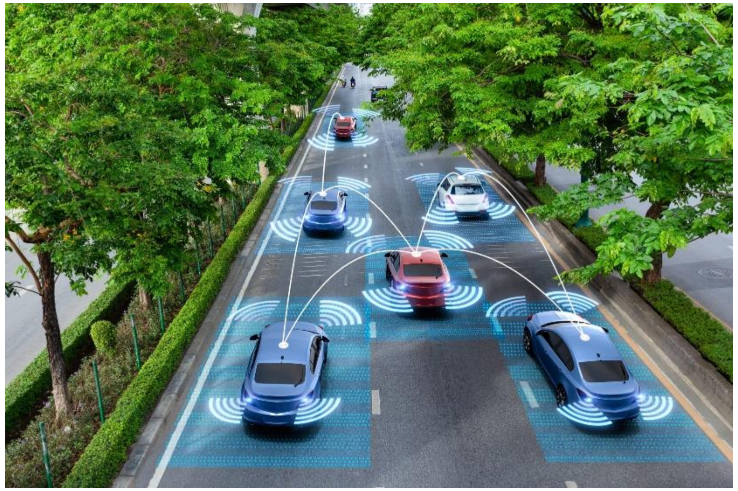


Main remarks and material

- Performance and operational requirements
- Further research is required to establish relevant requirements and implementation for different scenarios
- *Mattas et al. 2022. Driver models for the definition of safety requirements of automated vehicles in international regulations. Application to motorway driving conditions. Accident Analysis & Prevention Volume 174, September 2022, 106743. https://doi.org/10.1016/j.aap.2022.106743*
- *github.com/ec-jrc/JRC-FSM*
- *https://www.highd-dataset.com/*

ADS and traffic

Automated vehicles and traffic efficiency



- A general narrative exists about the positive impact of automated vehicles on traffic efficiency and congestion as if they were designed to this goal
- In reality international discussions about regulations setting requirements for automated vehicles focus at most on the need “to ***not unnecessarily disrupt the normal flow of traffic***” without any reference to any ambition to reduce congestion or improve efficiency
- The dichotomy originates from the ***societal emphasis on technofix***, where technologies are asked to address the challenges that we as society are unable to fix ourselves

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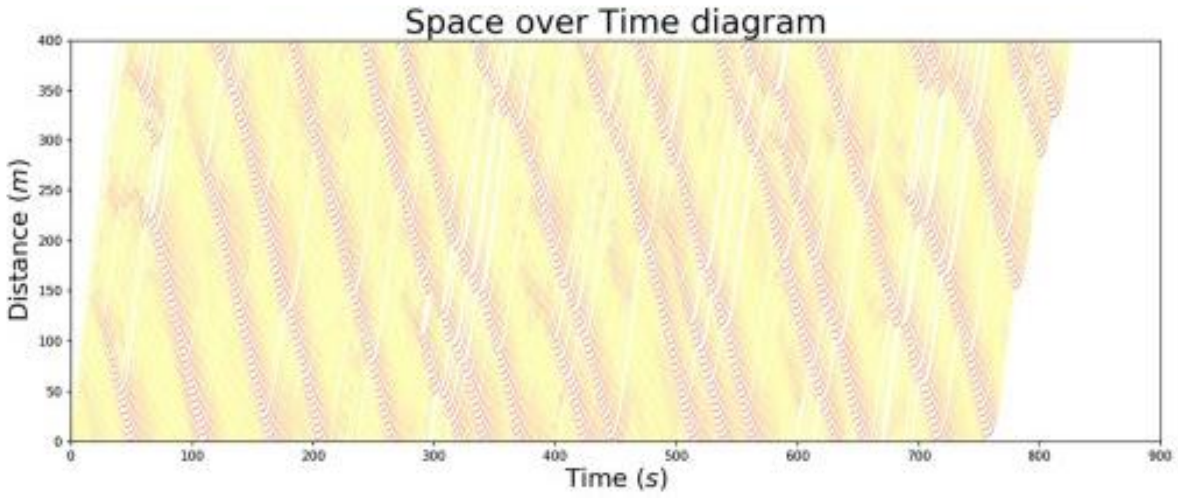
Automated vehicles and traffic efficiency

- As any other technology, AVs will operate as they are designed to operate and there is no reason to believe that they will inevitably make traffic more efficient

- Vehicles are developed by their manufacturers. Are vehicle manufacturers going to design their vehicle so that they generate an efficient traffic?
- How to encourage manufacturers to design system that in addition to safety and comfort will also make traffic flow more efficient

Traffic oscillations

- Traffic oscillations arise when in an unsteady flow **vehicles fluctuate between slow- and fast-moving status**.
- Negatively impact travel time and fuel/energy consumption as well as increase the frequency of safety critical situations



- The formation can be triggered by a sudden reduction of road capacity downstream but can also appear spontaneously (phantom traffic jams).
- *Can AV requirements be set to prevent the formation of oscillations or at least reduce their impacts?*

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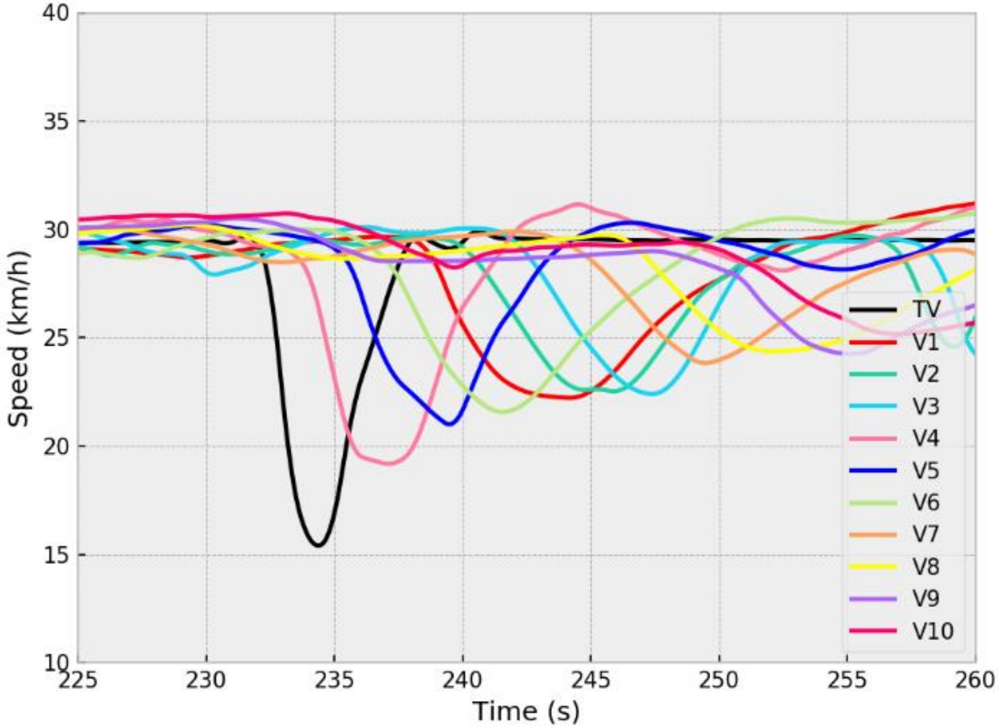
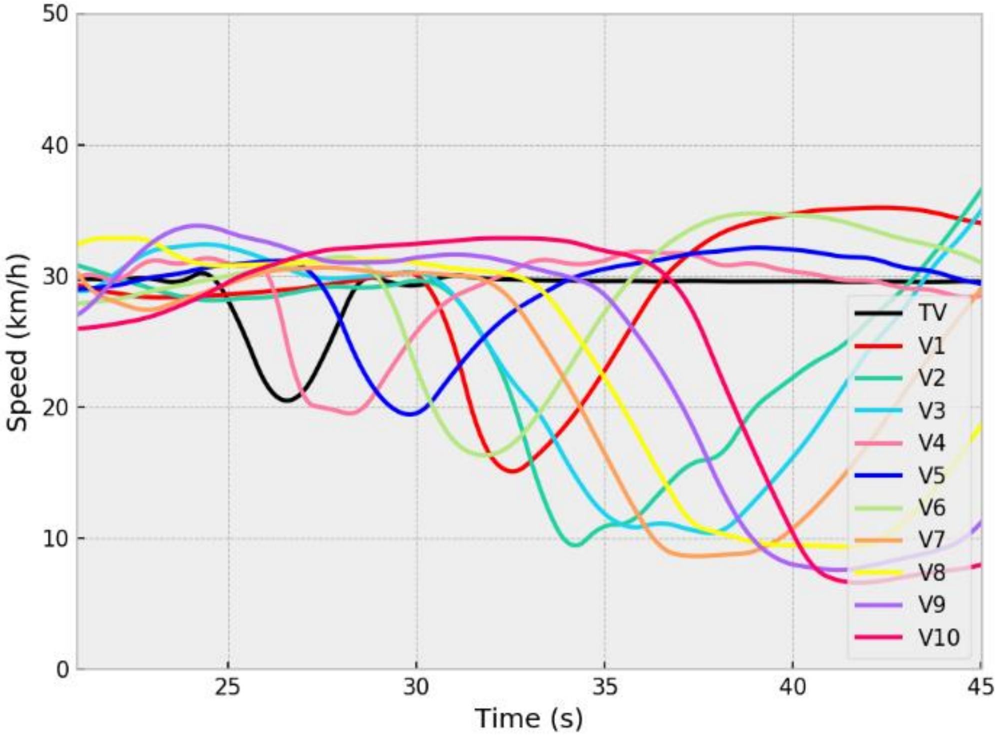
String Stability

- The **String Stability** is the property of a platoon of vehicles to dampen the amplitude of a perturbation as it travels upstream.

String Stable Platoon



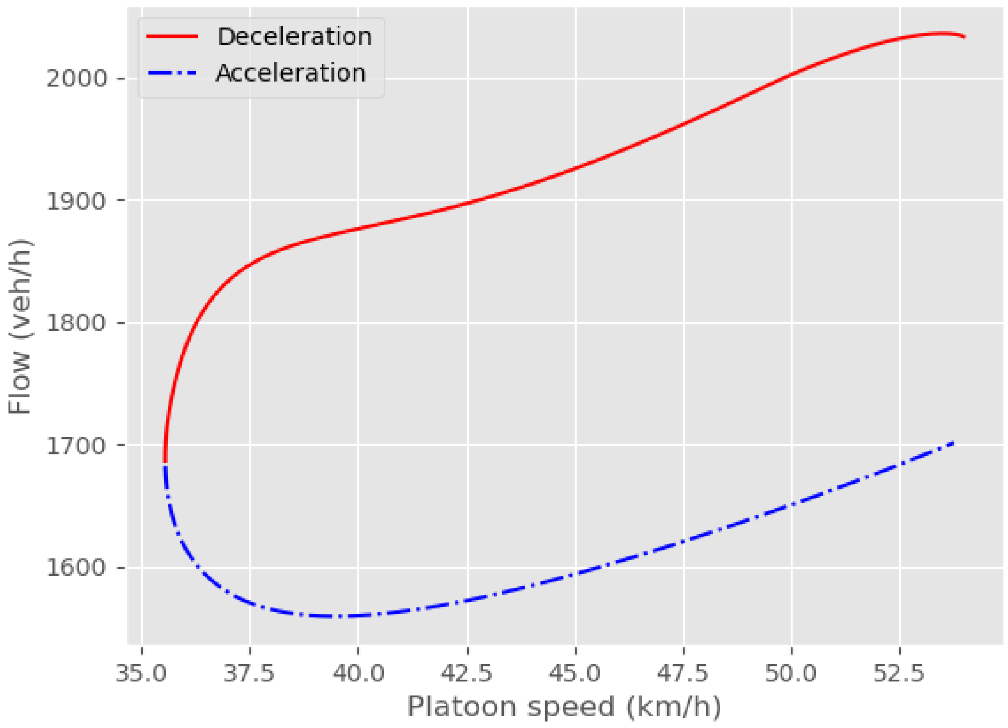
String Unstable Platoon



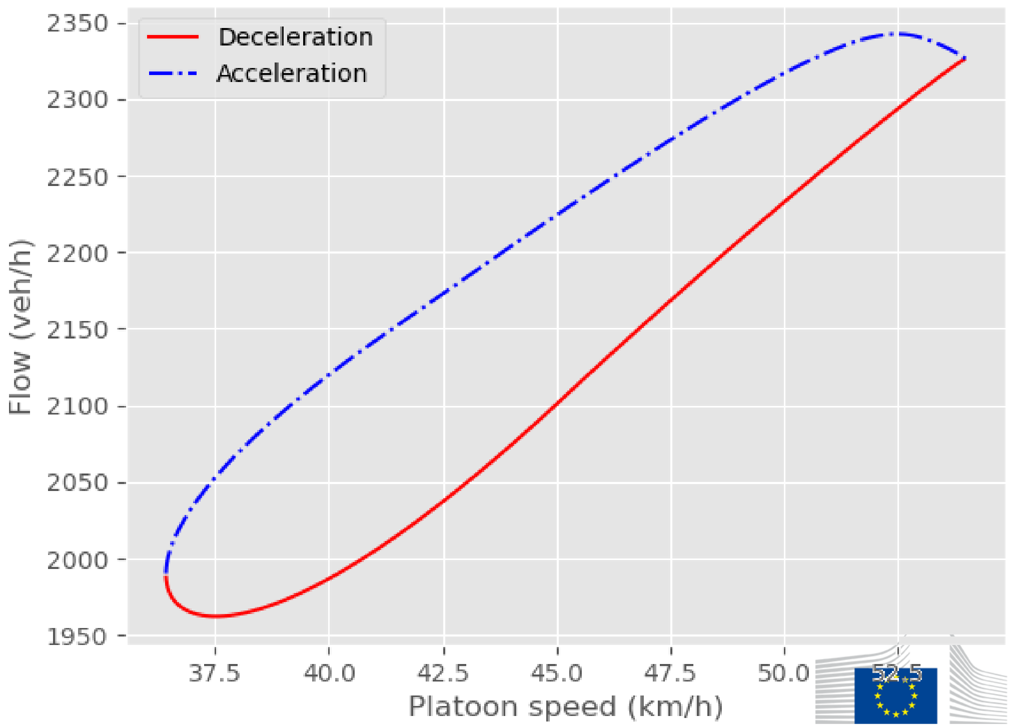
Traffic Hysteresis

- The **Traffic Hysteresis** is a loss in flow of a platoon emerging from a perturbation. The acceleration flow is lower than the deceleration one.

Hysteresis



Negative Hysteresis



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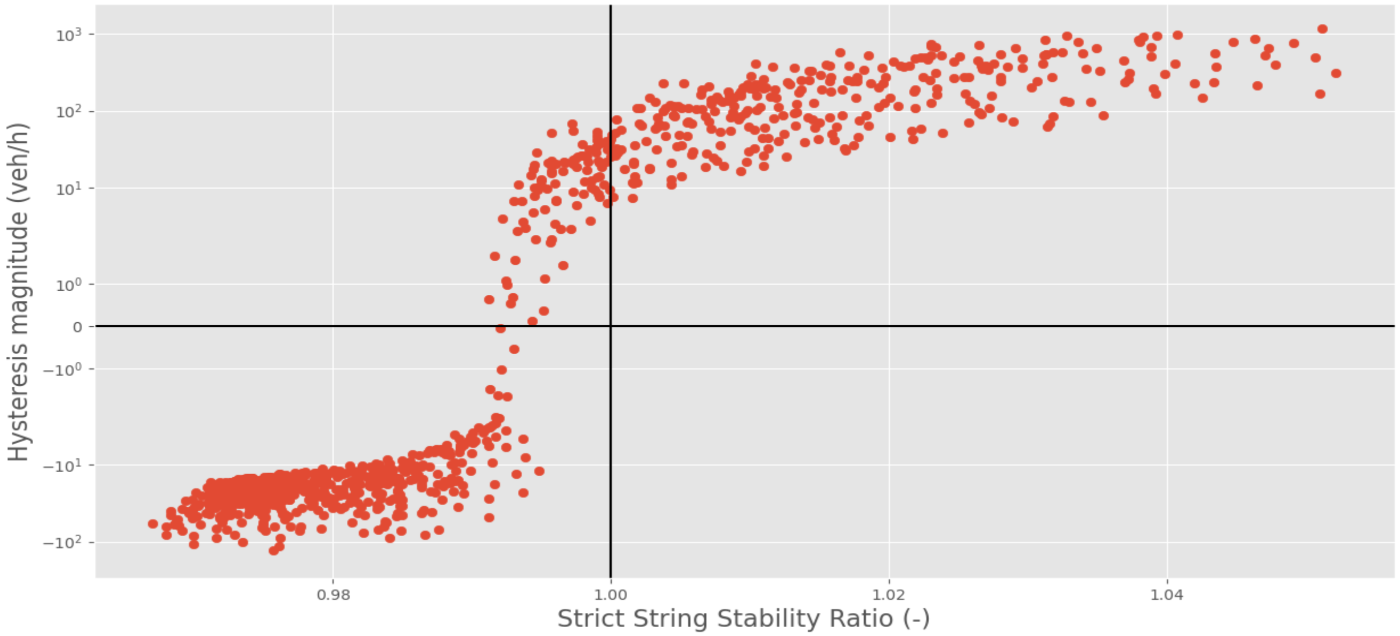
Hysteresis – Stability IDM simulations

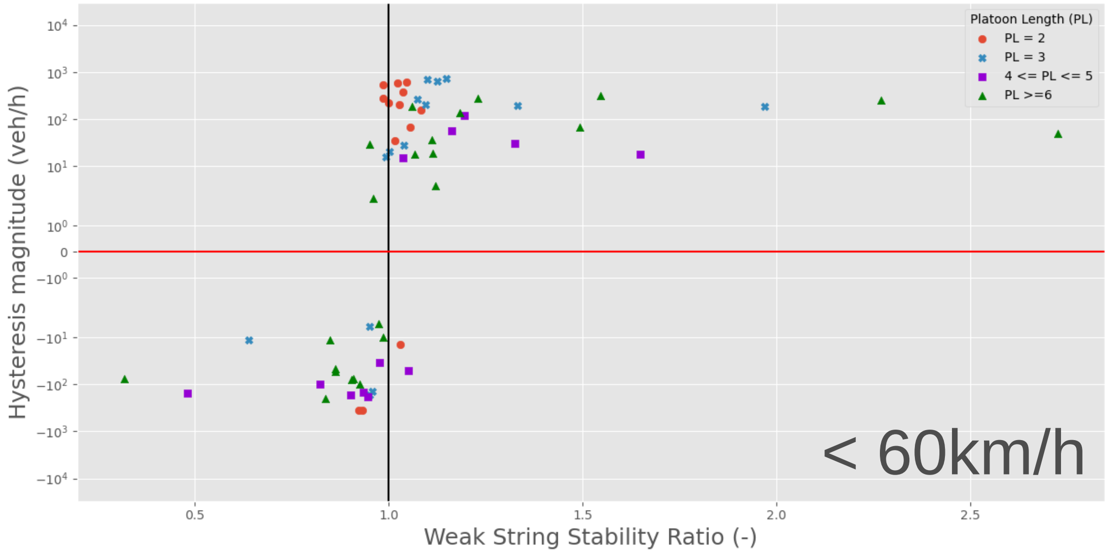


1) The most stable platoons produced small negative hysteresis.
2) There have been string stable hysteretic platoons.
3) **All string unstable platoons resulted to high values of hysteresis.**

Hysteresis – Stability HighD

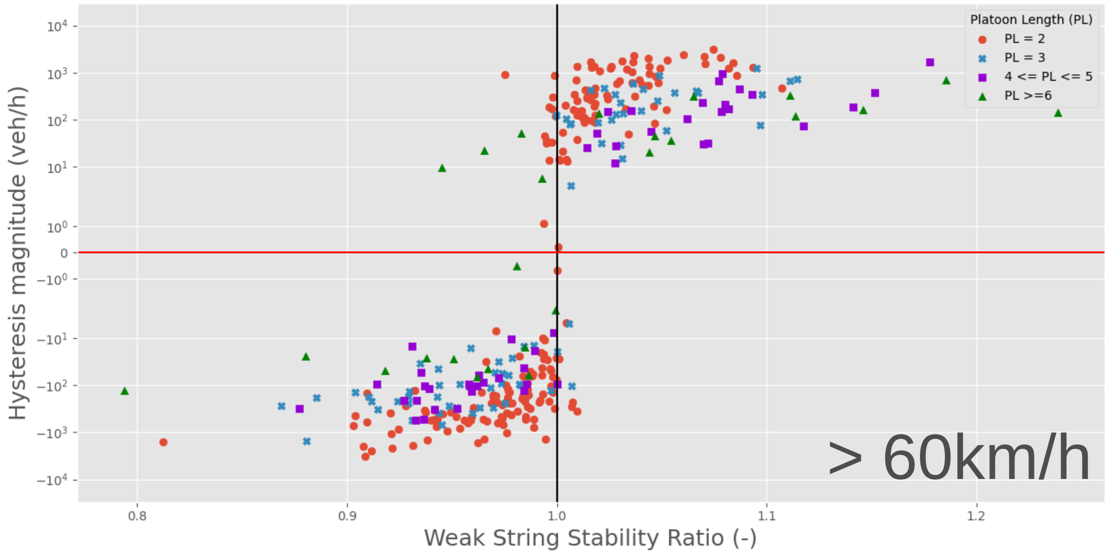
406 human driven platoons with deceleration/acceleration occurrences

Weak string stability ratio and hysteresis calculate per each one



1) **All string unstable platoons resulted in high values of hysteresis.**

2) **Most string stable platoons resulted in negative hysteresis values**.

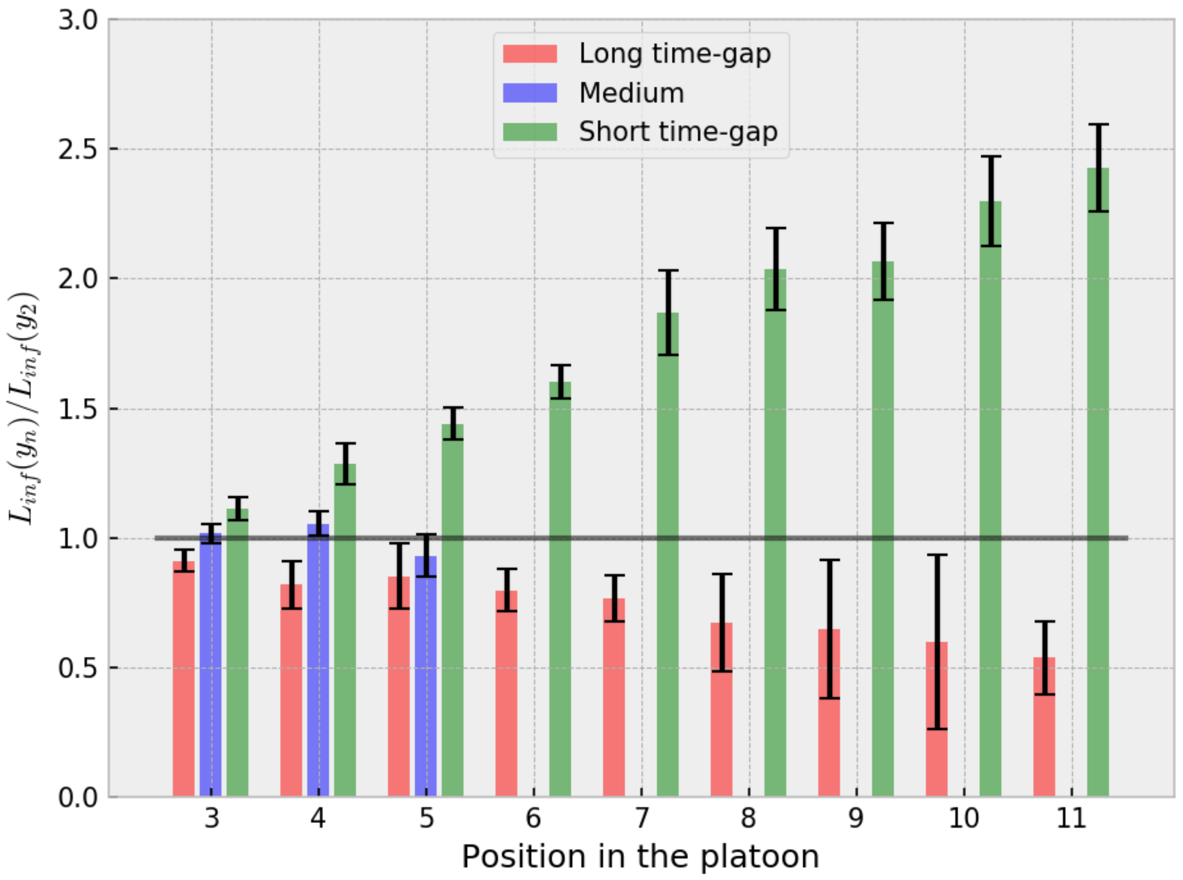


ACC string stability OpenACC

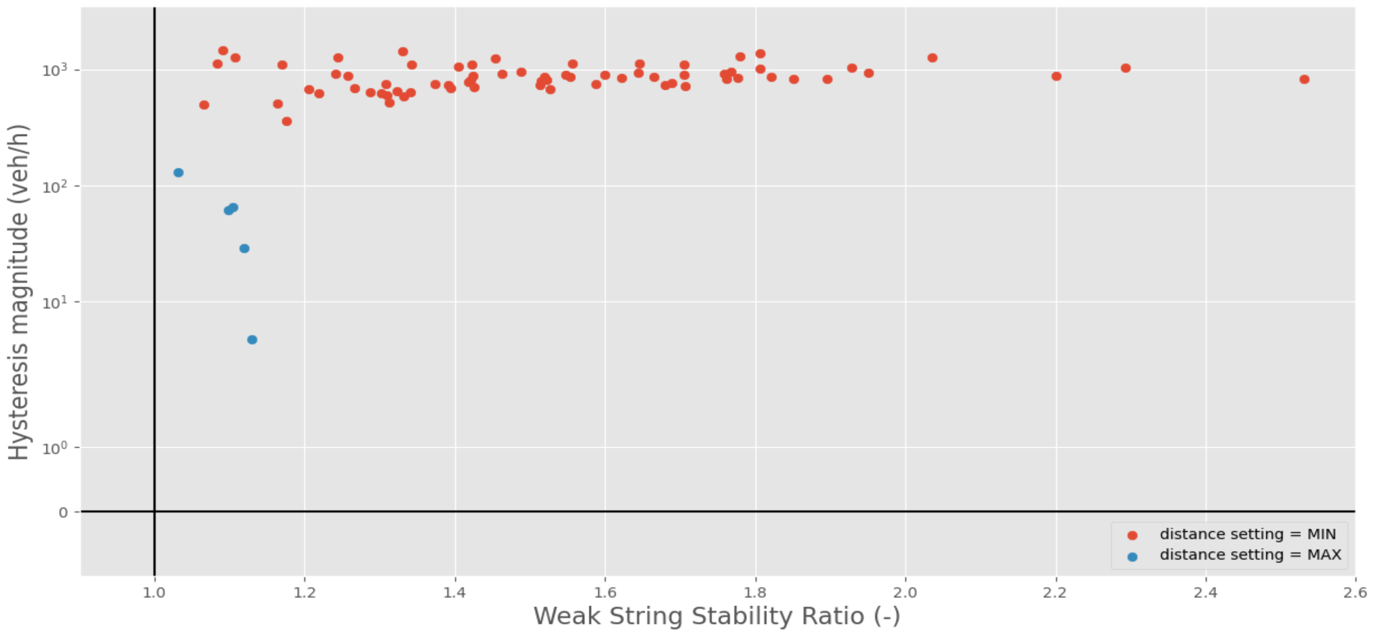
OpenACC dataset, with real data from on road and test-track experiments

Commercial ACC controllers tend to be string unstable

For the shortest time-gap, instability becomes more substantial



Hysteresis – Stability AstaZero



1) **All string unstable platoons resulted to high values of hysteresis.**
2) Short desired distance implies more string instability and hysteresis at the same time.

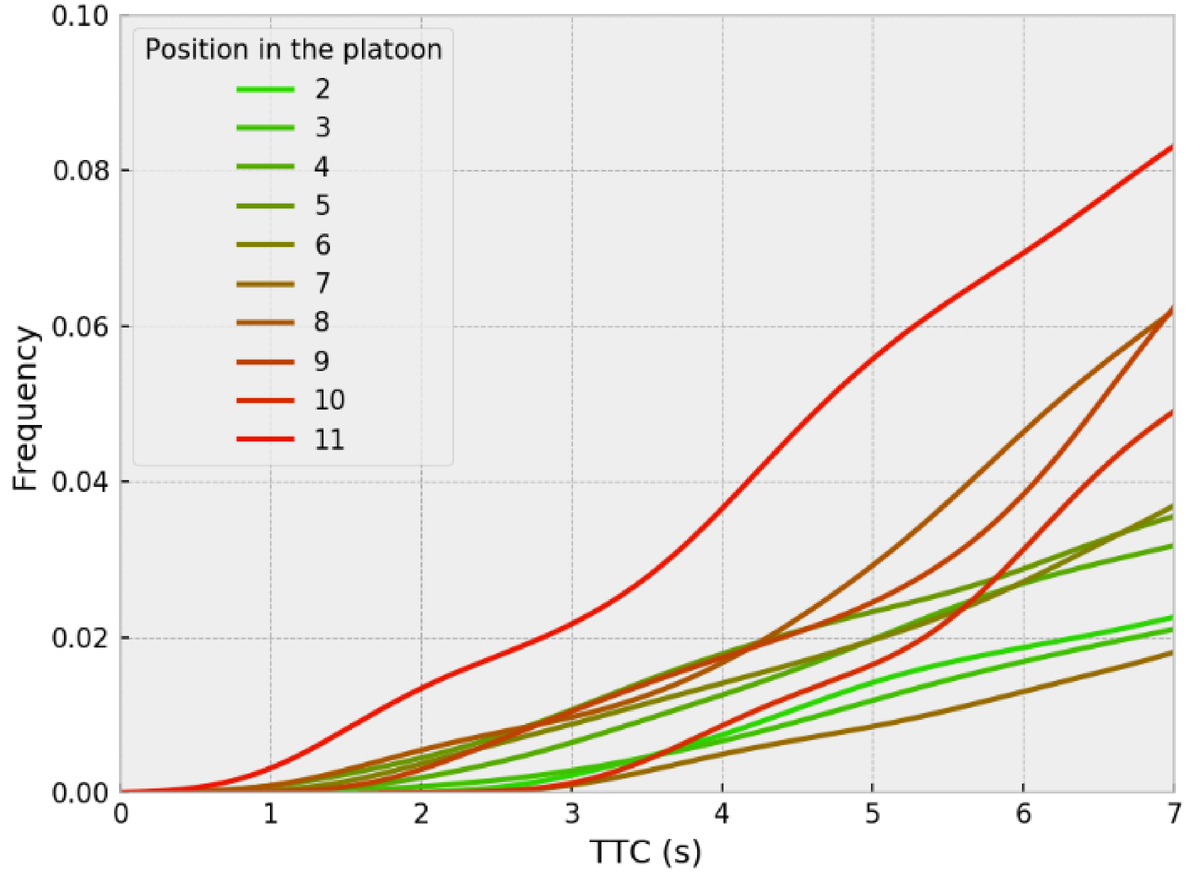
Instability impact on safety

The ACC platoons tested are found to be hysteretic

Moreover, the instability and hysteresis shows to have direct impact on the energy consumption and on safety

What is the market advantage for developing string stable controllers?

What is the role of regulation?



UN R157 revision and string stability

- On the basis of the scientific evidence collected about the performance of ACC systems* it was possible to introduce in the legislation the following:
  - 2.21. *"String instability"* is when a disturbance in the speed profile of the vehicle in front is amplified by the following vehicle.
  - 5.1.1.2. The system shall **demonstrate anticipatory behaviour** in interaction with other road user(s), in order **to ensure stable, low-dynamic, longitudinal behaviour** and risk minimising behaviour when critical situations could become imminent, e.g. with pedestrians or cutting-in vehicles.
  - 5.2.3.3. […] the vehicle shall readjust the following distance at the next available opportunity without any harsh braking **implementing strategies aiming to address significant *string instability*** in order to not disrupt traffic flow, unless an emergency manoeuvre would become necessary. […]

Main remarks and material

- Efforts needed to use ADS to improve traffic efficiency
- Research on traffic flow relevant requirements
- Further research is required on validating string stability

- *Ciuffo et al 2021. "Requiem on the positive effects of commercial adaptive cruise control on motorway traffic and recommendations for future automated driving systems" Transportation Research Part C: Emerging Technologies Volume 130, September 2021, 103305.* https://doi.org/10.1016/j.trc.2021.103305
- *Makridis et al. 2020. "Empirical Study on the Properties of Adaptive Cruise Control Systems and Their Impact on Traffic Flow and String Stability". Transportation Research Record: Journal of the Transportation Research Board. Volume 2674, Issue 4.* https://doi.org/10.1177/0361198120911047
- *Mattas et al. 2023. "On the Relationship between Traffic Hysteresis and String Stability of Vehicle Platoons" Transportation Research Part B: Methodological Volume 174, August 2023, 102785.* https://doi.org/10.1016/j.trb.2023.102785

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Thank you!

European Commission