Document FRAV-06-13
6th FRAV session
29 October 2020
Transmitted by the experts from the EC Joint Research Centre

European Commission

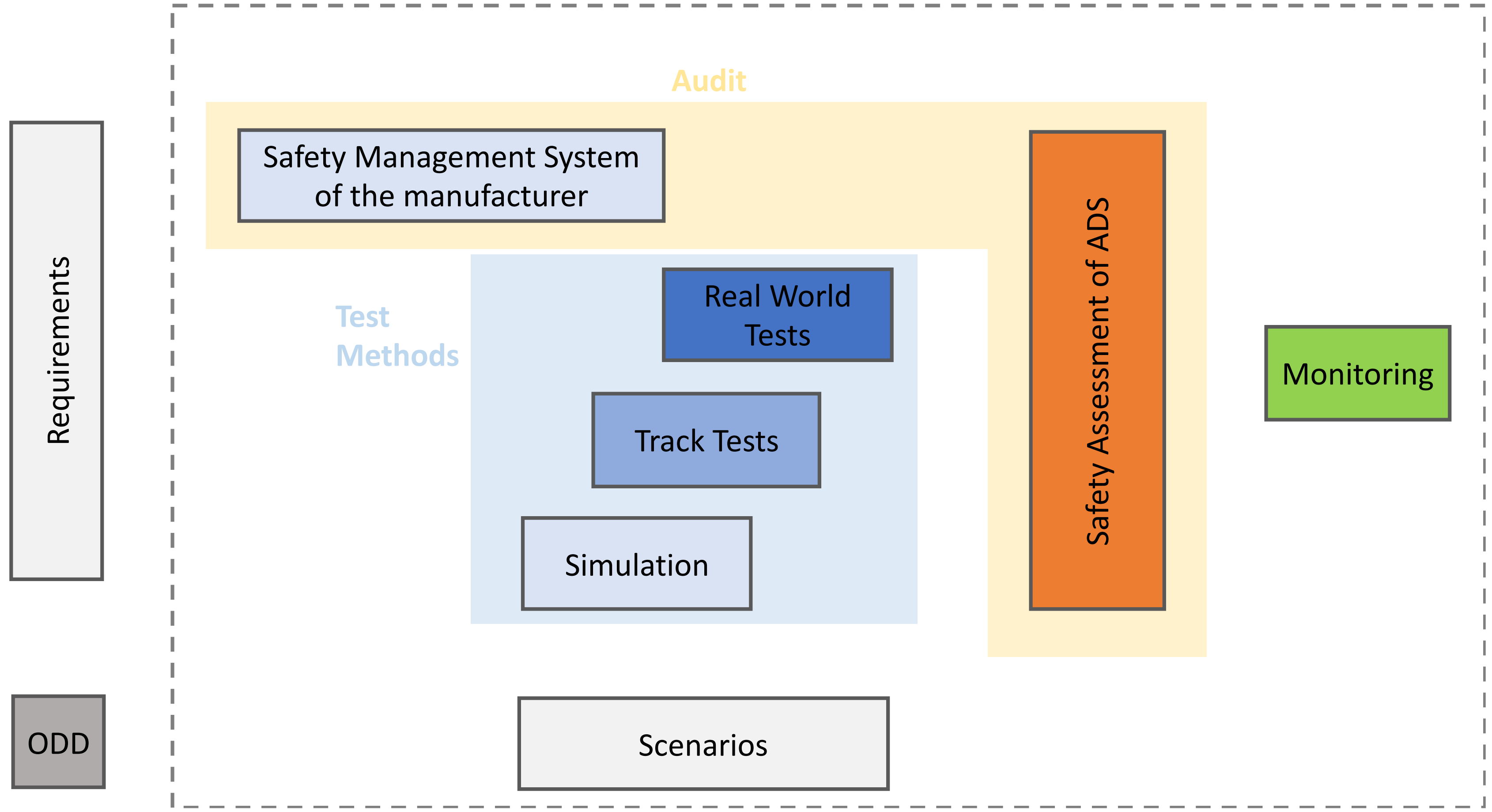
Possible additional requirements for Automated Driving Systems String Stability

29 October 2020

*K. Mattas, **B. Ciuffo***

Joint Research Centre

Assessment of ADS safety in GRVA/VMAD*



* *VMAD-13-03 NATM MASTER DOCUMENT*

Requirements on traffic

- The assessment of requirements in VMAD has mainly focused on safety and on the high-level concept that "*an automated/autonomous vehicle* ***shall not cause any non-tolerable risk****', meaning that automated/autonomous vehicle systems, under their automated mode ([ODD/OD]), shall* ***not cause any traffic accidents*** *resulting in injury or death that are* ***reasonably foreseeable and preventable***"
- FRAV discussions have repeatedly noted that vehicles operating in automated mode should not **unnecessarily disrupt the normal flow of traffic**, relating to the notion that vehicles in automated mode should behave in ways that other road users can anticipate

String stability

- String stability can be described as the *capability of the ADS to react to a perturbation in the speed profile of the leading vehicle with a perturbation in its speed profile of lower or equal absolute magnitude independently from the driving conditions*

- String stability is relevant to the introduction and amplification of stop-and-go waves in congested traffic

- String stability would be an important requirement in terms of

  - **Traffic efficiency**
  - **Safety**
  - **Energy consumption**

String stability for ACC vehicles

- More than 20 years ago Adaptive Cruise Control has promised to solve traffic instability and increase safety
- Early studies have showed the risk that ACC could have been string unstable
- A full research stream has started to (theoretically) investigate how to address string stability mainly with V2V communication in place
- But how do commercial ACC systems operate?
- Driven by user's comfort and without requirements, commercial ACCs make traffic unstable with strong traffic and safety implications

Studying ACC performance

- To support the definition of requirements for ADSs, in 2018 the JRC has started to study ACC performances

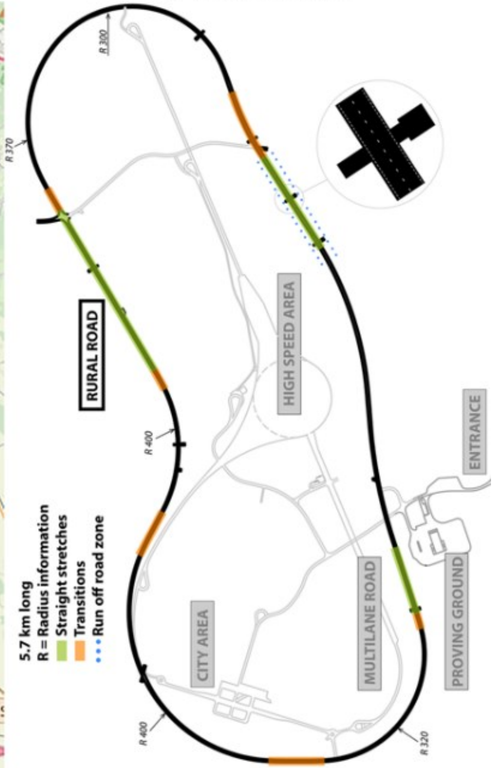
Campaign	Ispra-Cherasco (N.1)	Ispra-Vicolungo (N.2)	AstaZero (N.3)	ZalaZone (N.4)
Leading vehicles	Fiat 500X, Volvo XC40, VW Polo	Mitsubishi SpaceStar	Audi A8	Smart BME ADdv, Octavia RS
Driving modes of leading vehicles	Human	Human	CC/ACC	CC/ACC
Vehicles involved in car-following	Hyundai Ioniq hybrid, Volvo XC40	KIA Niro, Mitsubishi Outlander PHEV, Ford S-Max, Peugeot 3008 GT Line, VW Golf E, Mini Cooper	Tesla Model 3, BMW X5, Mercedes A Class, Audi A6	Tesla Model X, Tesla Model 3, Tesla Model S, Mercedes-Benz GLE 450 4Matic, Jaguar I-Pace, BMW I3 s, Audi E-tron, Toyota Rav 4, Mazda 3, Audi A4 Avant
Driving modes of following vehicles	Human, ACC	Human, ACC	Human, ACC	Human, ACC
Time gap settings	Short	Short	Short and long	Short, long, medium and mixed (Short and long)

Studying ACC performance (locations)

JRC - Cherasco
~152km Highway

JRC - Vicolungo
~43km Highway

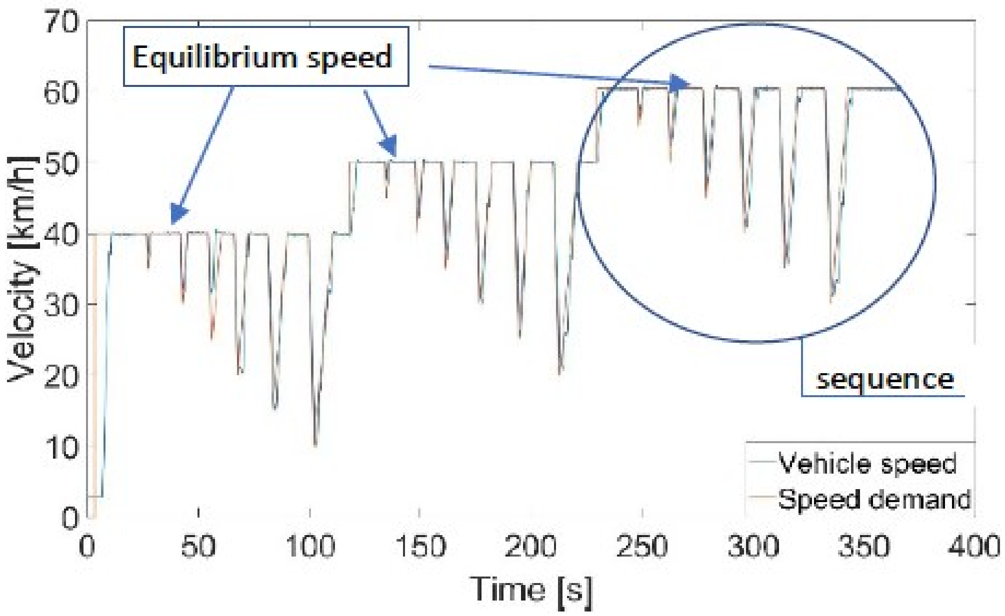
AstaZero
5-7km Rural

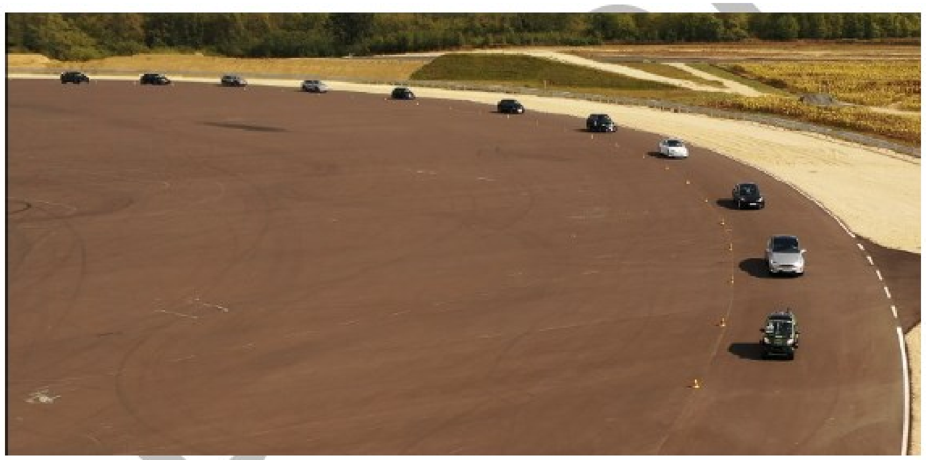


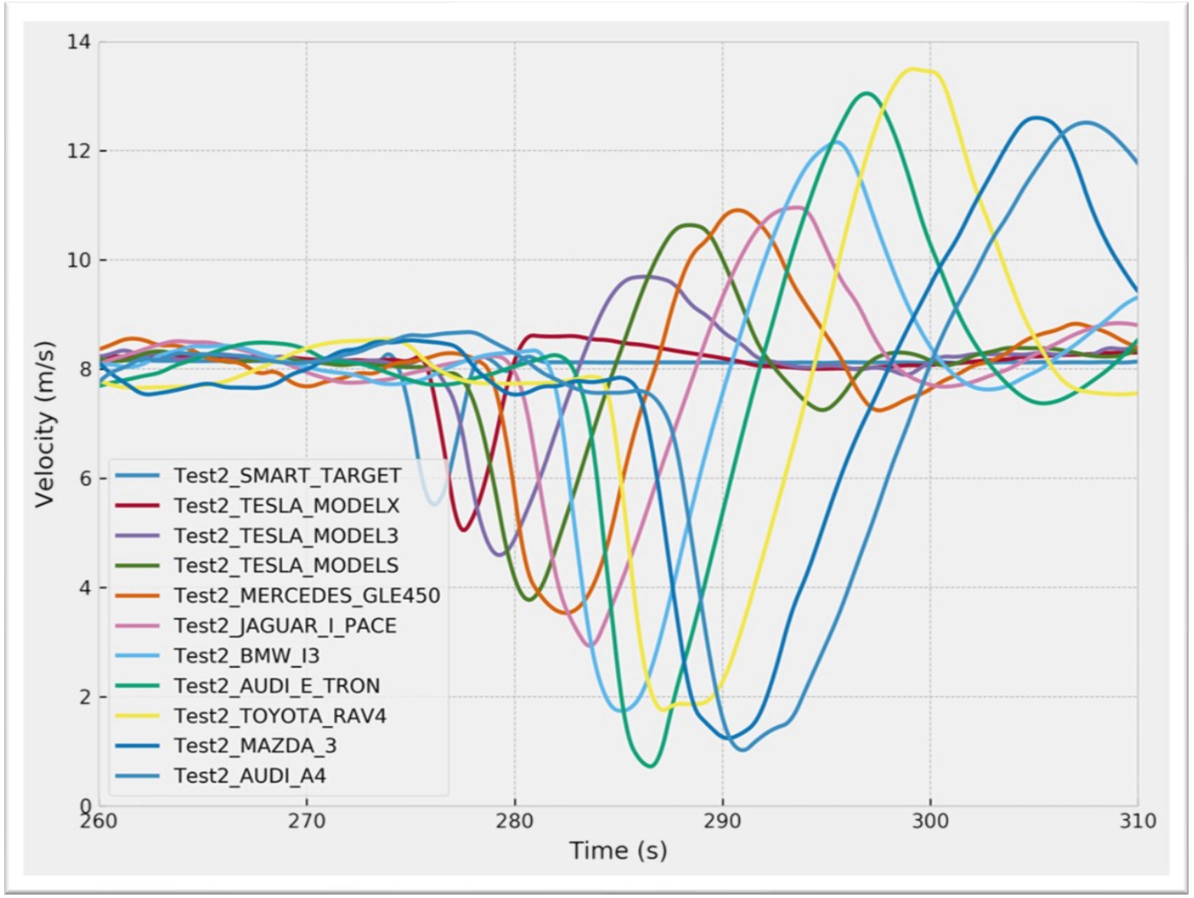
Studying ACC performance (vehicles)

Vehicles	Max power (kW)	Drive-Fuel	Engine displacement (cc)	Battery capacity (kWh)	Propulsion type	Top speed (km/h)	Model year
(L) Fiat (500X)	103	diesel	1956	-	ICE	190	2016
Volvo (XC40)	140	diesel	1969	-	ICE	210	2018
(L) VW (Polo)	63	Gasoline and liquid propane gas	1390	-	ICE	177	2010
Hyundai (Ioniq hybrid)	104	gasoline	1580	1.56	HEV	185	2018
(L) Mitsubishi (SpaceStar)	59	gasoline	1193	-	ICE	173	2018
KIA (Niro)	77.2	gasoline	1580	8.9	PHEV	172	2019
Mitsubishi (Outlander PHEV)	99	gasoline	2360	12	PHEV	170	2018
Peugeot (5008 GT Line)	130	diesel	1997	-	ICE	208	2018
VW (Golf E)	100	electricity	-	35.8	BEV	150	2018
Mini (Cooper)	100	gasoline	1499	-	ICE	210	2018
Ford (S-Max)	110	diesel	1997	-	ICE	196	2018
(L) Audi (A8)	210	diesel	2967	-	ICE	250	2018
Tesla (Model 3)	150	electricity	-	79	BEV	210	2019
BMW (X5)	195	diesel	2993		ICE	230	2018
Mercedes (A Class)	165	gasoline	1991	-	ICE	250	2019
Audi (A6)	150	diesel	1968	-	ICE	246	2018
(L) Smart (BME Addv)	-	-	-	-	-	-	-
(L) Skoda (Octavia RS)	180	gasoline	1984	-	ICE	250	2019
Tesla (model X)	386	electricity	-	90	BEV	250	2016
Tesla (model 3)	250	electricity	-	79	BEV	250	2019
Tesla (model S)	244	electricity	-	75	BEV	225	2018
Mercedes-Benz (GLE 450 4Matic)	270	gasoline	2999	31.2	HEV	250	2019
Jaguar (I-Pace)	294	electricity	-	90	BEV	200	2019
BMW (I3 s)	135	gasoline	647	33.2	HEV	160	2018
Audi (E-tron)	300	electricity	-	83.6	BEV	200	2019
Toyota (Rav 4)	115	gasoline	2487	41.8	HEV	180	2019
Mazda (3)	96	gasoline	1998	-	ICE	197	2019
Audi (A4 Avant)	140	gasoline	1984	0.69	HEV	238	2019

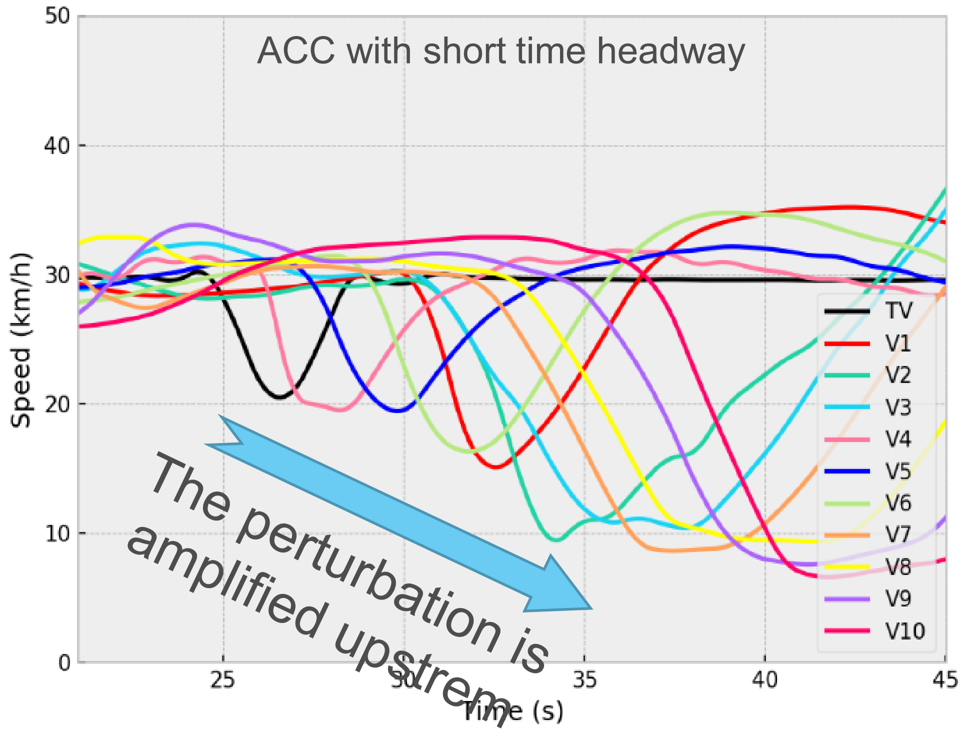
Some results

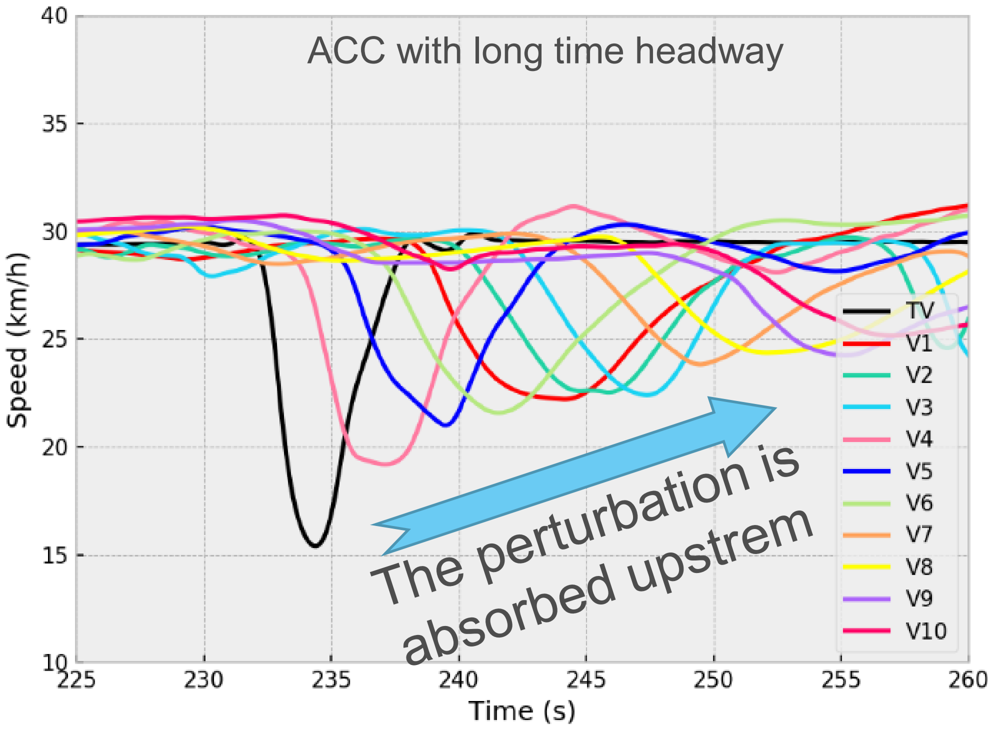






String stability – Results from ACC tests

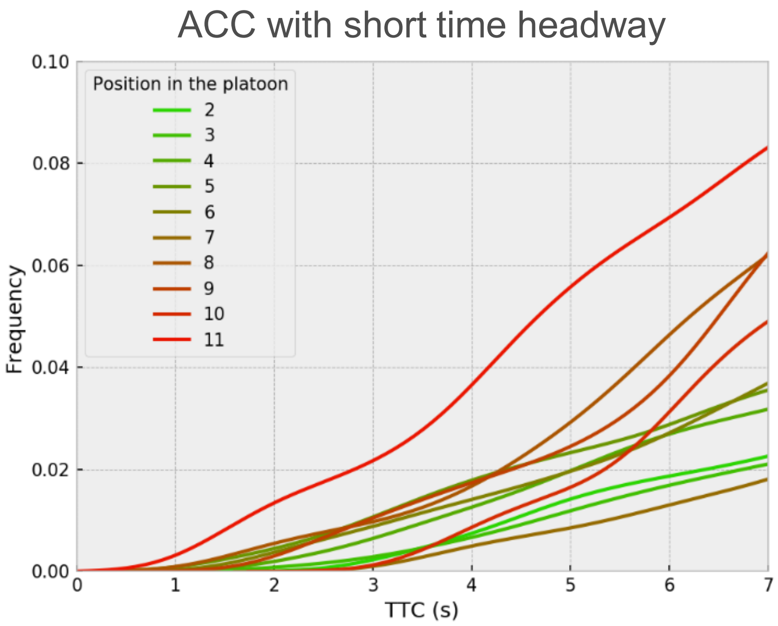


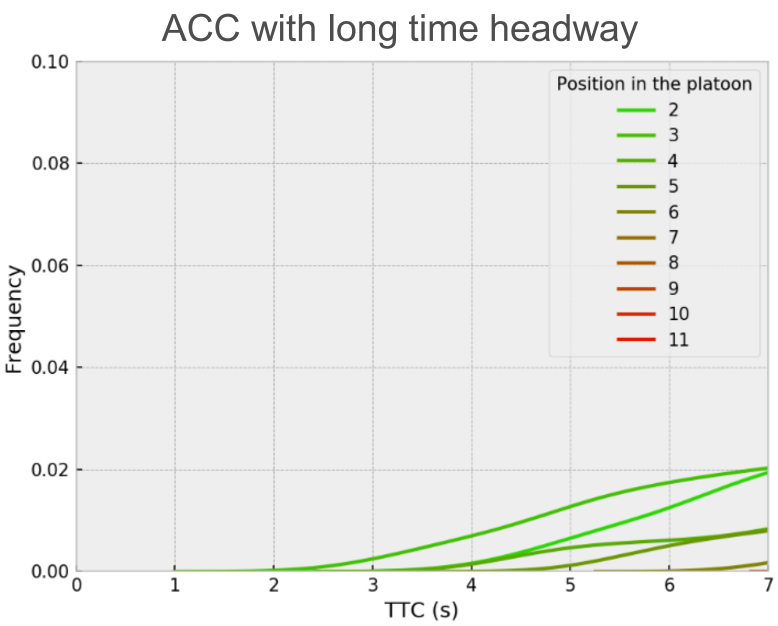


- By amplifying the perturbation upstream string unstable vehicles generate significant traffic disturbances and introduces considerable safety risks as the deceleration magnitude increases along the platoon

European Commission

String stability – Implications for safety





- The probability of TTC<1.5 increases as the vehicle moves backward in the platoon in case of string-unstable vehicles.
- **An AV safely tested alone may turn into an unsafe platoon of vehicles**

European Commission

String stability requirements – Next steps

- Data and analysis are publicly available
  - openACC report: https://arxiv.org/abs/2004.06342
  - https://data.jrc.ec.europa.eu/dataset/9702c950-c80f-4d2f-982f-44d06ea0009f
- After completing the analysis of string stability implications JRC work currently focuses on
  - **Defining a test procedure to verify string stability**
  - **Defining the conditions for which string stability also increase traffic efficiency (also without connectivity)**

Keep in touch

EU Science Hub: ec.europa.eu/jrc

@EU_ScienceHub

EU Science Hub – Joint Research Centre

EU Science, Research and Innovation

Eu Science Hub

Thank you

European Commission