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openACC. An open database of car-following data to study the properties of commercial ACC systems (TRBAM-21-00360)

SCAN ME

Workshop 1015 - From Traffic Flow Modeling of Connected and Automated Vehicles to Transportation Guidelines, Policies and Specifications: Lessons Learned and Opportunities Missed

21 January 2020

*M. Makridis, K. Mattas, **B. Ciuffo***

Joint Research Centre

JRC Mission

As the science and knowledge service of the Commission our mission is to support EU policies with independent evidence throughout the whole policy cycle.

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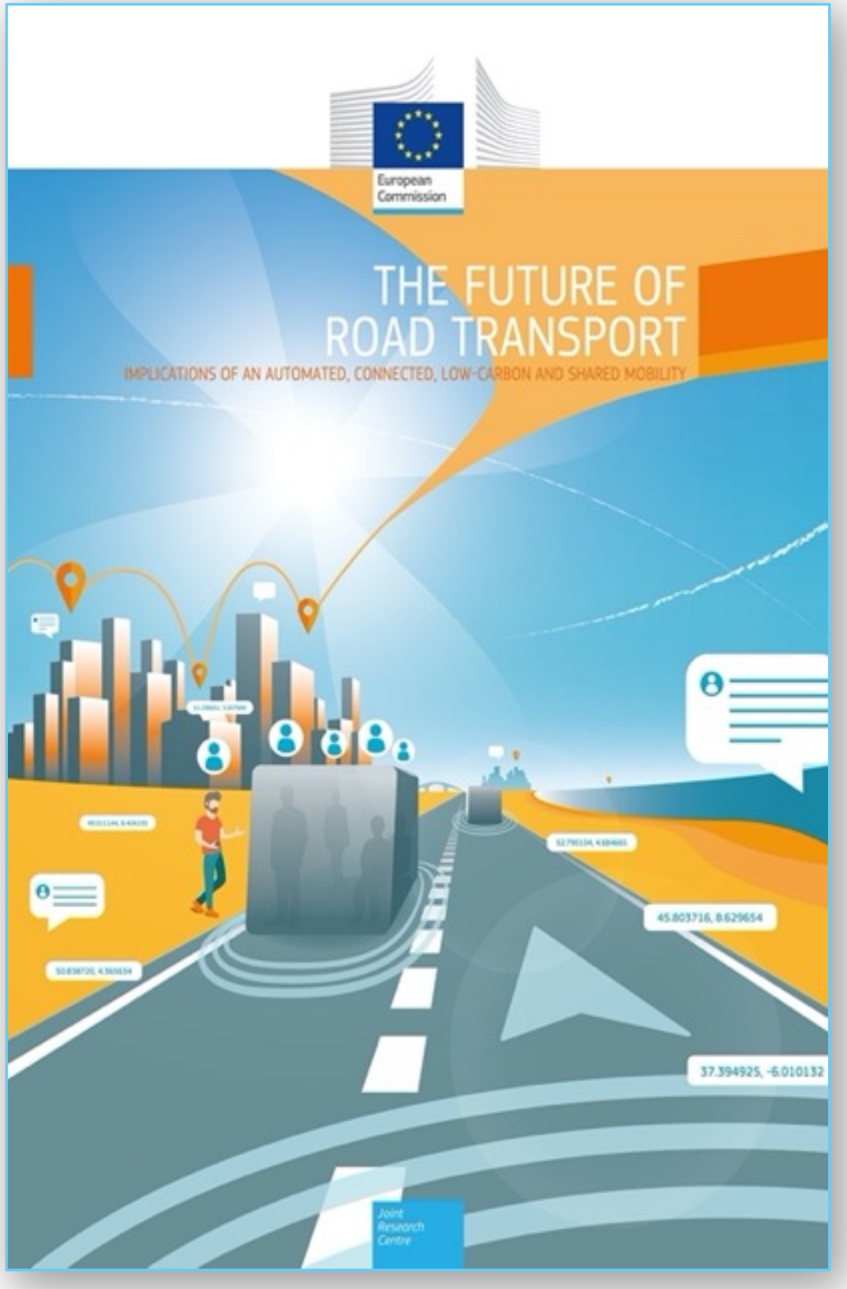

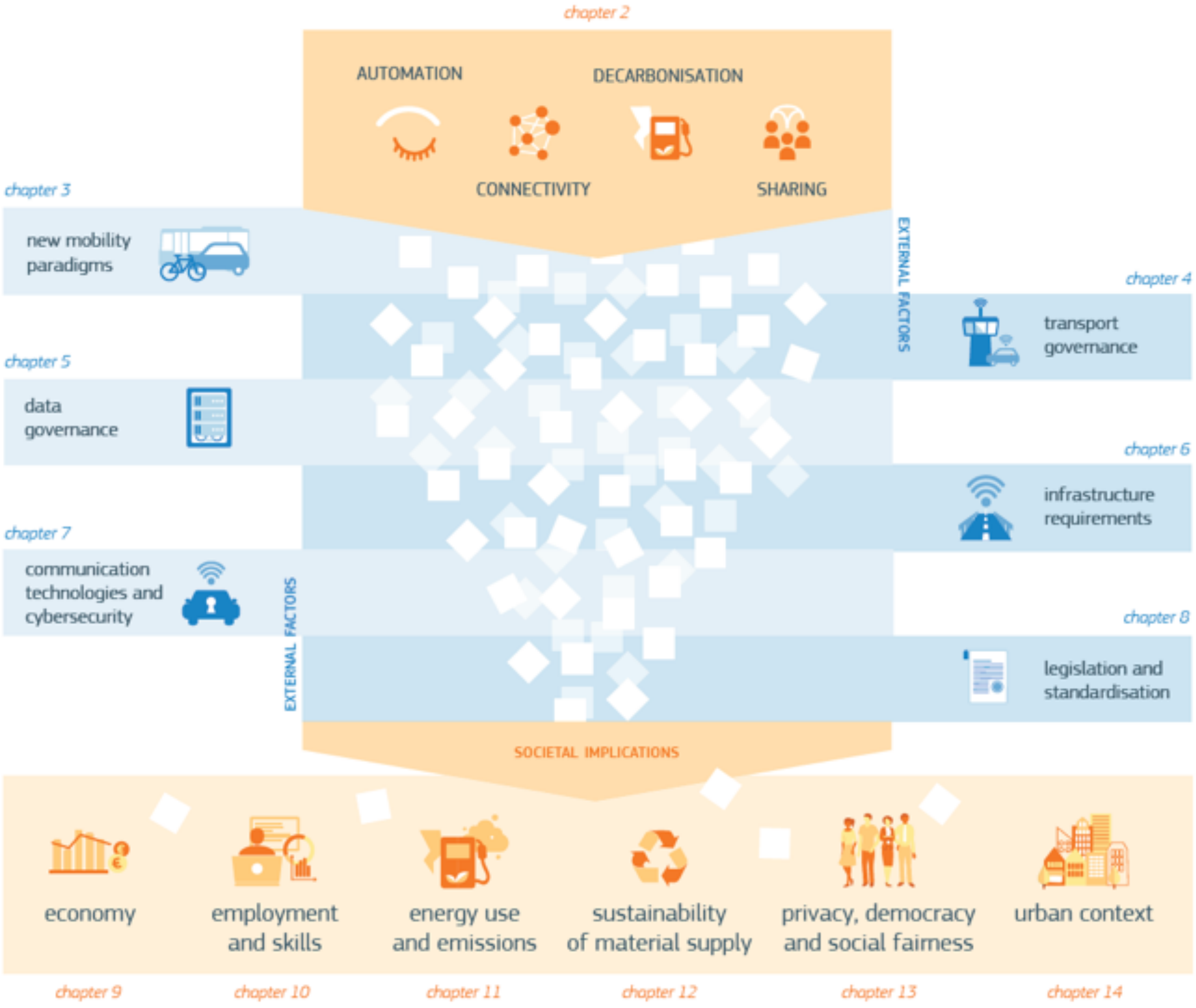

Available at:
https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/future-road-transport

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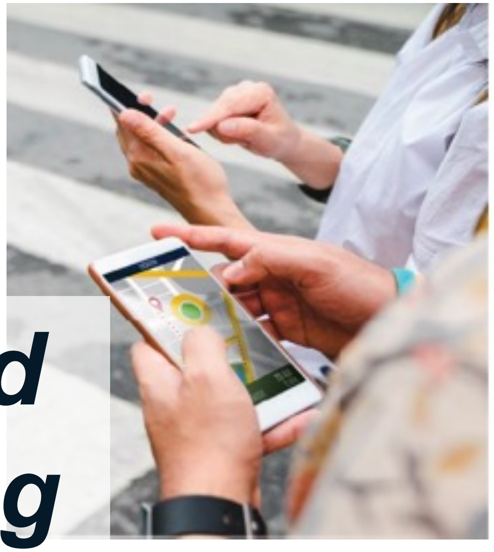
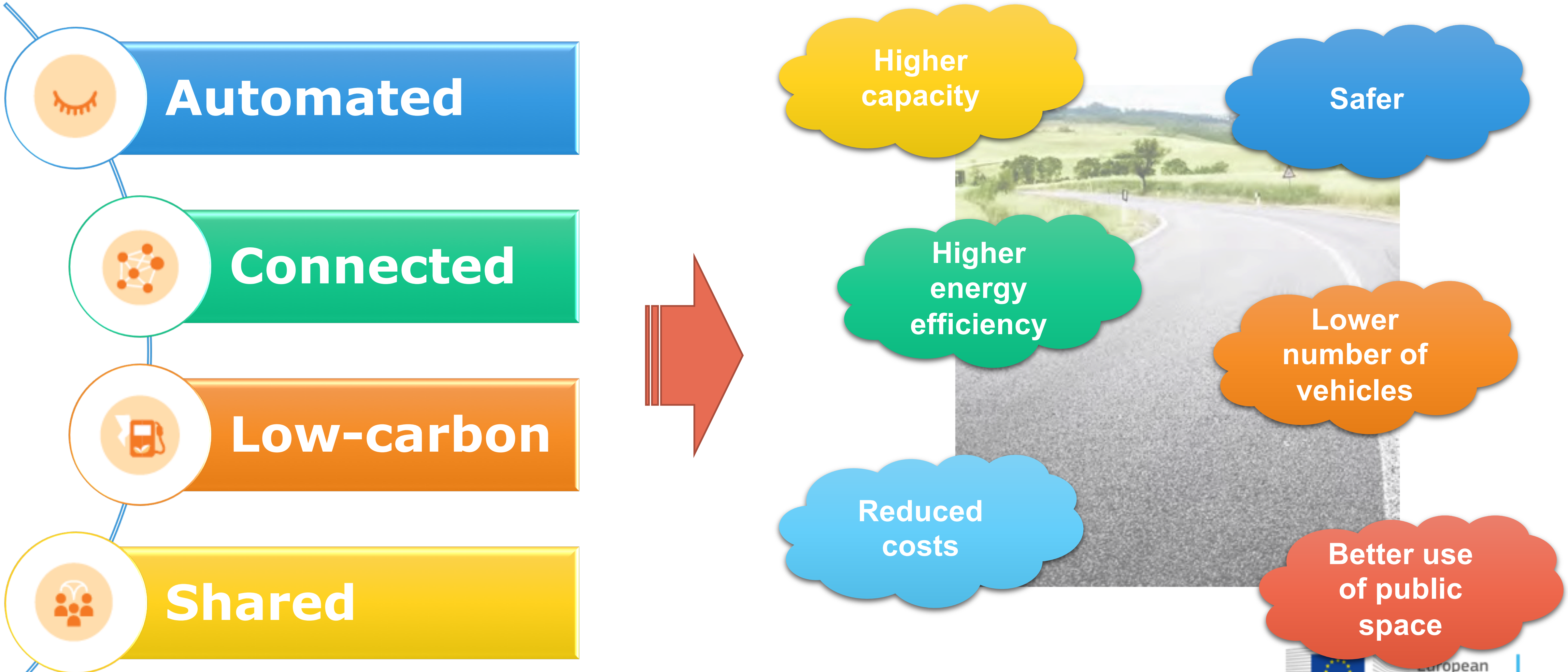
Disrupting transport



*A storm of **new technologies and business models** is **transforming** everything about **how we get around** and how we **live our lives***

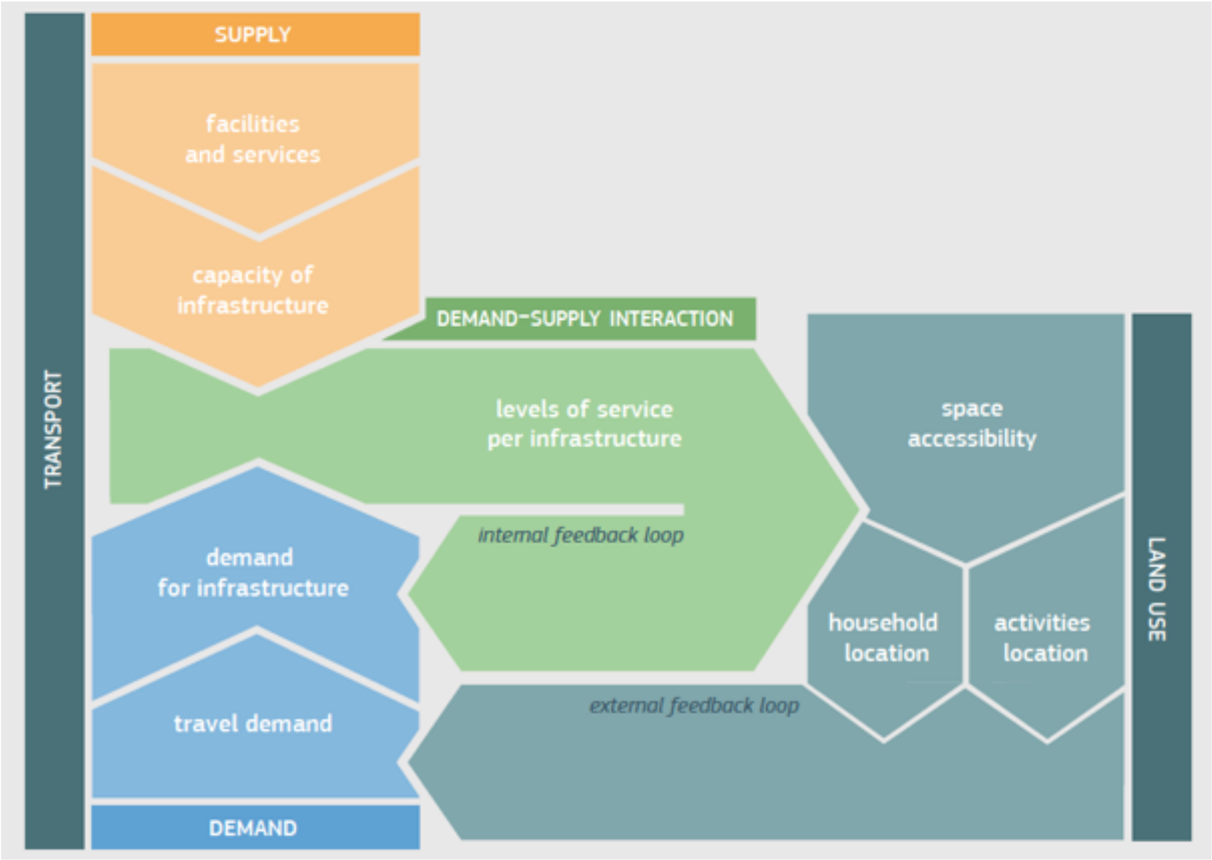
Claimed impacts of four trends



Transport complexity

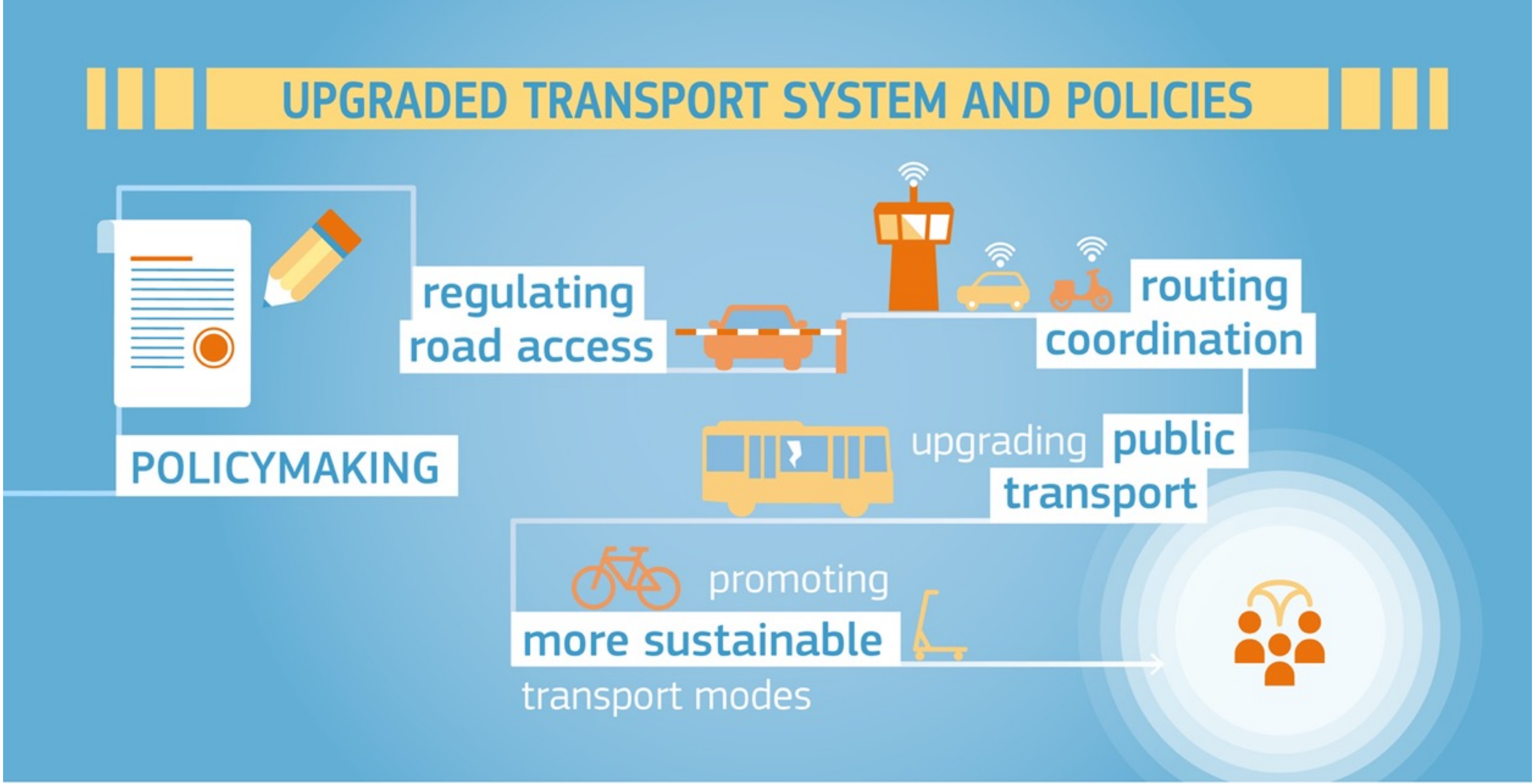
Transport systems are «**internally complex systems**, made up of many elements influencing each other both directly and indirectly, often nonlinearly, and with many **feedback cycles**»*.

Transport policies have **implications** for the **economy**, **land use**, **environment**, **quality of life**, and **social cohesion**. In this respect, they have a «*bearing on many, often conflicting, interests*»*



* Cascetta, 2009

NEW TECHNOLOGIES ALONE ARE NOT THE SOLUTION



#MobilityEU #Facts4EUFuture

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The power of personalized communication

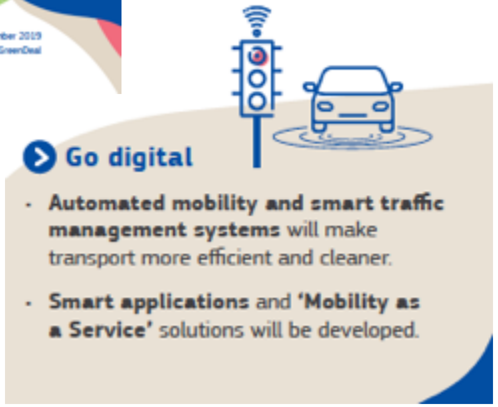
Tradable Travel Permits

Traffic Management 4.0

System Optimum

Access Management

EU policies: the European Green Deal



- Previous references
  - COM(2018) 283: Connected, **Cooperative** and Automated Mobility
  - C-ITS Platform (EC, 2017): Public authorities as «**Orchestra Conductor**»

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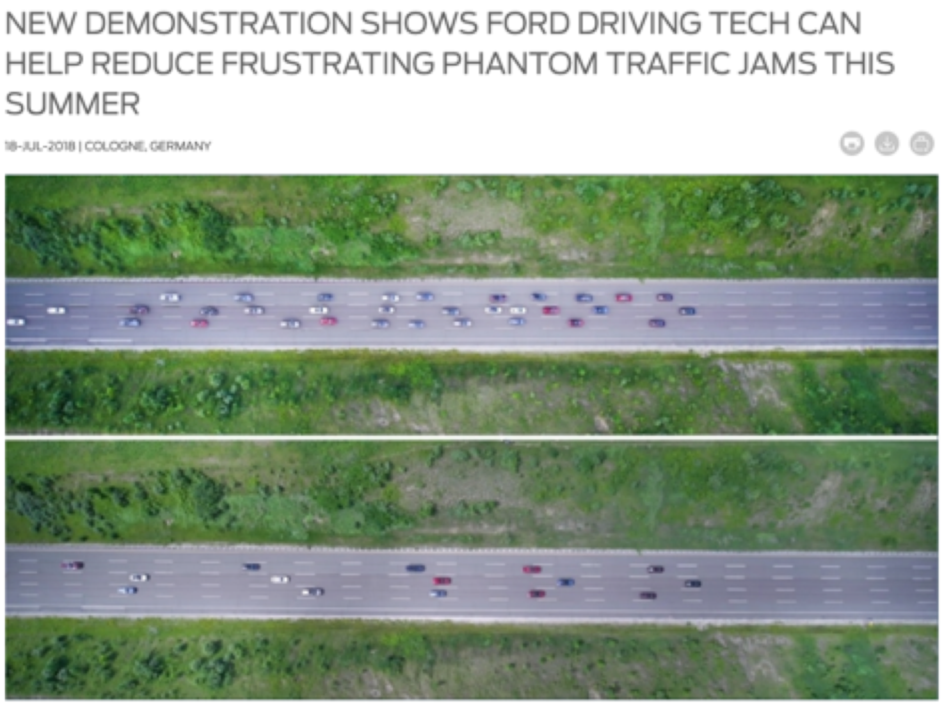
How likely is this to happen?

What can we learn from ACC?

Background on ACC

- Since late 90s, ACC is attracting the attention of researchers
- ACC was expected to
  - **Increase comfort and reduce fuel consumption and emissions** (Marsden et al., 2001, Vahidi and Eskandrian, 2003, Ioannou and Stefanovic 2005, Ford, 2019, …)
  - **Eliminate congestion** (Treiber and Helbing, 2001, Ioannou and Stefanovic, 2005, …)
  - **Increase safety** (Xiao and Gao, 2010, …)



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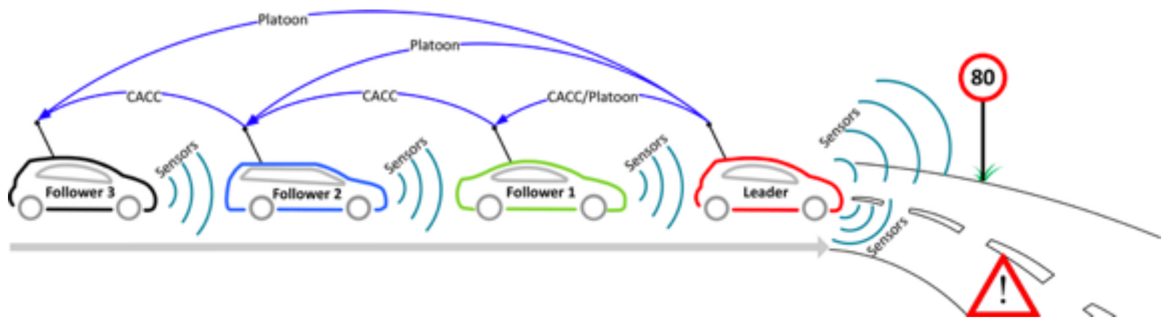
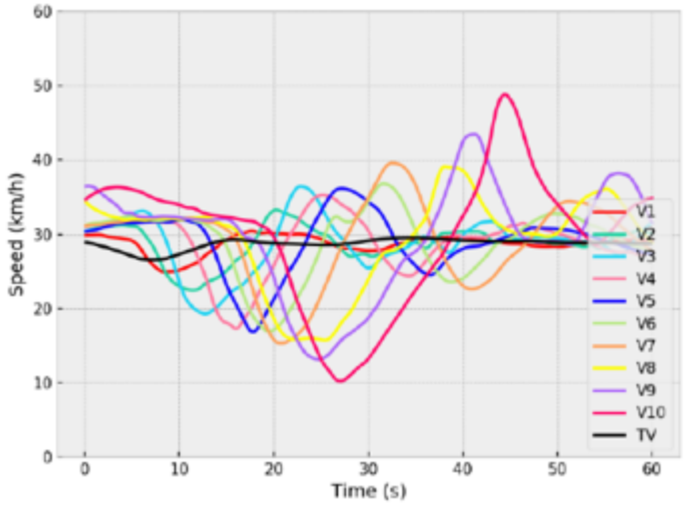
Background on ACC

- Soon after the first studies researchers started to realize that **string stability might have been an issue** (Zhou and Peng, 2005, Martinez and Canudas-de-Wit, 2007, Kesting et al., 2007, 2008, Xiao and Gao, 2011, Davis, 2012, Ploeg et al., 2014, Farnam and Salrette, 2019, etc.
- **V2V and V2I communication** was identified as the way to address this problem
  - several studies continued to propose ways to use communication to improve traffic using CACC systems



What do we see on the road today?

- **Although known for the last 20 years, several studies have reported string unstable commercial ACC systems** (Milanes and Shaldover, 2014, Knoop et al., 2019, Gunter et al., 2019, Makridis et al, 2020a,b,c, Ciuffo et al., 2021)!!!



Main reasons and possible implications for traffic research

1. Lack of V2V and V2I communication in market vehicles
2. No actual requirements for string-stability in ACC systems by Regulators (no regulations on ACC requirements but only an ISO standard)
3. No interest for traffic-efficient ACC systems by OEMs (systems requirements comfort-driven)
4. Proportionality principle by road authorities

Is there a risk that a research community having road authorities as main stakeholders becomes irrelevant with new automated driving systems?!?

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ADS/ADAS Requirements

- Vehicle regulations are defined at UNECE level
- A new Working Party on ADSs has been setup in 2019
- First UN Regulation on ALKS (<60km/h) adopted in 2020

ALKS Regulation 157

- Requirements. The activated system shall:
  - comply with traffic rules
  - not cause any collisions reasonably foreseeable and preventable

ALKS Regulation 157

- Requirements. The activated system shall:
  - comply with traffic rules
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  - 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.

Operational requirement

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

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Performance requirement

- avoid a collision with a cutting in vehicle if If the cutting in vehicle is 30 cm inside the lane and

$$TTC > \frac{u_{rel}}{6 * 2} + 0.35\ s$$

Proposal for Amendment to ALKS Regulation 157 for increasing the max speed to 130 km/h

- Requirements. The activated system shall:
  - comply with traffic rules
  - not cause any collisions reasonably foreseeable and preventable
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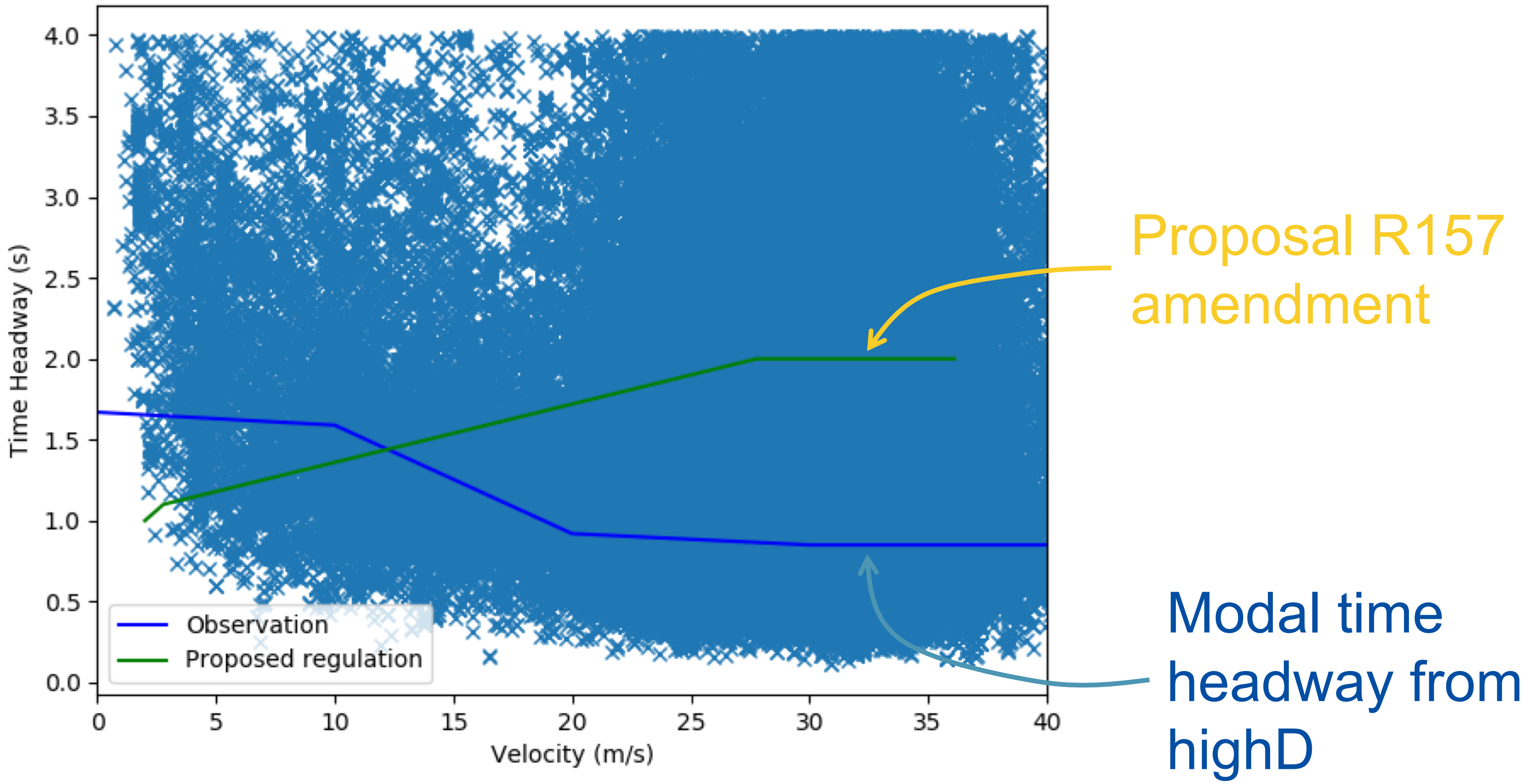
60	16.67	1.6	26.7
70	**19,44**	**1.7**	**33,1**
80	**22,22**	**1.8**	**40,0**
90	**25,00**	**1.9**	**47,5**
100	**27,78**	**2.0**	**55,6**
110	**30,56**	**2.0**	**61,1**
120	**33,33**	**2.0**	**66,7**
130	**36,11**	**2.0**	**72,2**

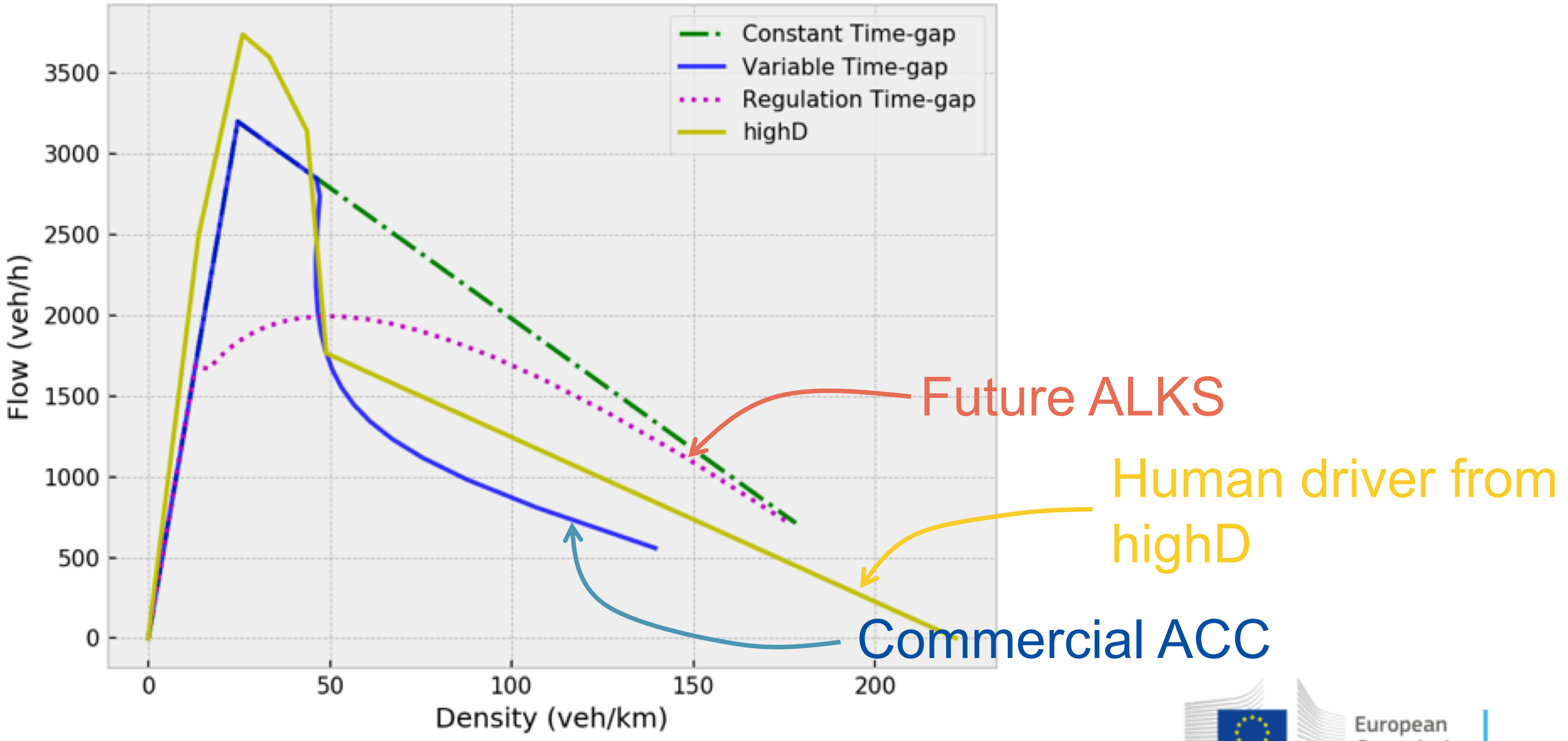
Comparison with traffic data



Source: highD dataset (https://www.highd-dataset.com/details)

Theoretical effect on traffic flow

Traffic fundamental diagram



The way forward

- The **traffic community must start to collaborate with vehicle regulatory bodies**
  - Our role is to ensure that new vehicle technologies will be able to deliver what they promise and be integrated in the future multimodal traffic management system
- We need to **use their language and understand their mindset** (mainly safety driven)
- We need to **integrate our traffic simulation tools with their vehicle simulation models**
  - We need a solid base of data to develop better vehicle models -> **OpenACC**

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OpenACC

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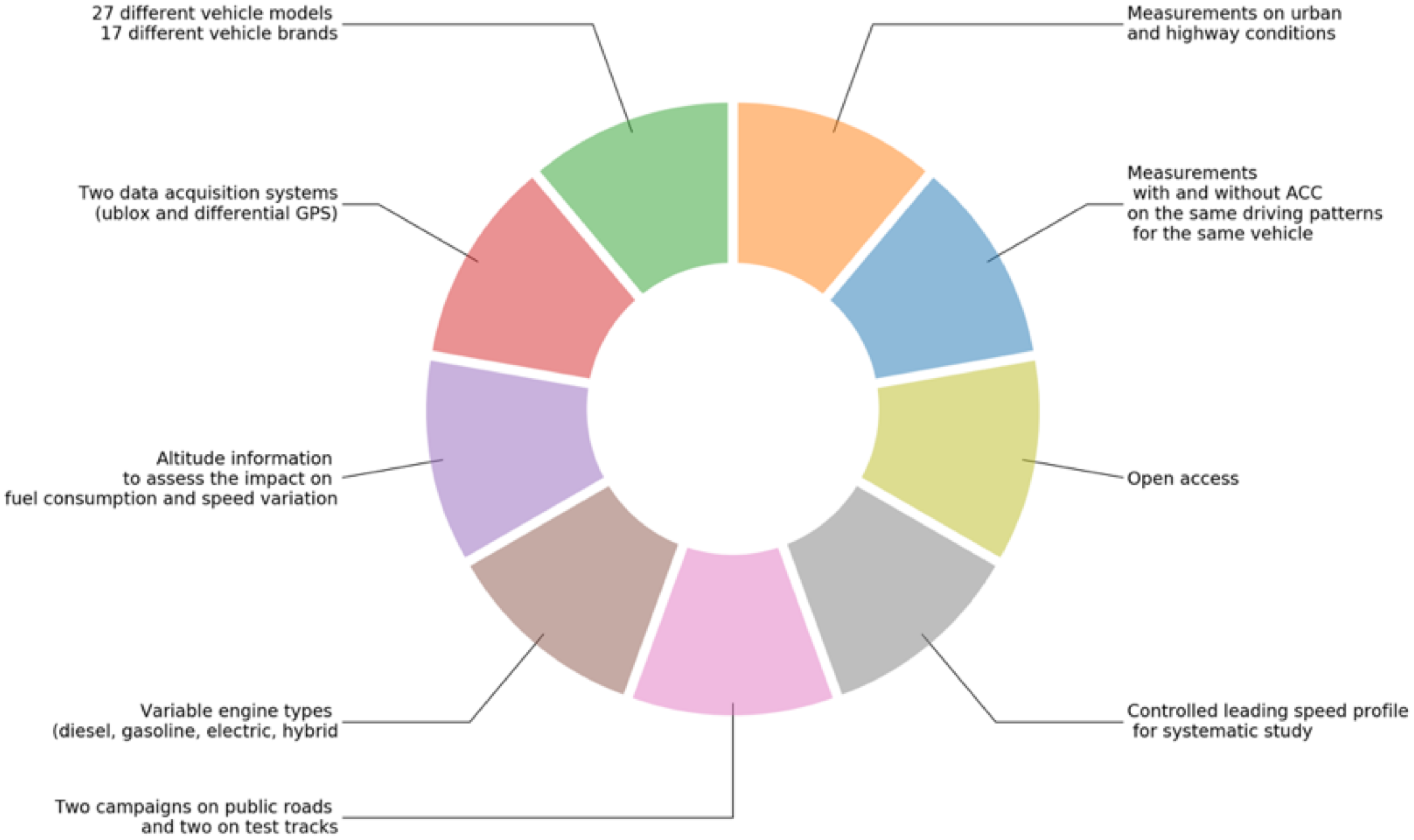
An **open**, **free** and **evolving** database of car-following (CF) experiments with ACC vehicles

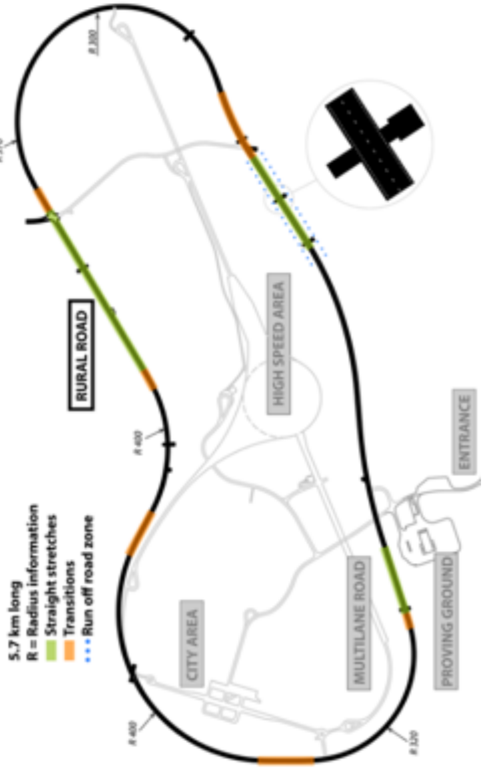


openACC – Test sites

JRC - Cherasco
~152km Highway

JRC - Vicolungo
~43km Highway

AstaZero
5-7km Rural



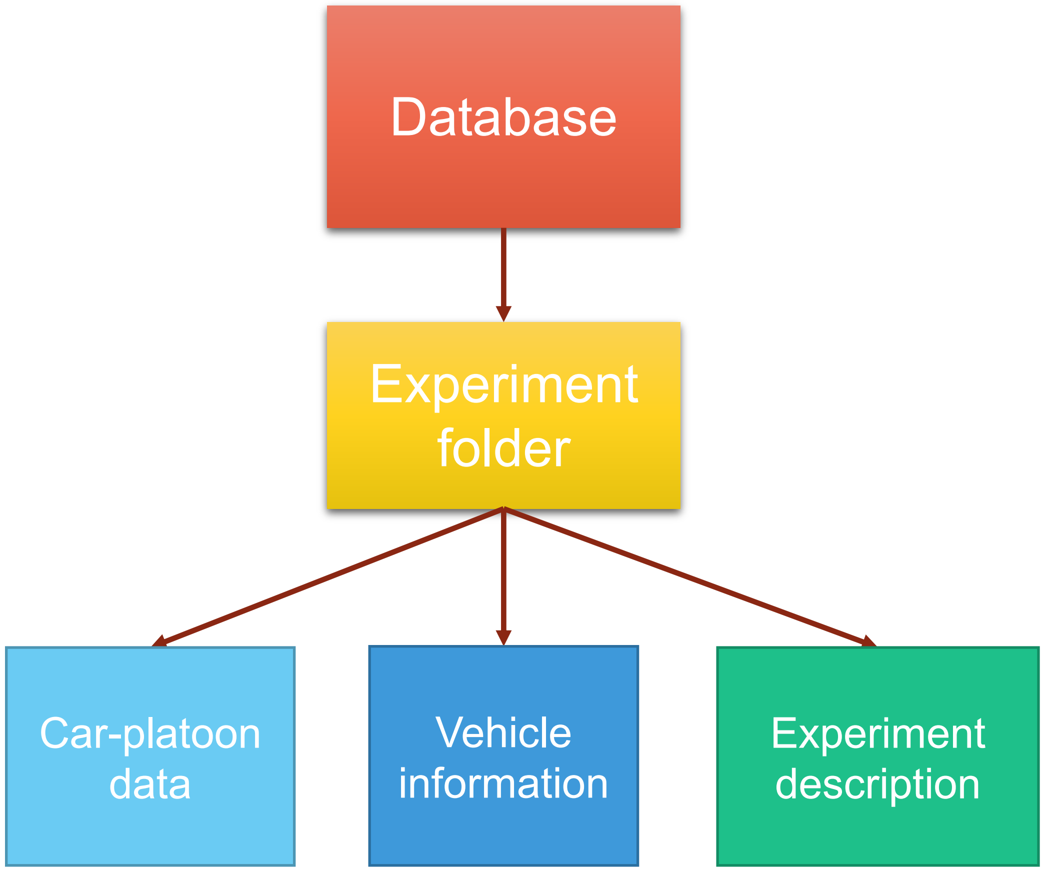
openACC - Test campaigns

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	
Time gap settings	Short		Short		Short and long		Short, long, medium and mixed (Short and long)	
Driving modes of following vehicles	Human	ACC	Human	ACC	Human	ACC	Human	ACC
Duration (h)	5.70	5.28	4.31	5.69	3.12	15.59	5.32	50.88
Distance (km)	569	519	399	602	206	1029	188	1683

openACC - 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

Database structure and information



Column ID	Description	Units
Time	Common time frame for all vehicles	s
Speed	Magnitude of Speed (Doppler)	m/s
Lat	Latitude	rad
Lon	Longitude	rad
Alt	Altitude	m
E	East (x) coordinate in the local ENU plane (common center for all vehicles)	m
N	North (y) coordinate in the local ENU plane (common center for all vehicles)	m
U	Up (z) coordinate in the local ENU plane (common center for all vehicles)	m
VE	Speed in the East direction of the local ENU plane	m/s
VN	Speed in the North direction of the local ENU plane	m/s
VU	Speed in the Up direction of the local ENU plane	m/s
IVS	IVS computed from raw GNSS data after bumper to bumper correction.	m
Driver	The driver of the vehicle: "Human" for manual driving, "ACC" for ACC driving.	$-$

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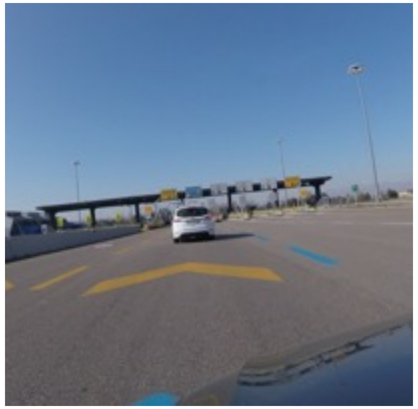
Test execution and challenges



- Measurement systems
  - E1,2. Vehicles instrumented with **GNSS** receivers for position (x,y,z) and speed detection, and with **OBD readers**
  - E3,4. Vehicles instrumenented with several GNSS receivers and OBD readers
- Manual processing for removing parts with weak data coverage and with external disturbances to the car-following experiment
- Data provided at 10Hz (for lower-frequency detection spline interpolation was used). All data collected synchronized and fused

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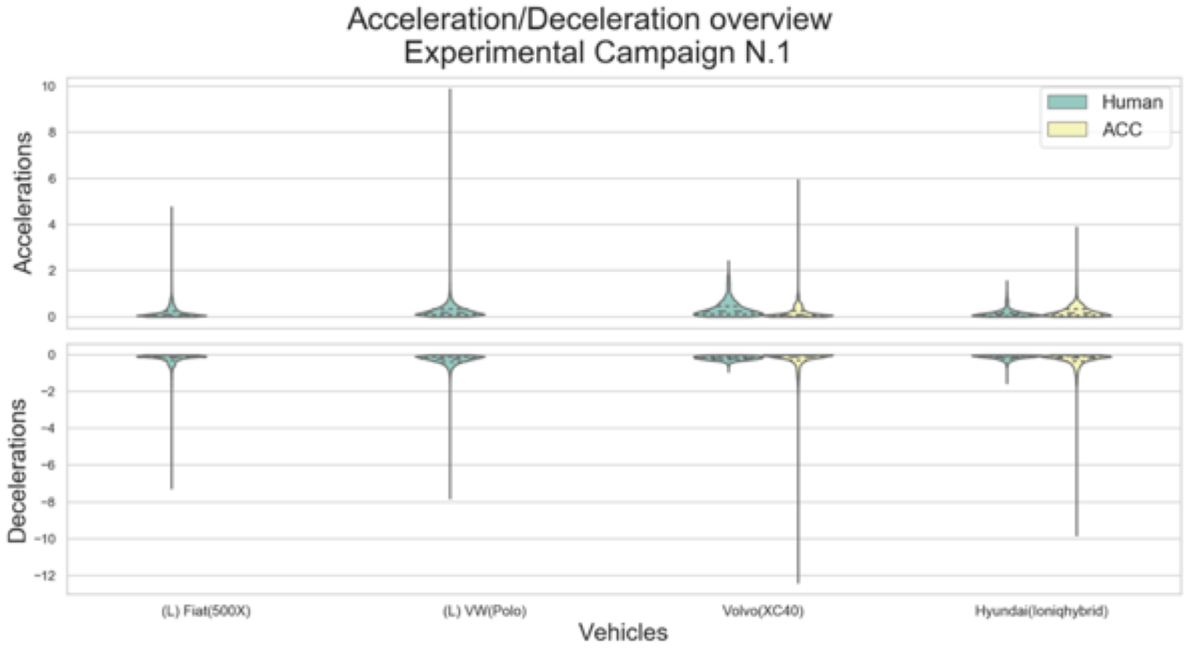
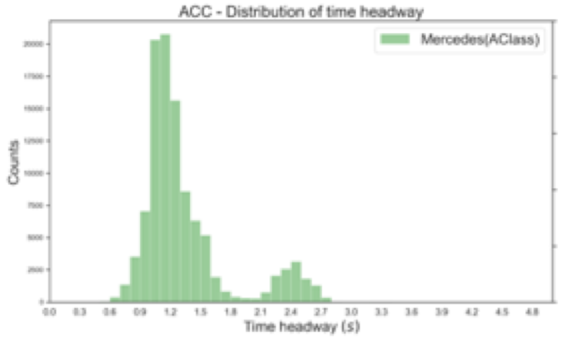
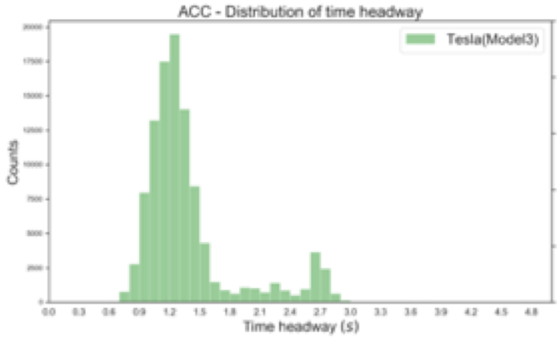
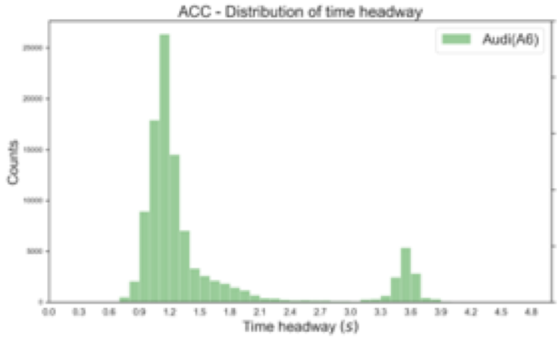
Preliminary analysis

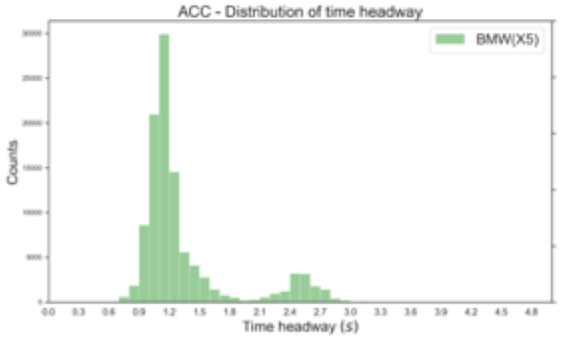
- Acceleration and headway/ reaction time distributions
- String Stability
- Traffic Hysteresis and safety











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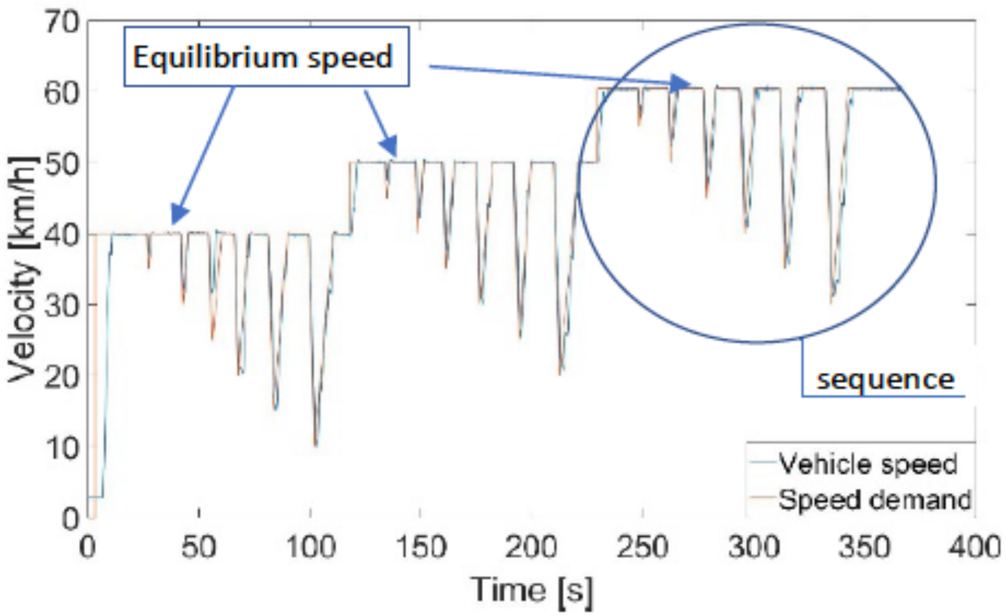
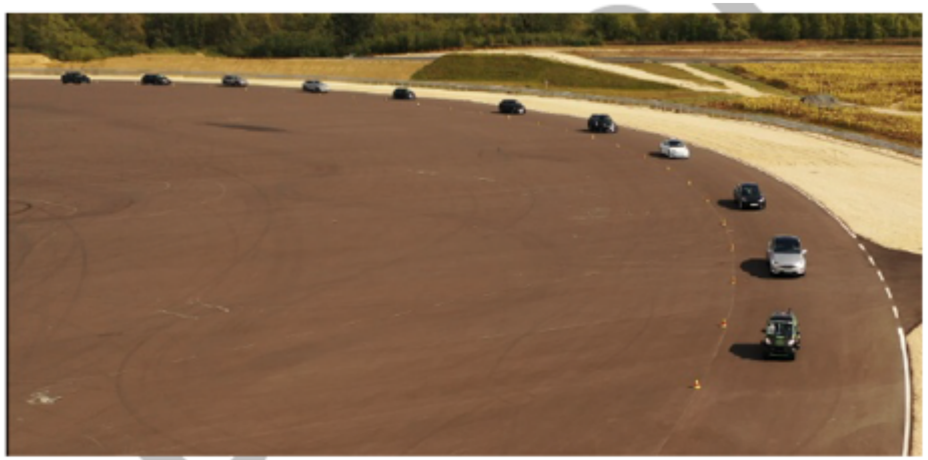
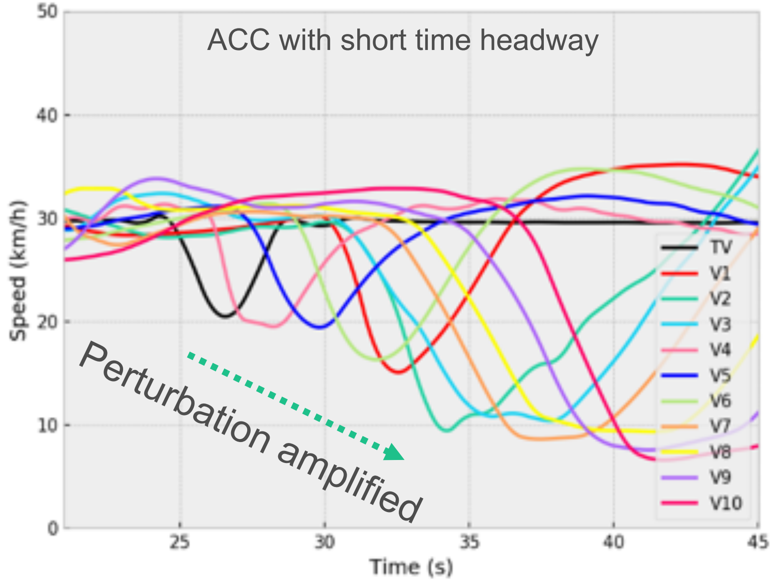
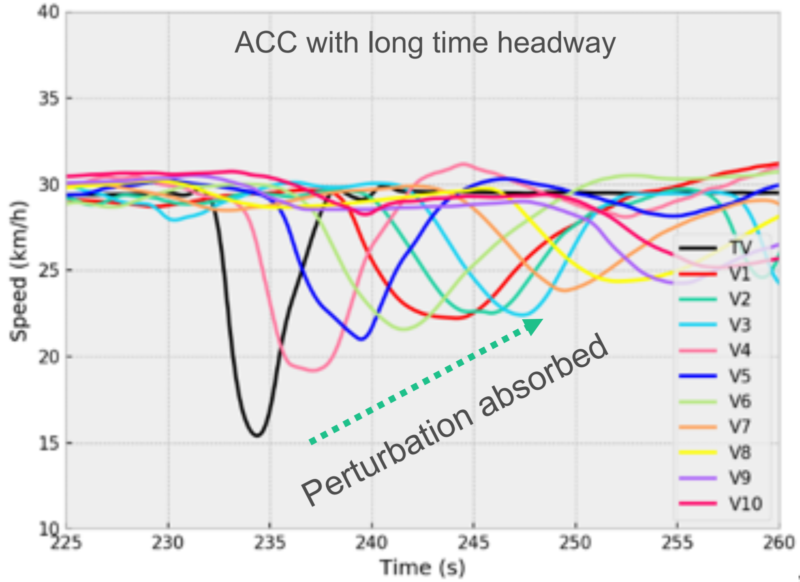
String stability

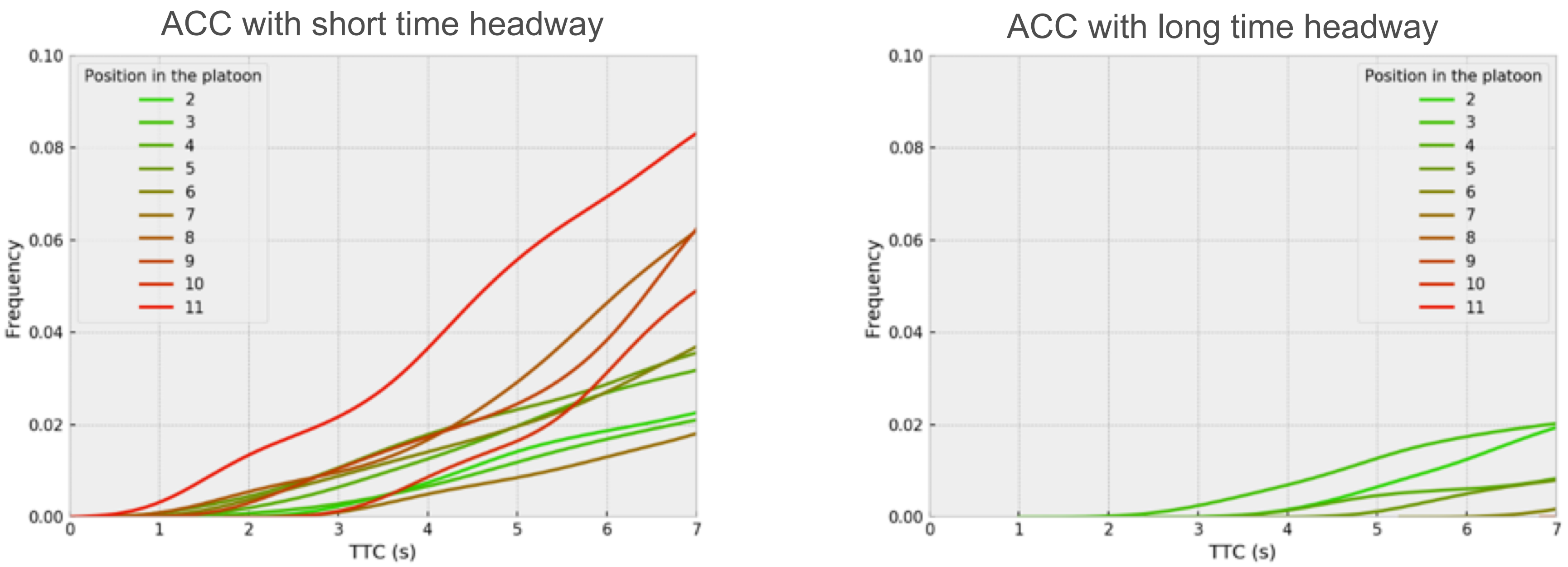






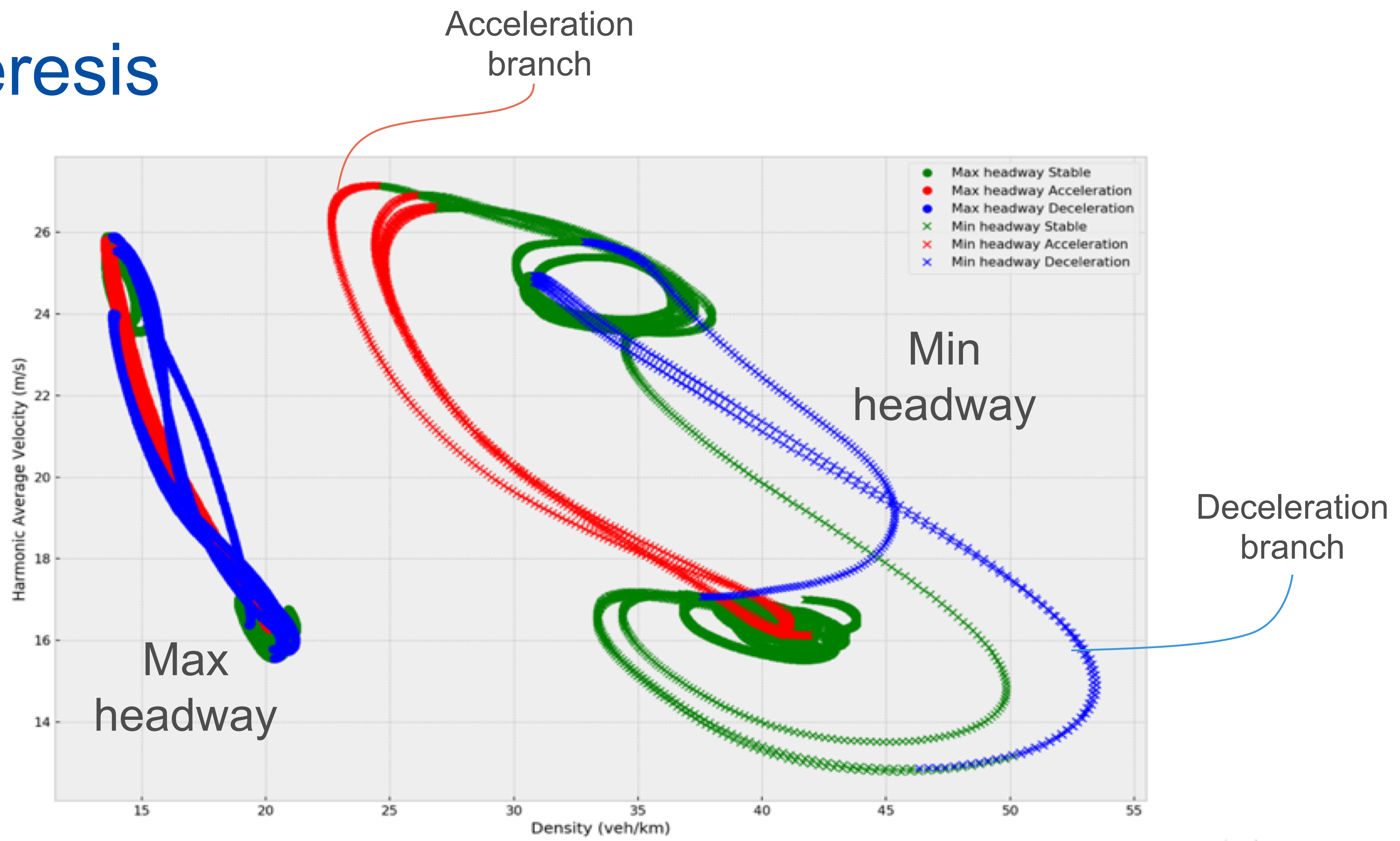


String stability – Implications for safety



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

Hysteresis



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Results

- Bringing experimental and modelling evidence about ACC operations the following **two requirements are now included in the list considered for future ADS regulations**:
  - ADS shall **not unnecessary disturb the normal flow of traffic**
  - ADS shall be **string stable**
- If they are accepted, we will need to define performance and operational requirements to make them applicable

Conclusions

- Road transport is expected to **drastically change in the next future** thanks to new technologies
- There is reasonable risk that **this will not lead to a more efficient and more sustainable transport** sector unless proper governance is introduced and vehicles requirements include the traffic perspective
- **Traffic research community must get closer to automotive industry and vehicle regulators**
- It will be crucial to **upgrade our models to better reproduce vehicle operations**
- **OpenACC wants to support this process by providing insights into new vehicle technologies**

Thank you

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