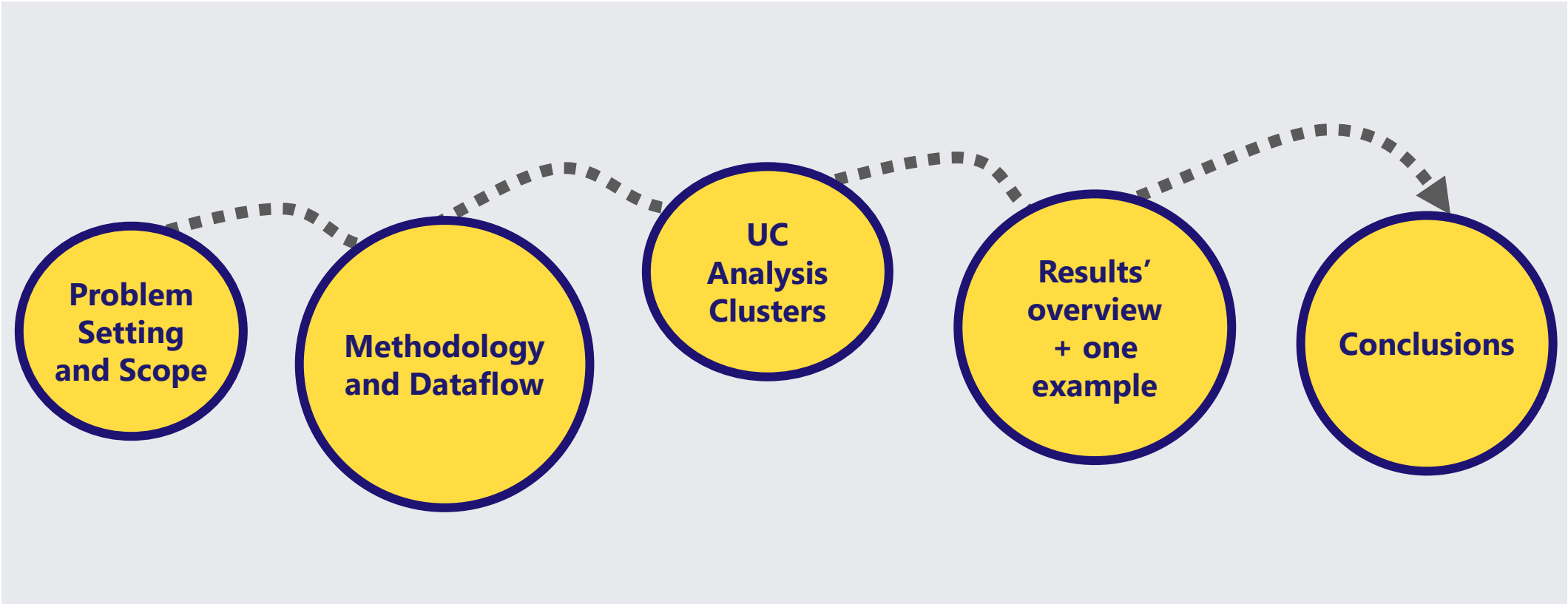
Hi-Drive
FINAL EVENT
25 NOVEMBER 2025

TECHNICAL EVALUATION RESULTS

Anastasia Bolovinou | ICCS

#Effects and Impact Assessment

Contents

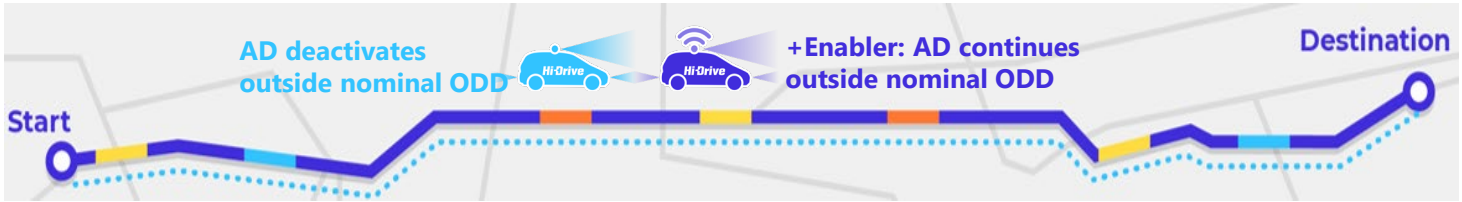

Problem Setting and Scope
Methodology and Dataflow
UC Analysis Clusters
Results' overview + one example
Conclusions

Problem setup : Hi-Drive Automated Driving Functions (ADFs) in action

BADF

Baseline ADF – BADF

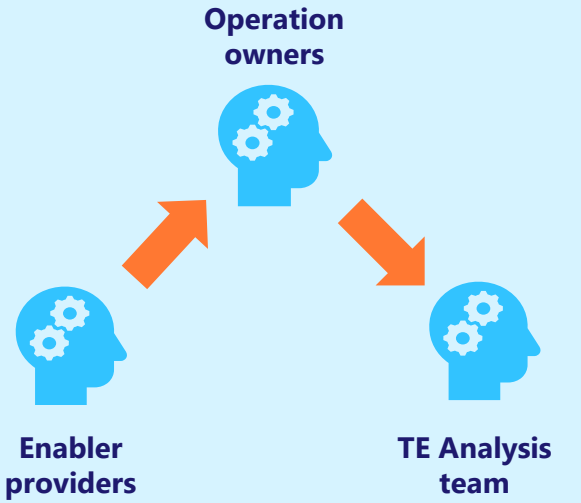
- Limited ODD
- No Enablers included
- Could still be introduced to the market, e.g., fulfils safety requirements
- Serves for comparison with EADF to evaluate Enablers



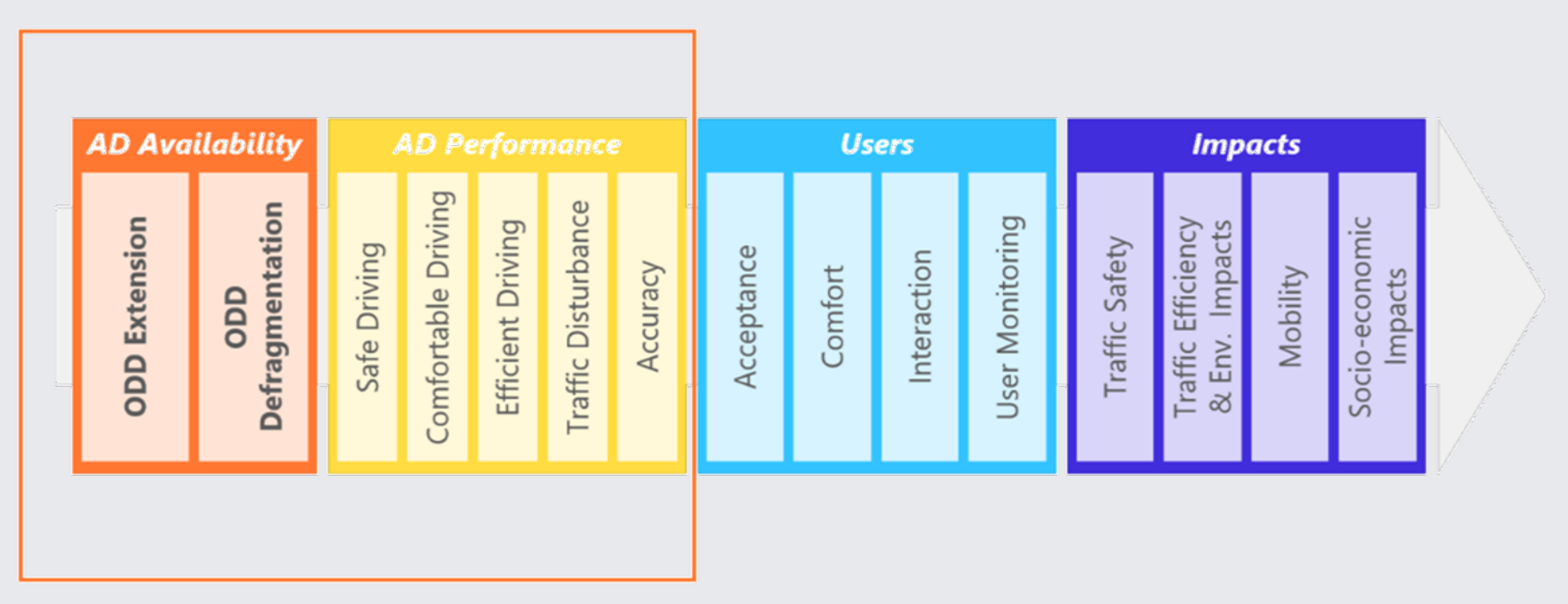
EADF

ADF with Enablers – EADF

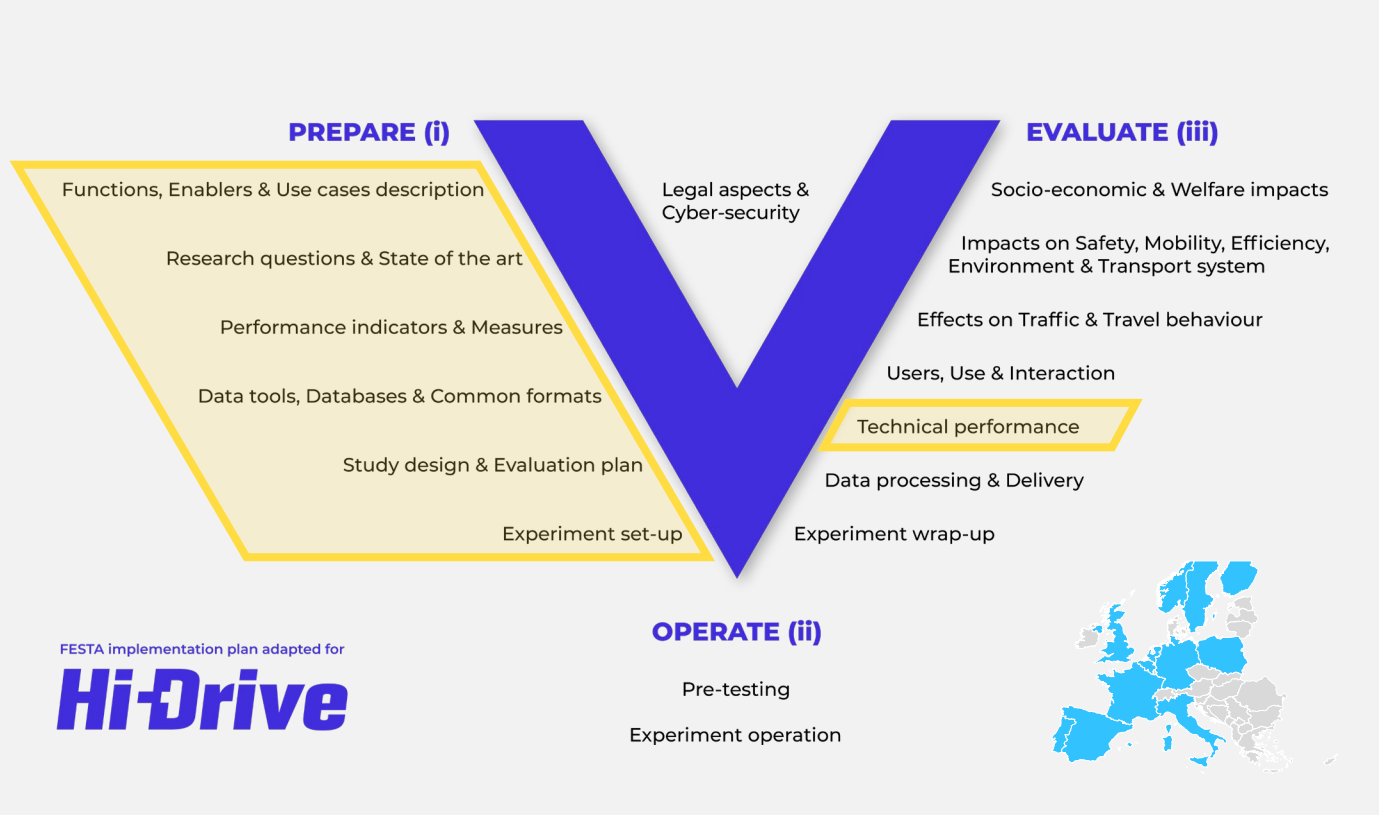
- Extended ODD
- Enablers incorporated



Technical Evaluation Scope



Technical Evaluation overview



Based on pools of data from Hi-Drive Operations…

- **Evaluate the technical performance of enablers**
  - **In nominal ODD**
  - **In extended ODD**

(Compare with Baseline ADFs and/or Manual driving by using statistical tests)

Methodology and dataflow (1/3)

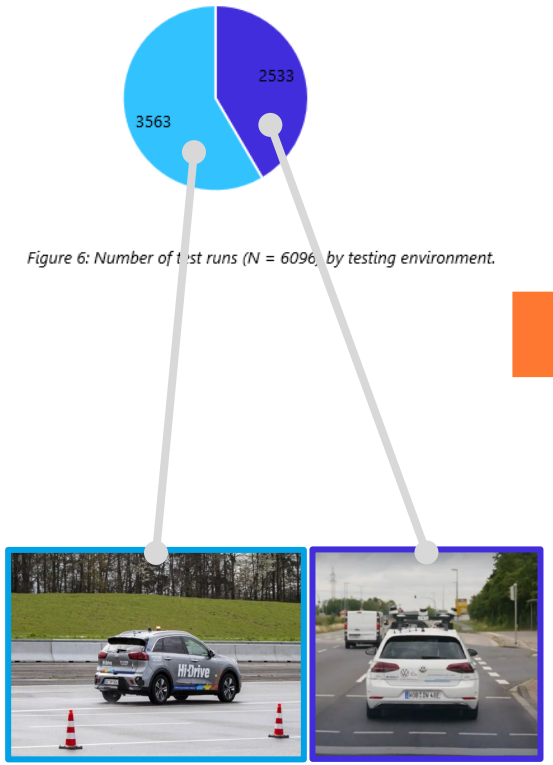


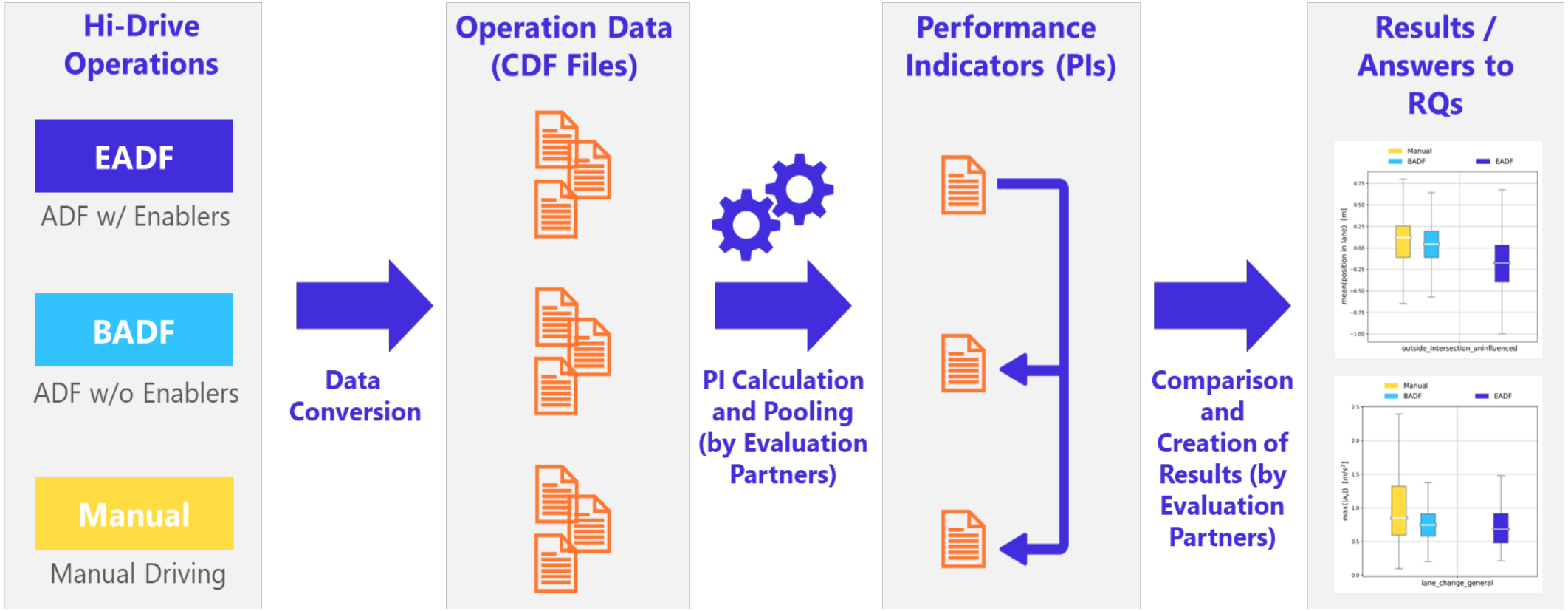
Figure 6: Number of test runs (N = 6096) by testing environment.

Ego vehicle kinematics	Driver and system behaviour	Driver and system behaviour	Lanes and objects surrounding the ego vehicle
• Velocity(m/s) • Longitudinal acceleration (m/s^2) • Lateral acceleration (m/s^2) • Yaw rate (rad/s) • Position in lane (m)	• Steering wheel angle (rad) • Brake pedal position (%) • Throttle pedal position (%) • Active gear (gear number) • Safety driver intervention (seconds from scenario start) • Indicator status (category) • Brake light status (category) • ESP status (on/off)	• ABS status (on/off) • ACC status (category) • Activation of AEB (on/off) • ADF status (category) • Lane keeping status (category) • Enabler status (category)	• Object id (integer) • Object class (category) • Relative position to ego x (m) • Relative position to ego y (m) • Relative longitudinal speed to ego (m/s) • Relative lateral speed to ego (m/s) • Lane assignment (left/right/ahead/behind) • For the "leading" object ahead (in addition to signals for object surrounding the ego vehicle): • Time gap to lead vehicle (s) • Longitudinal acceleration (m/s^2) • Lateral acceleration (m/s^2) • Position in lane (m) • Brake light status (yes/no)

High-level research question	Medium-level research question	PIs
To what extent do the enablers extend the AD functionality?	To which environmental conditions do the enablers extend the ODD?	%driving scenario instances managed per relevant condition; %time AD active, %time AD available per relevant condition
	To which road infrastructure elements do the enablers extend the ODD?	%driving scenario instances managed per relevant condition; %time AD active, %time AD available per relevant condition
	To which driving scenarios do the enablers extend the AD functionality?	%driving scenario instances managed per relevant condition %time AD active, %time AD available per relevant condition

Efficiency: What is the effect of AD and its enablers on efficient driving behaviour?	What is the effect of AD and its enablers on longitudinal driving stability?	mean(v) std(v) std(THW) sum(ax) for ax>0 Number of braking events
Interaction with traffic: What is the effect of AD and its enablers on interacting with other road users?	What is the effect of AD and its enablers on the distance to surrounding road users?	min(THW) std(THW) min(TTC) mean(THW) min(2D_TTC) 2D_TTC_side
Lane keeping: What is the effect of AD and its enablers on position in the lane?	What is the effect of AD and its enablers on variation of lane position?	std(position in lane)
	What is the effect of AD and its enablers on the preferred lane position?	mean(position in lane)

Methodology and dataflow (2/3)



Methodology and dataflow (2/3)

Challenging ODD zone driving

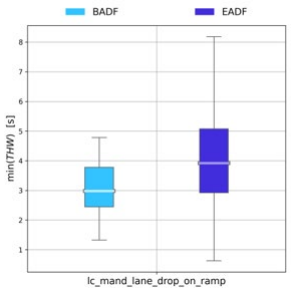
Analysis zone: trip part including challenging ODD

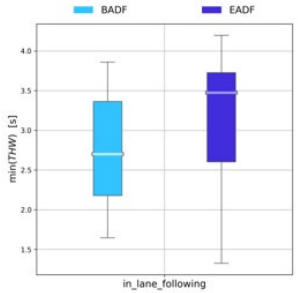
Test run ODD zone decomposed into Driving Scenarios' sequence

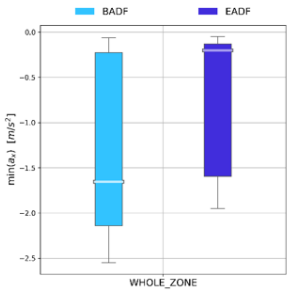
Nominal ODD driving

Analysis zone: entire trip within ODD

Test run decomposed into Driving Scenarios' sequence



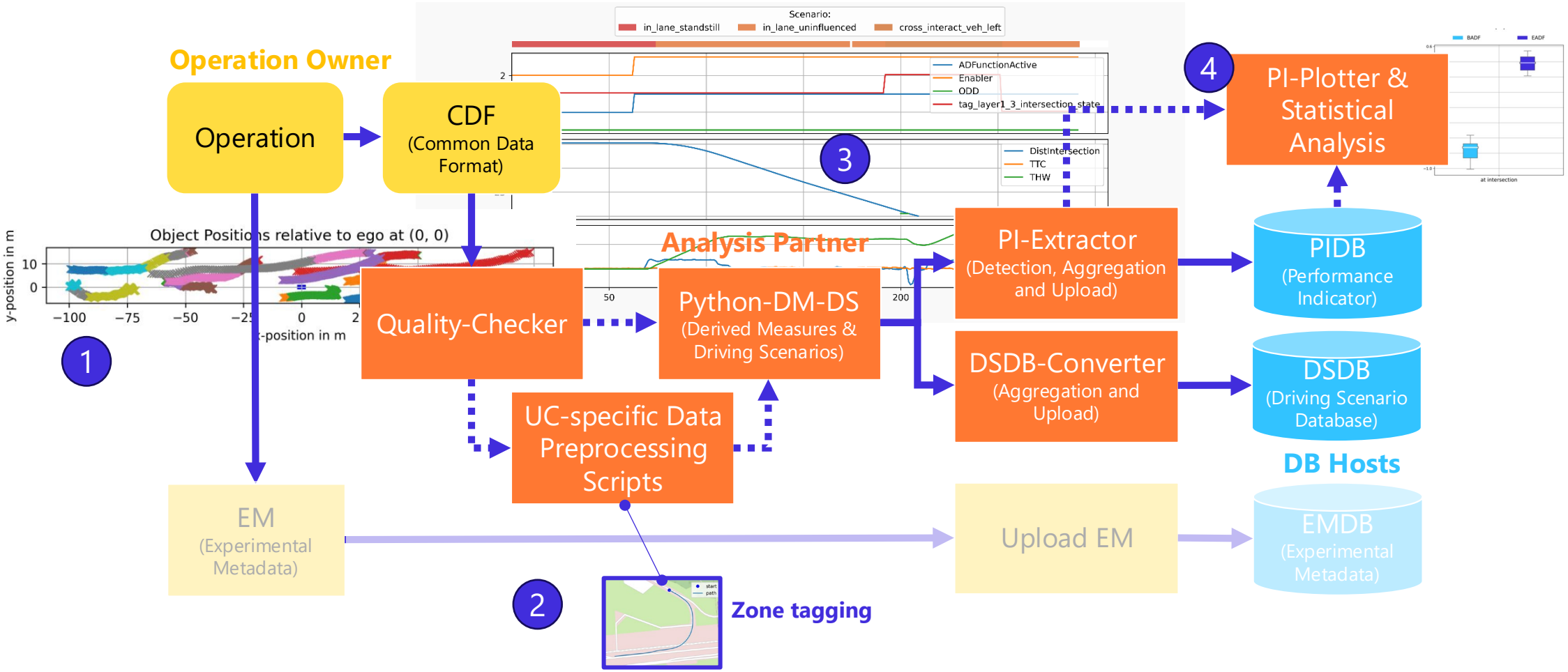




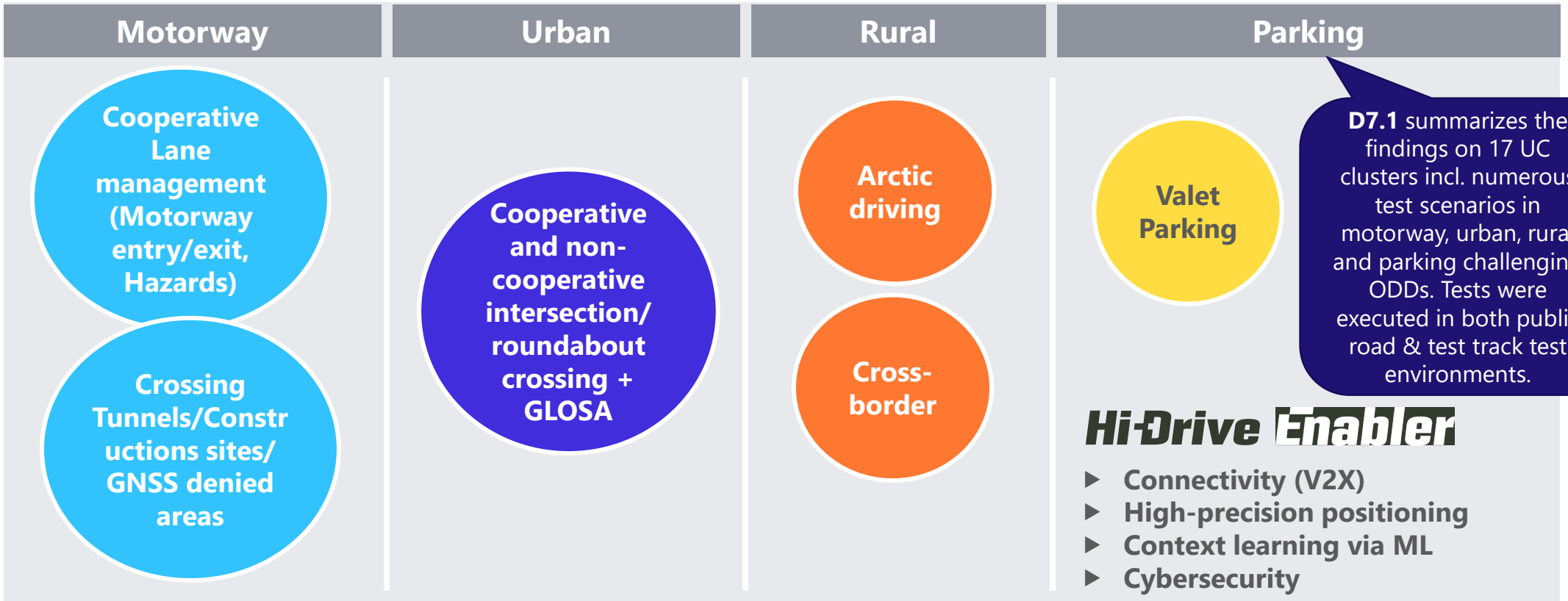
Predecessor project

L3Pilot Driving Automation

Methodology and dataflow (3/3)



Analysis UC clusters overview (17 UC clusters in total)



DIVE-IN INTO ONE UC CLUSTER :

COOPERATIVE LANE MERGING & MERGING AWARENESS ON MOTORWAY ENTRY VIA V2V (TWO PASSENGER VEHICLES)

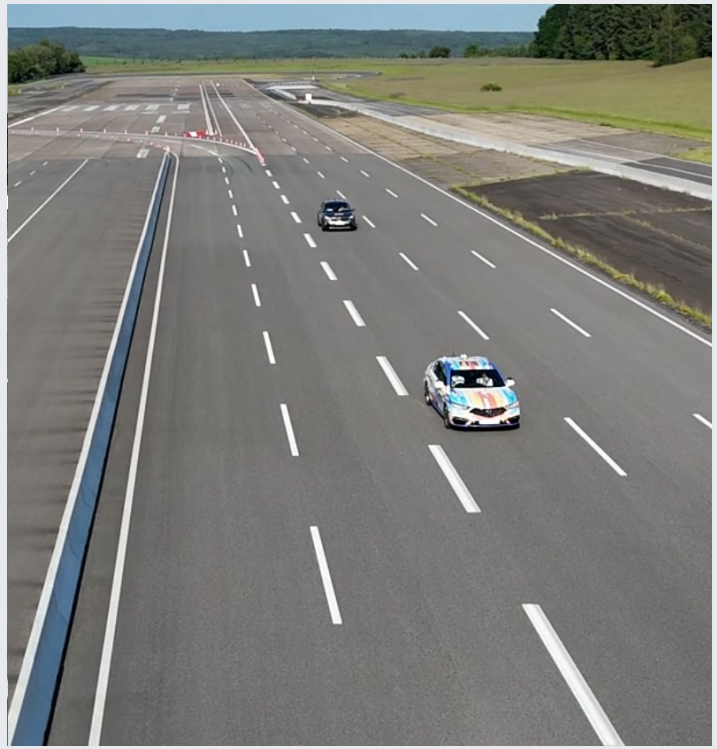
ODD limitations at highway merging sections

- ~20% of time driven in AD mode on highways challenged by lane changes and cut-in scenarios[1].
- At merging sections, NLOS conditions usually degrade AD operation:
  - Ramp vehicles might not see approaching highway vehicles in time and understand if they yield or not
  - Highway vehicles cannot always interpret in time if and how ramp vehicles will merge
- **Result**
  - ramp vehicles (without right of way) are safer if manually driven (limited ODD)
  - Highway vehicles might need to react with sudden decelerations depending on ramp vehicles behaviors (improvable ODD)

[1]L3pilot deliverable D6.5: "Pilot reporting outcomes" & L3pilot deliverable D7.4: "impact evaluation results", available at https://l3pilot.eu/downloads.html

V2V for cooperative automated merging

- Continuous and real-time exchange of messages including explicit maneuvering intentions and reactions enables "Cooperative Maneuvering" at the merging section
  - All vehicles continuously transmit their current "planned trajectory"
  - Ramp vehicle notifies merge intention by a "desired trajectory"
  - If feasible, highway vehicle adapts its planned trajectory to accommodate ramp vehicle's merge
  - When recognized, ramp vehicle changes desired into the planned trajectory and merges smoothly

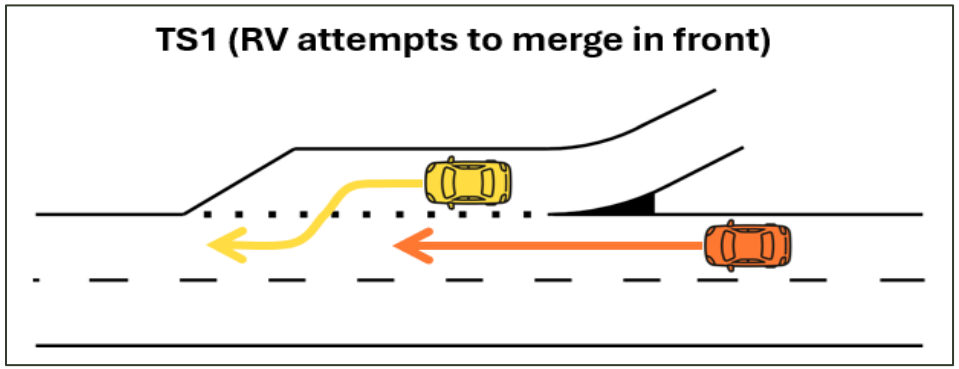


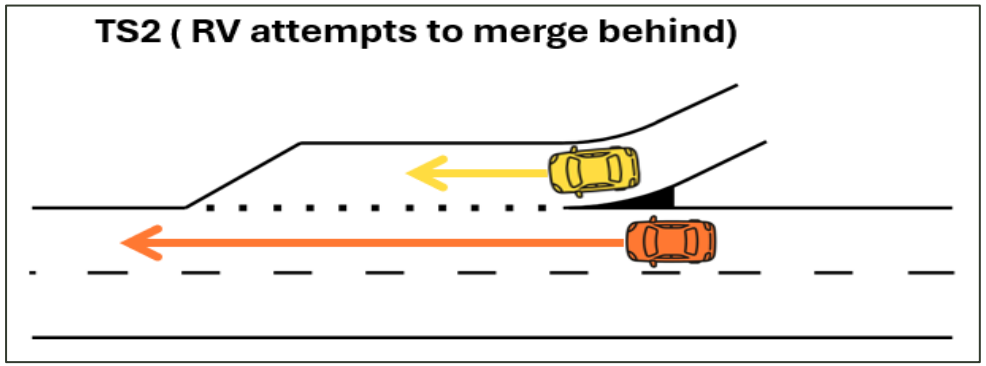
Implementation and Integration

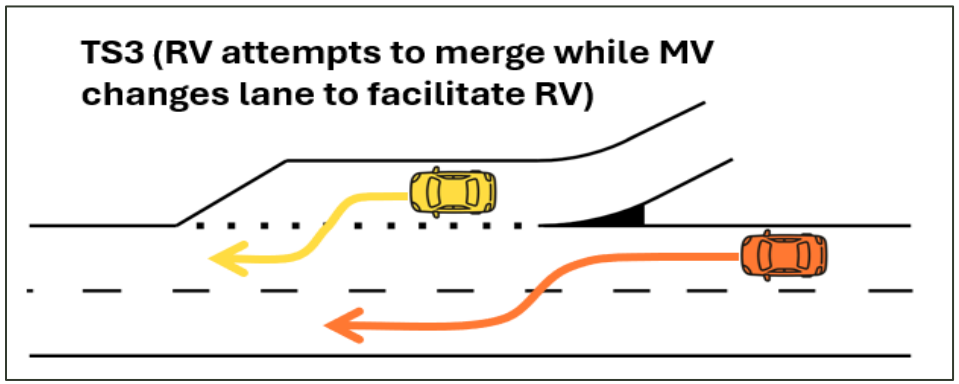
- V2V Enabler integrated in Hyundai prototypic highway chauffeur ADF
  - Based on ETSI ITS G5 (WiFi-like direct short-range communications)
  - Maneuver Coordination Messages (MCMs[1], including exchanged trajectories) constantly broadcasted at 10Hz
- Functional interoperability validated vs similar (but independent) implementations from Honda and FEV.io
- Extensively tested with proving ground trials under multiple use cases and scenarios and compared vs baseline implementations (without V2V)

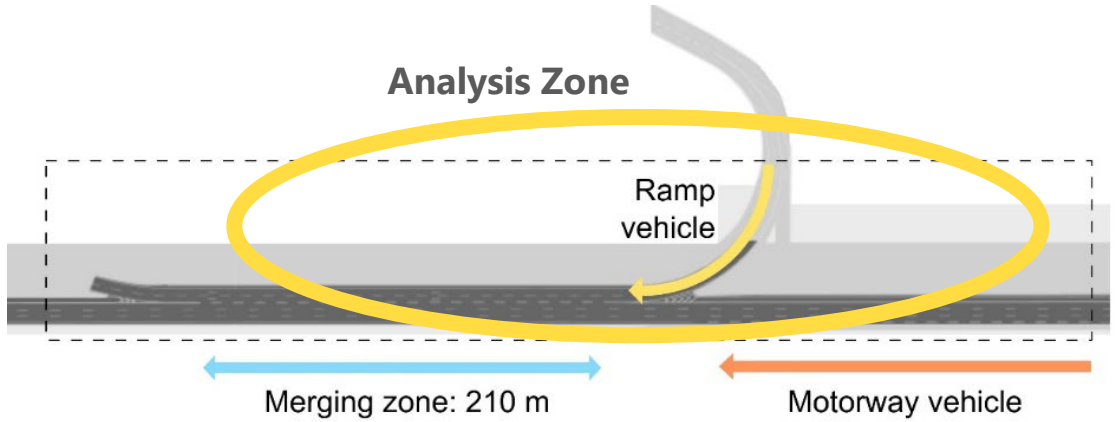
[1]Under Standardisation at ETSI TC ITS (ETSI TR 103 578 & ETSI TS 103 561)

Three Test Scenarios









Research Area 1: Effects on ODD extension

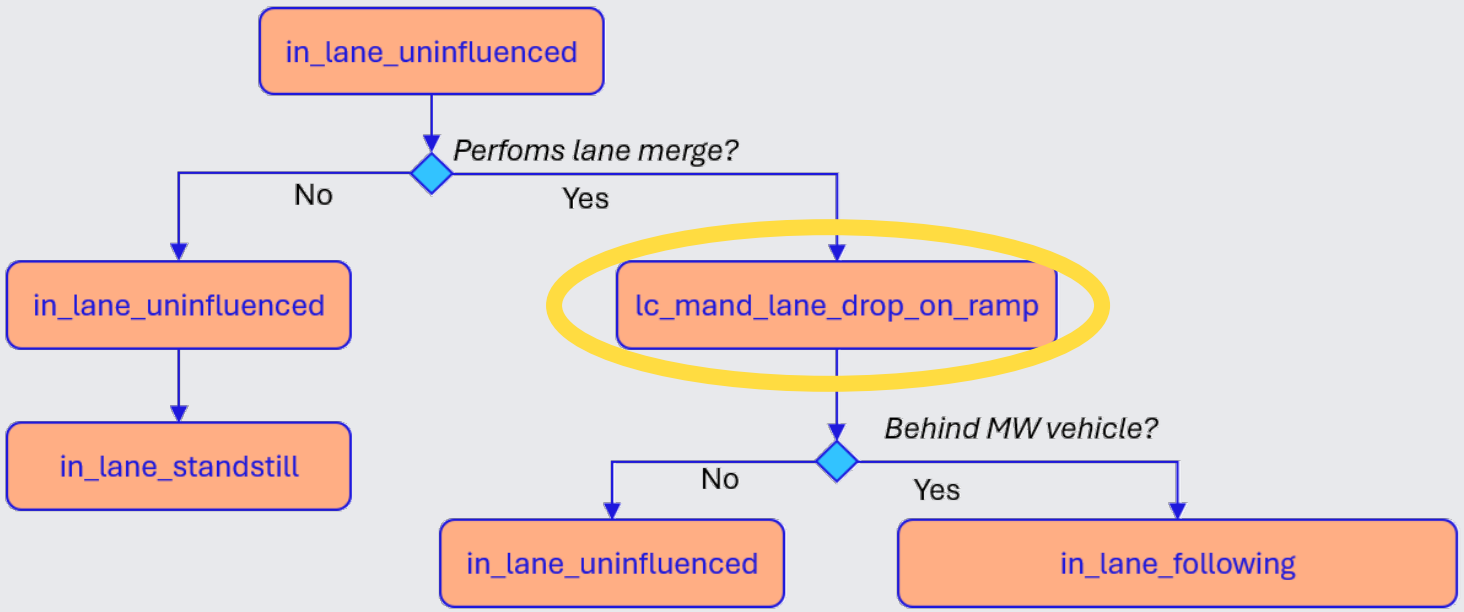
Per test: *Was the ramp vehicle able to merge? If so, where did it merge with respect to the motorway vehicle?*

	BADF			EADF		
Target TS	**% merge in front**	**% merge behind**	**% merge total**	**% merge in front**	**% merge behind**	**% merge total**
TS1	**6.9%**	**35.3%**	42.2%	**100.0%**	**0.0%**	100.0%
TS2	**13.3%**	**85.7%**	99.0%	**2.8%**	**97.2%**	100.0%
TS3	n.a.	n.a.	**34.8%**	n.a.	n.a.	**98.6%**

- **TS1, TS3: A drastic increase of the percentage of successful merge attempts when adding the enabler**
- In TS2, the percentage of successful merges is already close to 100% in BADF
  - showing that not having V2V is sufficient for the ADF to cope with this simplistic 2-actors scenario

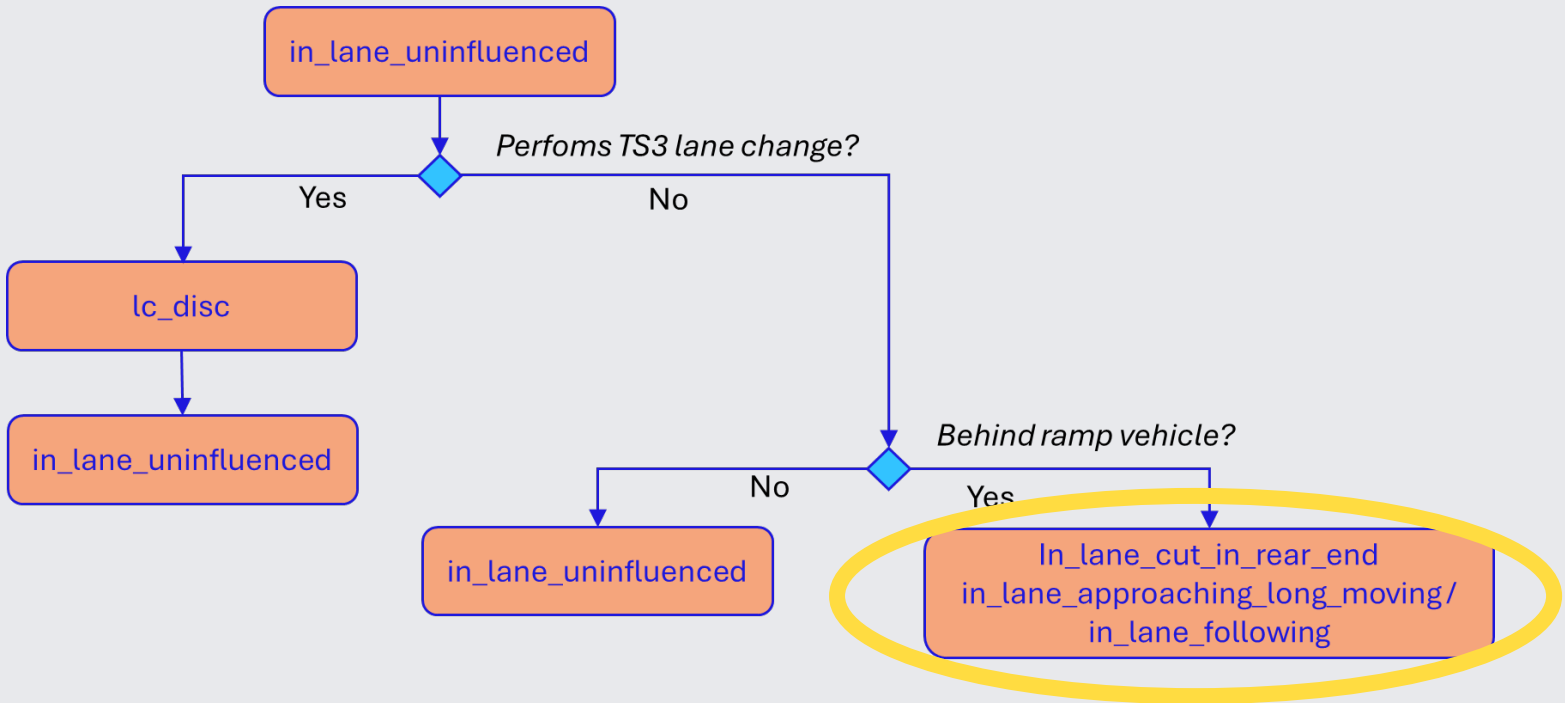
Research Area 2: Effects on ADS driving behaviour

Driving Scenarios tree-graph for the ramp vehicle

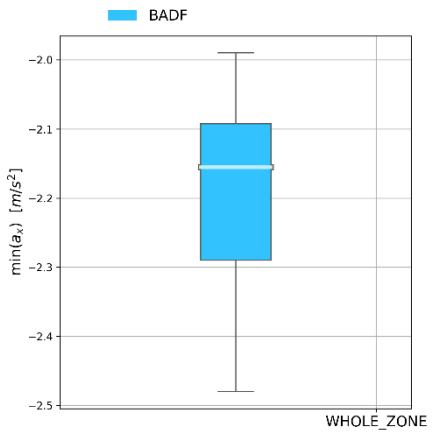


Research Area 2: Effects on ADS driving behaviour

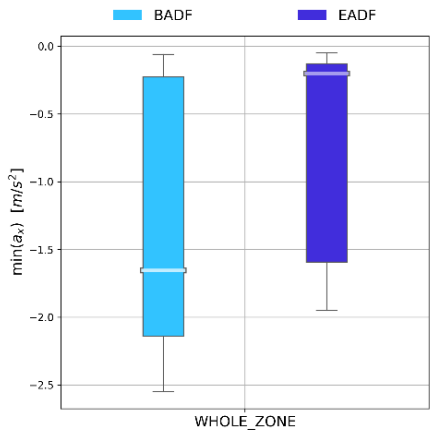
Driving Scenarios tree-graph for the motorway vehicle



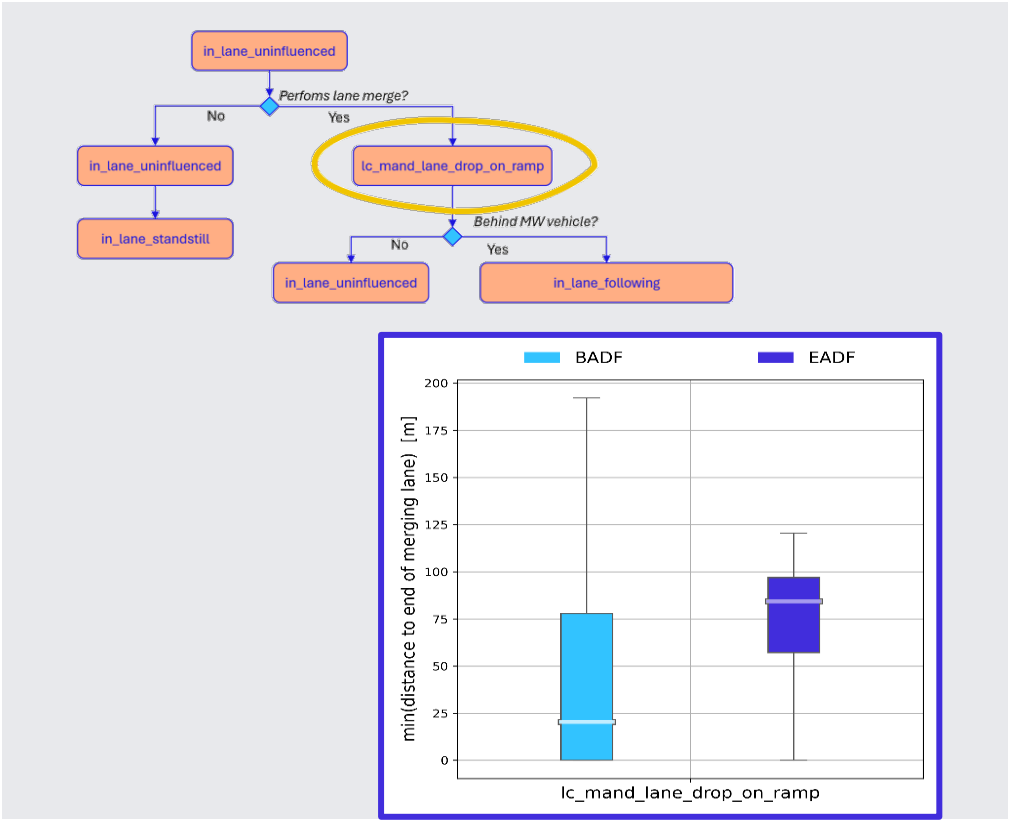
Research Area 2: Effects on ADS driving behaviour



No lane merge



With lane merge

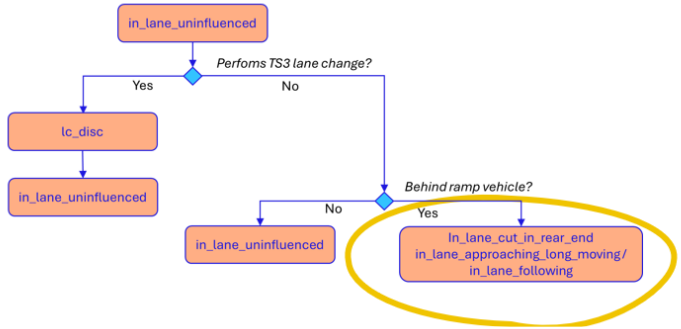


Ramp vehicle perspective: the lane merge manouvre

Without enabler:
merge happens close to the end of the merging zone
With enabler:
merge happens earlier

Research Area 2: Effects on ADS driving behaviour

Motorway vehicle perspective: Cut-in / approaching / following after the ramp vehicle has merged in front



	PI	P	Change [%]	Median BADF	Median EADF
Comfort	std (ax) [m/s²]	0.003	9.6	0.64	0.70
	min (ax) [m/s²]	<0.001	545	-0.1	-0.65
	max (ax) [m/s²]	0.007	8.7	2.1	2.3
	mean (ax) [m/s²]	0.16	13.0	0.34	0.39
Efficiency	std (v) [km/h]	0.35	-2.26	9.81	9.59
Interaction with Traffic	min (THW) [s]	<0.001	58.1	1.69	2.66
	min (TTC) [s]	<0.001	332.9	3.34	14.47
	mean (THW) [s]	<0.001	30.1	2.15	2.79

With enabler:

- Larger Time Headway
- Larger Time-To-Collision
- Realised by EADF using marginally higher decelerations than BADF

Conclusions

- Functional interoperability among various implementations of cooperative manoeuvring by different vehicle owners.

- Very positive ODD extension results with V2V
  - In the challenging Test Scenarios TS1 and TS3, the percentage of trials where the ramp vehicle was able to merge increased from less than 50% without enabler to (almost) 100% with enabler.

- ADF driving behaviour with V2V
  - Results confirm favourable effects of the enabler in terms of safety in interaction with other traffic (larger THW) and efficiency in merging in a convenient average distance of 85 meters from the end of the merging lane.

GOING BACK TO THE OVERVIEW ...

Key take away messages & outlook

- Results in terms of ODD extension were very positive in both public roads and test track (reaching 100% of successful test runs in many UCs)
  - **Infra:** Motorway entries/exits/tunnels/CS
  - **Weather:** Lanes covered by snow
  - **DDT:** Overtaking
- Results on safe driving behaviour and interaction with surrounding traffic were very positive in test tracks.
  - Extension of FoV via V2X proved substantially useful under urban occlusion and motorway hazards situations
- Results on efficient driving performance were positive during both AD active and MRM execution, outperforming driving under BADF.

- D7.1 lays the foundations for future research on advanced AD functionality development and testing as it includes all the details on experimental setups, dedicated performance indicators per type of enabler and per AD driving behaviour research area as well as the challenges and items of future work that resulted from the analysis
  - Evaluation of EADF behaviour in controlled test environments is more straightforward than this in public roads since the Enablers' effects can be more easily isolated and analysed.
  - After establishing these first PoCs, experimentation in test tracks with more actors in order to increase realism is recommended as future work.
- This work complements the technical evaluation on technology enabler's features reported in Hi-Drive deliverable D2.3 *Outlook of future enablers KPIs for AD/CAD* (Bellotti et al., 2025)
- Evaluation of impacts under AD different penetration rates can be accomplished in simulations, check impact assesement Deliverables and next presentation.

Hi-Drive

FINAL EVENT

25 NOVEMBER 2025

Anastasia Bolovinou| ICCS
anastasia.bolovinou@iccs.gr

hi-drive.eu

company/hi-drive

Co-funded by the
European Union under
Horizon 2020 programme
Grant Agreement No. 101006664

Supported by the
European Concil
Automotive R&D