INFRAMIX

INFRAMIX overview and highlights

Martin Dirnwoeber / AustriaTech

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 723016.

Project overview

Duration: 1 June 2017-31 May 2020

EC Funding: 5M €

Coordinator: AustriaTech

Consortium:

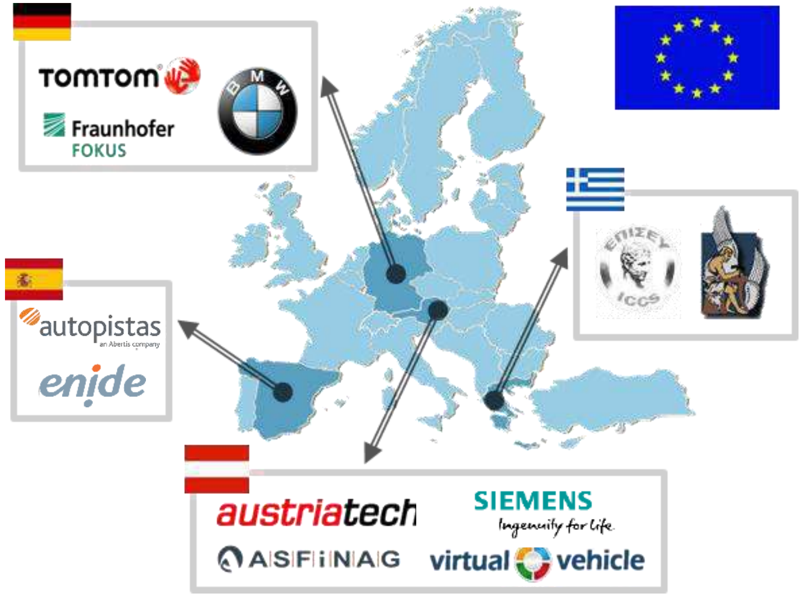
AustriaTech, ICCS,

Asfinag, Fraunhofer, Siemens Mobility,

Virtual Vehicle, Autopistas,

Enide, Technical University of Crete,

TomTom, BMW



Avoiding decrease of safety and efficiency by infrastructure support

Mixed traffic situations will increase

→

Mixed traffic situations will decrease efficiency and safety

→

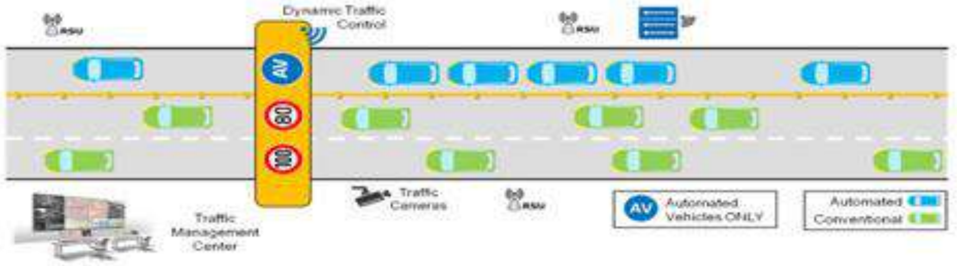
Infrastructure support can increase efficiency and safety

Support from infrastructure at different levels

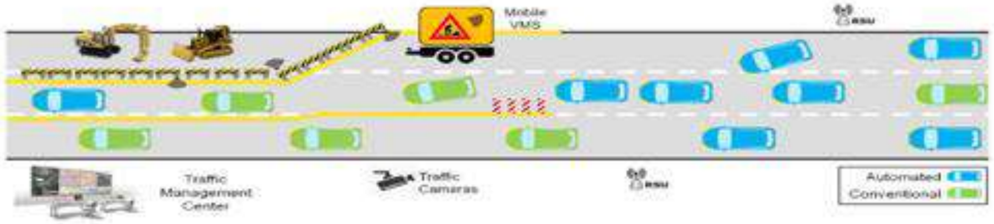
Support perception capability of AVs	• extend e-horizon (e.g. road works with lane deviations or incidents ahead) including information on detailed lane layout in road work zones
Improve conditions for AV manoeuvres	• Lane change advice before an on-ramp creating more space for merging (automated) vehicles
Support drivers of conv. vehicles	• New lane markings for AD lanes
Improve traffic situation	• Provide recommendations to connected and automated vehicles to increase efficieny (e.g. gap advice in bottlenecks)

3 Scenarios – 3 key areas

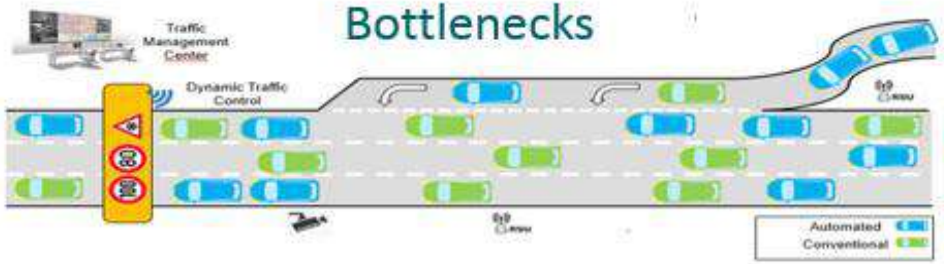
Dynamic lane assignment to automated driving



Roadworks zone



Bottlenecks



Approach and highlights

Solutions	Evaluation	Recommen-dation
Traffic control strategies	Simulation – microscopic	Infrastructure classification
Estimation algorithms	Simulation – submicroscopic	Safety parameters
Digital infra elements	Real world implementation	Roadmap
Physical infra elements	Hybrid – simulation and real world	Exploitation plans

Poll question

What will be the most important function of digital road infrastructure?

- supporting automated vehicles functions
- facilitating new ways of traffic management through interaction with automated and connected vehicles
- integrating new mobility services in the transport system (e.g. by management of intermodal hubs)
- enabling new ways of road maintenance

INFRAMIX

Martin Dirnwoeber

austriatech

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 723016.

INFRAMIX online final conference

Physical and digital infrastructure

Daniel Tötzl, Siemens Mobility Austria GmbH

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 723016.

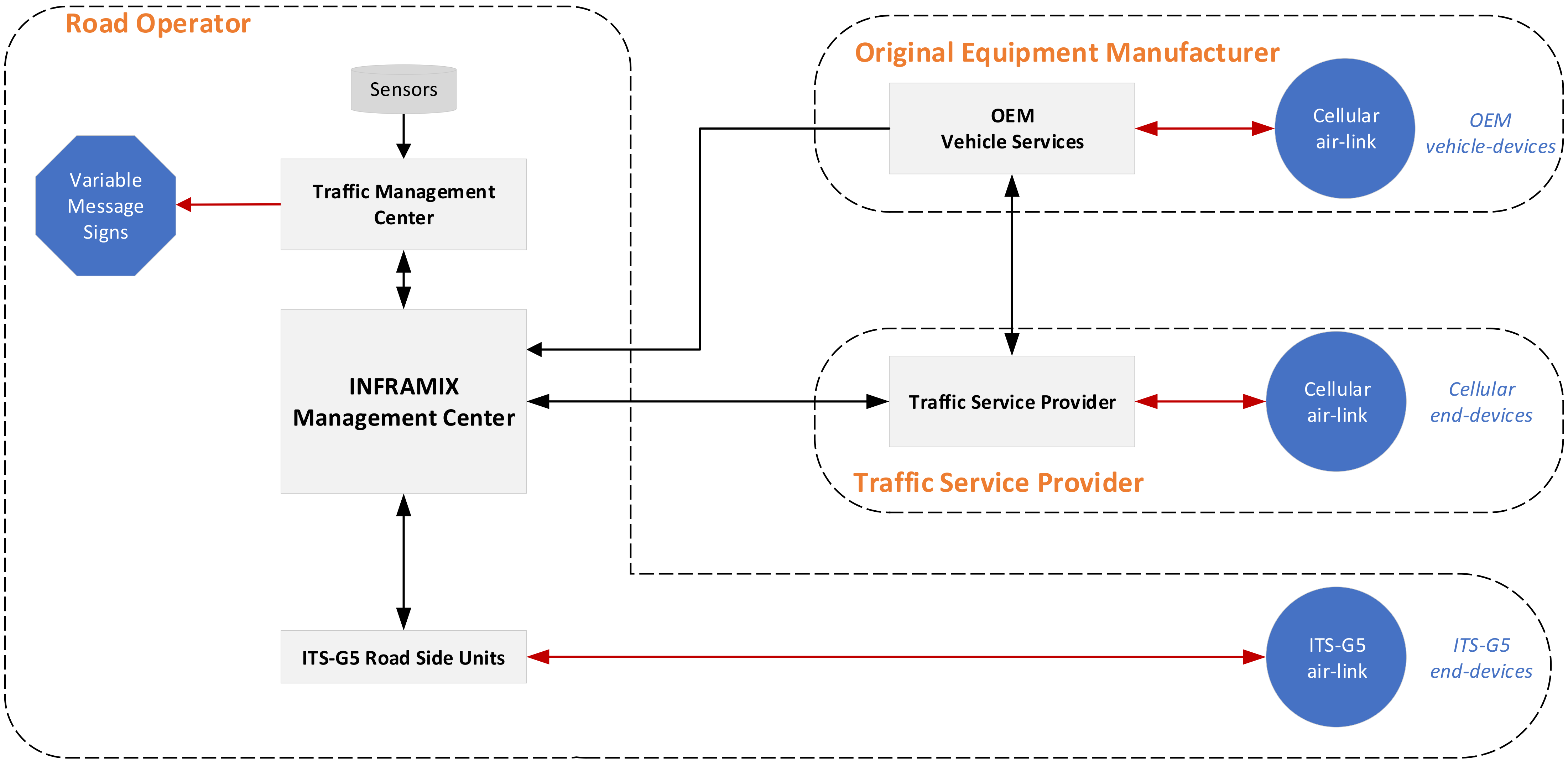
Initial situation & objectives

- Design and development of infrastructure elements
  - Considering existing systems
  - Design & development of system enhancements

- Traffic Management
  - Integration of new traffic control & estimation algorithms
  - Analysis of required input-data
  - Implementation of data-interfaces

- Communication between the infrastructure and end users
  - Analysis of visual "needs" and gaps for conventional vehicles
  - Application of a digital hybrid communication
  - Application & enhancement of existing standardized message-types

INFRAMIX architecture



INFRAMIX end-to-end process

INFRAMIX

Repetitive 3-step approach:

Data provision → **Evaluation & Processing** → **Distribution**

Provision of traffic data

Provided by:
- Road Operator
- Traffic Service Provider
- Original Equipment Manufacturer

Traffic Estimation &
Traffic Control Strategies

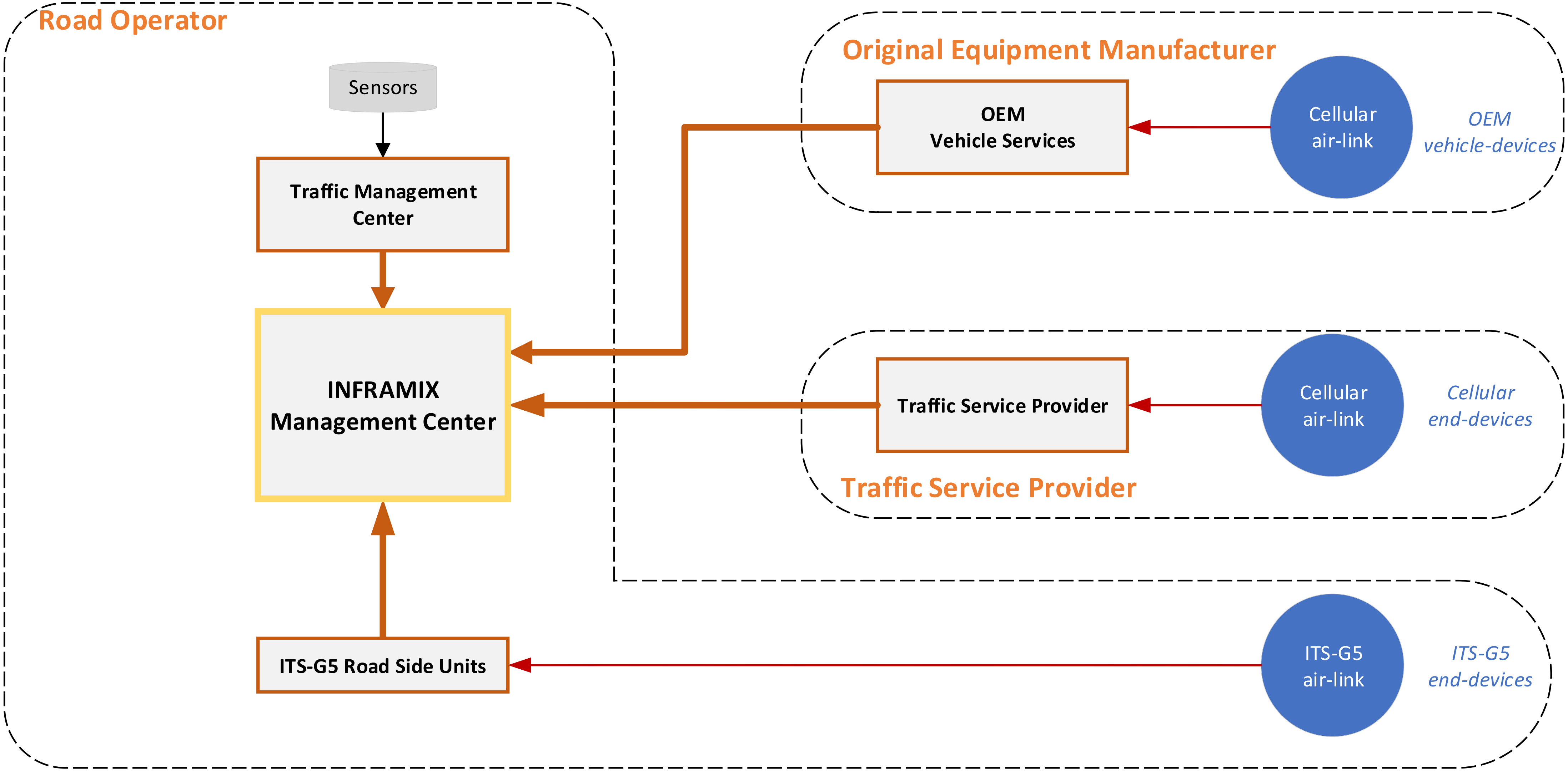
Performed by:
- Road Operator

Traffic control commands

Performed by:
- Road Operator
- Traffic Service Provider
- Original Equipment Manufacturer

Data provision

Data provision → Evaluation & Processing → Distribution

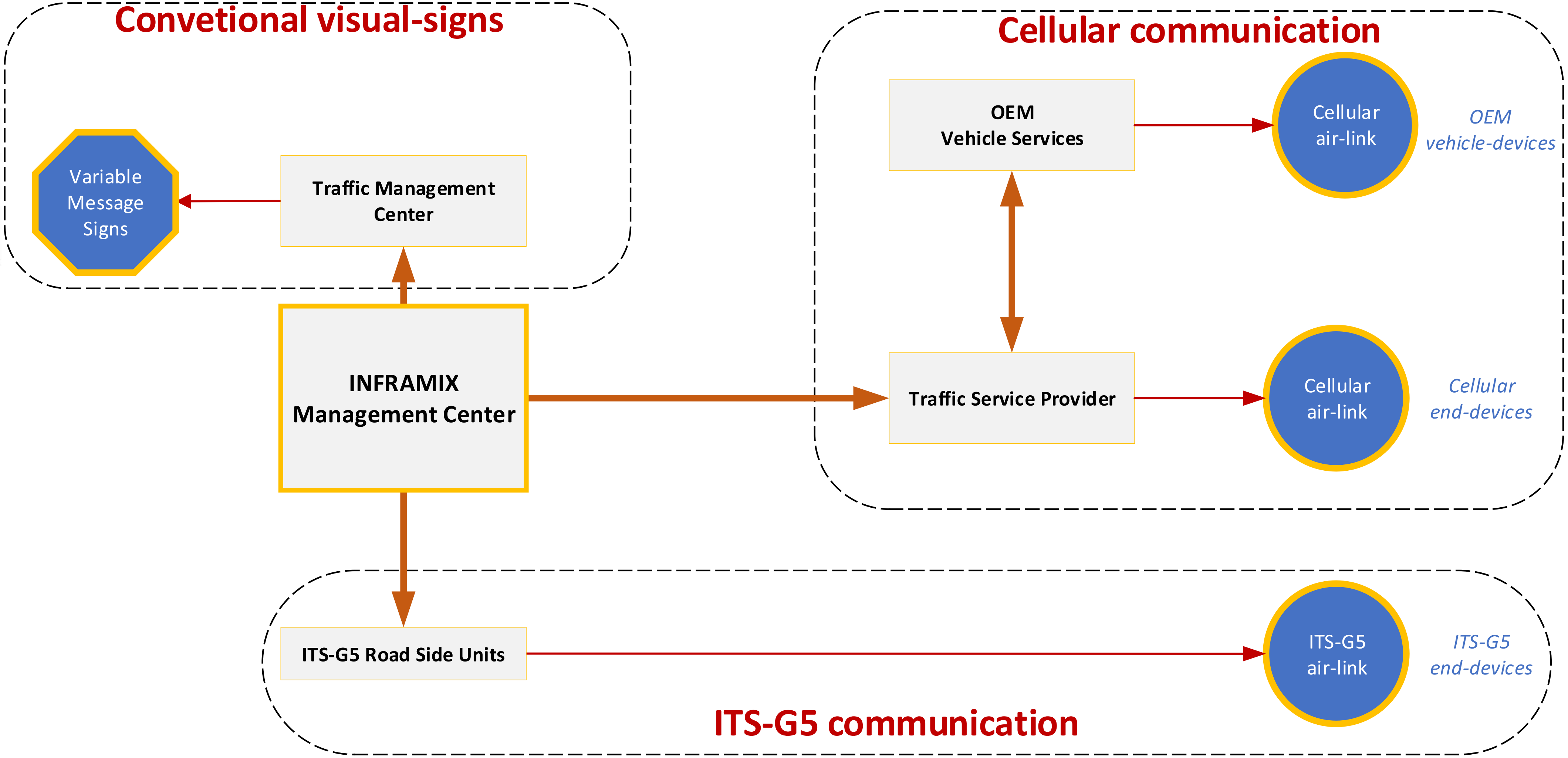


Evaluation & Processing

- INFRAMIX Management Center processes traffic data in order to perform:
  - Traffic estimation algorithms
  - Traffic control algorithms

- Provides traffic management capabilities to execute:
  - Dynamic Lane assignment
  - Time-gap advices
  - Variable speed limits
  - Lane change advices

Distribution



Conclusion

- The INFRAMIX end-to-end solution underlines the combined effect of different stakeholders to support the mixed traffic
- The resulting system architecture reveals the importance of having one reliable central source to perform a generic traffic management
- Digital hybrid-communication approach reveals positive effects for supporting the future arising mixed traffic

Thank you for your attention!

Daniel Tötzl

daniel.toetzl@siemens.com

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 723016.

Q & A

INFRAMIX

INFRAMIX online final conference

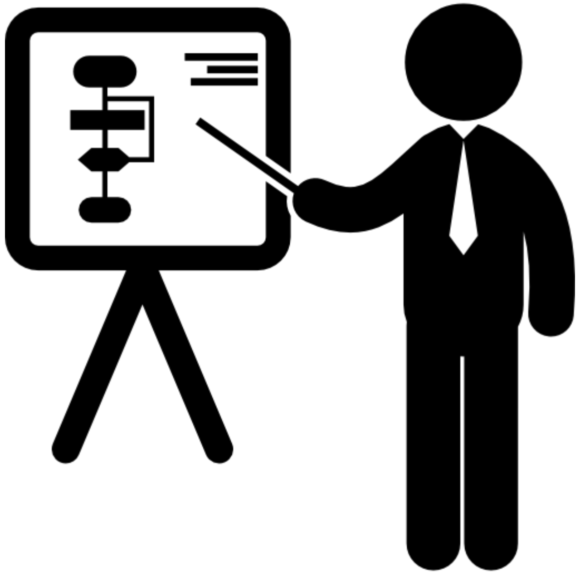
ISAD classes

Dr. Panagiotis Lytrivis / ICCS

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 723016.

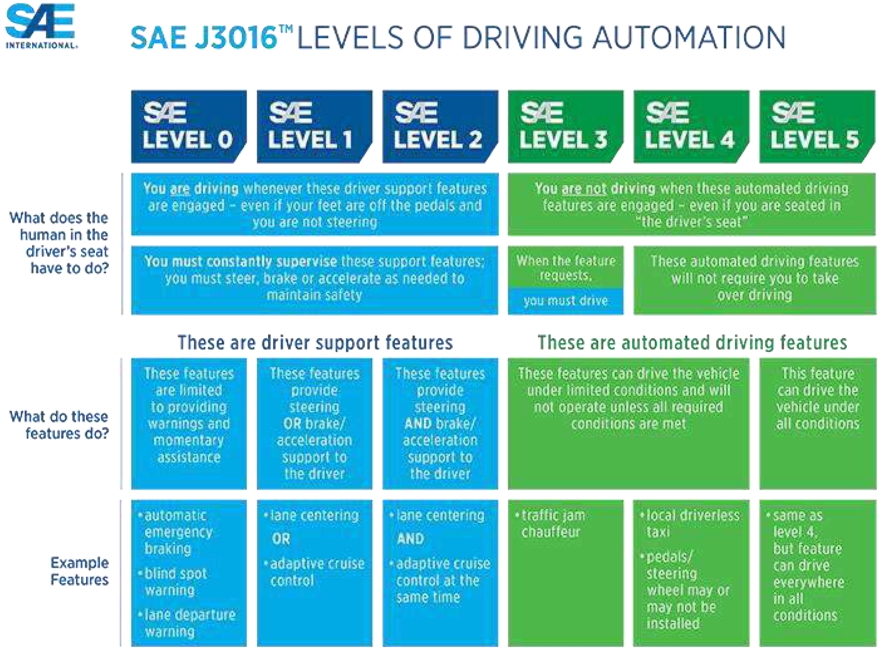
Outline

- Motivation
- Methodology
- ISAD classes overview
- Conclusions & Next steps
- Sources



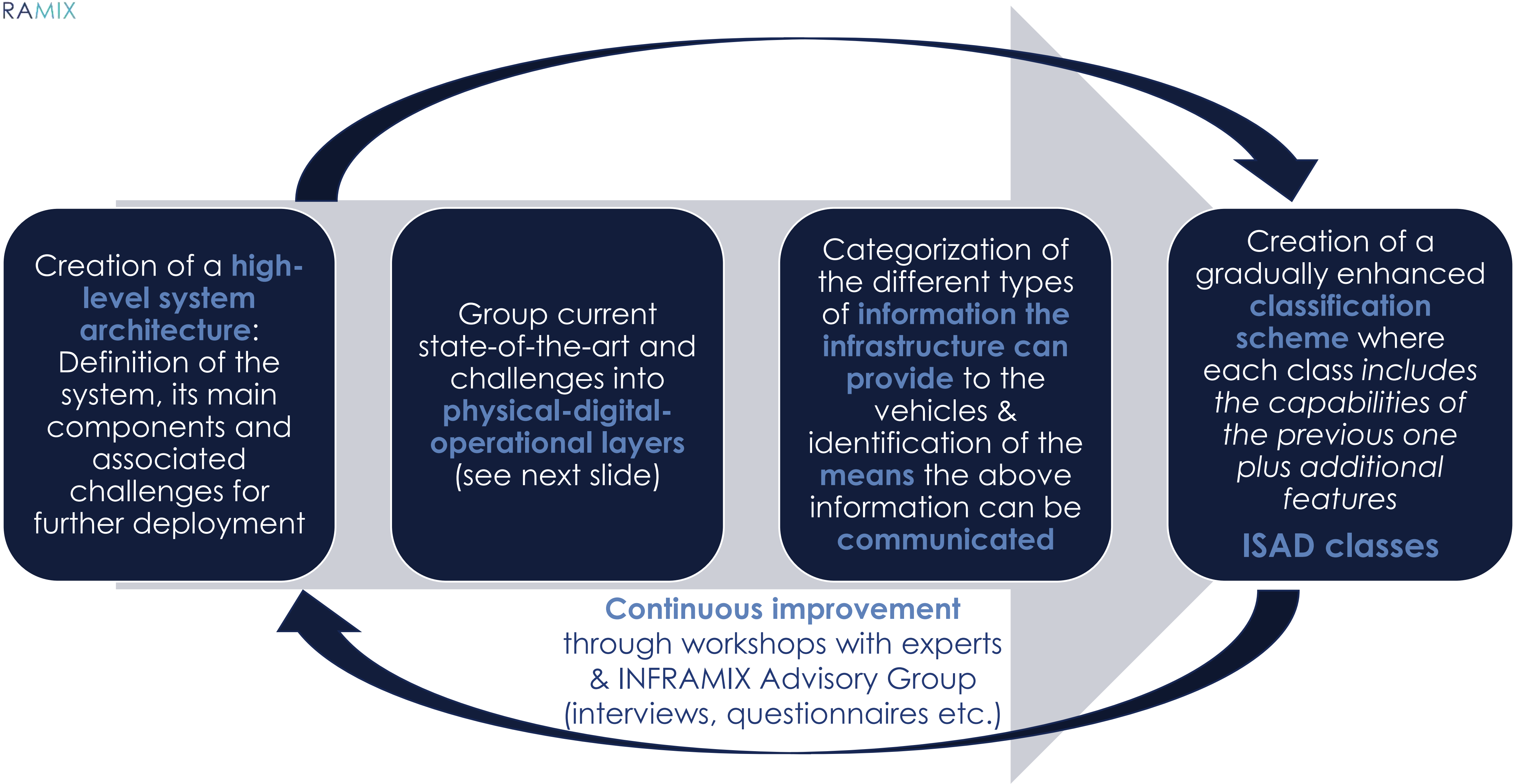
Motivation

- The focus in the recent years is mainly on the **“vehicle” side** of the transport ecosystem
  - Automated driving (AD) (evolution of ADAS)
  - Taxonomy of AD (SAE levels)
- Role of the **infrastructure** in AD:
  - Support the **transition period** and **mixed traffic**
  - Enhance **electronic horizon** of connected and automated vehicles
  - Facilitate the **cooperation** between different types of vehicles with different capabilities
  - **Manage** and control **traffic** in an efficient and safe way avoiding potential bottlenecks
  - Provide consistent **electronic** and **visual signals** for all types of vehicles



Taxonomy (ISAD classes)

ISAD – Methodology



Road Infrastructure – Physical, Digital & Operational

Traffic-management functions which facilitate the traffic flow by providing information or guidance

Operational

Road Infrastructure

The road, road signs, road markings, communication infrastructure and so on that form part of the physical world where vehicles operate

Static and dynamic digital representations of the physical world with which AVs interact

Digital

Physical

INFRAMIX

ISAD Classes

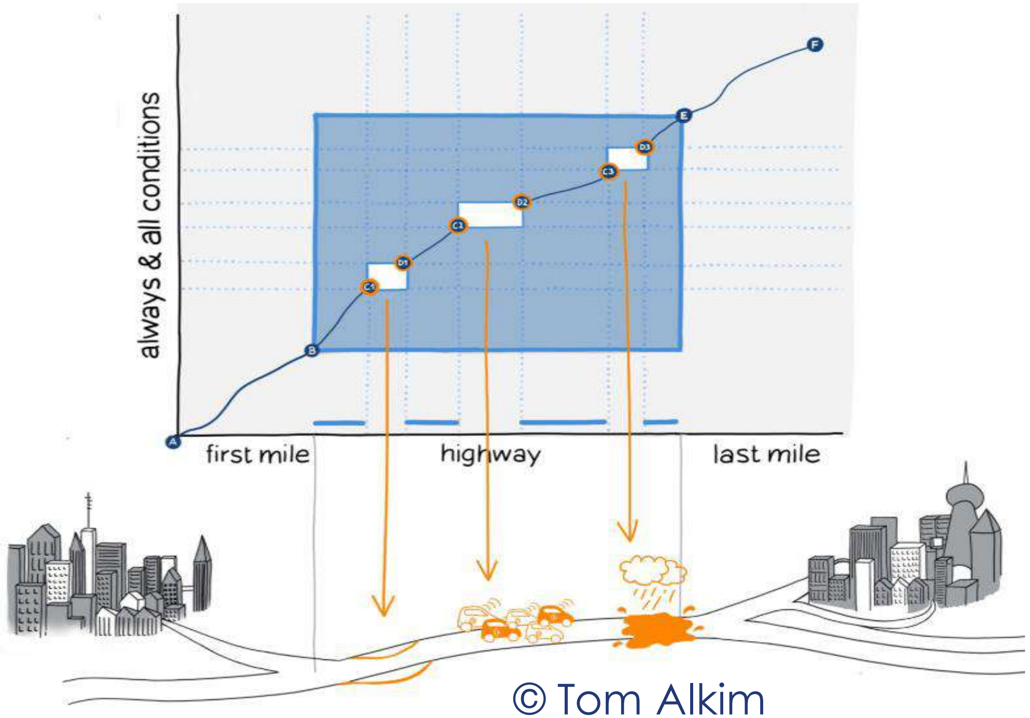
- Incremental classes

"E": typical/conventional

"A": most advanced

	Level	Name	Description	Digital information provided to AVs			
				Digital map with static road signs	VMS, warnings, incidents, weather	Microscopic traffic situation	Guidance: speed, gap, lane advice
Conventional infrastructure	E	Conventional infrastructure / no AV support	Conventional infrastructure without digital information. AVs need to recognise road geometry and road signs.				
Conventional infrastructure	D	Static digital information / Map support	Digital map data is available with static road signs. Map data could be complemented by physical reference points (landmarks signs). Traffic lights, short term road works and VMS need to be recognized by AVs.	X			
Digital infrastructure	C	Dynamic digital information	All dynamic and static infrastructure information is available in digital form and can be provided to AVs.	X	X		
Digital infrastructure	B	Cooperative perception	Infrastructure is capable of perceiving microscopic traffic situations and providing this data to AVs in real-time.	X	X	X	
Digital infrastructure	A	Cooperative driving	Based on the real-time information on vehicle movements, the infrastructure is able to guide AVs (groups of vehicles or single vehicles) in order to optimize the overall traffic flow.	X	X	X	X

Conclusions & Next steps



© Tom Alkim

- The goal of the work is to provide a **guide for incremental upgrades** of the road infrastructure (physical, digital)
- The work was targeting **highways** but could be easily extended to **urban** and rural roads
- Enhancement of the scheme to become a **dynamic** and continuous classification based on current road situation, offered TMC capabilities, etc.
- Investigate how ISAD can support closing the **ODD** (Operational Design Domain) gaps

Sources

1. Book on C-ITS (Chapter 14)

- Amditis, A., Lytrivis, P., Papanikolaou, E., Carreras, A., Daura, X. (2019).
- "Road infrastructure taxonomy for connected & automated driving".
- Chapter 14 in: Lu, M. (ed.). Cooperative intelligent transport systems. Towards high-level automated driving, IET, pp. 309–325

Chapter 14

Road infrastructure taxonomy for connected and automated driving

Angelos Amditis[1], Panagiotis Lytrivis[1], Evdokia Papanikolaou[1], Anna Carreras[2] and Xavier Daura[2]

14.1 Introduction

The majority of the research efforts related to automated driving is focused on the vehicle side. Only recently, the role of the road infrastructure and how it can support the gradual insertion of Automated Vehicles (AVs) attracted attention. In particular, the upgrades of the infrastructure in terms of connectivity, along with Traffic-Management Centres (TMCs) deployment, are recognized as indispensable parts for data exchange and management of mixed vehicle traffic flows. Apart from the minimum road infrastructure quality standards (e.g. clear lane markings, visibility of signs), the kind of support provided by the infrastructure to the AVs (e.g. availability of highly accurate maps, guidance via wireless messages, detailed weather information and recommendations for optimum route) is important information which is expected to increase the use of automated functions while driving.

The taxonomy of the infrastructure and the relevant requirements to support cooperative traffic have been investigated by many researchers. An early attempt to cluster infrastructure in different levels was made in [1]. At the lowest level, named 'the infrastructure supported', the road infrastructure supports vehicle decision-making, while at the highest level, named 'the infrastructure controlled', the infrastructure has the full traffic control in all driving situations. Almost a decade later, preliminary infrastructure requirements have been set for a coordinated automated road transport future, as it is envisioned in [2]. In [3], the potential support that the road infrastructure could provide towards automation in road transport is pointed out. Furthermore, in [4], a cooperative road transportation future is presented where the infrastructure has an indispensable role.

[1]Institute of Communication and Computer Systems (ICCS), I-SENSE Group, Athens, Greece
[2]Innovation Department, Abertis Autopistas España, Barcelona, Spain

2. Infrastructure Classification Scheme (D5.4)

- Public deliverable available online: https://www.inframix.eu/wp-content/uploads/D5.4-Infrastructure-Classification-Scheme.pdf

Thank you for your attention!

Dr. Panagiotis Lytrivis

Senior Researcher, ICCS

panagiotis.Lytrivis@iccs.gr

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 723016.

INFRAMIX

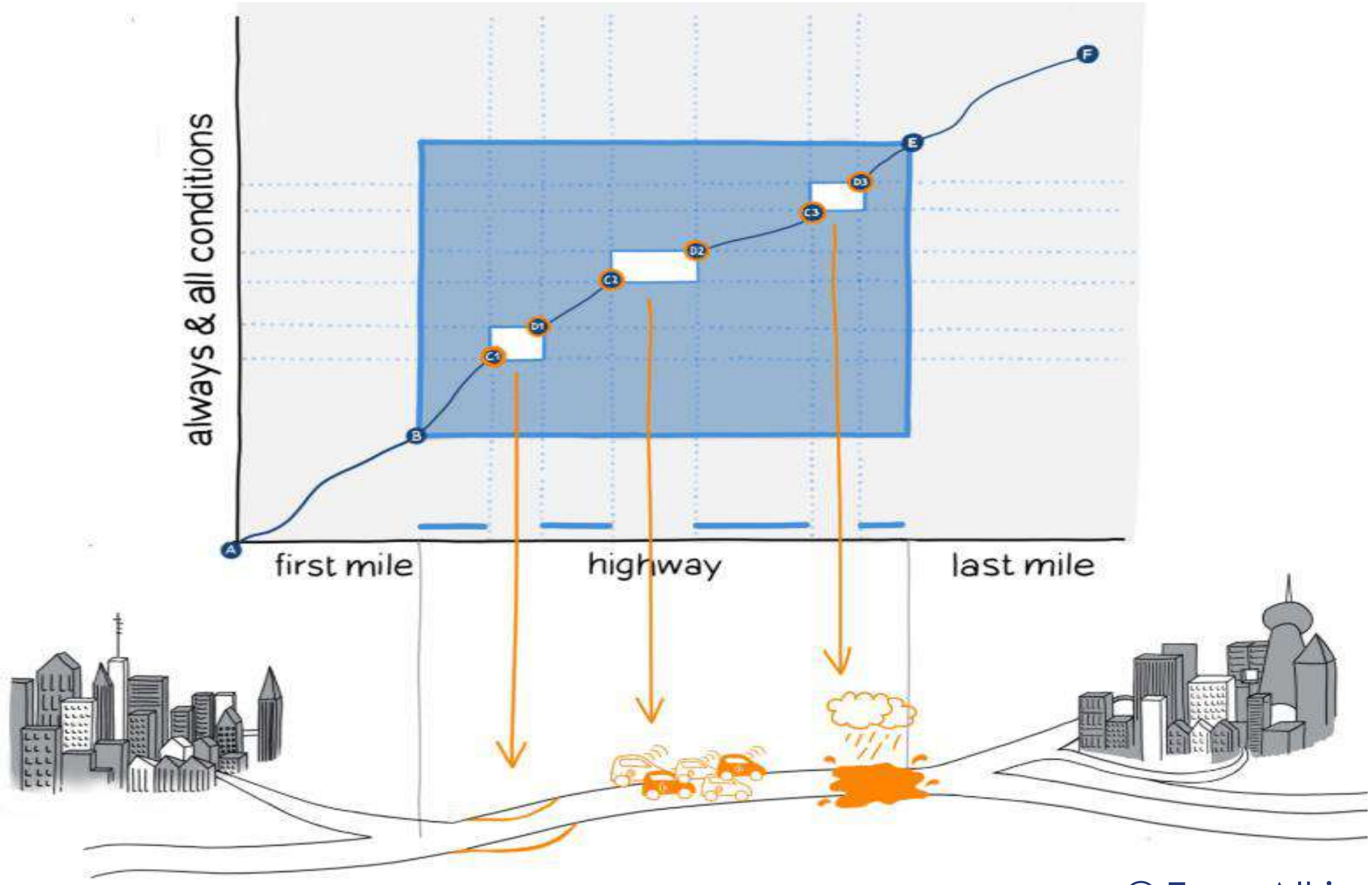
INFRAMIX online final conference

ISAD classes examples

Yannick Wimmer / ASFINAG

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 723016.

Infrastructure can help to close ODD* gaps by providing support

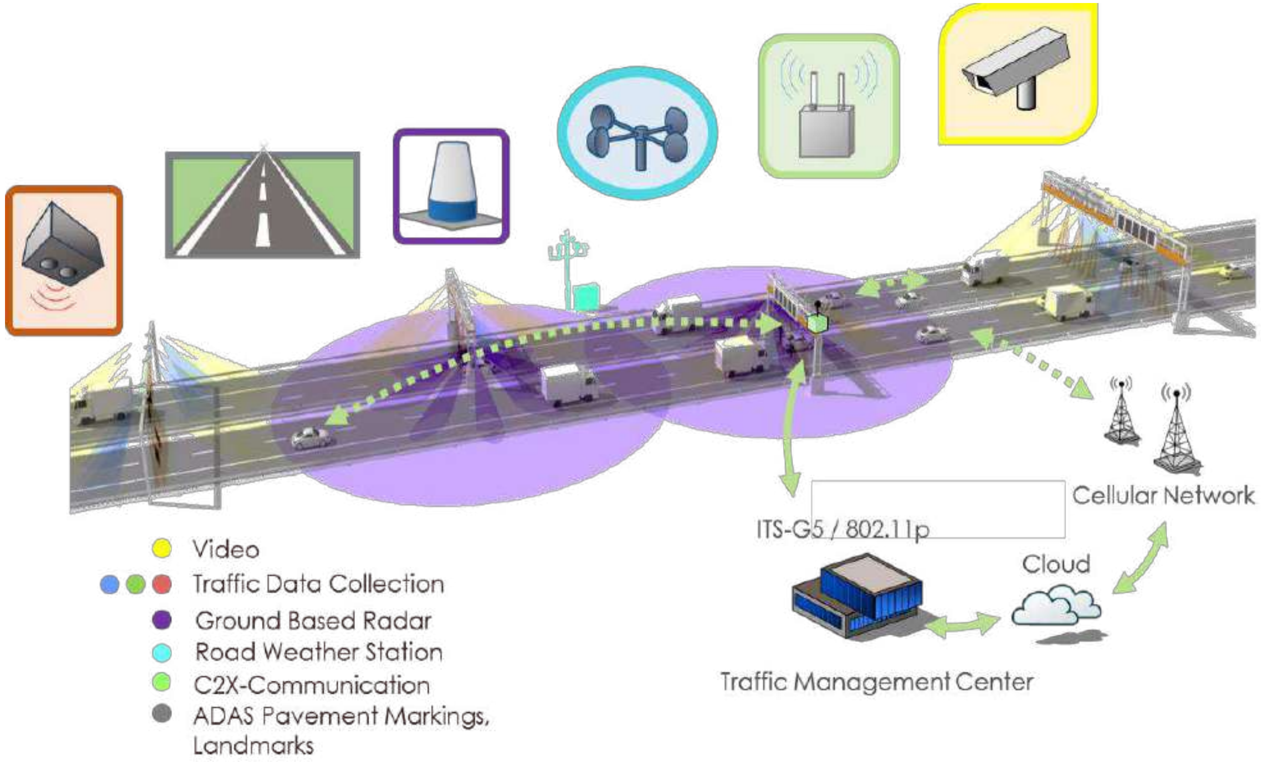


© Tom Alkim

*ODD: Operational design domain

Connecting Infrastructure and Vehicles improves traffic

Infrastructure equipment on Austrian motorways



Dynamic Displays:
Events are served by the **traffic control center**

Weather Station → **Environment data**

Traffic Detectors → **Traffic data collection**

Cameras → **Video detection**

Radar Sensors → **Trajectory detection**

C-ITS-Roadside Units for **ITS-G5 communication**

Data interface for **cellular applications**

ISAD Classification Scheme

	ISAD	Name	Infrastructure side	AV side	Digtial information provided to AVs: Digital map with road signs	VMS warnings, incidents, weather	Microscopic traffic situations	Guidance: speed, gap, lane advice
Conventional infrastructure	E	Conventional infrastructure / no AV support		Road geometry and road signs have to be recognized by AVs on their own				
	D	Static digital information / map support	Digital map data (including static road signs) complemented by physical reference points	Traffic lights, short-term road works and VMS have to be recognized by AVs on their own				
Digital infrastructure	C	Dynamic digital information	All static and dynamic information can be provided to the AVs in digital form	AVs perceive infrastructure support data				
	B	Cooperative perception	Infrastructure is capable of perceiving microscopic traffic situations	AVs perceive infrastructure support data in real time (C-ITS Day 1)				
	A	Cooperative driving	Infrastructure is capable of perceiving vehicle trajectories and guide single AVs (or AV groups)	AVs are guided by the infrastructure in order to optimise traffic flow (C-ITS Day 2+)				

ISAD Classification Scheme (Carreras et al. 2018)

	ISAD	Name	Infrastructure side	AV side	Digtial information provided to AVs: Digital map with road signs	VMS warnings, incidents, weather	Microscopic traffic situation	Guidance: speed, gap, lane advice
Conventional Infrastructure	E	Conventional infrastructure / no AV support		Road geometry and road signs have to be recognized by AVs on their own				

ISAD Classification Scheme (Carreras et al. 2018)

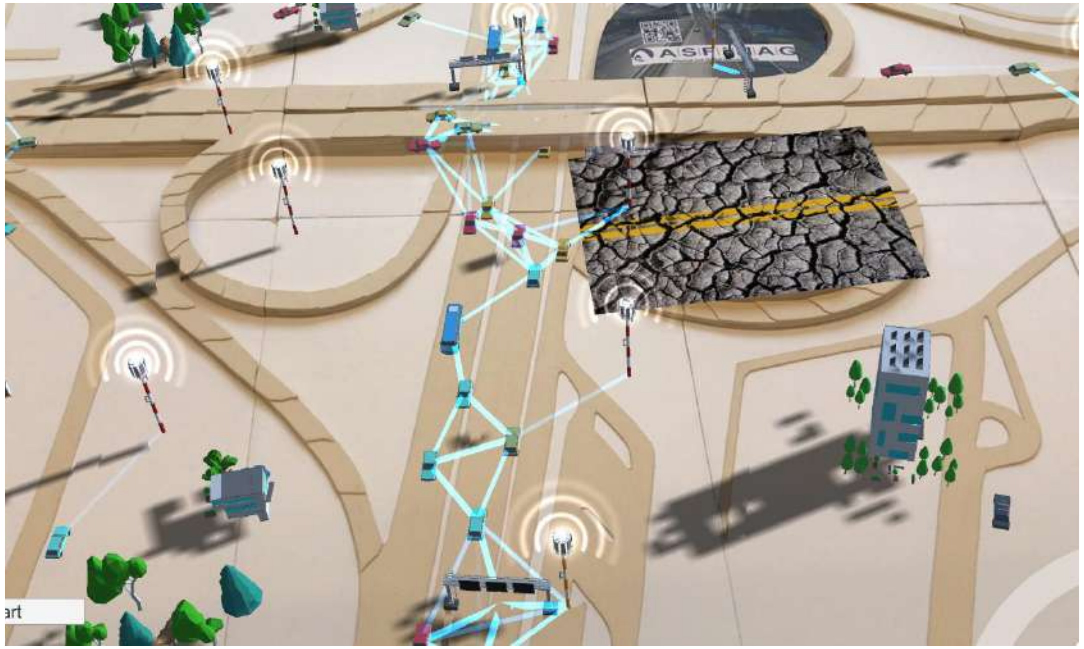
	ISAD	Name	Infrastructure side	AV side	Digtial information provided to AVs: Digital map with road signs	VMS warnings, incidents, weather	Microscopic traffic situation	Guidance: speed, gap, lane advice
Conventional Infrastructure	E	Conventional infrastructure / no AV support		Road geometry and road signs have to be recognized by AVs on their own				
	D	Static digital information / map support	Digital map data (inlcuding static road signs) complemented by physical reference points	Traffic lights, short term road works and VMS have to be recognized by AVs on their own				

ISAD Classification Scheme (Carreras et al. 2018)

	ISAD	Name	Infrastructure side	AV side	Digtial information provided to AVs: Digital map with road signs	VMS warnings, incidents, weather	Microscopic traffic situation	Guidance: speed, gap, lane advice
Conventional Infrastructure	E	Conventional infrastructure / no AV support		Road geometry and road signs have to be recognized by AVs on their own				
	D	Static digital information / map support	Digital map data (inlcuding static road signs) complemented by physical reference points	Traffic lights, short term road works and VMS have to be recognized by AVs on their own				
Digital Infrastructure	C	Dynamic digital information	All static and dynamic information can be provided to the AVs in digital form	AVs perceive infrastructure support data				

ISAD Classification Scheme (Carreras et al. 2018)

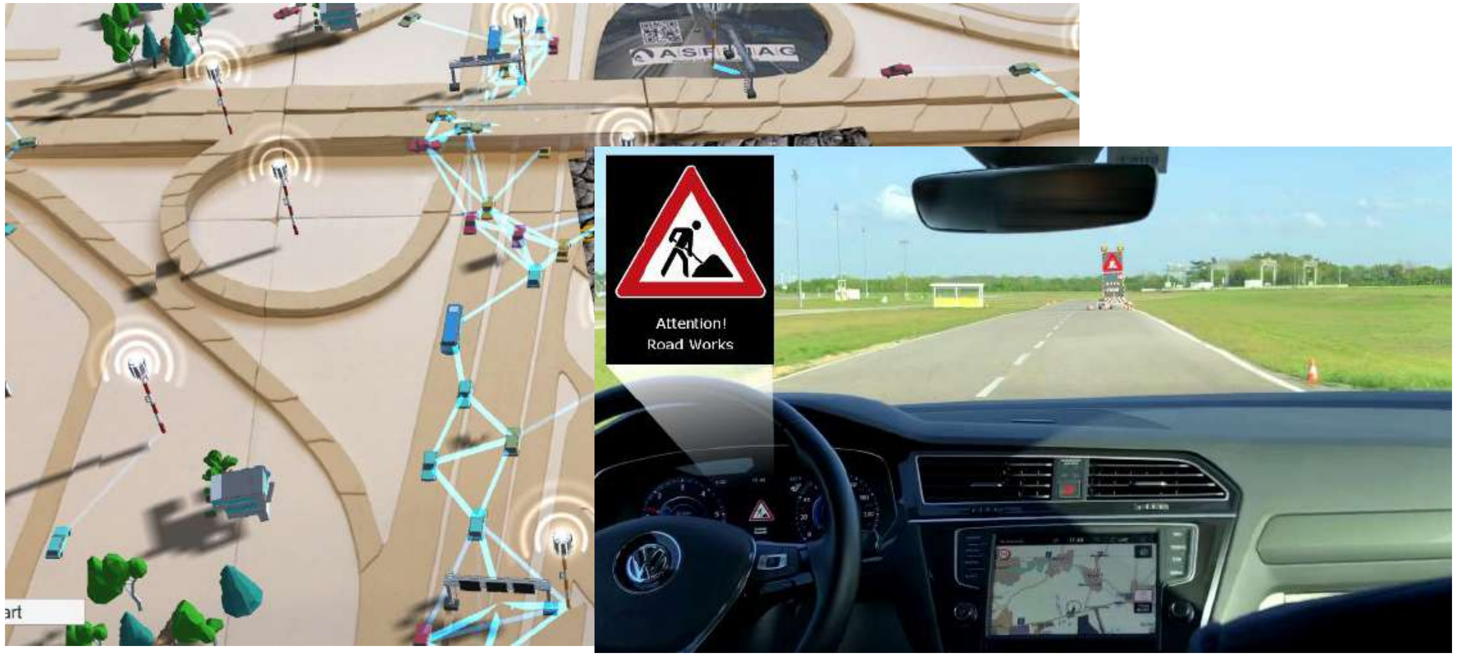
	ISAD	Name	Infrastructure side	AV side	Digtial information provided to AVs: Digital map with road signs	VMS warnings, incidents, weather	Microscopic traffic situation	Guidance: speed, gap, lane advice
Conventional Infrastructure	E	Conventional infrastructure / no AV support		Road geometry and road signs have to be recognized by AVs on their own				
	D	Static digital information / map support	Digital map data (inlcuding static road signs) complemented by physical reference points	Traffic lights, short term road works and VMS have to be recognized by AVs on their own				
Digital Infrastructure	C	Dynamic digital information	All static and dynamic information can be provided to the AVs in digital form	AVs perceive infrastructure support data				
	B	Cooperative perception	Infrastructure is capable of percieving microscopic traffic situations	AVs perceive infrastructure support data in real time (C-ITS Day 1)				



ISAD Classification Scheme (Carreras et al. 2018)

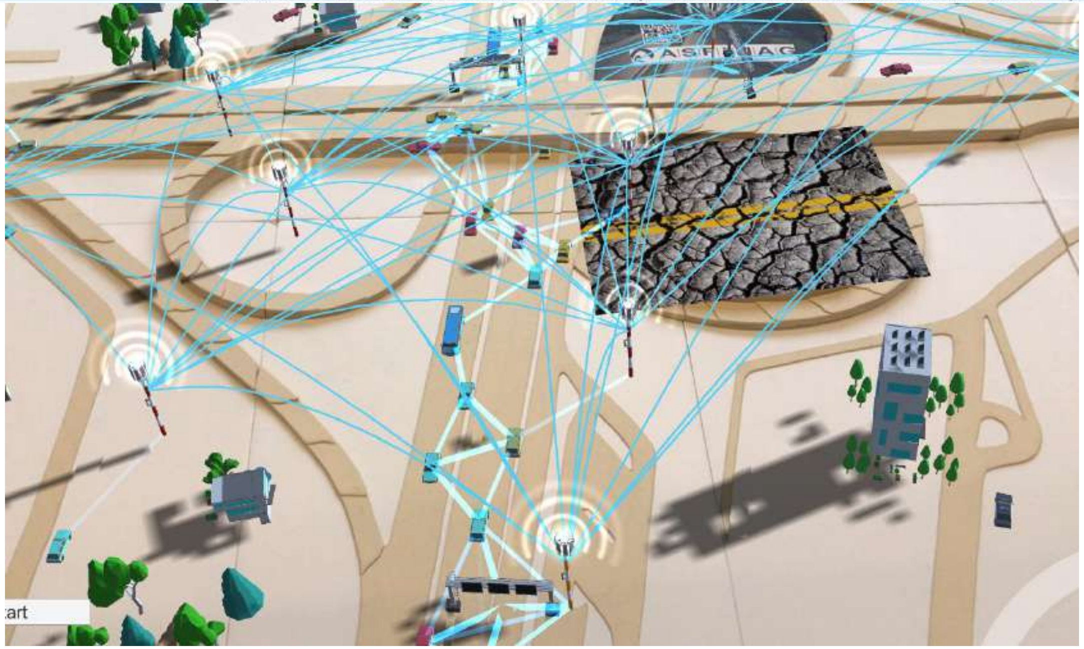
	ISAD	Name	Infrastructure side	AV side	Digital map with road signs	VMS warnings, incidents, weather	Microscopic traffic situation	Guidance: speed, gap, lane advice
Conventional Infrastructure	E	Conventional infrastructure / no AV support		Road geometry and road signs have to be recognized by AVs on their own				
	D	Static digital information / map support	Digital map data (inlcuding static road signs) complemented by physical reference points	Traffic lights, short term road works and VMS have to be recognized by AVs on their own				
Digital Infrastructure	C	Dynamic digital information	All static and dynamic information can be provided to the AVs in digital form	AVs perceive infrastructure support data				
	B	Cooperative perception	Infrastructure is capable of percieving microscopic traffic situations	AVs perceive infrastructure support data in real time (C-ITS Day 1)				

Digtial information provided to AVs



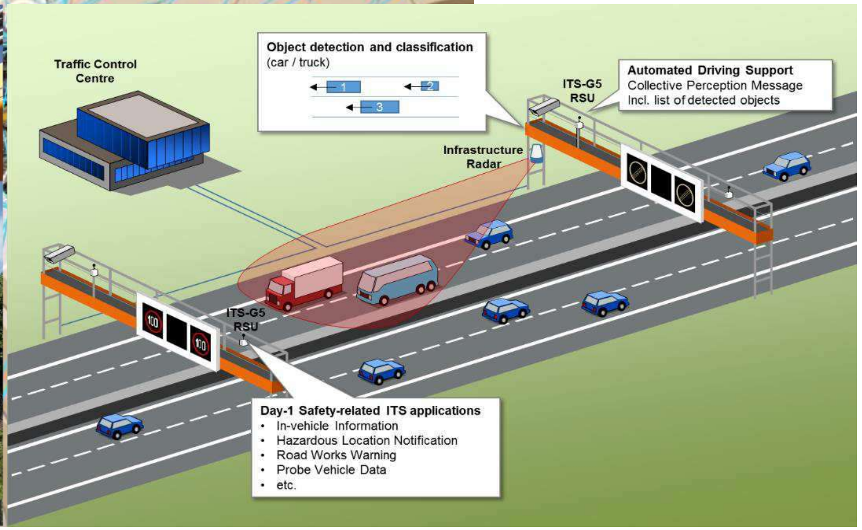
ISAD Classification Scheme (Carreras et al. 2018)

	ISAD	Name	Infrastructure side	AV side	Digtial information provided to AVs: Digital map with road signs	VMS warnings, incidents, weather	Microscopic traffic situation	Guidance: speed, gap, lane advice
Conventional Infrastructure	E	Conventional infrastructure / no AV support		Road geometry and road signs have to be recognized by AVs on their own				
	D	Static digital information / map support	Digital map data (inlcuding static road signs) complemented by physical reference points	Traffic lights, short term road works and VMS have to be recognized by AVs on their own				
Digital Infrastructure	C	Dynamic digital information	All static and dynamic information can be provided to the AVs in digital form	AVs perceive infrastructure support data				
	B	Cooperative perception	Infrastructure is capable of percieving microscopic traffic situations	AVs perceive infrastructure support data in real time (C-ITS Day 1)				
	A	Cooperative driving	Infrastructure is capable of percieving vehicle trajectories and guide single AVs (or AV groups)	AVs are guided by the infrastructure in order to optimize traffic flow (C-ITS Day 2+)				



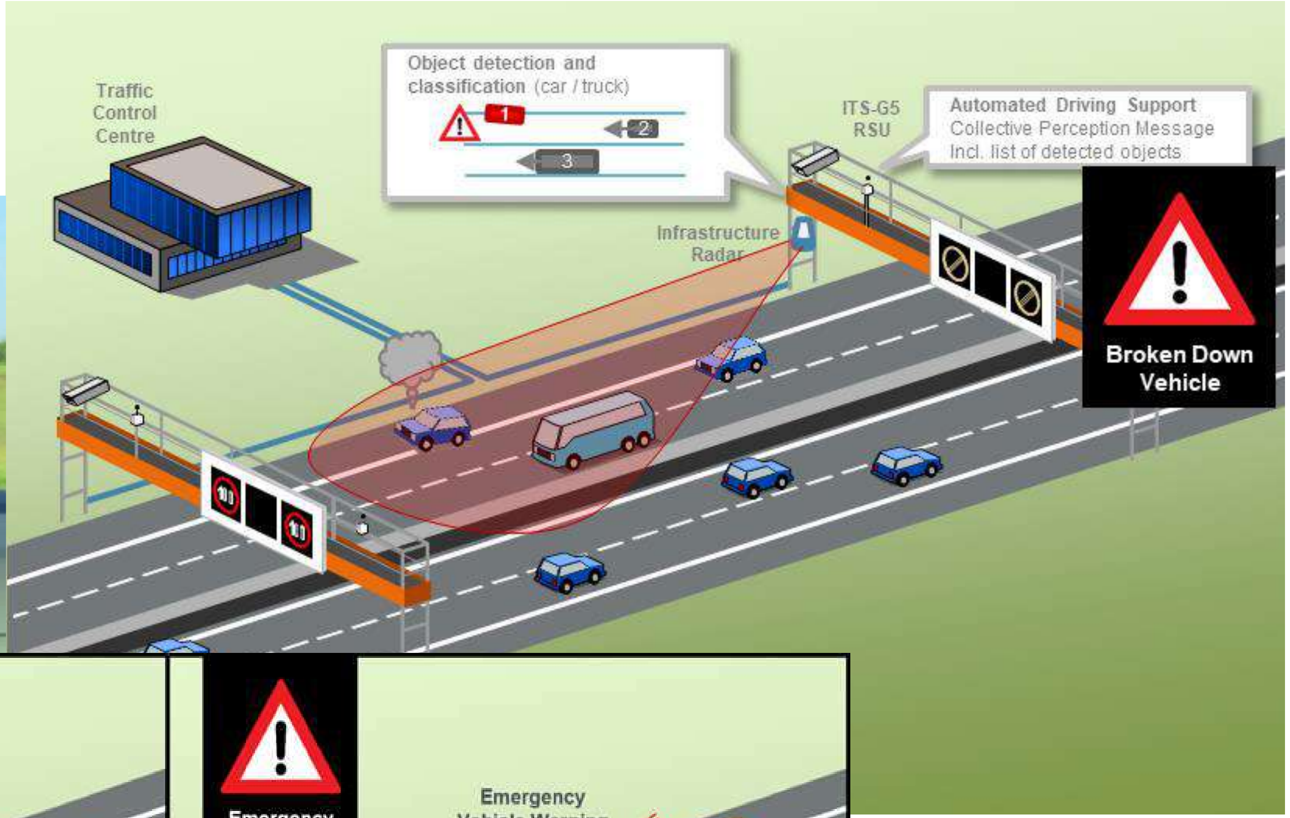
ISAD Classification Scheme (Carreras et al. 2018)

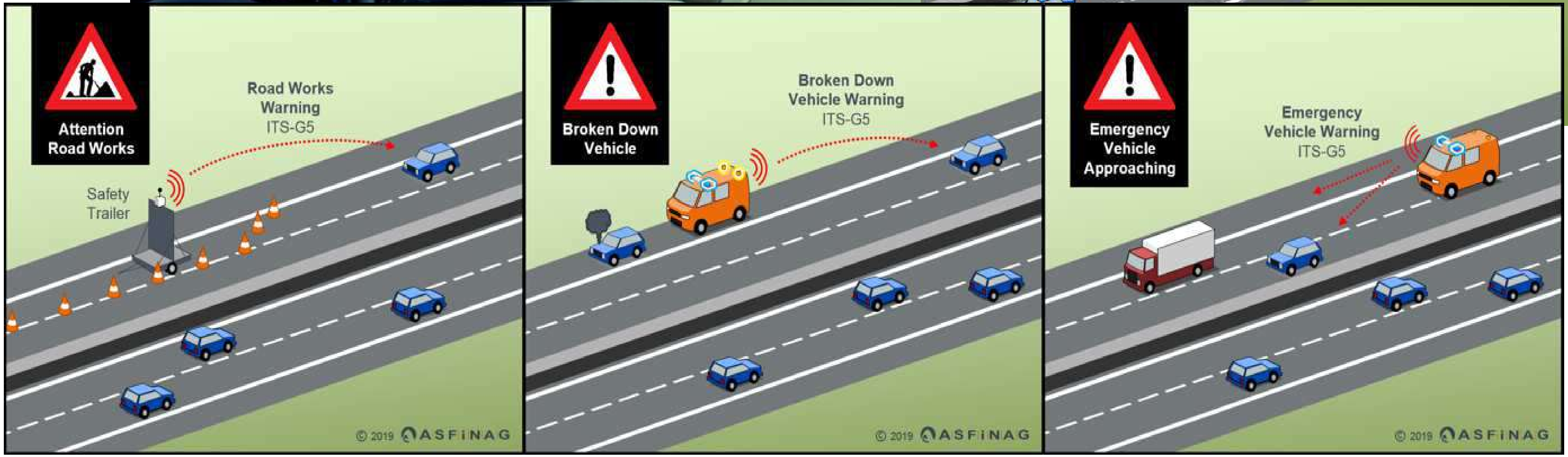
	ISAD	Name	Infrastructure side	AV side	Digtial information provided to AVs: Digital map with road signs	VMS warnings, incidents, weather	Microscopic traffic situation	Guidance: speed, gap, lane advice
Conventional Infrastructure	E	Conventional infrastructure / no AV support		Road geometry and road signs have to be recognized by AVs on their own				
	D	Static digital information / map support	Digital map data (inlcuding static road signs) complemented by physical reference points	Traffic lights, short term road works and VMS have to be recognized by AVs on their own				
Digital Infrastructure	C	Dynamic digital information	All static and dynamic information can be provided to the AVs in digital form	AVs perceive infrastructure support data				
	B	Cooperative perception	Infrastructure is capable of percieving microscopic traffic situations	AVs perceive infrastructure support data in real time (C-ITS Day 1)				
	A	Cooperative driving	Infrastructure is capable of percieving vehicle trajectories and guide single AVs (or AV groups)	AVs are guided by the infrastructure in order to optimize traffic flow (C-ITS Day 2+)				



INFRAMIX

Examples of C-ITS Use Cases





Poll

Preliminary Austrian ISAD classification

Thank you for your attention!

Yannick Wimmer

ASFINAG

Yannick.Wimmer@asfinag.at

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 723016.

Traffic Estimation and Control Strategies

Ioannis Papamichail
Technical University of Crete, Greece

Vasileios Markantonakis, Aneza Doko and Markos Papageorgiou

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 723016.

Traffic state estimation and traffic control algorithms for mixed vehicle traffic

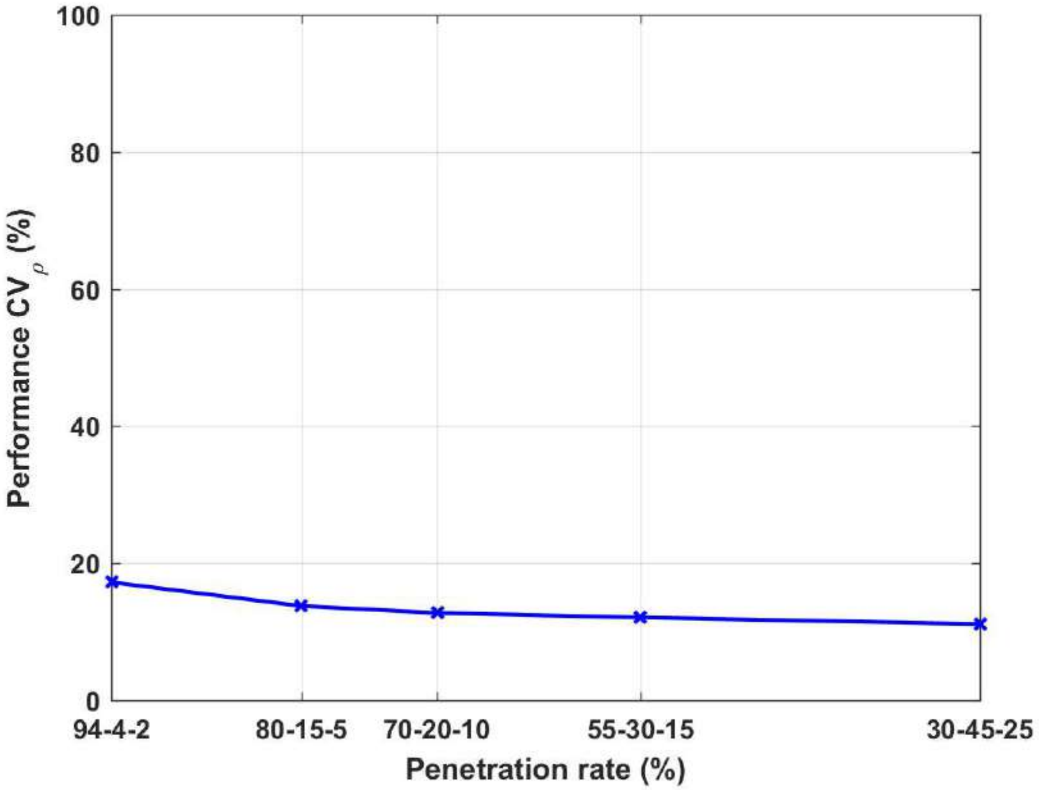
- Traffic state estimation for mixed vehicle traffic
  - The cross-lane case
  - The per-lane case
- Traffic control algorithms for mixed vehicle traffic
  - Dynamic lane assignment
  - ACC parameters adaptation
  - Lane-change advice
  - Mainstream traffic flow control via VSL
- Software tools and interfaces have been developed for use within the co-simulation environment and the IMC

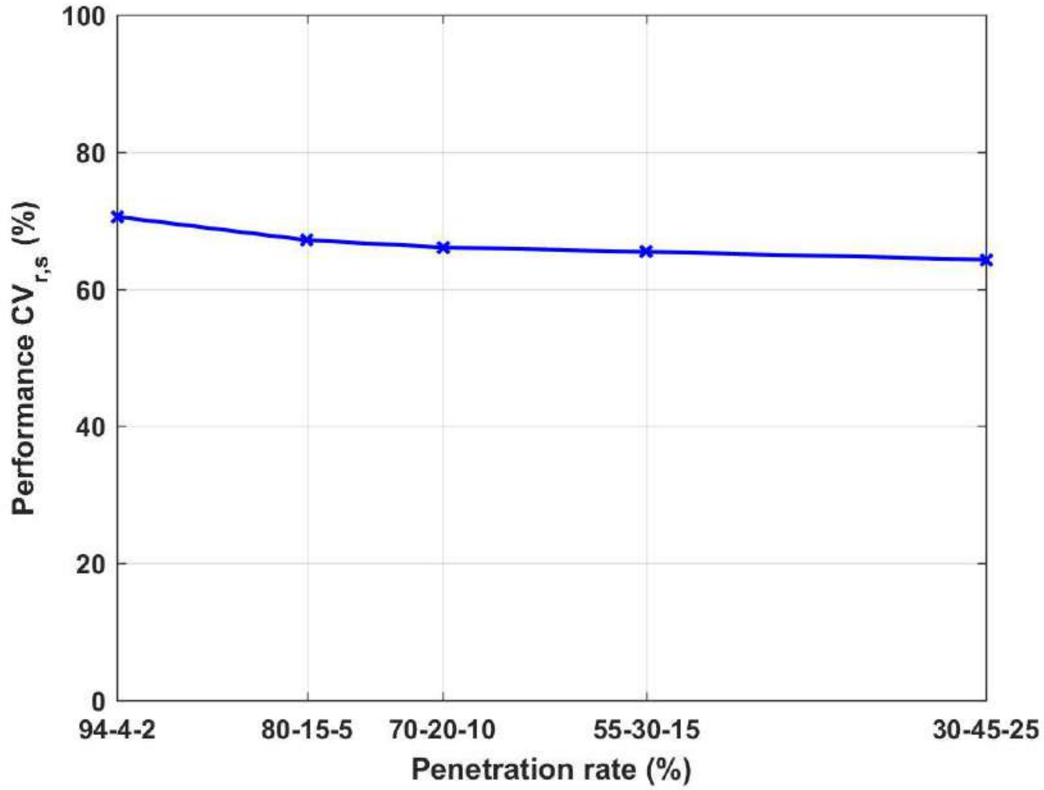
Traffic estimation for mixed vehicle traffic

INFRAMIX

- In conventional traffic, real-time traffic data are provided by spot sensors positioned at appropriate locations.
- Connected vehicles may communicate their position, speed and other relevant information, i.e. they can act as mobile sensors.
- This allows for a sensible reduction (and, potentially, elimination) of the necessary number of spot sensors, which would lead to sensible reduction of the purchase, installation and maintenance cost for traffic monitoring.
- Developments considered both the aggregated (cross-lane) case and the case of lane-based estimation, which is essential for some control applications.
- Information is provided by connected vehicles and is fused with measurements stemming from a minimum number (necessary for flow observability) of spot sensor measurement.
- Lane change information from connected vehicles has been exploited to assess the level of lateral flows.
- Robust and practice relevant tools have been developed.

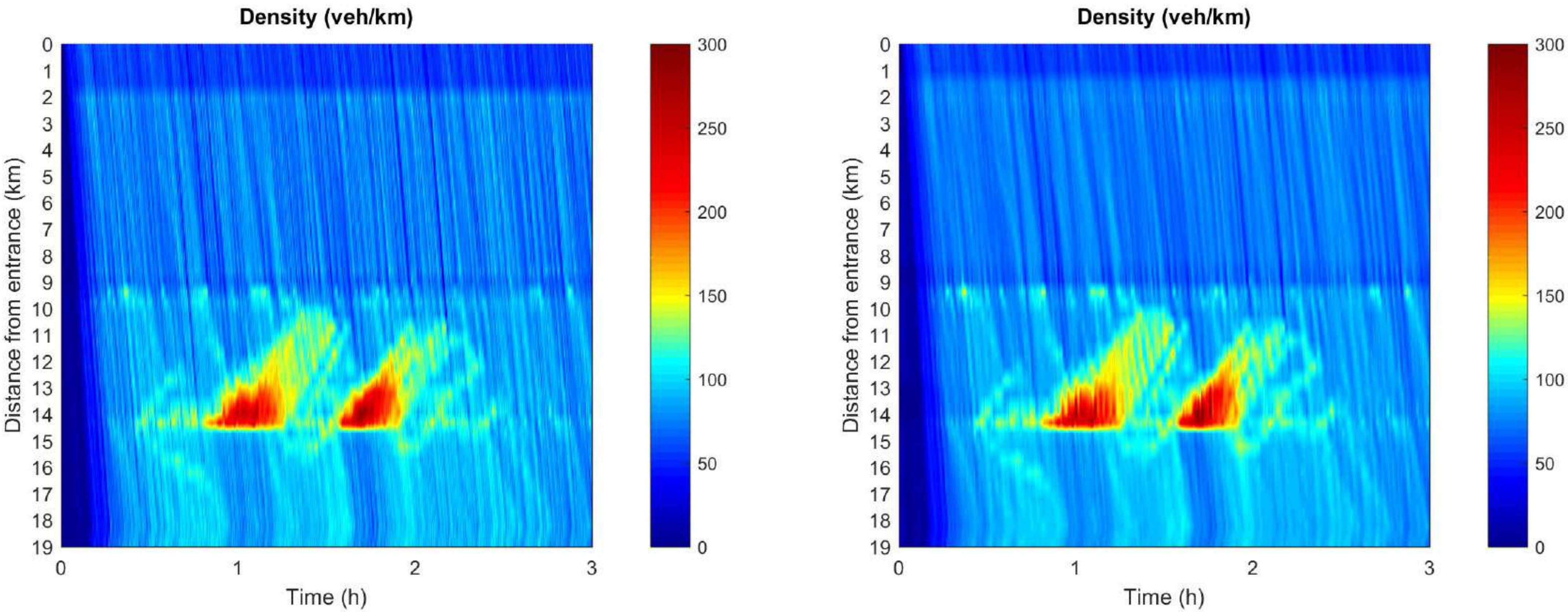
Traffic estimation for mixed vehicle traffic: The cross-lane case





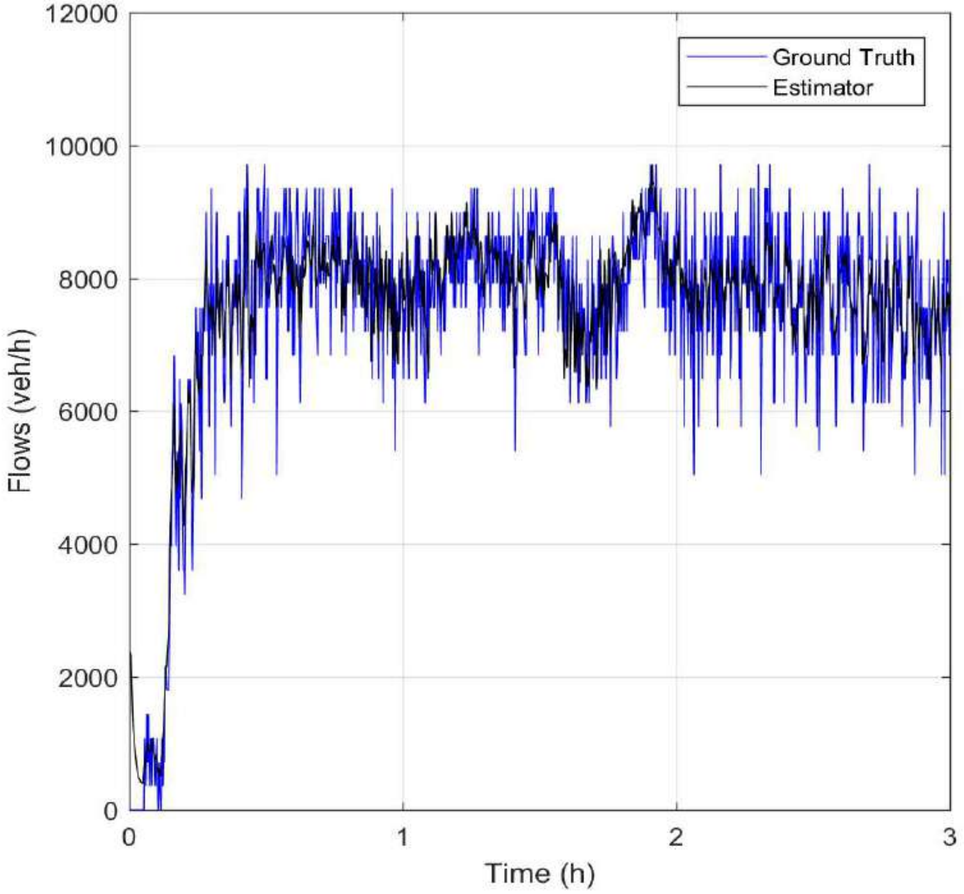
Coefficient of Variation (CV) for density (left) and ramp flow (right) estimations calculated for various penetration rates

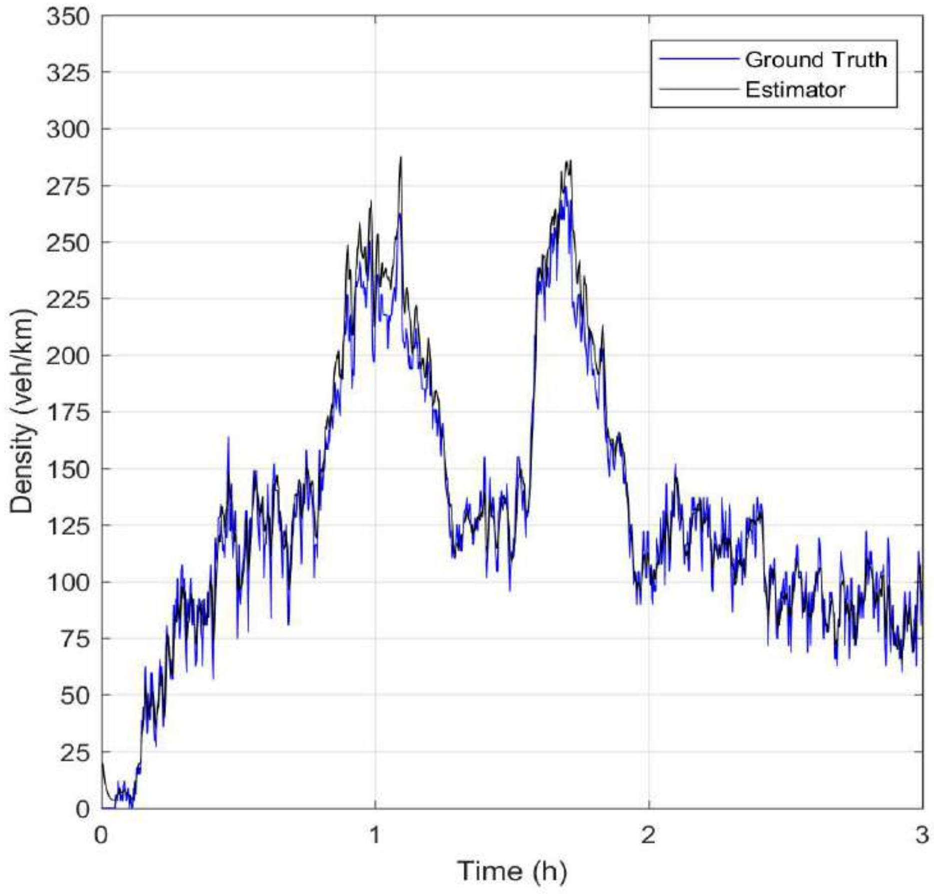
Traffic estimation for mixed vehicle traffic: The cross-lane case



Comparison between real (left) and estimated (right) density for mixed traffic with a 70% penetration rate of connected vehicles (30% CV - 45% CCV – 25% AV)

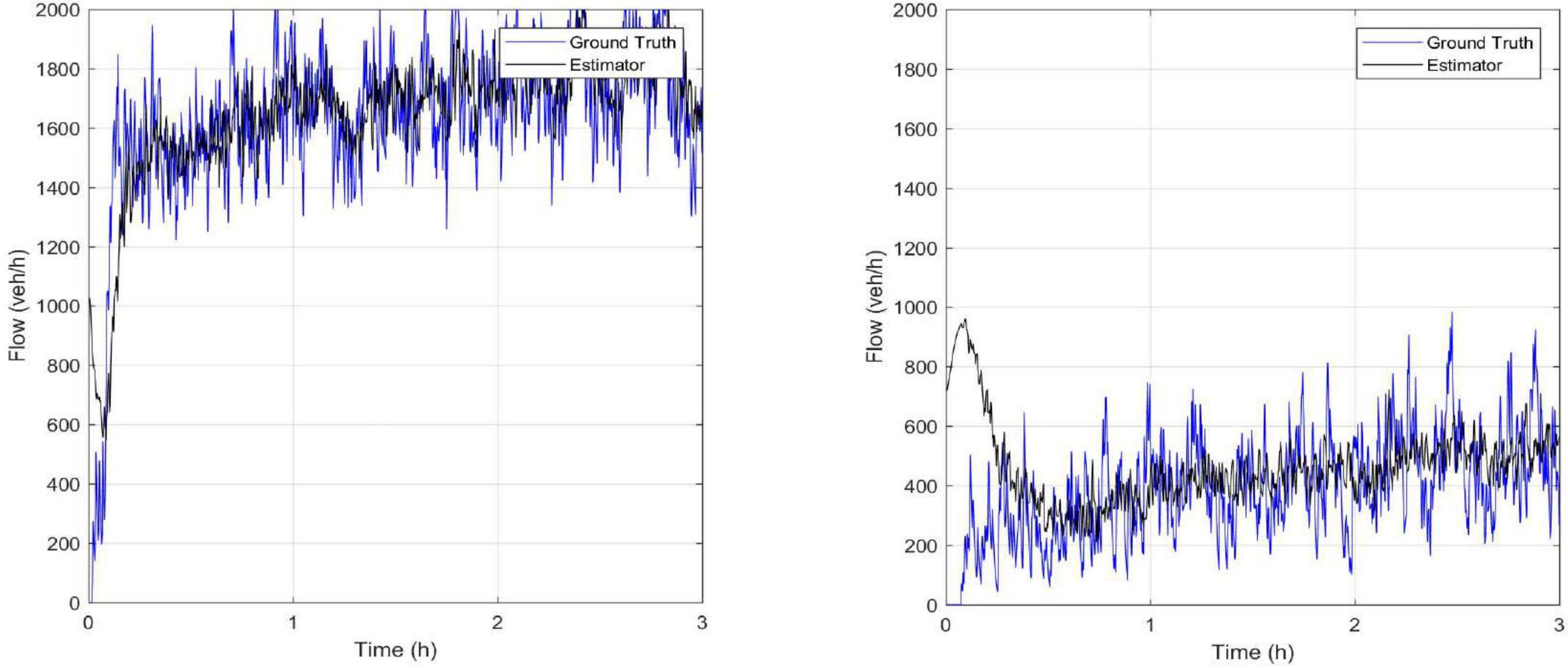
Traffic estimation for mixed vehicle traffic: The cross-lane case





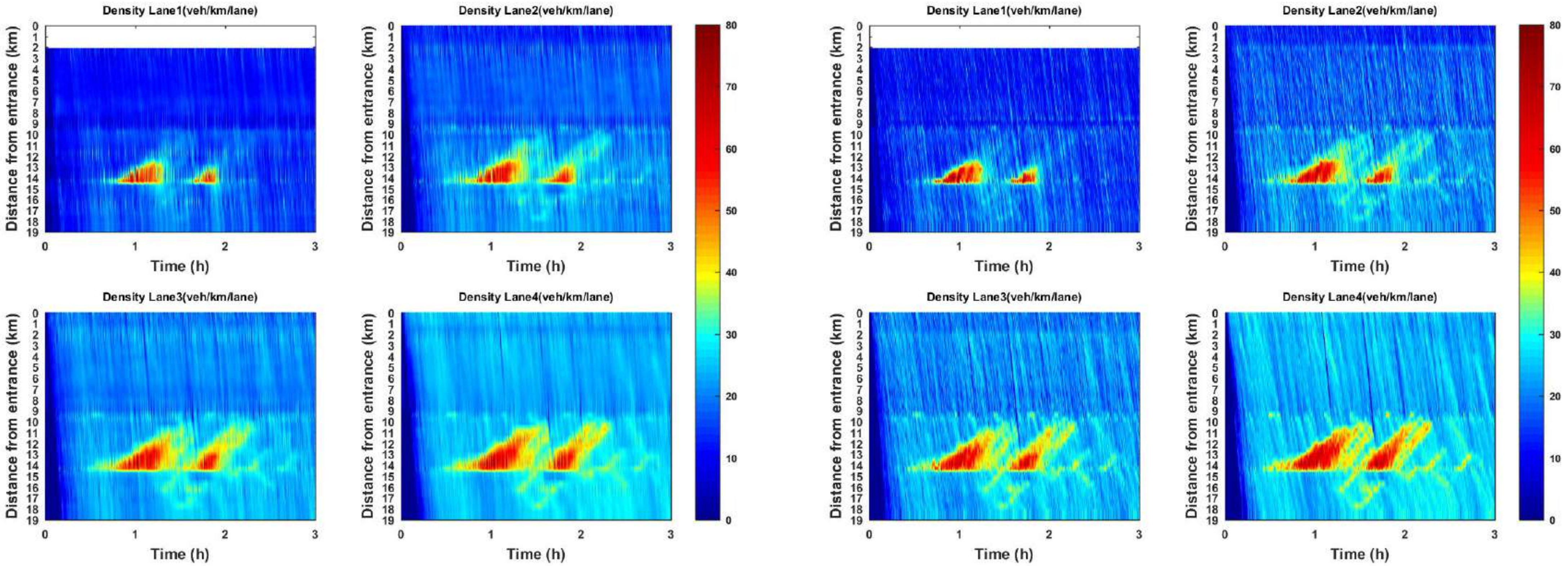
Comparison between real (blue) and estimated (black) flows and densities at the bottleneck area for mixed traffic with a 70% penetration of connected vehicles

Traffic estimation for mixed vehicle traffic: The cross-lane case



Comparison between real (blue) and estimated (black) ramp flows for mixed traffic with a 70% penetration of connected vehicles; on-ramp (left) and off-ramp (right)

Traffic estimation for mixed vehicle traffic: The per-lane case



Comparison between real (left) and estimated (right) density per lane for mixed traffic with a 70% penetration rate of connected vehicles

Traffic control algorithms for mixed vehicle traffic

- The automotive industry has mainly focused on designing algorithms that optimize the behaviour of an individual vehicle, rather than on optimizing the overall efficiency of the traffic network.
- This vehicle-centric approach needs to be appropriately extended in mixed traffic conditions to also benefit traffic flow capacity and efficiency, particularly in heavy traffic conditions, as, for example, during rush hours, at bottlenecks locations.
- Appropriate novel traffic management concepts have been developed which will enable the exploitation of existing or emerging vehicle automation and connectivity towards increased traffic flow efficiency.

Traffic control algorithms for mixed vehicle traffic

Algorithms have been developed for:

- Dynamic lane assignment for AVs based on traffic conditions and penetration rate
- ACC time-gap adaptation to maximize capacity and throughput in critical traffic conditions and near bottlenecks (e.g. lane drop, sag, tunnel etc.).
- Lane-change advice (for individual connected vehicles) aimed to maximise the benefits for both individual drivers (of connected vehicles) and the overall traffic flow.
- Mainstream traffic flow control via VSL (using VMSs and V2I communication) for maximum traffic efficiency in mixed traffic.

Traffic control algorithms for mixed vehicle traffic: Dynamic lane assignment

A simple threshold-based control strategy has been developed:

- We consider a motorway stretch divided into *n* segments and a flow capacity that is obtained around a critical density ρ_{cr}.
- Only one specific lane can be assigned to AVs, as long as some conditions are met.
- The location of the lane (e.g. right or left lane) and the minimum number of consecutive segments ($\leq n$) that are required for the activation of a dedicated lane are preselected by the operator considering traffic management goals as well as safety parameters.
- There is a predefined minimum period of activation.
- Adequate physical infrastructure adaptations have been considered by the co-simulation environment in order to achieve availability and consistency of information for all types of vehicles. CVs can be informed using VMSs at the beginning of each segment, while AVs receive the information as well specific lane-change advices via communication well in advance.

Traffic control algorithms for mixed vehicle traffic: Dynamic lane assignment

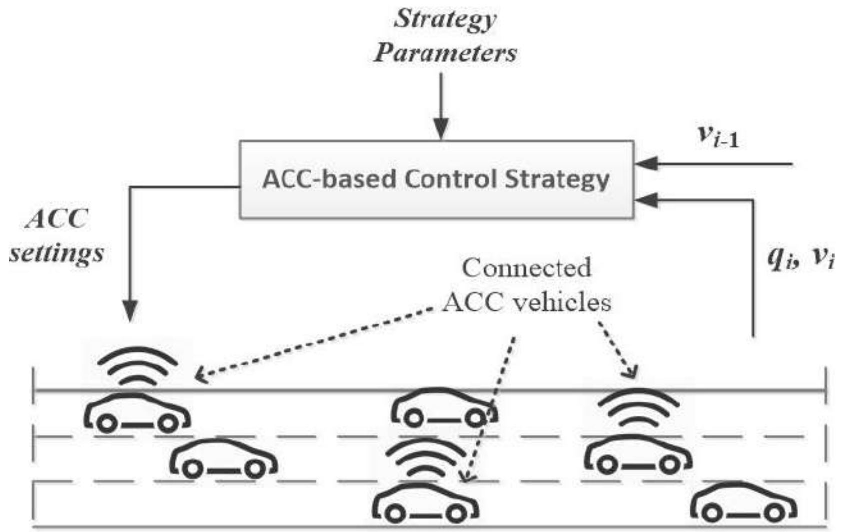
- From the results it can be concluded that in most of the simulations the situation is beneficial for AVs, especially when traffic demand (density) is low and the penetration of AVs is 25%, but it is not for the rest of the traffic. This leads to a deterioration of the calculated KPIs for the whole population.
- The results are not really sensitive with respect to the values used for the max thresholds.
- As expected, whenever areas around sets of on/off-ramps are included in the assignment logic the results are a bit better compared to the opposite case. Of course, this is due to the fact that the lane assigned is always the fast one and inclusion of these areas leads to assignments that continue through the network without interruptions that may lead to more weaving. The DLA controller is able to deactivate these segments on its own based on the density thresholds used.

Traffic control algorithms for mixed vehicle traffic: ACC time-gap adaptation

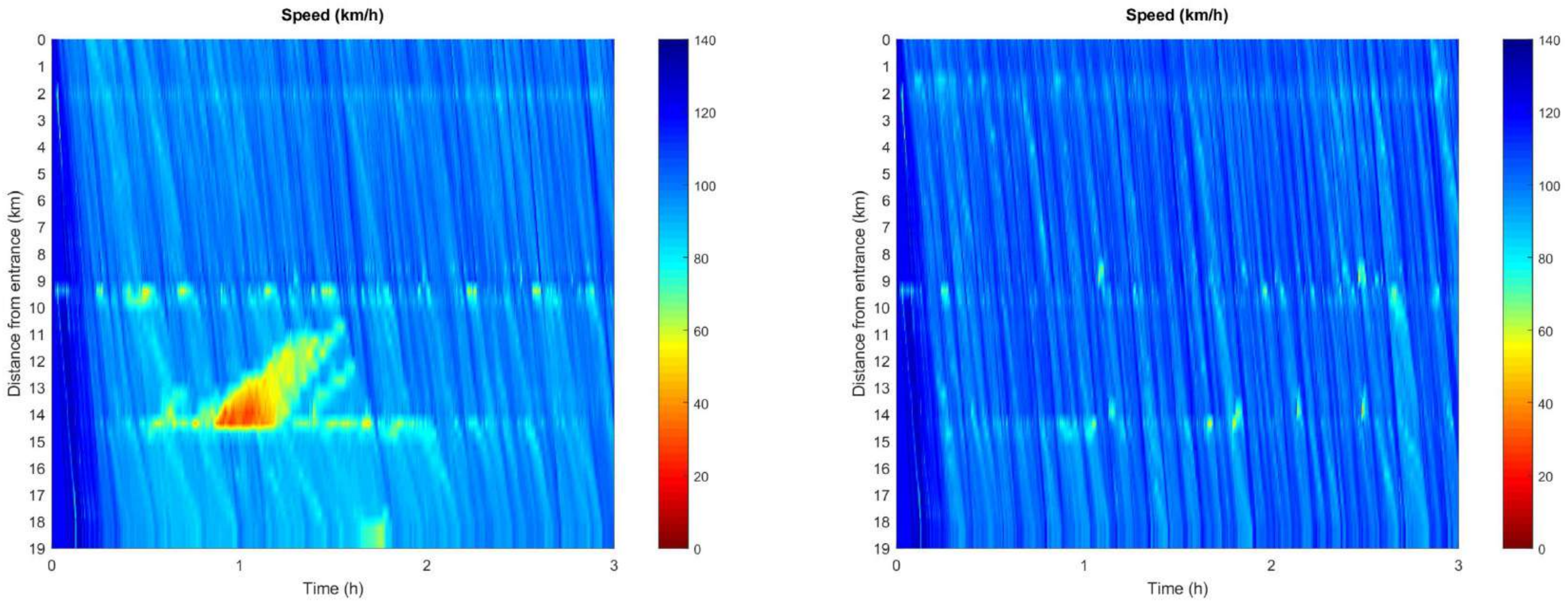
The main philosophy behind the proposed concept is to:

- leave the ACC-settings untouched at their driver-selected values if traffic flow is clearly under-critical so as to limit interventions only to traffic situations that call for efficiency increase; and
- change the ACC-settings gradually as appropriate to improve the flow efficiency when critical traffic states are imminent or present.

The proposed control strategy is only dependent on real-time information about the current traffic conditions and is actually activated only when, where and to the extent needed.

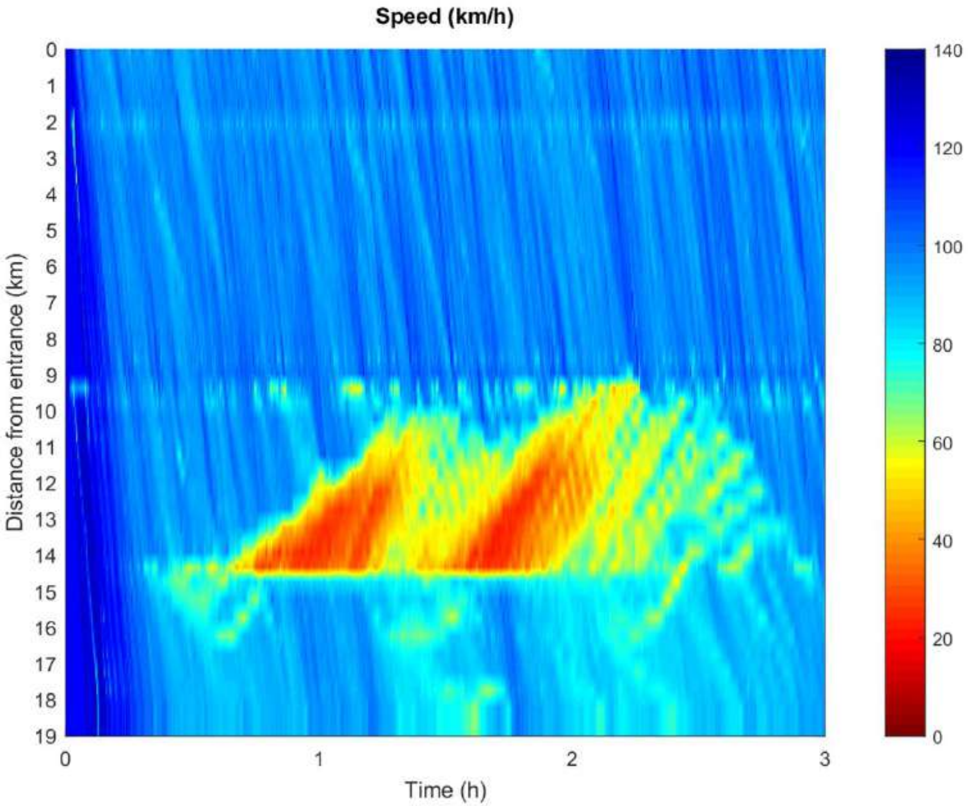


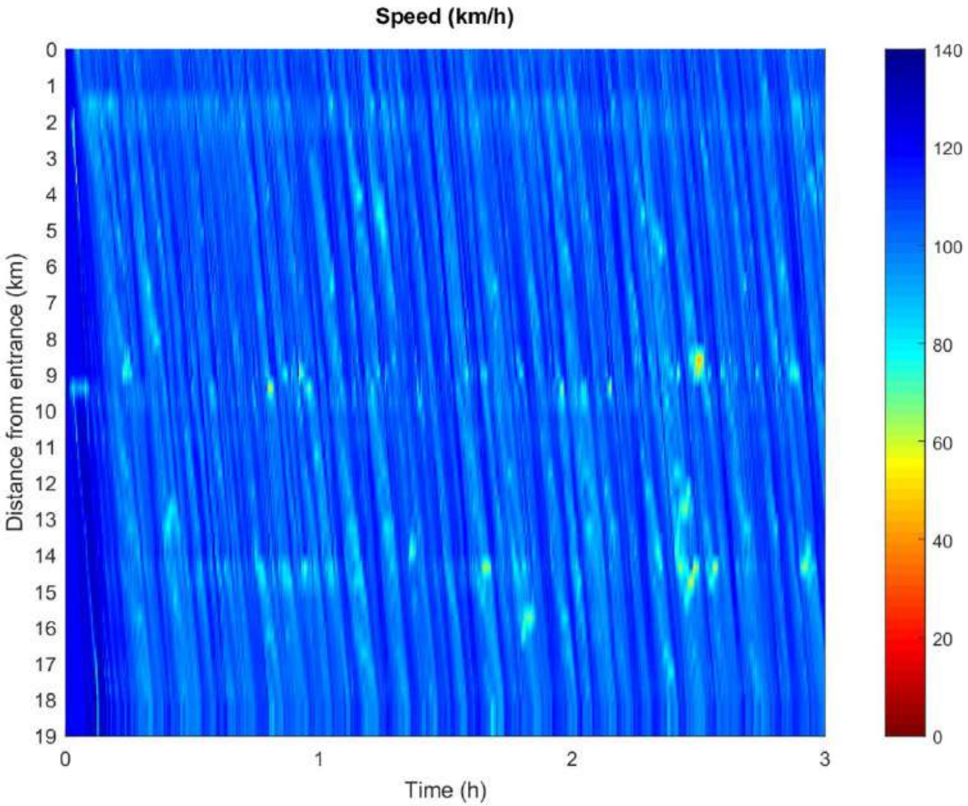
Traffic control algorithms for mixed vehicle traffic: ACC time-gap adaptation



Spatio-temporal diagrams of speed (no-control and control) for mixed traffic with a 45% penetration rate of connected vehicles (55% CV - 30% CCV – 15% AV)

Traffic control algorithms for mixed vehicle traffic: ACC time-gap adaptation



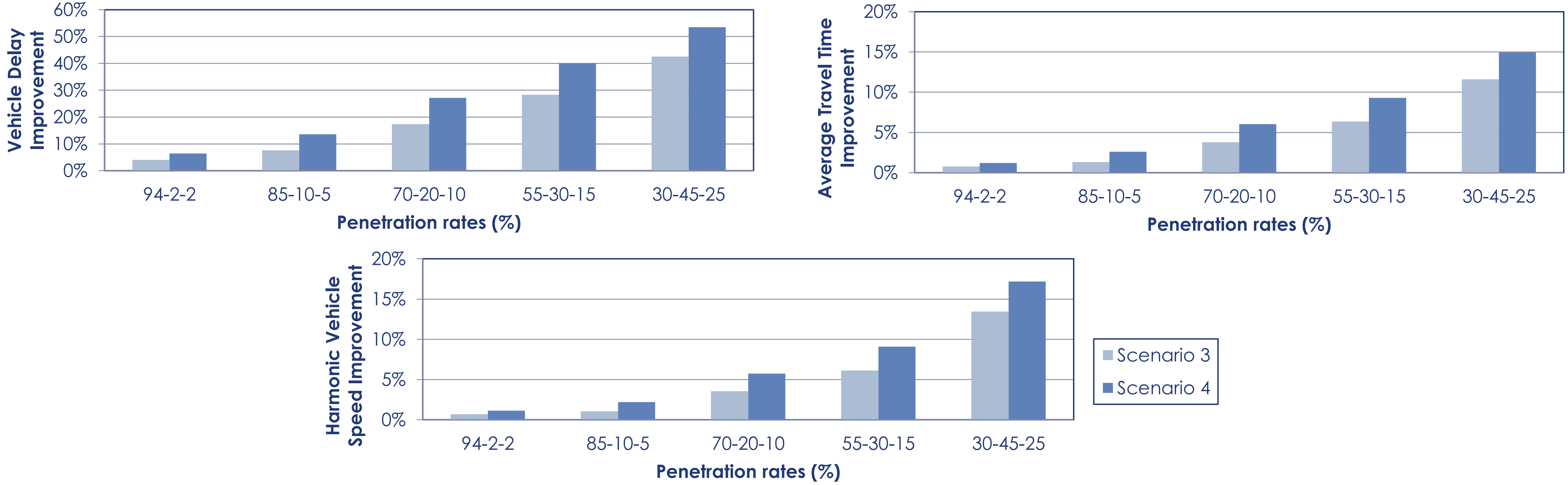


Spatio-temporal diagrams of speed (no-control and control) for mixed traffic with a 70% penetration rate of connected vehicles (30% CV - 45% CCV – 25% AV)

Traffic control algorithms for mixed vehicle traffic: ACC time-gap adaptation

For the no-control scenario, vehicles are using a range of different default time-gap values:1.1 sec for slow CVs and CCVs, 0.9 sec for fast CVs and CCVs, 1.4 sec for slow AVs and 1.4 for fast AVs.

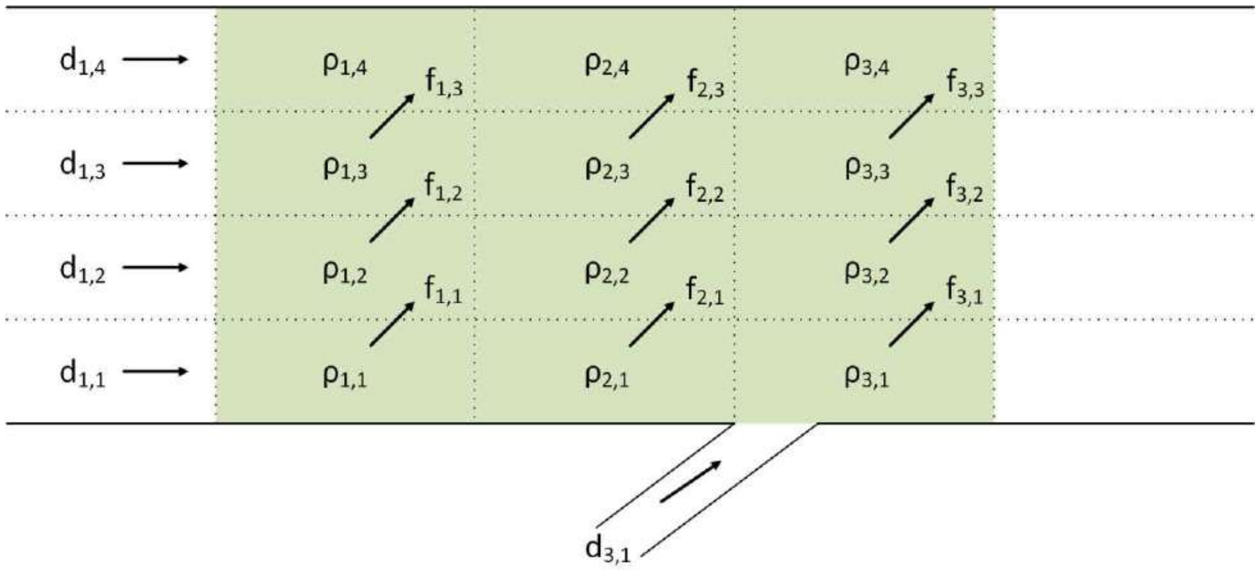
For the control scenario 3 we use 1.0 sec as the minimum time-gap suggested, while for he control scenario 4 we use 0.8 sec.



Traffic control algorithms for mixed vehicle traffic: Lane-change advice

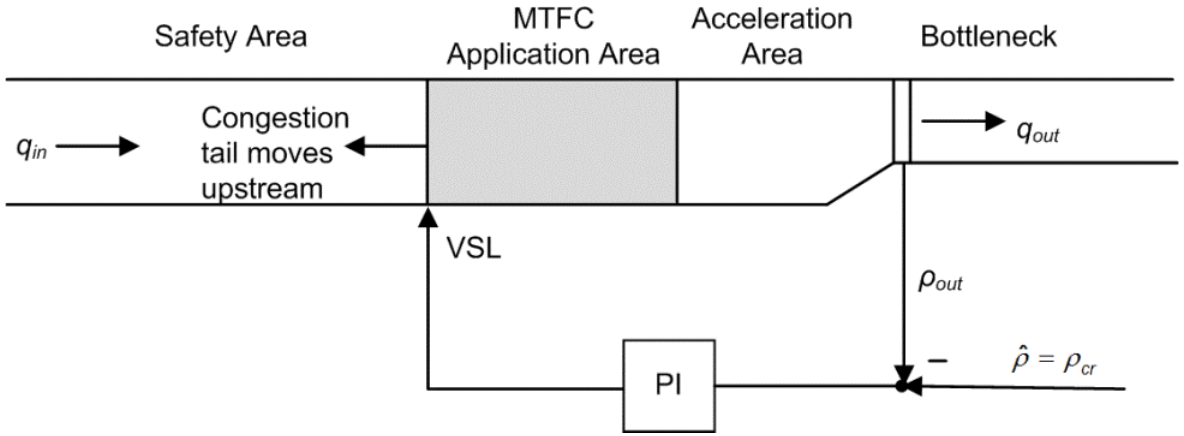
The problem of manipulating the lateral flows upstream of a bottleneck location in order to increase capacity and hence retard or avoid the creation of congestion is formulated as a Linear Quadratic (LQ) optimal control problem.

The solution to the formulated optimal control problem is given through an LQR in the form of a linear state feedback-feedforward control law.



Traffic control algorithms for mixed vehicle traffic: Mainstream traffic flow control

The main purpose of mainstream traffic flow control (MTFC) is to enable the mainstream traffic flow that is approaching areas with particular infrastructure layout, e.g. on-ramp merges, mainstream lane-drops or other bottlenecks, to take values that will allow the establishment of optimal traffic conditions for any appearing demand.



$$vsl(k) = vsl(k-1) + K_I(\hat{\rho} - \rho(k)) + K_P(\rho(k-1) - \rho(k))$$

Some VSL practical implementation aspects are taken into account.

Thank you for your attention!

Ioannis Papamichail

Technical University of Crete, Greece

ipapa@dssl.tuc.gr

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 723016.

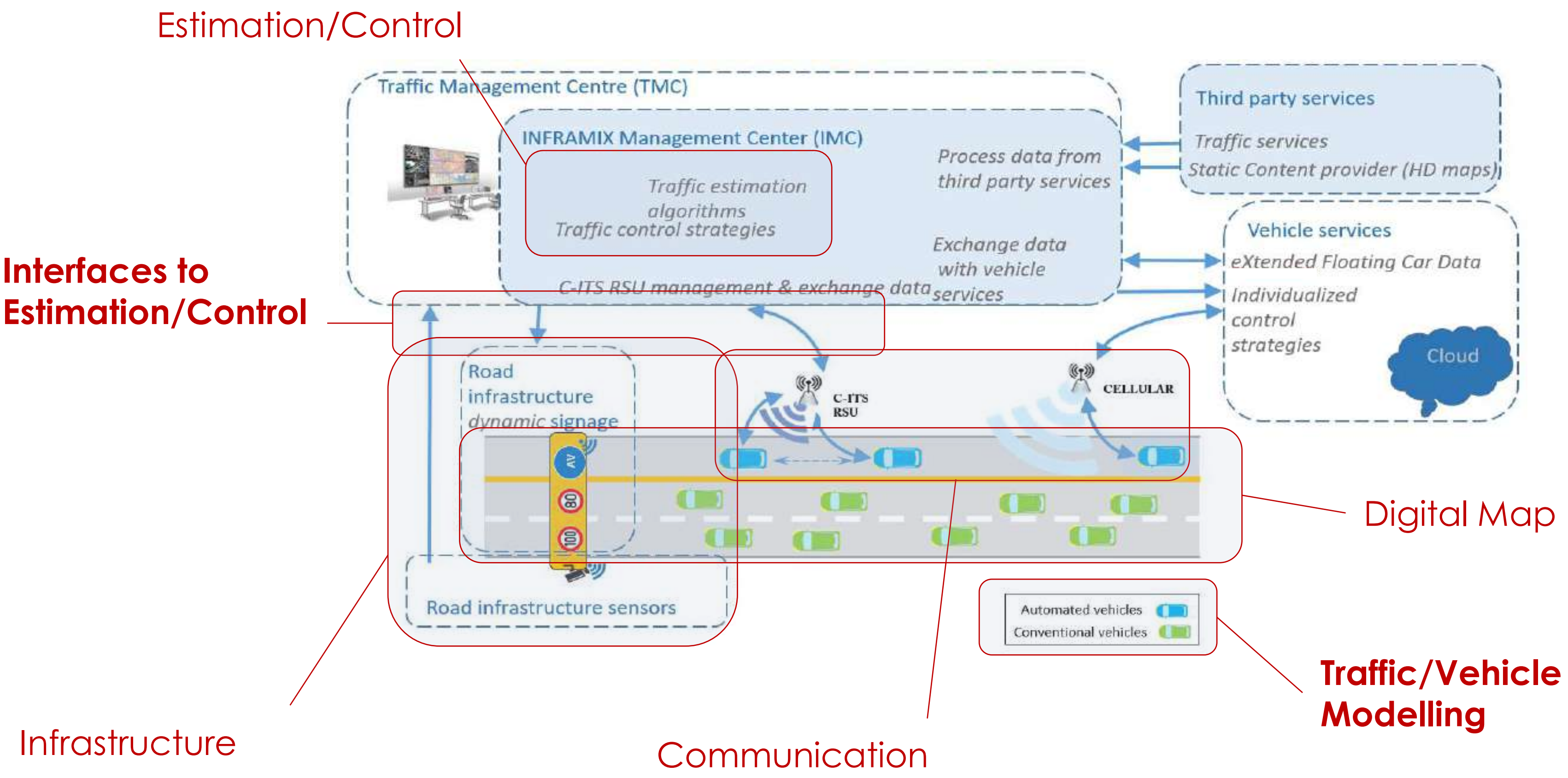
Microscopic Evaluations using the INFRAMIX Co-Simulation Framework

Karl Schrab
Fraunhofer FOKUS

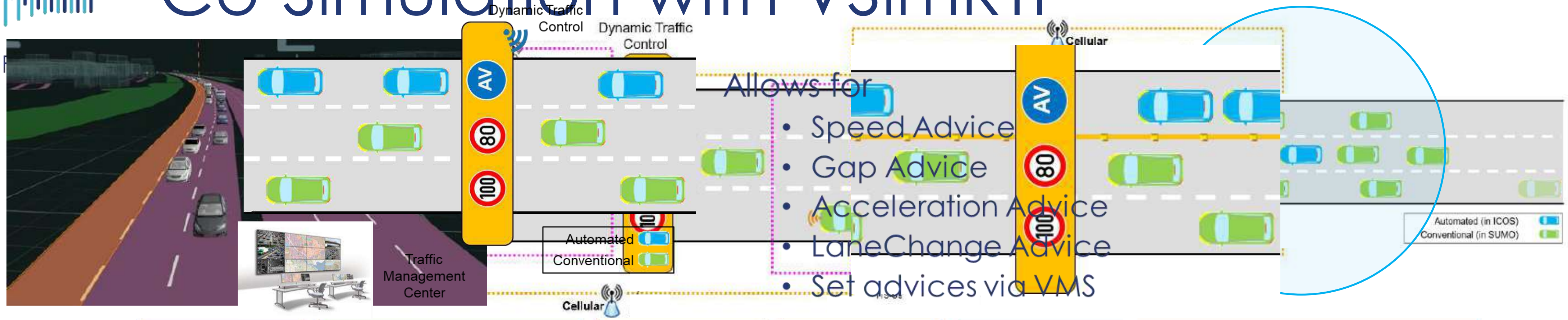
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 723016.

Individual Simulation Domains

Evaluation of INFRAMIX use cases and scenarios
requires a co-simulation framework

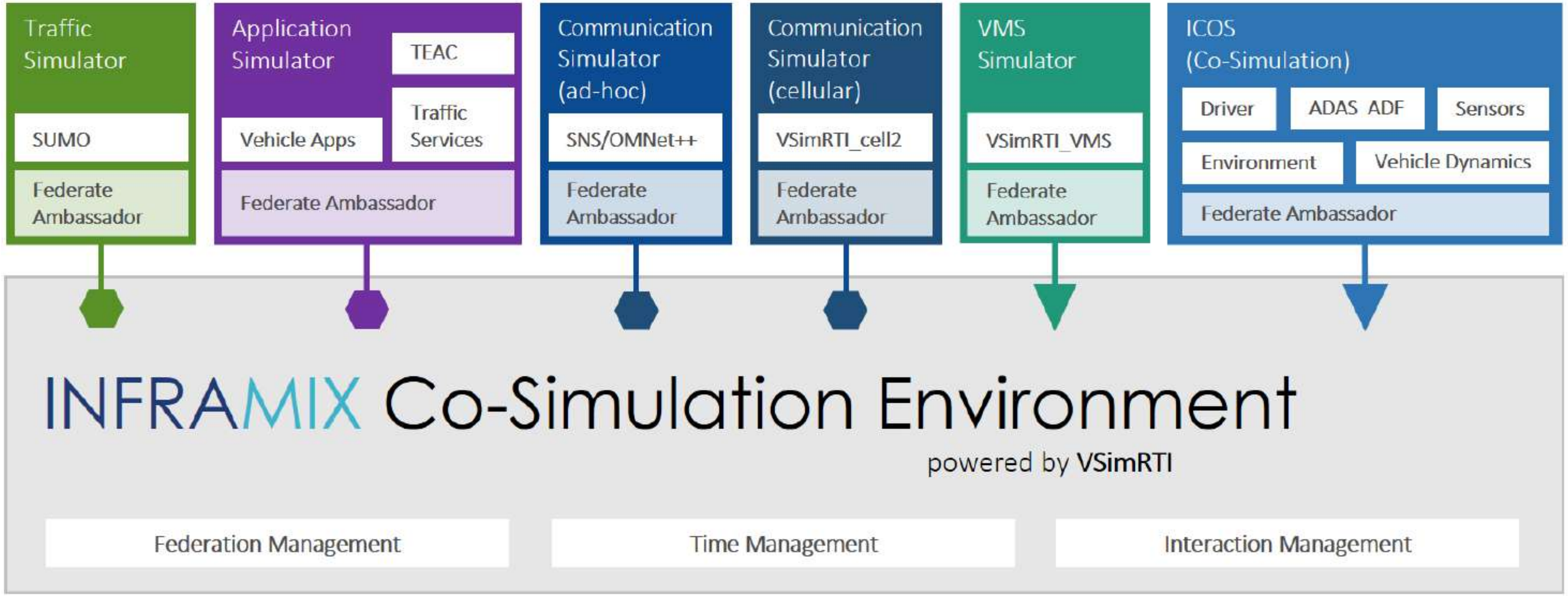


Co-Simulation with VSimRTI



Allows for

- Speed Advice
- Gap Advice
- Acceleration Advice
- LaneChange Advice
- Set advices via VMS



Simulation Modelling Aspects

Simulation Models include:

Highway segmentation

Variable Message Signs
(Speed and Lane Assignment)

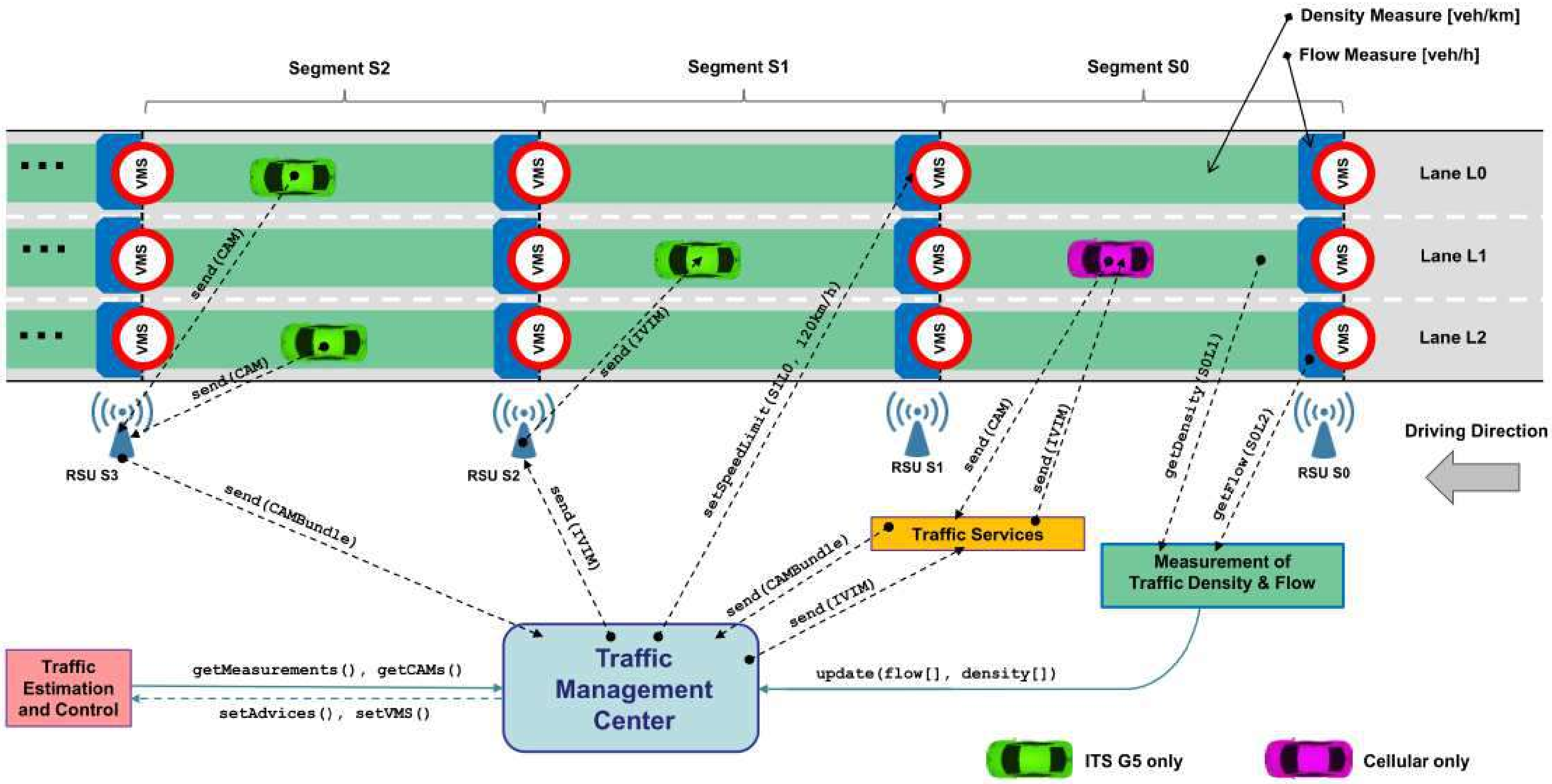
Sensors
(Spot sensors, Camera)

Different communication links
(ITS-G5, Cellular)

Traffic Services

Conventional & Automated Vehicles

Traffic Estimation And Control
(Software in the loop)

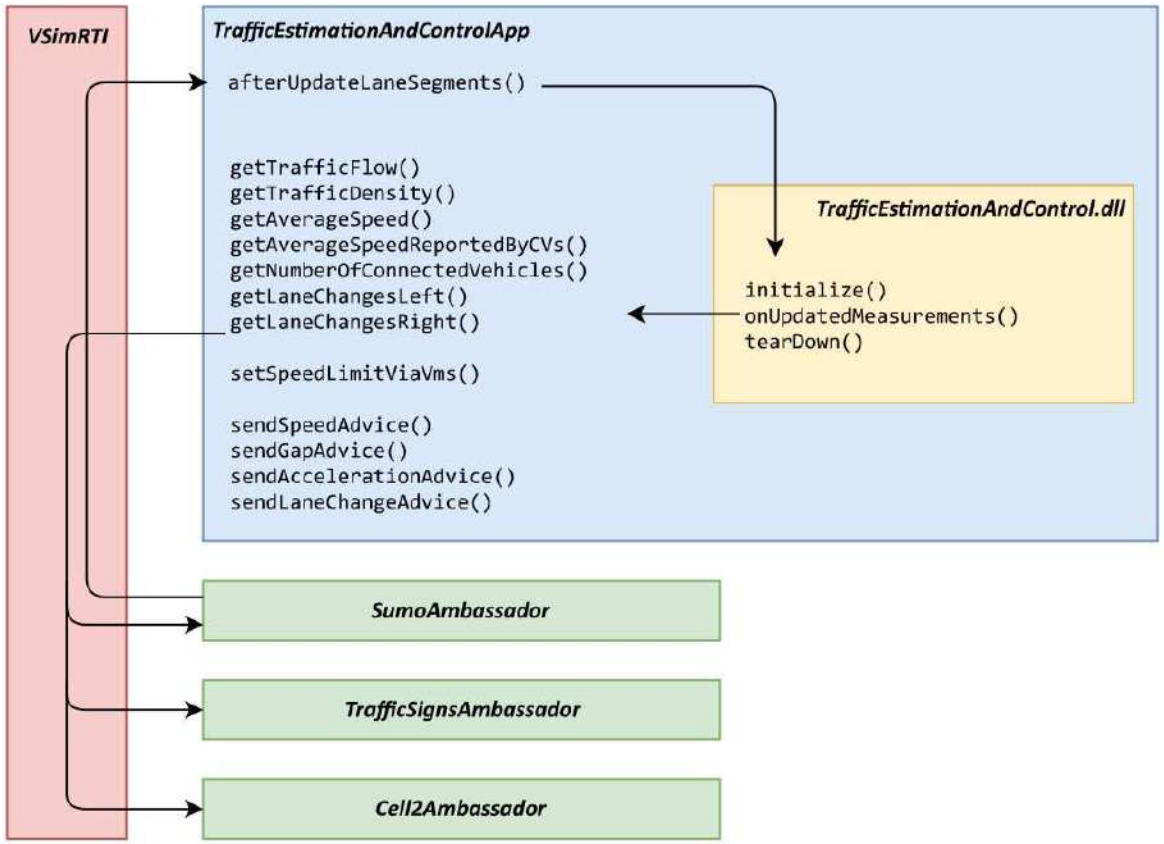


Integration of Control Algorithms

Algorithms encapsulated in DLL

Application with
- Interface
- Translation in co-simulation domains

Allows for
- Speed Advice
- Gap Advice
- Acceleration Advice
- LaneChange Advice
- Set advices via VMS



Simulation Scenario (AP7 Girona)

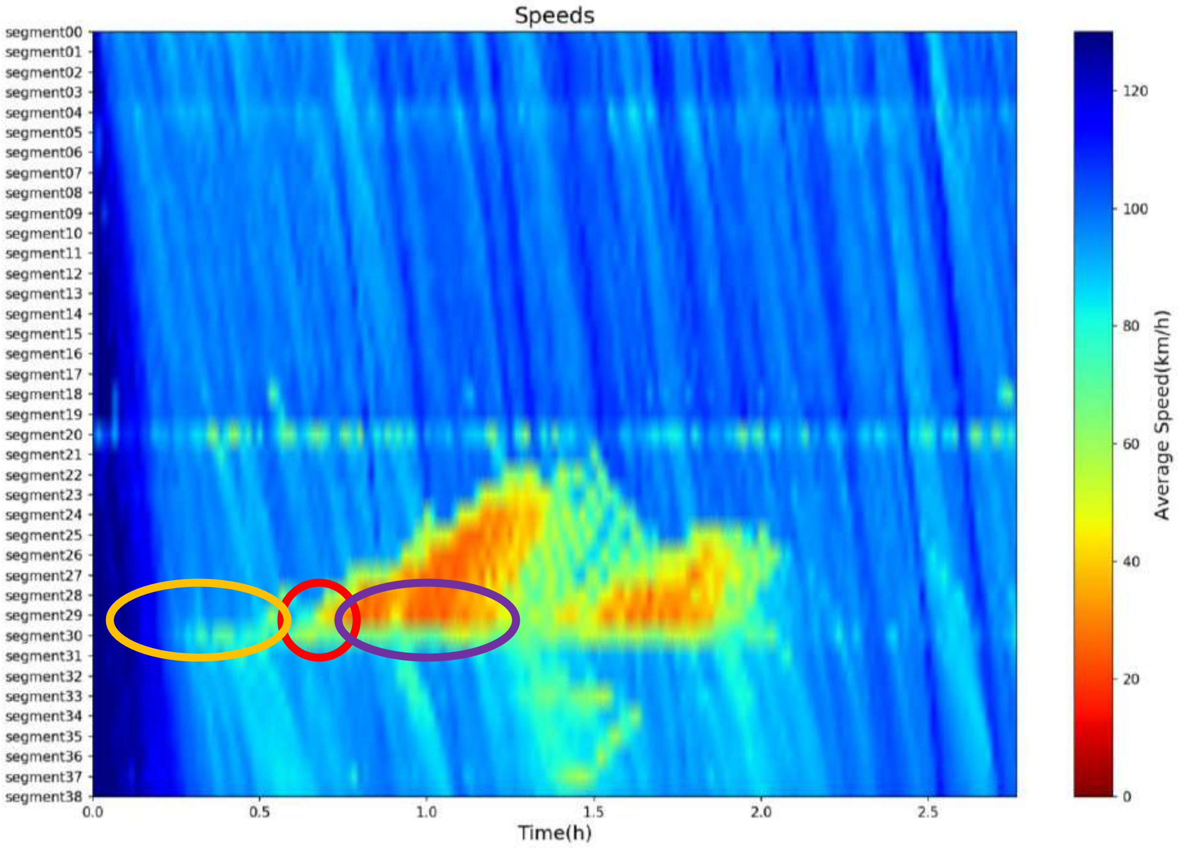
Dividing test site into 40 segments (~ 500 m each)

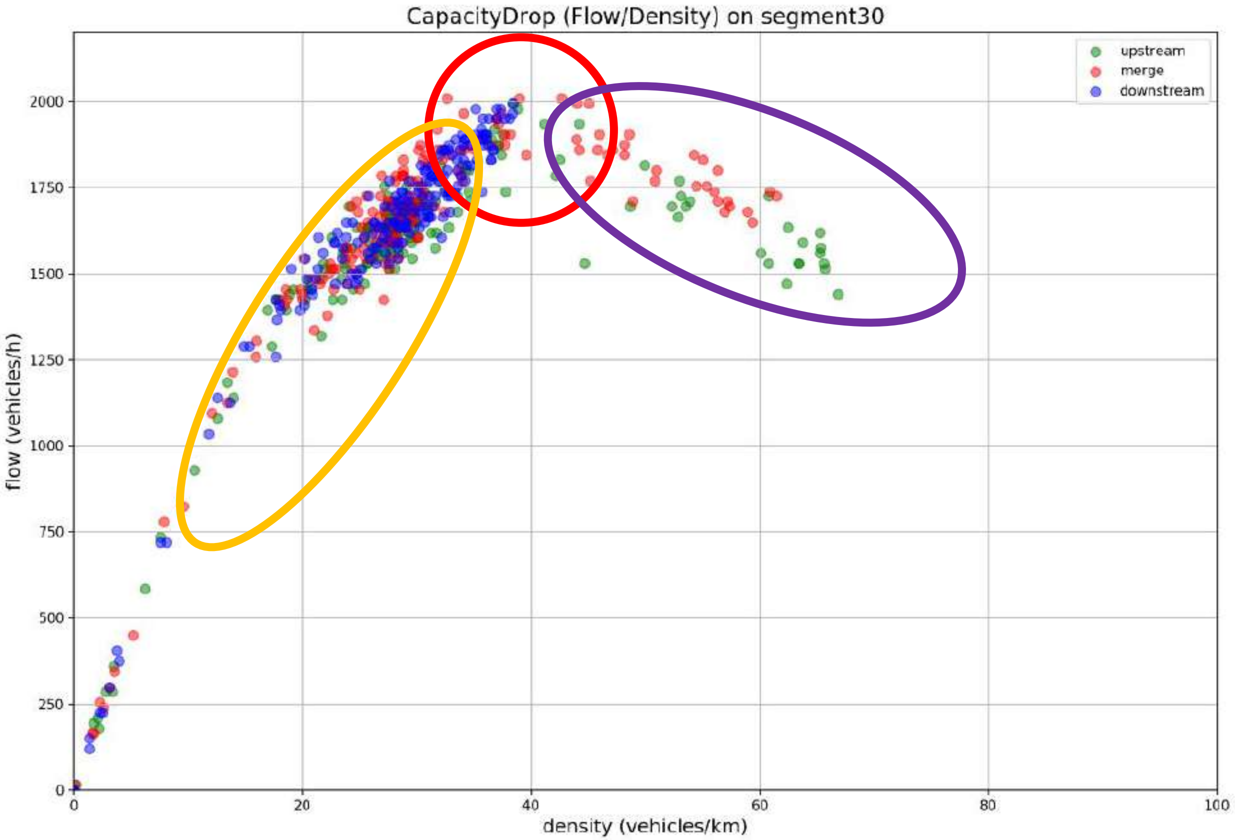
- Gantries with VMS and spot sensors at each segment entry

Used toll data from 28.07.2017 to create and calibrate traffic model

- **~ 125.000 trips**
  (87% Car, 11% Trucks, 2% Motorcycles)
- Increased traffic demand at on-ramp of segment 30 to produce capacity drop

Capacity Drop





Scenario Variations for Evaluation

General Parameters

- **P1 – Traffic Volume**
  - A: 08:00 - 10:00 (high traffic)
  - B: 10:00 - 12:00 (low traffic)
- **P2 – Communication Link**
  - A: No Communication with vehicles
  - B: Cellular communication
  - C: ITS-G5 with low RSU coverage (2 km)
  - D: ITS-G5 with high RSU coverage (0.5 km)
- **P3 – TMC Update Interval**
  - A: 10s
  - B: 60s
- **P4 – Penetration Rates**
  - CCVs: [0-100%]
  - AVs: [0-100%]

DLA Parameters

› **P5 – AV Lane Position**
- A: leftmost lane
- B: rightmost lane

Bottleneck Parameters

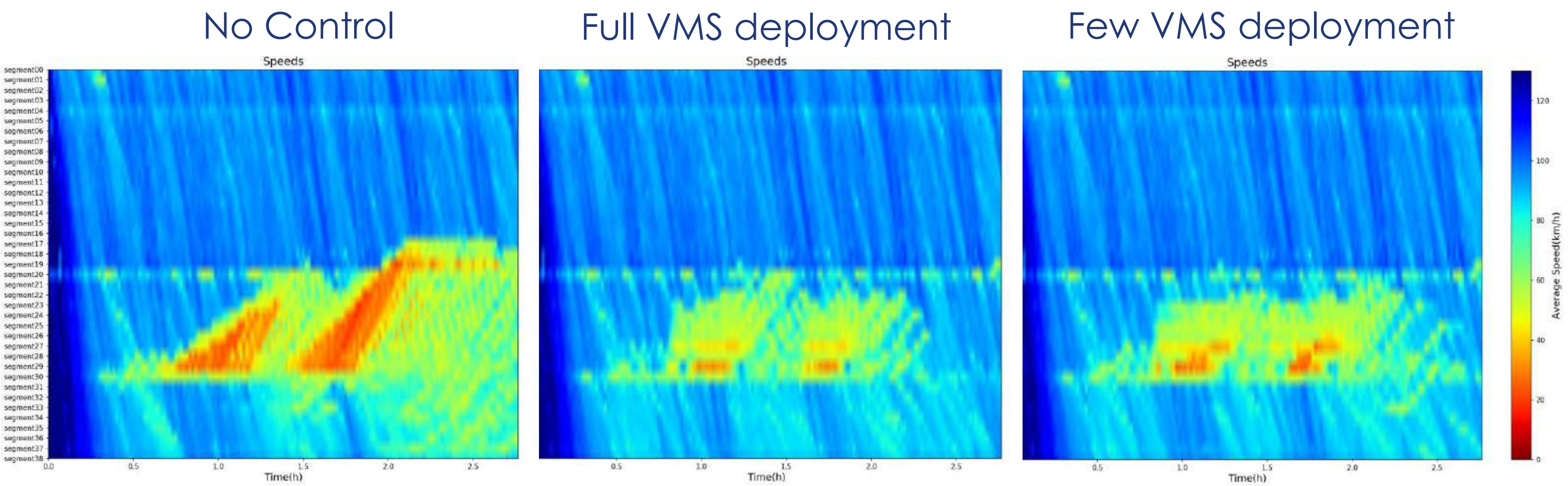
› **P5 – Segmentation**
- A: VMS for each segment
- B: VMS for some segments only
- C: No infrastructure, virtual segments only

› **P6 – Algorithm Variations**
- A: Speed Advices
- B: Lane Change Advices
- C: Speed Advices, Lane Change Advices
- D: Time-Gap & Acceleration Advices

Evaluating the **VSL Controller** (1)

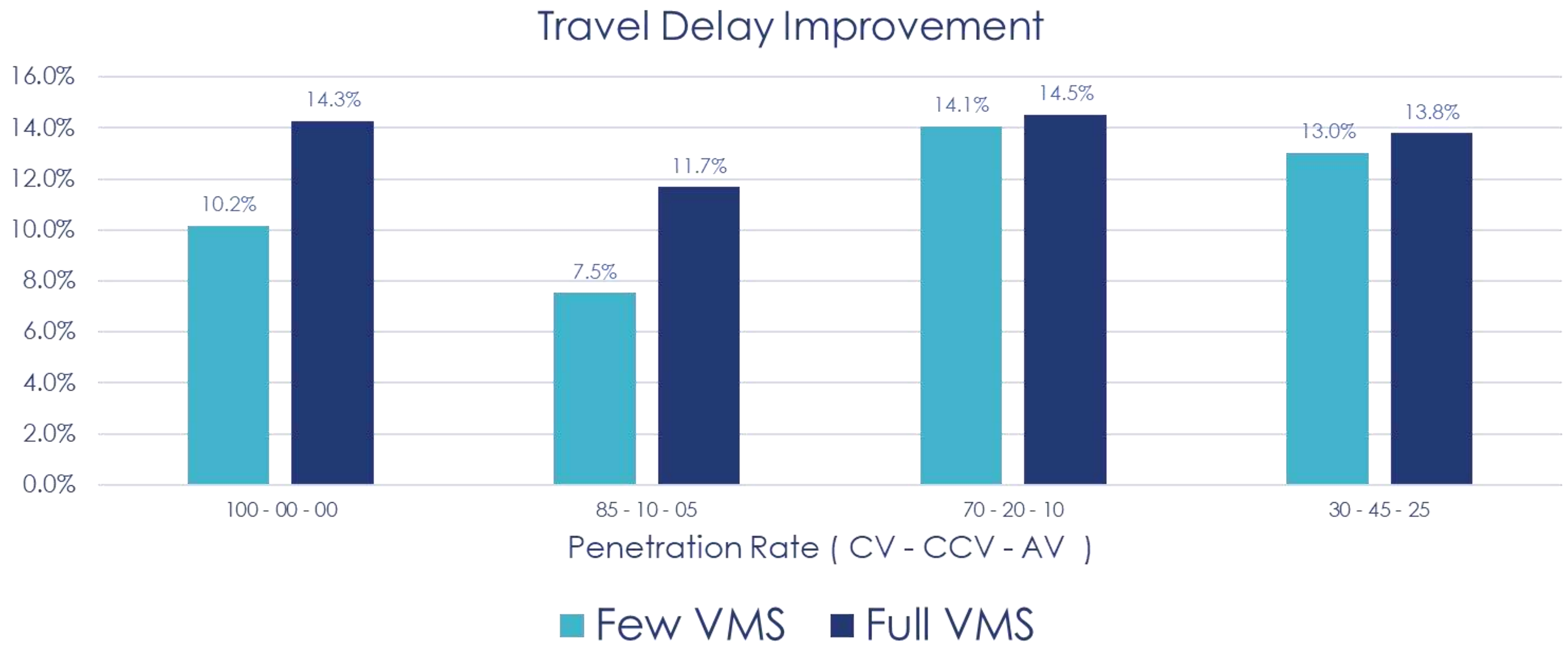
1. Analysis of **Infrastructure Requirements (VMS)** for Variable Speed Limit Control

- A) Static Speed Signs / No Control algorithm active
- B) Variable Speed Signs for **each segment**
- C) Variable Speed Signs for **few segments** at strategic positions



Evaluating the **VSL Controller** (1)

1. Analysis of **Infrastructure requirements** for Variable Speed Limit Control



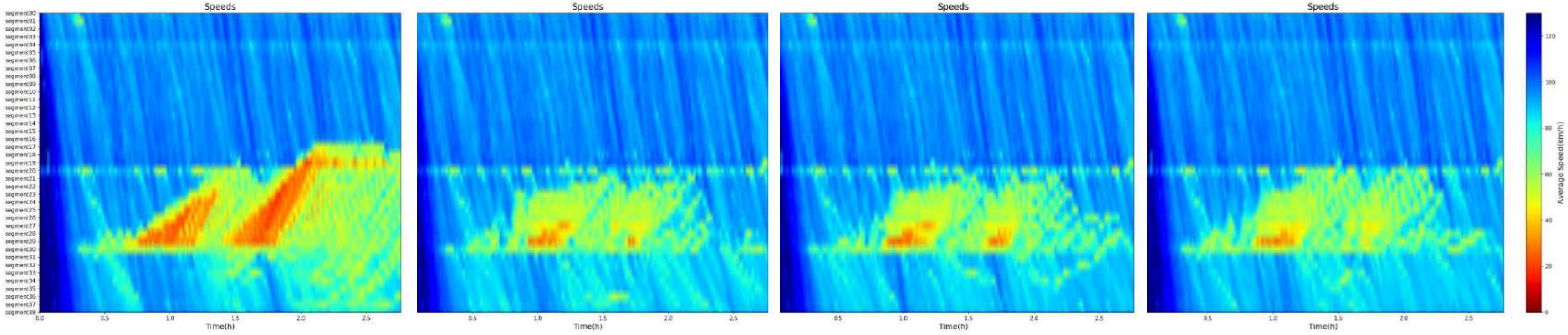
INFRAMIX

Evaluating the **VSL Controller** (2)

2. Analysis of **Communication Requirements (RSUs)** for Variable Speed Limit Control
   Instead of switching Variable Speed Signs, **Speed advices** are sent out all connected and automated vehicles, which adjust their speed accordingly.

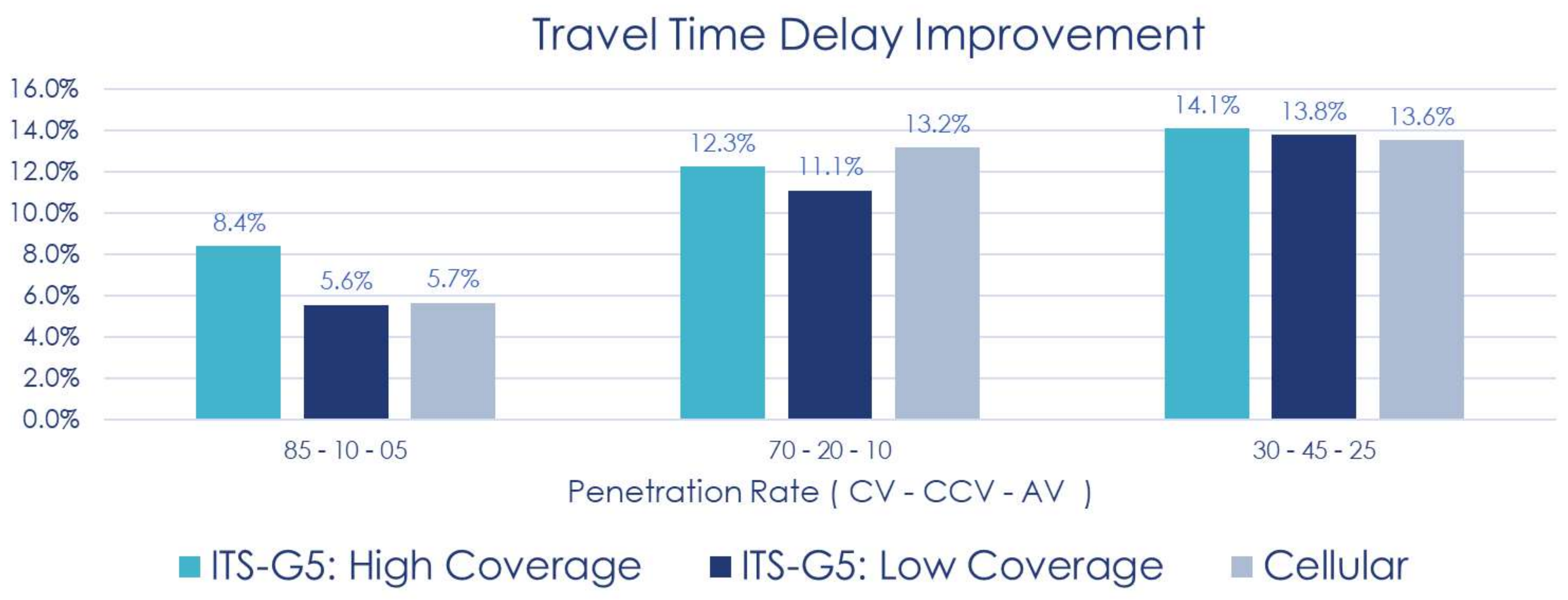
   - A) No control algorithm active
   - B) ITS-G5: **High coverage** of Road Side Units (every 500m)
   - C) ITS-G5: **Low coverage** of Road Side Units (every 2 km)
   - D) **Cellular: No Road Side Units**, use cellular communication (e.g. LTE)

No Control | ITS-G5: high RSU coverage | ITS-G5: low RSU coverage | Cellular



Evaluating the **VSL Controller** (2)

2. Analysis of **Communication Requirements (RSUs)** for Variable Speed Limit Control
   Instead of switching Variable Speed Signs, **Speed advices** are sent out all connected and automated vehicles, which adjust their speed accordingly.



Conclusions / Key Results

- Co-simulation environment VSimRTI was employed and enhanced to allow for an extensive evaluation of the developed traffic estimation and control algorithms
  - New application interface to seamlessly integrate external code (control algorithms)
  - New models for infrastructure elements (VMS, sensors)
  - Coupling of microscopic traffic simulation with and sub-microscopic vehicle simulation.

- A holistic microscopic simulation scenario was created and calibrated on the basis of the real-world traffic data
  - 24h of traffic in the simulation, with more than 125.000 vehicles on AP-7 Girona, mix of Trucks, conventional vehicles, connected vehicles, automated vehicles

- Analysed infrastructure and communication requirements for the VSL controller
  - Up to 15% improvement in traffic efficiency using variable speed limits displayed on VMS
  - Placing few VMS on strategic positions shows slightly lower performance than a full deployment
  - With a moderate penetration rate of connected vehicles, VSL control works without VMS / Gantries

Karl Schrab

Fraunhofer FOKUS

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 723016.

INFRAMIX online final conference

Martin Rudigier/Virtual Vehicle

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 723016.

Submicroscopic simulation

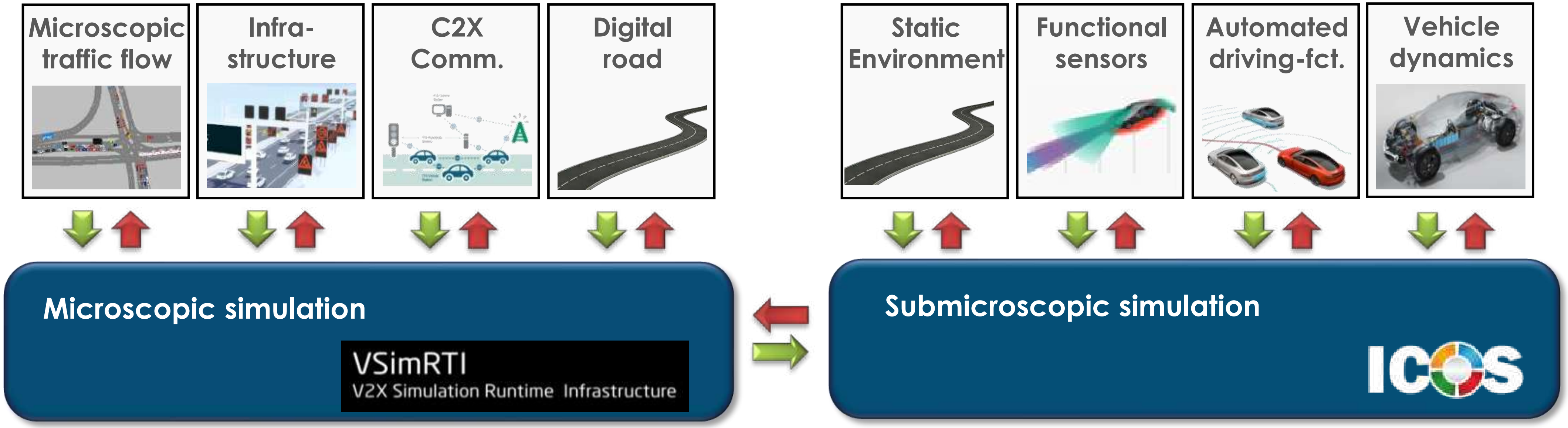
Submicroscopic simulation – Introduction

- Submicroscopic co-simulation
- Modules of the submicroscopic simulation
- Characteristics of submicroscopic simulation

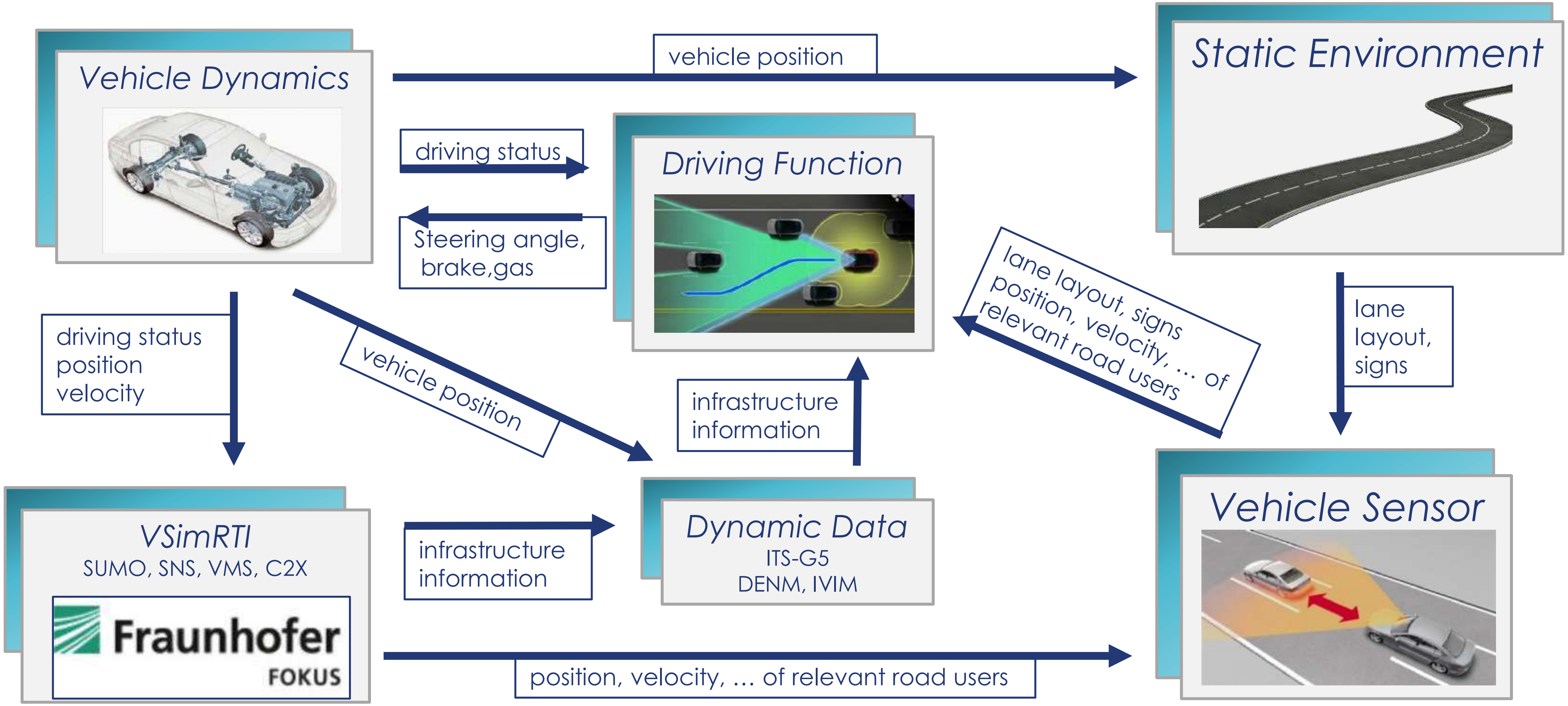
Scenarios and Results

- Road and Traffic
- Bottleneck - Onramp
- Bottleneck – Main road
- Roadworks zone

Submicroscopic simulationn



Submicroscopic simulation



Submicroscopic simulation

- Microscopic simulation
  - a huge number of vehicles
  - Low details on vehicle level
- Submicroscopic simulation
  - One vehicle
  - Detailed vehicle dynamic model
  - Sensor model
  - ADAS functions (ACC, LKA, …)
  - Automated driving functions (Trajectory planning, …)
- Co-simulation
  - To get the best of both worlds

Submicroscopic simulation

Submicroscopic simulation – Introduction

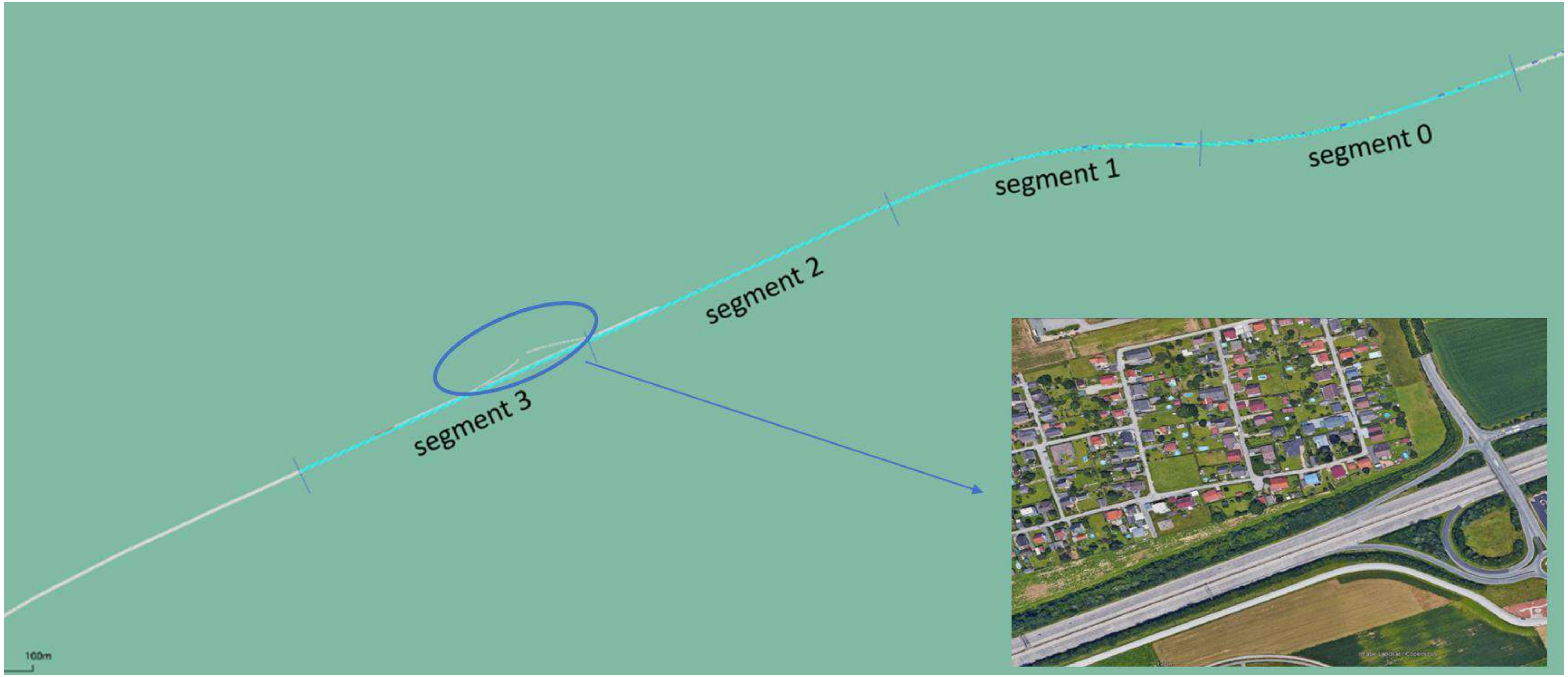
- Submicroscopic co-simulation
- Modules of the submicroscopic simulation

Scenarios and Results

- Road
- Traffic
- Bottleneck - Onramp
- Bottleneck – Main road
- Roadworks zone

Scenarios and results

Simulated part of the Austrian test site



Scenarios and results

Traffic flow:

Level of Service	Flow
	veh/h
LOS A	1580
LOS B	3065
LOS C	4410
LOS E	5180

Vehicle types:

Vehicle Type	Part of the flow
Conventional vehicles	64.5%
Automated vehicles	21.2%
Motorcycles	2.3%
Trucks	4.7%
Trailers	6.9%

Bottleneck onramp

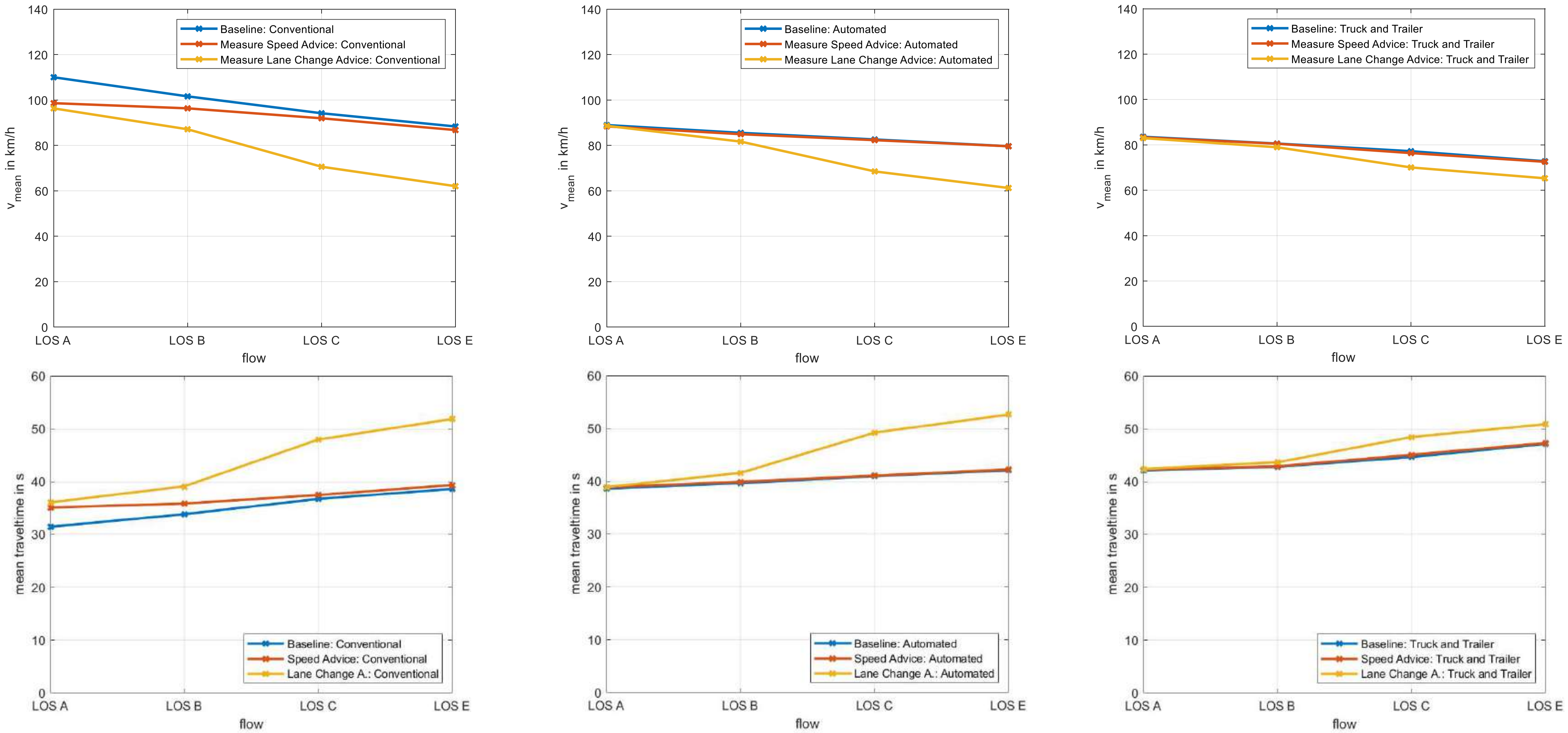
- VuT (Vehicle under Test) starts form the onramp
- Mixed traffic on the main road
- Baseline
  - VuT tries to merge without any help from the infrastructure
- Measure I
  - Via VMS and IVIM the speed of the traffic on the main road is reduced to 100km/h
- Measure II
  - Via VMS and IVIM the speed of the traffic on the main road is reduced to 100km/h
  - Automated vehicles on the main road receive an IVIM with a lane change recommendation

Bottleneck - onramp

	Demanded	Baseline	Measure I	Measure II
	Flow	Flow	Flow	Flow
	veh/h	veh/h	veh/h	veh/h
LOS A	1580	1603	1612	1609
LOS B	3065	3051	3059	3053
LOS C	4410	4397	4414	4368
LOS E	5180	4952	5008	4735

		Baseline	Measure I	Measure II
		Number of Stops	Number of Stops	Number of Stops
LOS A	VuT	0	0	0
LOS B	VuT	0	0	0
LOS C	VuT	3	4	4
LOS E	VuT	7	7	2

Bottleneck - onramp



Bottleneck – main road

- VuT starts on the main road
- Mixed traffic starts on the main road
- 10% of mixed traffic starts on the onramp

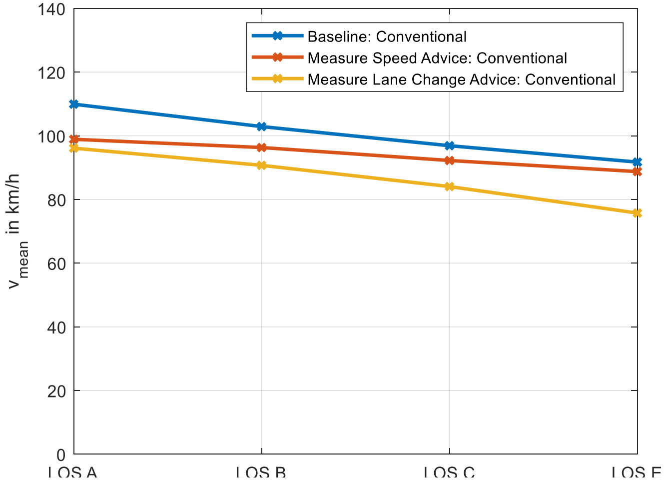
- Baseline
  - No measure supports the vehicles from the onramp when merging
- Measure I
  - Via VMS and IVIM the speed of the traffic on the main road is reduced to 100km/h
- Measure II
  - Via VMS and IVIM the speed of the traffic on the main road is reduced to 100km/h
  - Automated vehicles on the main road receive an IVIM with a lane change recommendation

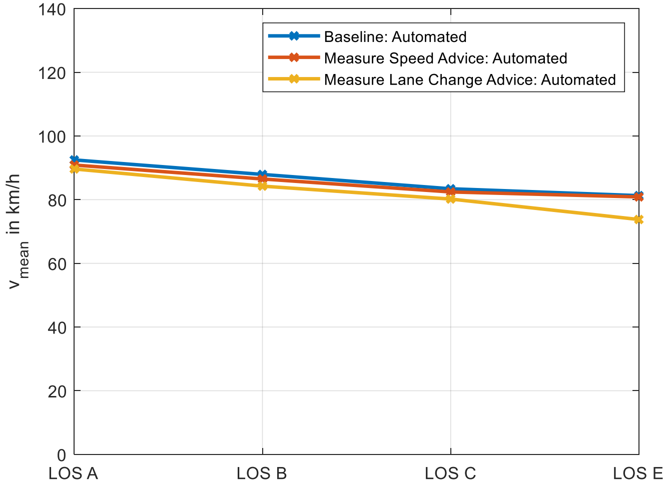
Bottleneck – main road

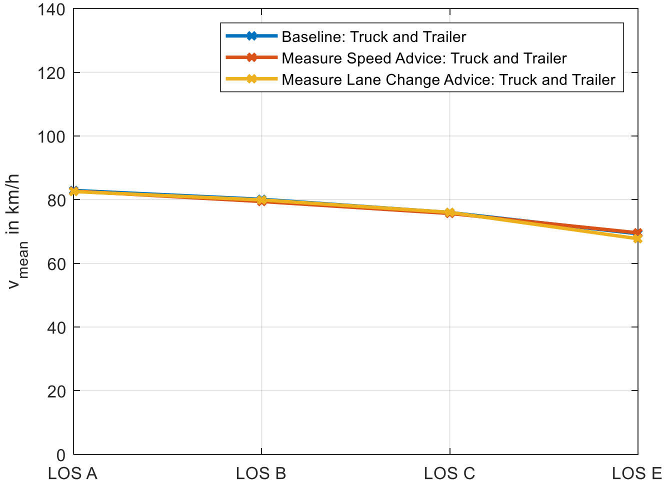
	Demanded	Baseline	Measure I	Measure II
	Flow	Flow	Flow	Flow
	veh/h	veh/h	veh/h	veh/h
LOS A	1580	1593	1584	1576
LOS B	3065	2995	2977	2971
LOS C	4410	3995	4000	3819
LOS E	5180	4567	4573	4026

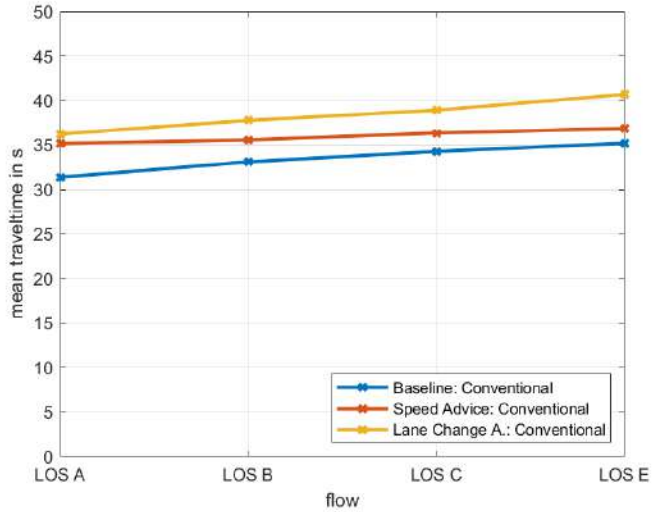
INFRAMIX

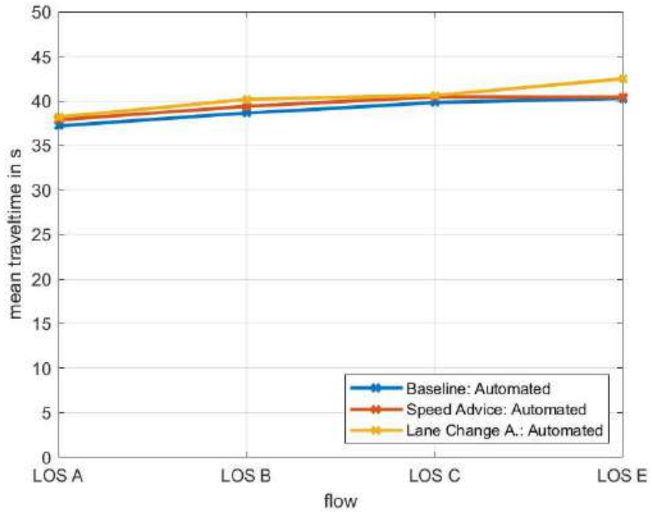
Bottleneck – main road

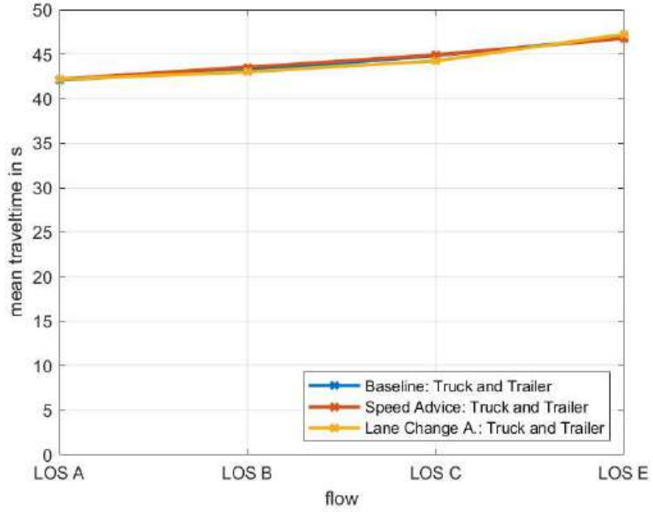












Roadworks zone

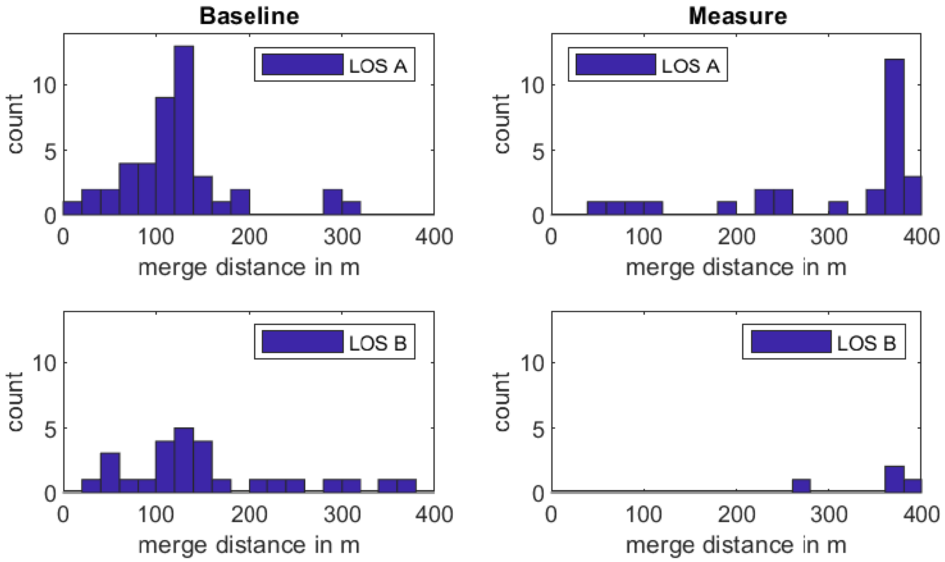
- In Segment 3 the rightmost lane is declared as an roadworks zone and blocked. Only 2 of 3 lanes remain for the traffic.
- The onramp is also closed
- The VuT and the mixed traffic drive at the main road.

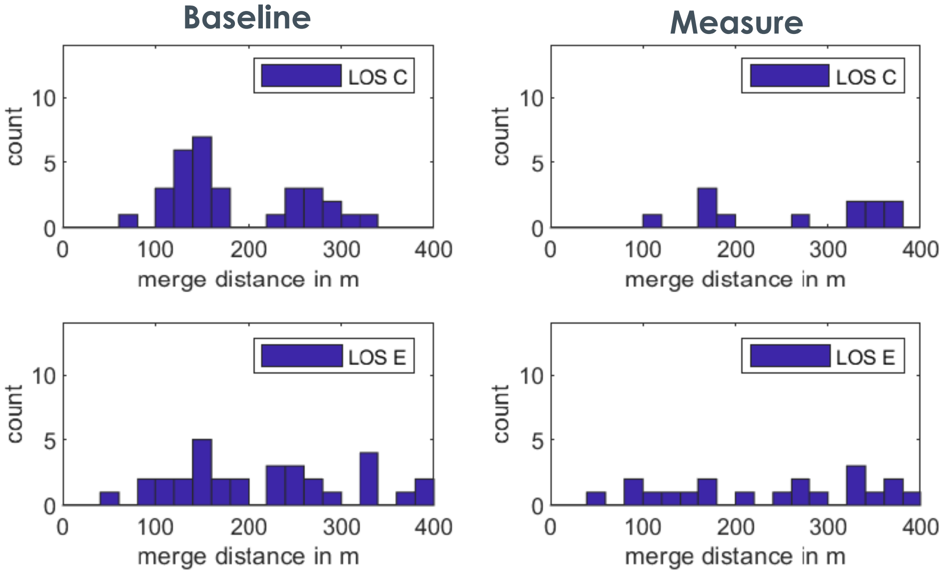
- Baseline
  - The VuT recognices with its own sensors the roadworks zone
- Measure
  - The VuT is informed via a DENM about the upcoming roadworkzone and can early start a lane change manouvre to merge into the 2 remaining lanes.

Roadworks zone

	Traffic flow, Baseline				Traffic flow, Measure			
	Mean	Deviation	Min	Max	Mean	Deviation	Min	Max
	veh/h	veh/h	veh/h	veh/h	veh/h	veh/h	veh/h	veh/h
LOS_A	1637	418	420	2580	1643	428.1	420	2580
LOS_B	2910	473.2	1402	4380	2963	475.3	1402	3780
LOS_C	3350	511.5	2340	4440	3370	515.5	2160	4260
LOS_E	3485	478.3	1620	4260	3483	462	1620	4200

	Baseline		Measure	
	Num. stopped	Num. Merged	Num. stopped	Num. merged
LOS A	3	34	0	27
LOS B	3	26	1	4
LOS C	3	26	2	12
LOS E	3	35	2	23





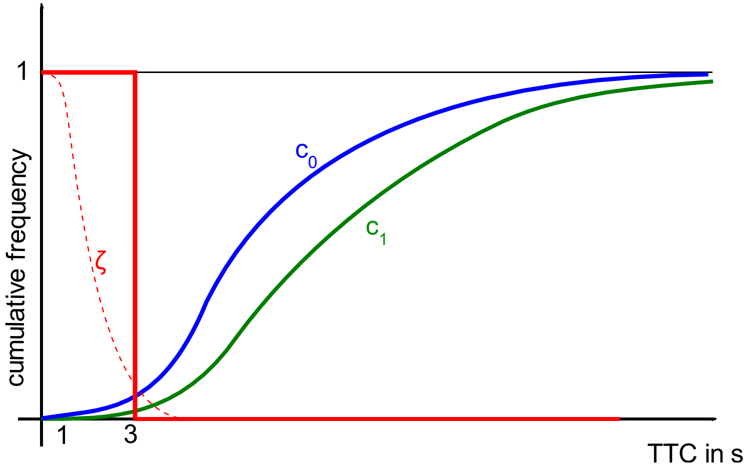
Thank you for your attention

Martin Rudigier

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 723016.

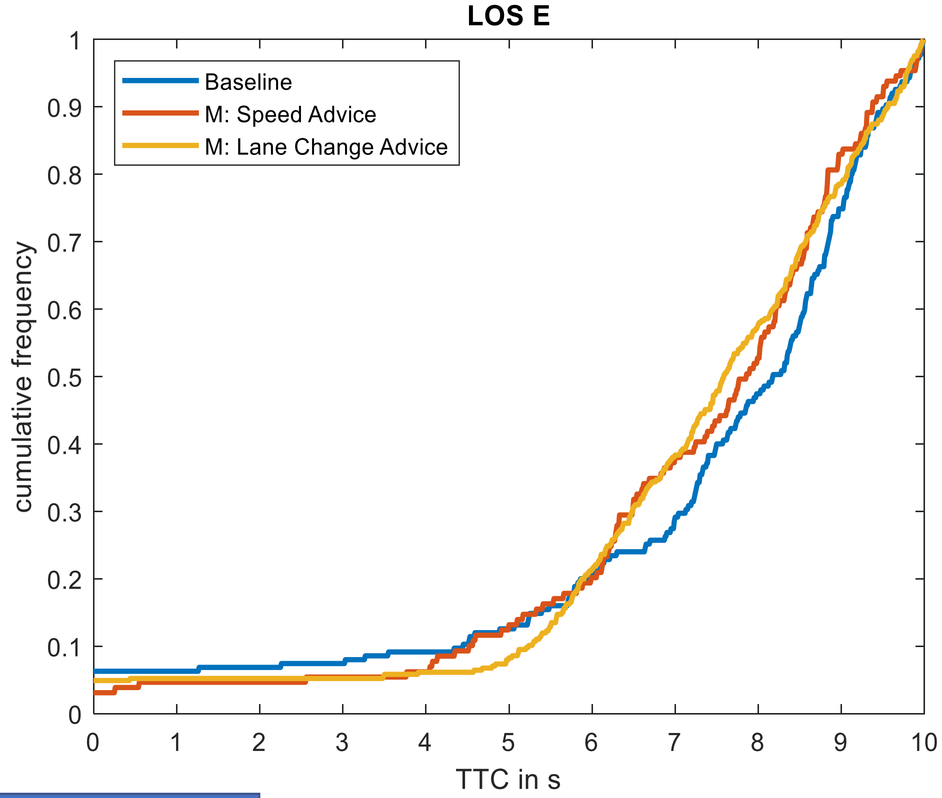
Backup

TTC as Safety KPI



$$KPI_{TTC} = \int_0^\infty \zeta(TTC).\left(c_0(TTC) - c_1(TTC)\right)dTTC$$

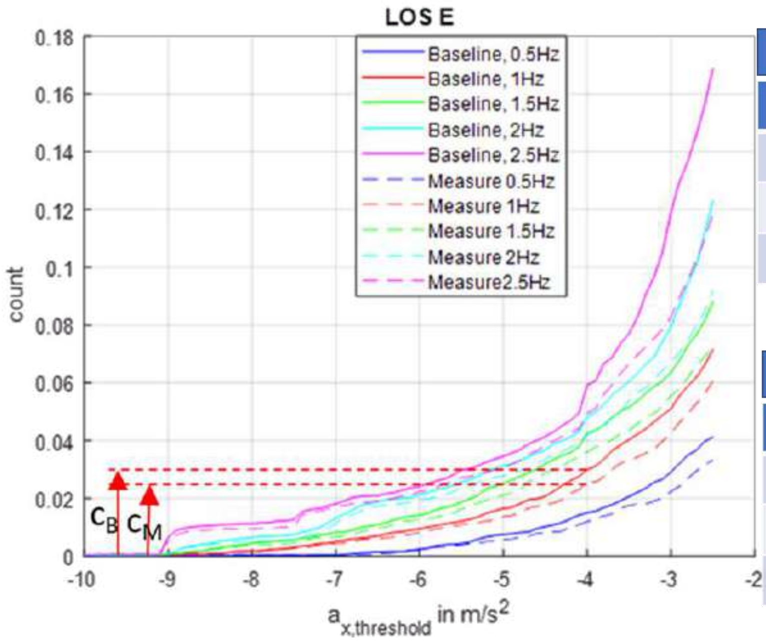
$$\zeta(TTC) = \begin{cases} 1..TTC \le TTC_{Th} \\ 0..TTC > TTC_{Th} \end{cases}$$



SC3UC3, Bottleneck, Onramp				
	LOS A	LOS B	LOS C	LOS E
$KPI_{TTC\ 3,Speed\ Advice}$	-52.8 %	-1.2 %	-14.4 %	6.6 %
$KPI_{TTC\ 3,\ Lane\ Change\ Advice}$	22.1 %	29.2 %	-2.7 %	4.8 %

Brake rate as Saftey KPI

- Idea
  - Count events, with acceleration lower than a threshold
- Acceleration not available, differentiate velocity
- Filter
- Threshold



SC3UC3, Bottleneck, Onramp, Speed Advice				
	LOS A	LOS B	LOS C	LOS E
C_B	0.88 %	2.05 %	2.90 %	3.00 %
C_M	0.86%	0.89 %	1.96 %	2.57%
$KPI_{BR,Speed\ Advice}$	2.7%	56.5%	32.3%	14.3%

SC3UC3, Bottleneck, Onramp, Lane Change Advice				
	LOS A	LOS B	LOS C	LOS E
C_B	0.88 %	2.05 %	2.90 %	3.00 %
C_M	9.14 %	17.06 %	20.08%	14.91 %
$KPI_{BR,\ Lane\ Change\ Advice}$	-932%	-733%	-592%	-397%

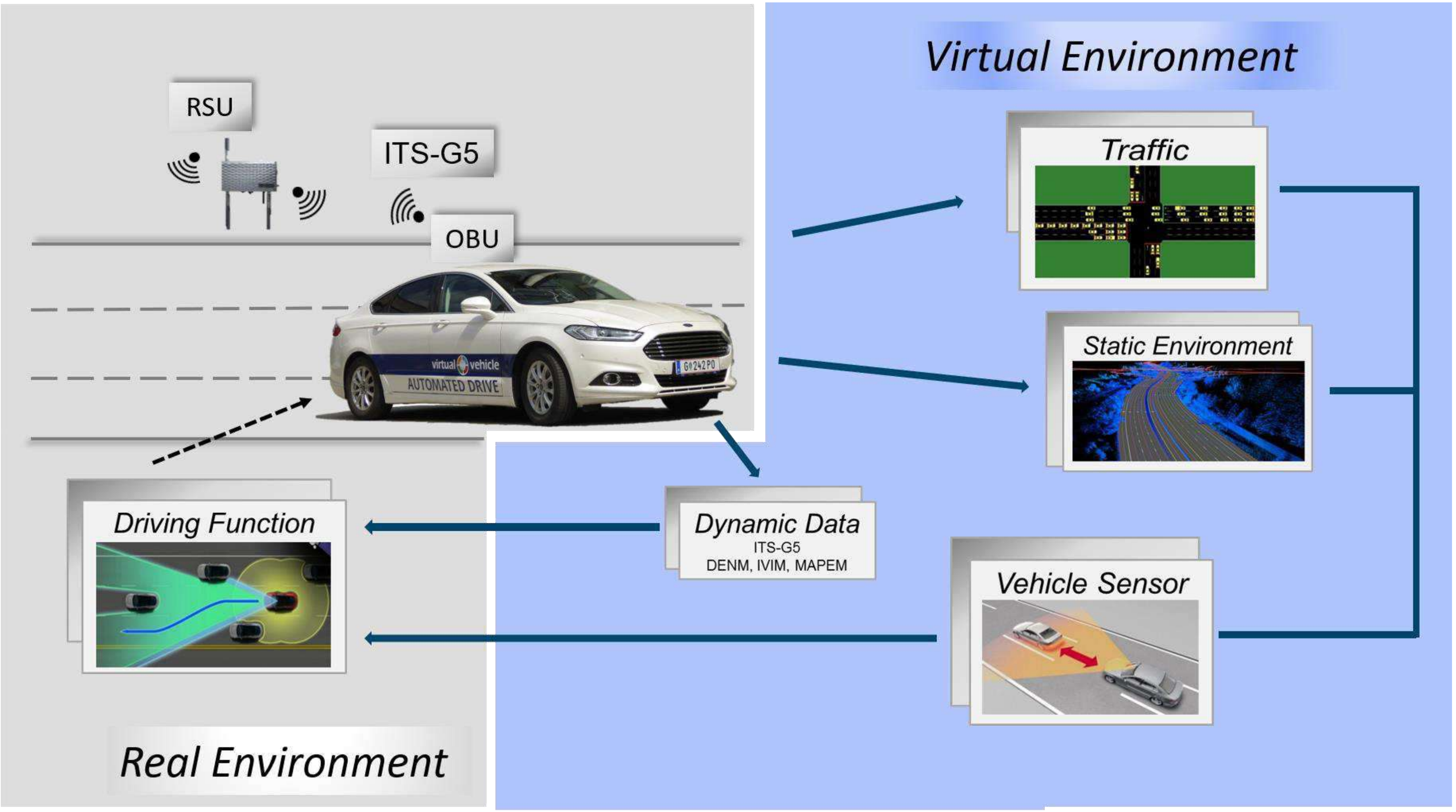
Hybrid Testing:

A Vehicle-in-the-Loop Methodology for Evaluating Automated Driving Functions in Virtual Traffic

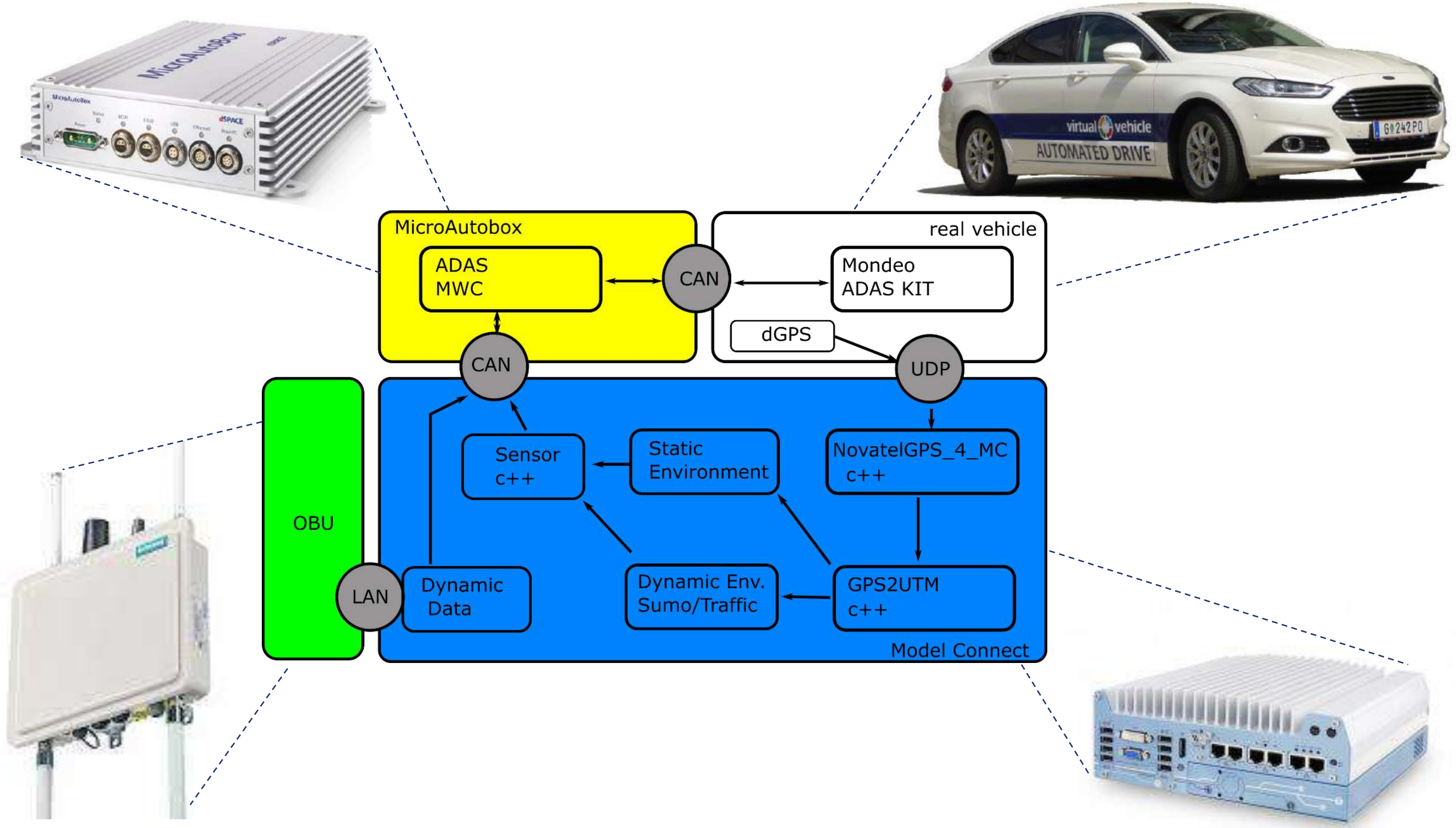
Dr. Selim Solmaz / Virtual Vehicle

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 723016.

Hybrid Testing Concept

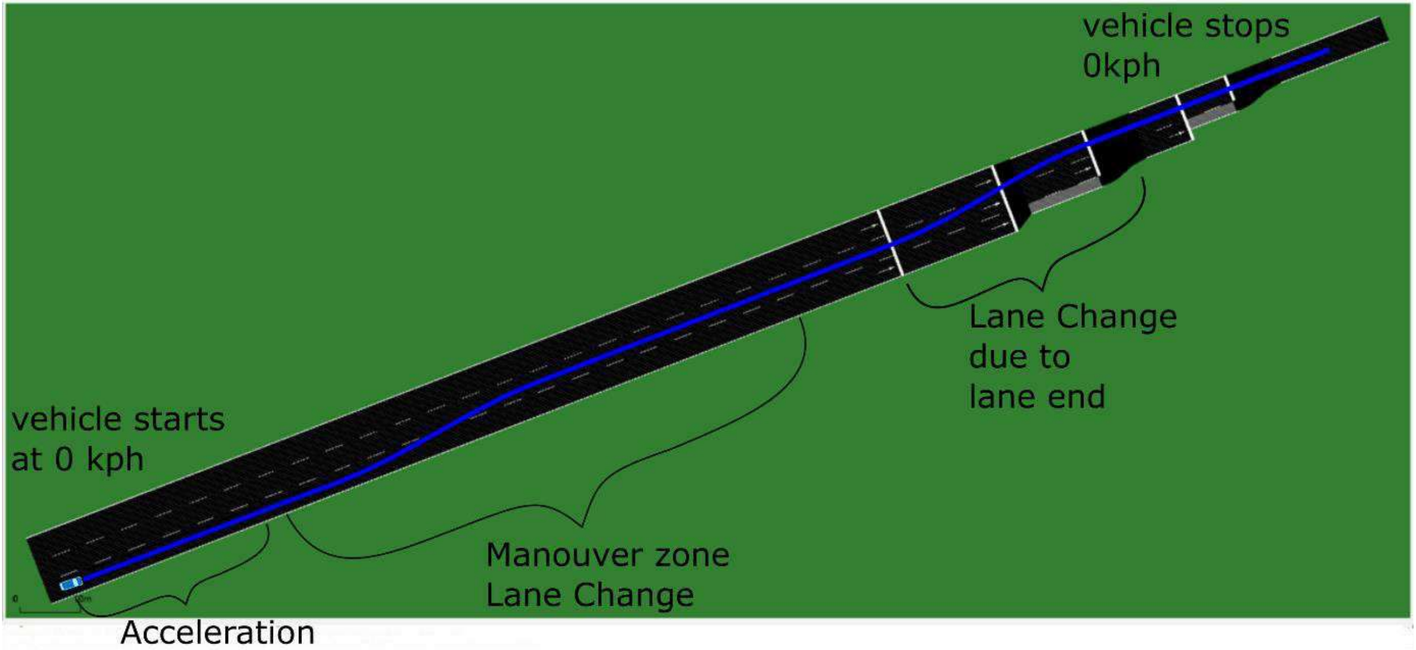


Hardware Components of Hybrid Testing



HD-Map of the Proving Ground

- Open drive map format (.xodr) file of the ÖAMTC *Lang-Lebring* proving ground near Graz
- A straight road section with approximate usable length of ~250 m and width of at least 10 m across the main testing zone
- 3 virtual lanes with a width of 3.5m each + additional maneuver space as buffer zone



Hybrid Testing Experiments and Scenarios

Exp. Stack 1) Onramp – Merge into the main road

- Without traffic
- With low traffic
- With high traffic

Exp. Stack 2) Main road – speed recommendation (IVIM)

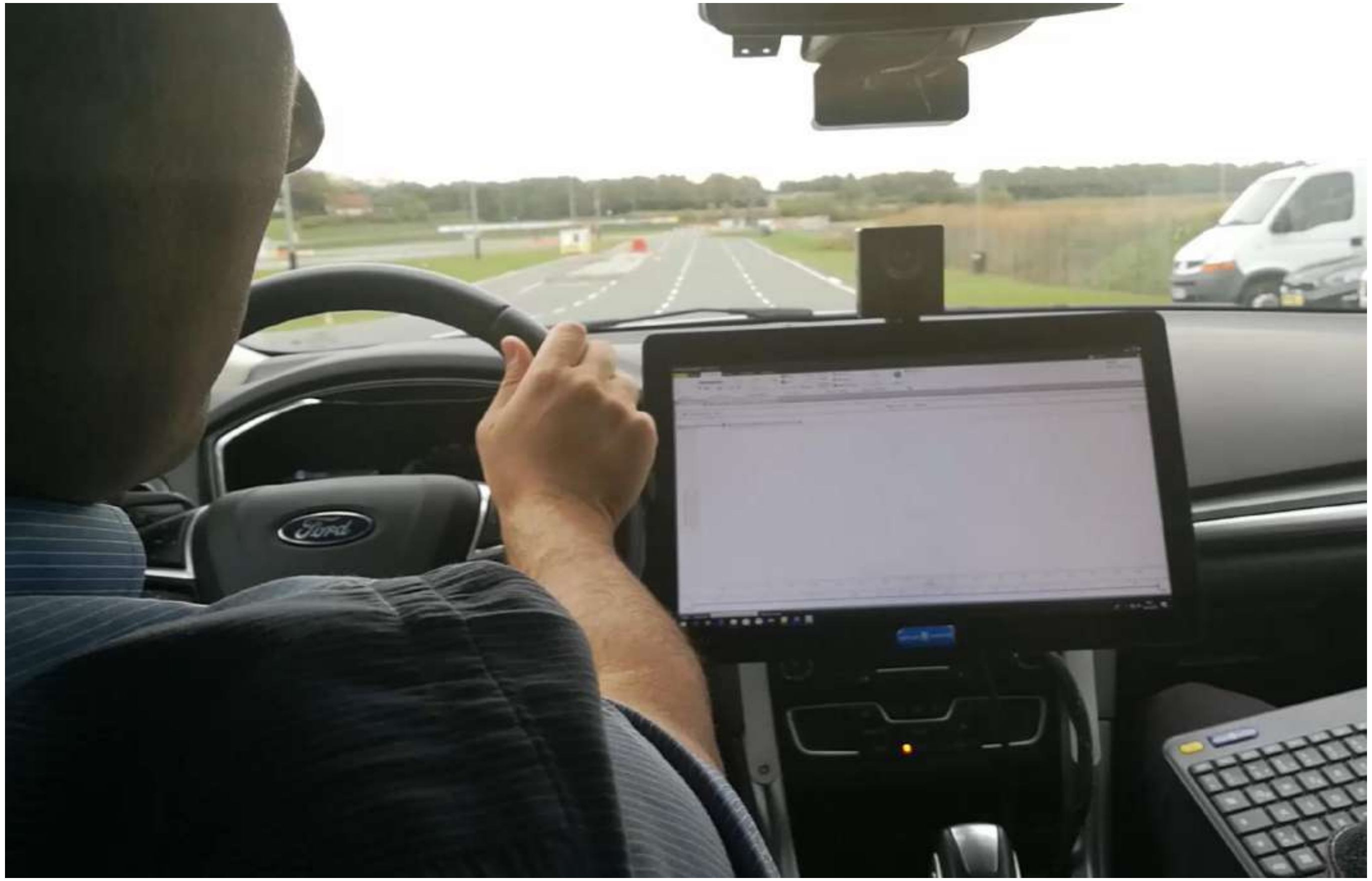
- Main road – without traffic
- Main road – without traffic & speed recommendation (IVIM)
- Main road – speed recommendation (IVIM) with vehicle in front & MWC overtakes
- Main road – speed recommendation (IVIM) with vehicle in front MWC adapts speed

Onramp Scenario: Merge into the main road

Scenario Description:

Merge into main road without traffic

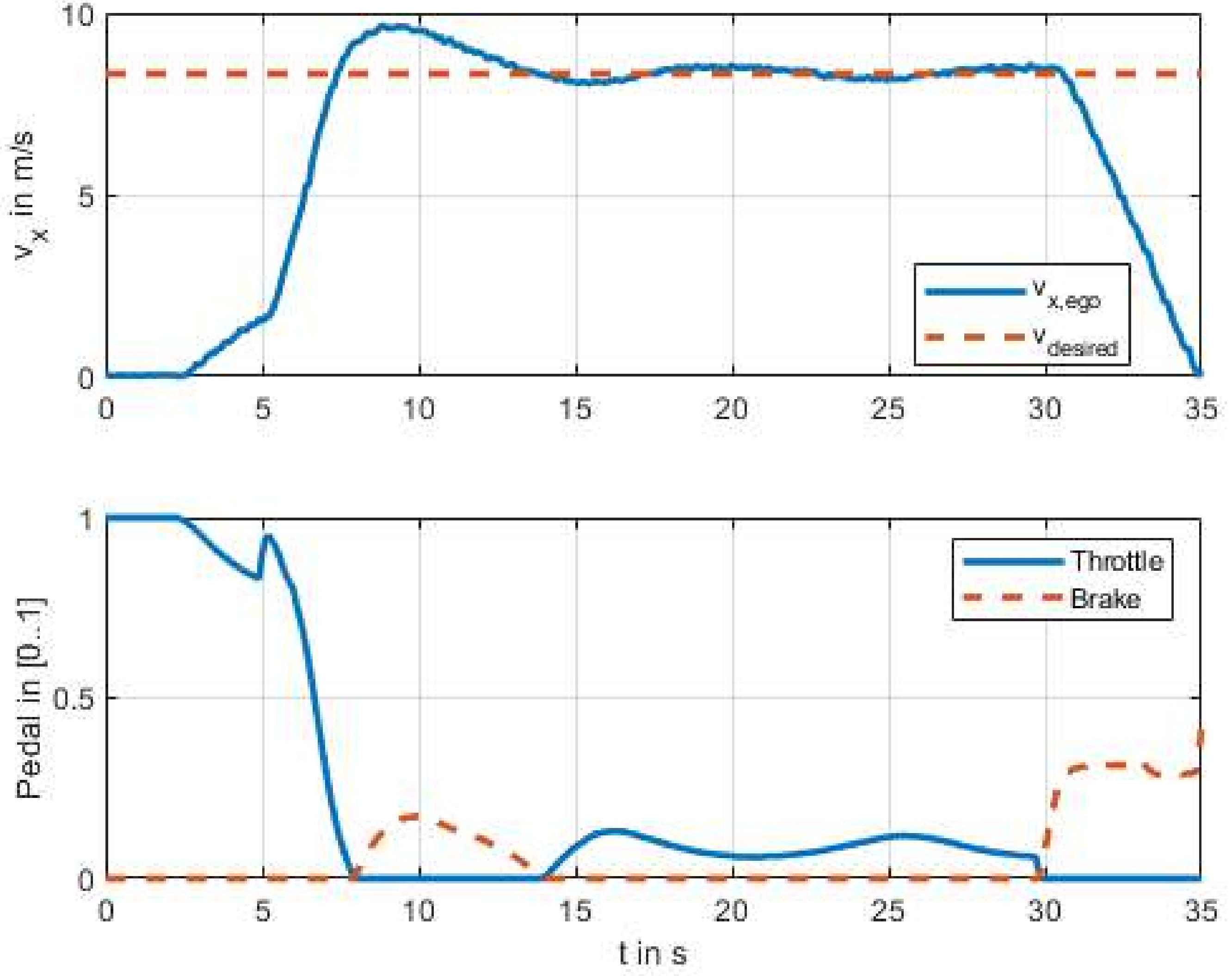
- VuT starts at the rightmost lane & accelerates to 30 km/h
- When the VuT reaches 20 km/h (parameter) it starts the lane change manoeuvre to merge into the main lanes (lane 2 and 3 from the right)
- No interfering traffic



Onramp Scenario: Merge into the main road

Merge into main road without traffic

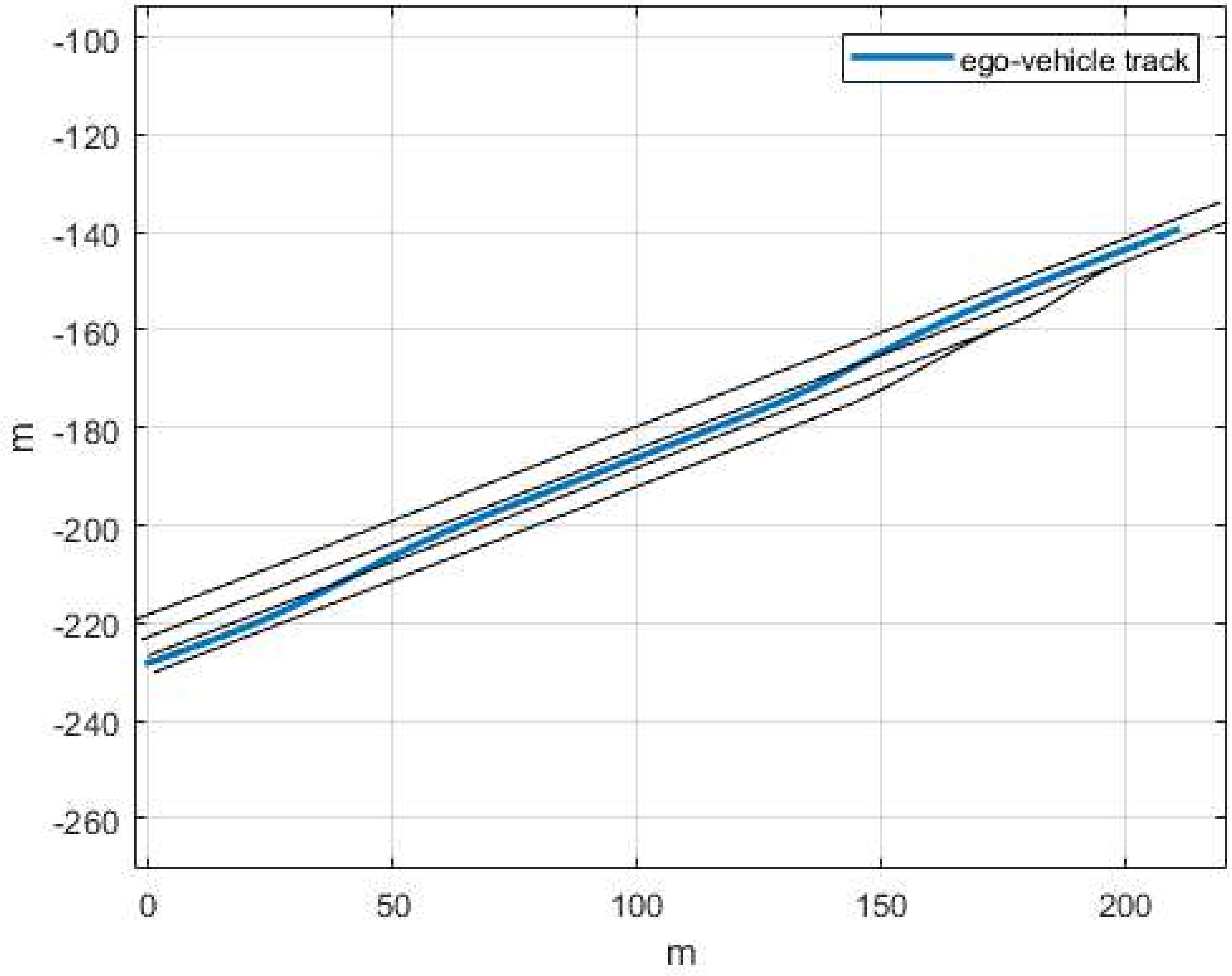
- Data Sample
- Postprocessing
- Longitudinal dynamics



Onramp Scenario: Merge into the main road

Merge into main road without traffic

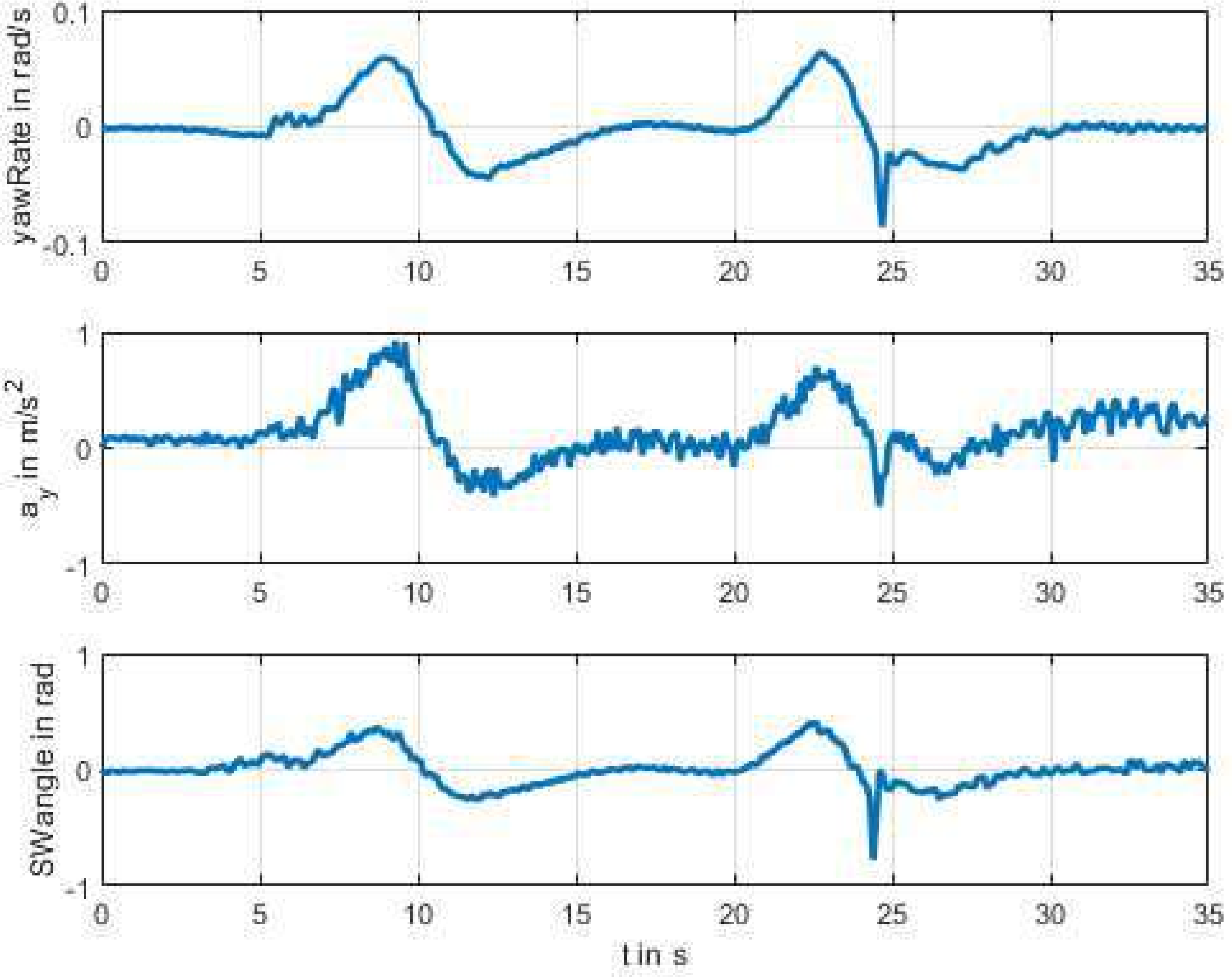
- Data Sample
- Postprocessing
- Ego-vehicle track



Onramp Scenario: Merge into the main road

Merge into main road without traffic

- Data Sample
- Postprocessing
- Lateral dynamics

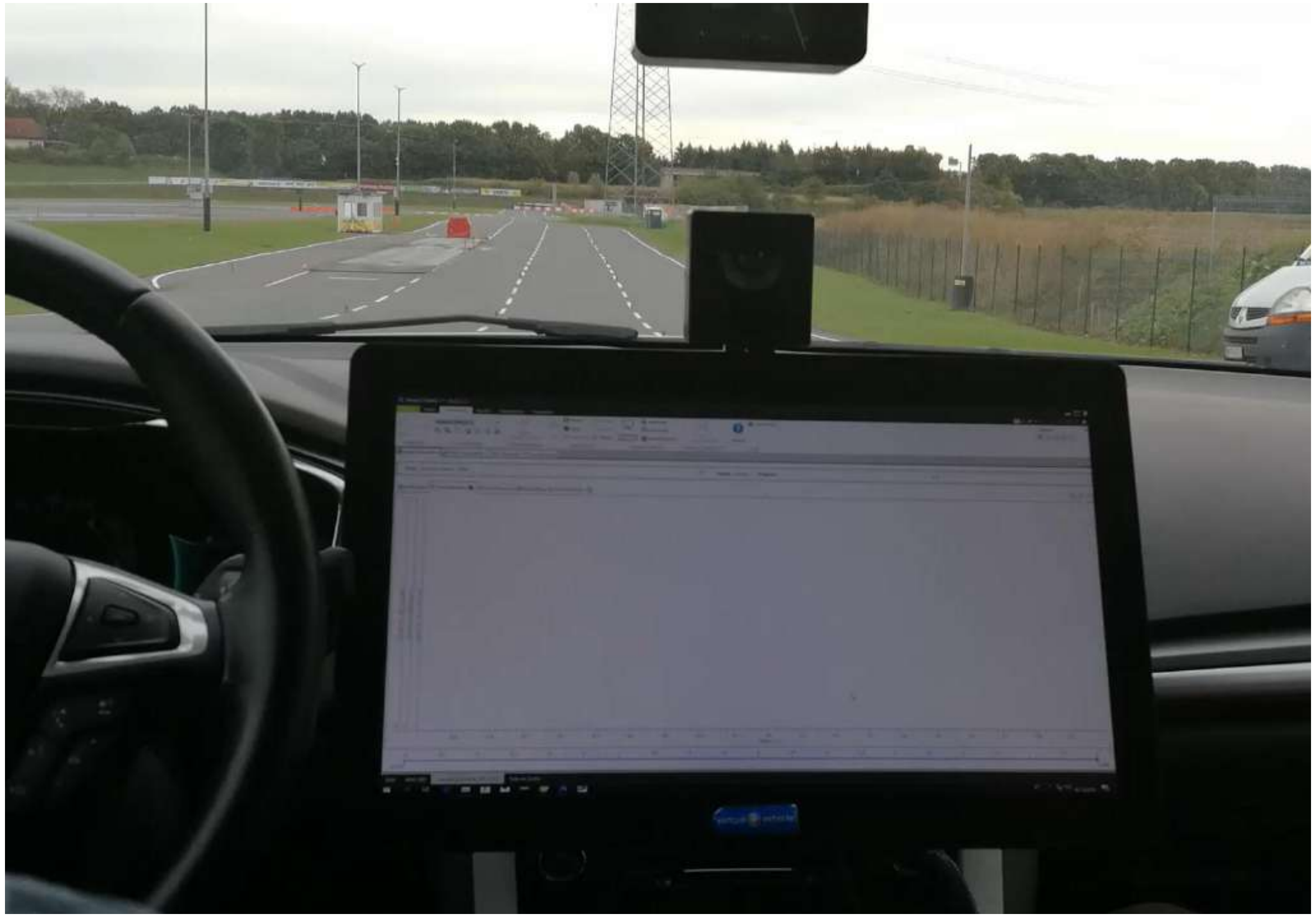


Onramp Scenario: Merge into the main road with Traffic

Scenario Description:

Merge into main road with low/high traffic

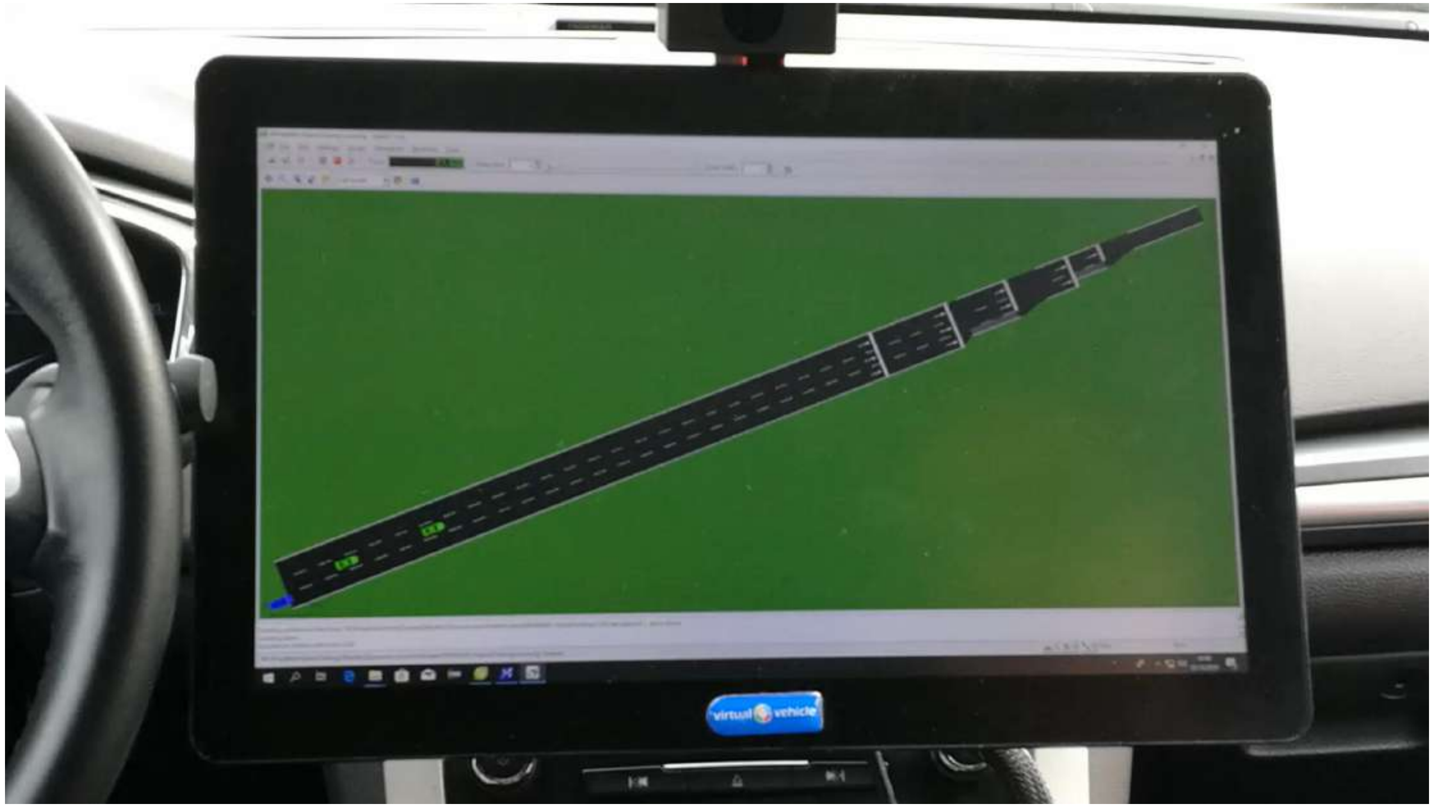
- VuT starts at the rightmost lane & accelerates to 30 km/h
- When the VuT reaches 20 km/h (parameter) it starts the lane change manoeuvre to merge into the main lanes (lane 2 and 3 from the right).
- Three vehicles on the main road



Onramp Scenario: Merge into the main road with Traffic

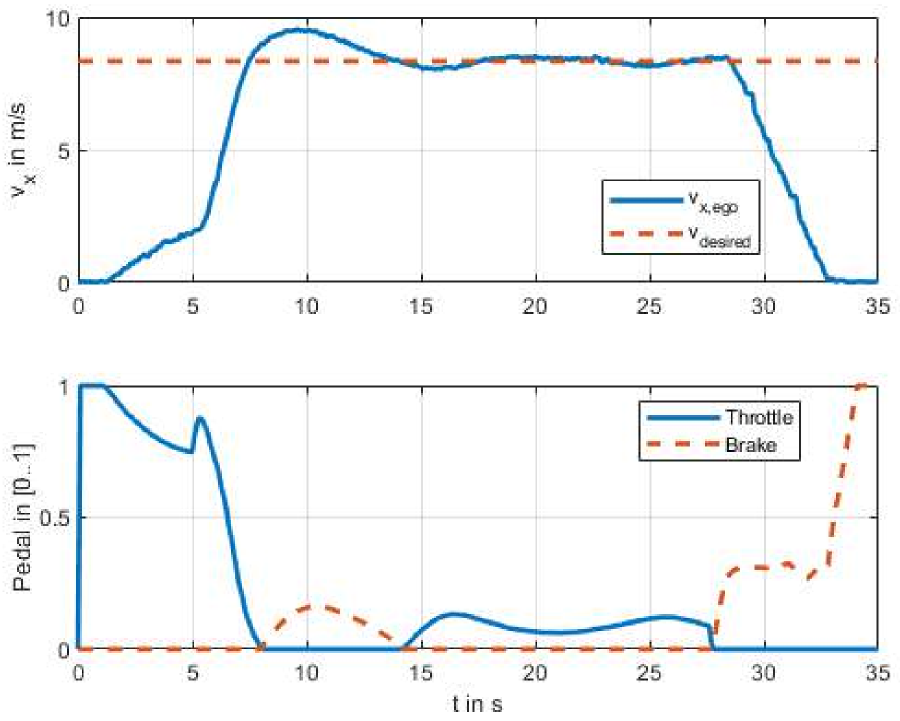
Merge into main road with high traffic

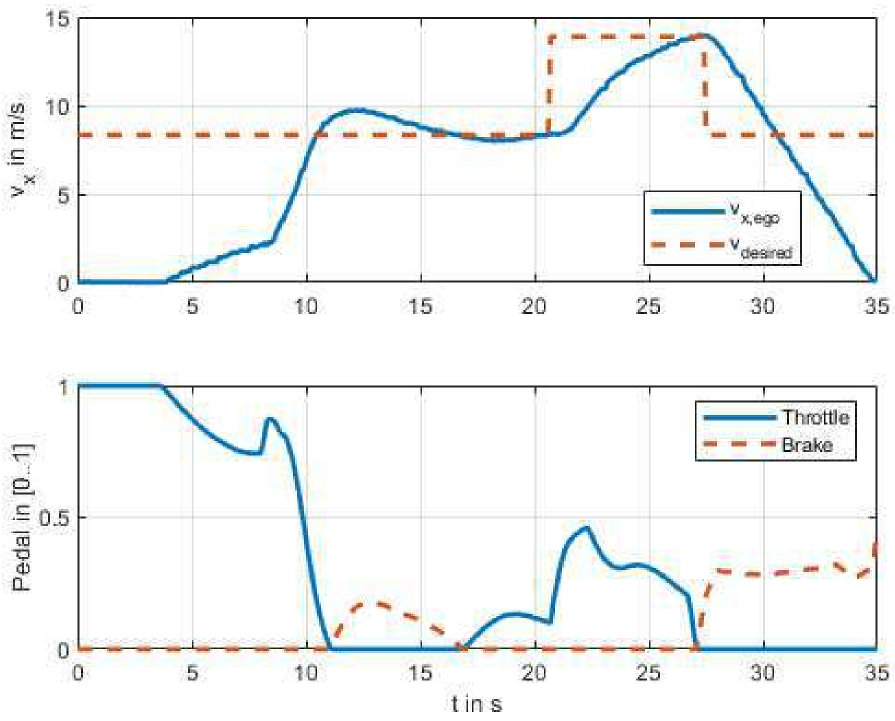
- Lane Change not possible, MWC performs a safety stop



Main road – max speed (IVIM) with vehicle in front, MWC adapts speed

- No Message vs. with ITS-G5 Message





Main road – max speed (IVIM) with vehicle in front, MWC overtakes

Scenario Description:

With max speed (IVIM), vehicles in front and MWC overtakes

- The VuT starts on the left side of the track on the middle lane (lane-2), accelerates from stand still to 30 km/h and changes the lane before the lane ends
- After ~100m from the start, the VuT receives an IVIM via its OBU with a new max. speed of recommendation of 50 km/h and accelerates to this speed but a slower vehicle in front of the VuT hinders the VuT reaching the new max speed without overtaking
- The VuT performs a lane change manoeuvre to overtake

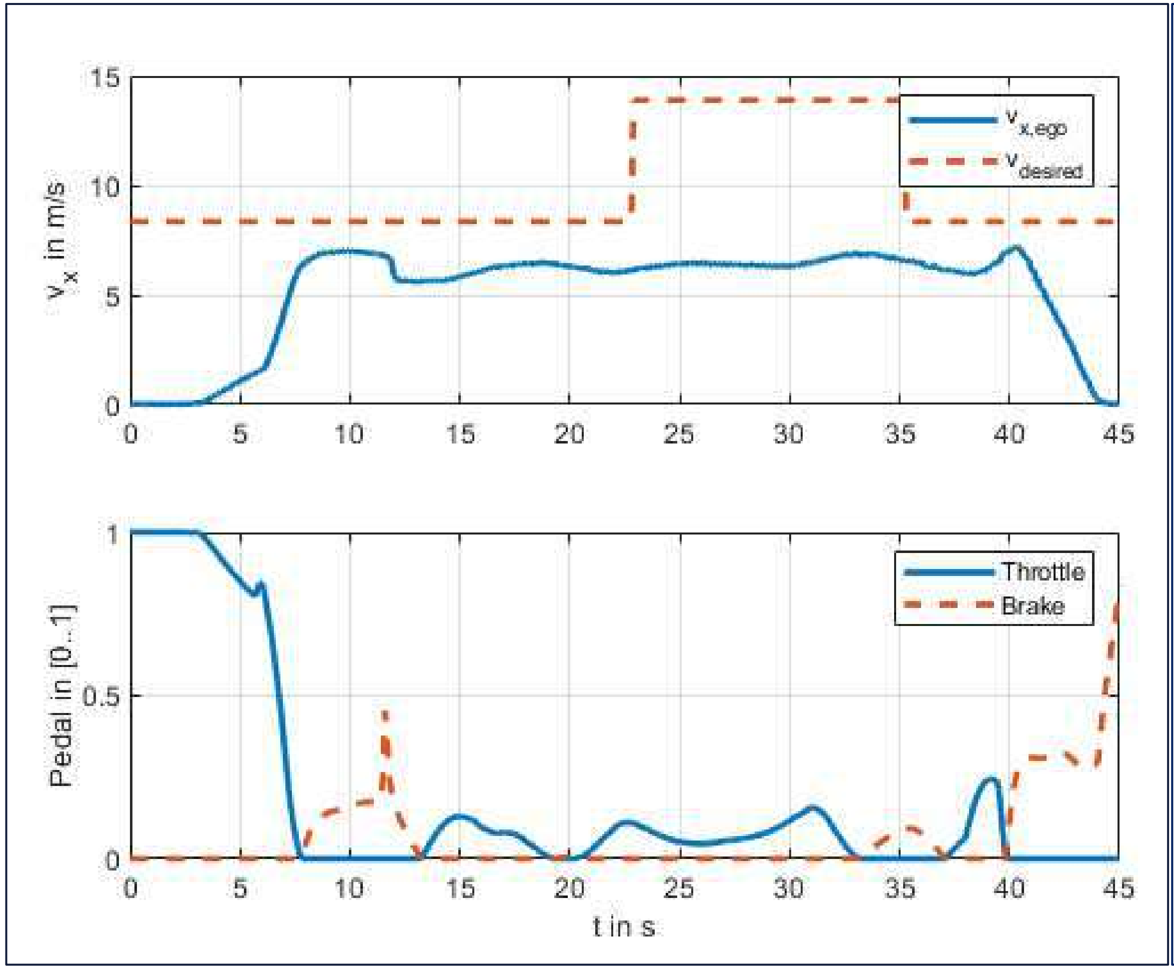
Main road – max speed (IVIM) with vehicle in front, MWC adapts speed

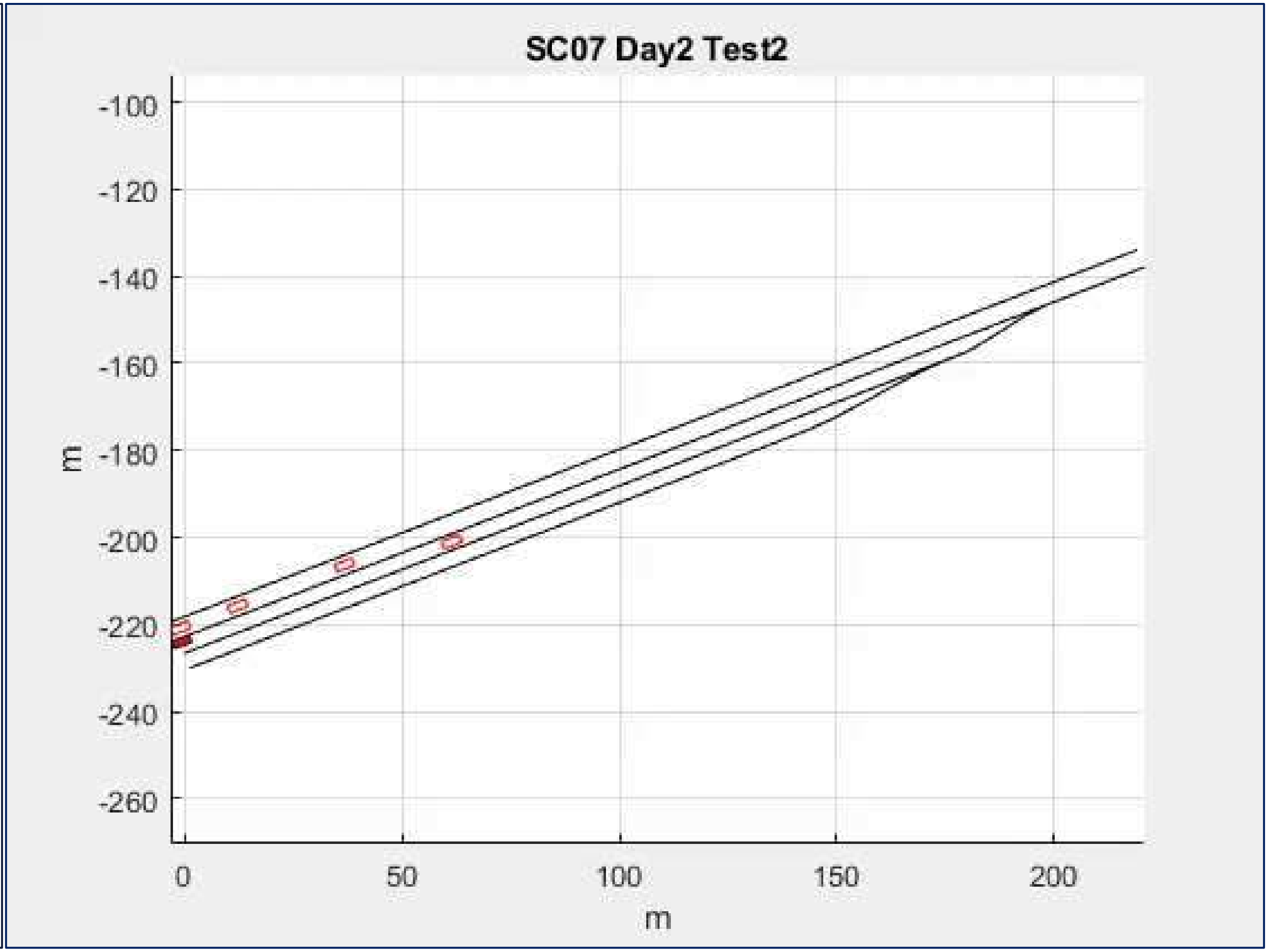
Scenario Description:

With max speed (IVIM), vehicles in front and MWC adapts speed

- The VuT starts on the left side of the track on the middle lane (lane-2), accelerates from stand still to 30 km/h and changes the lane before the lane ends
- After ~100m from the start, the VuT receives an IVIM via its OBU with a new max. speed of 40 km/h and accelerates to this speed
- A slower vehicle in front of the VuT hinders the VuT reaching the new max speed without overtaking forcing the VuT to follow behind it

Main road – max speed (IVIM) with vehicle in front, MWC adapts speed





Experiment (Stack-II) KPI Results

Scenario /Testday /Testrun	IVI send	IVI received	IVI Speed	VuT has adapted the speed	mean Speed VuT	mean speed VuT in rel. zone	mean speed all	min dist gap	min time gap	min TTC
-	-	-	km/h	-	km/h	km/h	km/h	m	s	s
4/2/1	no	no	N/A	no	30.7	30.1	30.7	N/A	N/A	N/A
5/2/1	yes	yes	40	yes	34.5	37.7	34.5	N/A	N/A	N/A
5/2/2	yes	yes	50	yes	36.4	41.9	36.4	N/A	N/A	N/A
6/2/1	yes	yes	50	no	34.2	36.1	29.7	11.7	1.17	4.85
6/2/2	yes	yes	50	no	34.2	36.3	29.4	13.82	1.33	5.2
7/2/1	yes	yes	50	no	28.3	27.1	25.1	2.04	0.4	1.36
7/2/2	yes	yes	50	no	23	23.4	19.1	3.34	0.5	3.46

Findings & Conclusion

- Repeatable and stable real-world proof of concept runs were demonstrated on the ÖAMTC Lang-Lebring Proving Ground
- Data Collected & proof-of-concept shown
- Comparison between sub-microscopic simulations were made
- Methodology particularly suitable to evaluate ADAS functions in various and randomized traffic scenarios
- Another potential utilization is for testing the effect of C-ITS messages on mixed traffic scenarios
- Potential extensions are possible and is planned for follow-up research activities:
  - Sensor modelling
  - 3D visualization integration
  - Integration of vehicular sensors to the co-simulation framework
  - Digital twin calibration

Thank you for your attention

Dr. Selim Solmaz

selim.solmaz@v2c2.at

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 723016.

INFRAMIX

INFRAMIX online final conference

Stamatis Manganiaris, ICCS

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 723016.

Users' Appreciation

Motivation - Background

The first period of coexistence of conventional, connected - conventional and automated vehicles will be very important for the future of intelligent transport.

User centric design of transport

+

Gradual and careful upgrade of the Road Infrastructure

to meet the expectations of users from the start

Inframix Targets

01 To prove the added value of Inframix developments to the daily lives of people

02 To evaluate the users' acceptance of Inframix developments

Evaluation Methodology

- 2 demonstration events (Girona, Graz)
- 2 workshops (Barcelona, Graz)
- Up to 11 Research Questions
- 3 scenarios
  - Dynamic Lane Assignment
  - Roadworks
  - Bottlenecks (on-ramps, lane drops, tunnels etc.)
- Digital questionnaires, paper questionnaires, videos, passengers' experience in demonstrations

Evaluation Methodology

Research categories

3 Users' Appreciation Factors

Users' appreciation factor	Research question	S1_UC1	S1_UC2	S1_UC3	S2_UC1	S2_UC2	S3_UC1	S3_UC2	S3_UC3
Behaviour change	RQ1.1 Behaviour change	x	x	x	x	x	x	x	x
Willingness to use	RQ2.1 Willingness to use	x	x	x	x	x	x	x	x
Perceived usability	RQ3.1 Traffic management	x		x			x	x	x
	RQ3.2 Learnability	x	x	x	x	x	x	x	x
	RQ3.3 Intuitiveness	x	x	x	x	x	x	x	x
	RG3.4 Understandability	x	x	x	x	x	x	x	x
	RQ3.5 Timing and number of signs	x	x	x	x	x			
	RQ3.6 Correct information	x	x	x	x	x	x	x	x
	RQ3.7 No distraction	x	x	x	x	x	x	x	x
	RQ3.8 Immediate Reaction	x	x	x	x	x	x	x	x
	RQ3.9 Potential benefit	x	x	x	x	x	x	x	x

Evaluation Methodology

- Expected impacts
  - On drivers, passengers, transport operators and traffic conditions
  - On traffic efficiency, safety

- Top 2 box + Bottom 2 box methodology was followed:
  - The top 2 box score is the sum of percentages for the top two highest points on satisfaction appreciation or awareness.
  - The bottom 2 box score is the sum of percentages for the top two lowest points on satisfaction, appreciation or awareness.

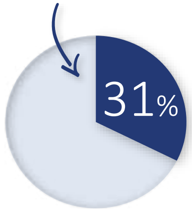
Focusing on those who have the **strongest** feelings.

Participants per event

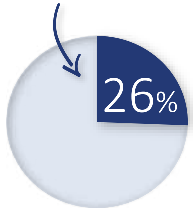
- Spanish workshop (Barcelona), 40 people
- Spanish demonstration (Girona)
    - Scenario 1 28
    - Scenario 2 20
    - Scenario 3 21
- Austrian workshop (Graz), 40 people
- Austrian demonstration (Graz), 20 people

Indicative percentage of women participants

Girona demonstration



Graz workshop

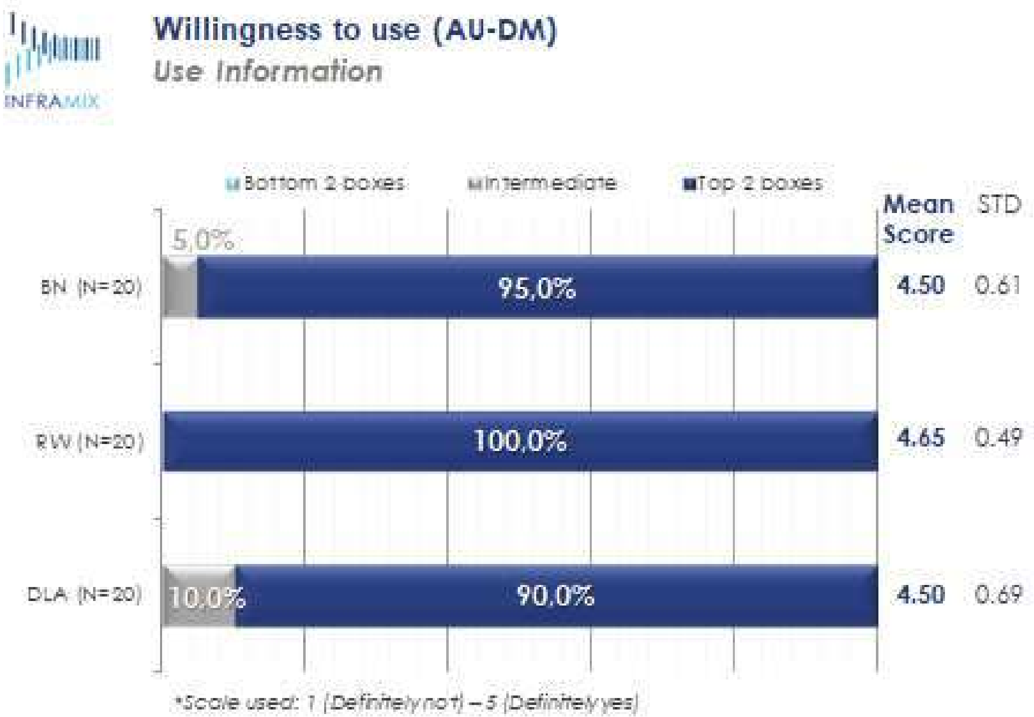


Results

Willingness to use

Do users state that are willing to use the information provided by the Intelligent Transport System?

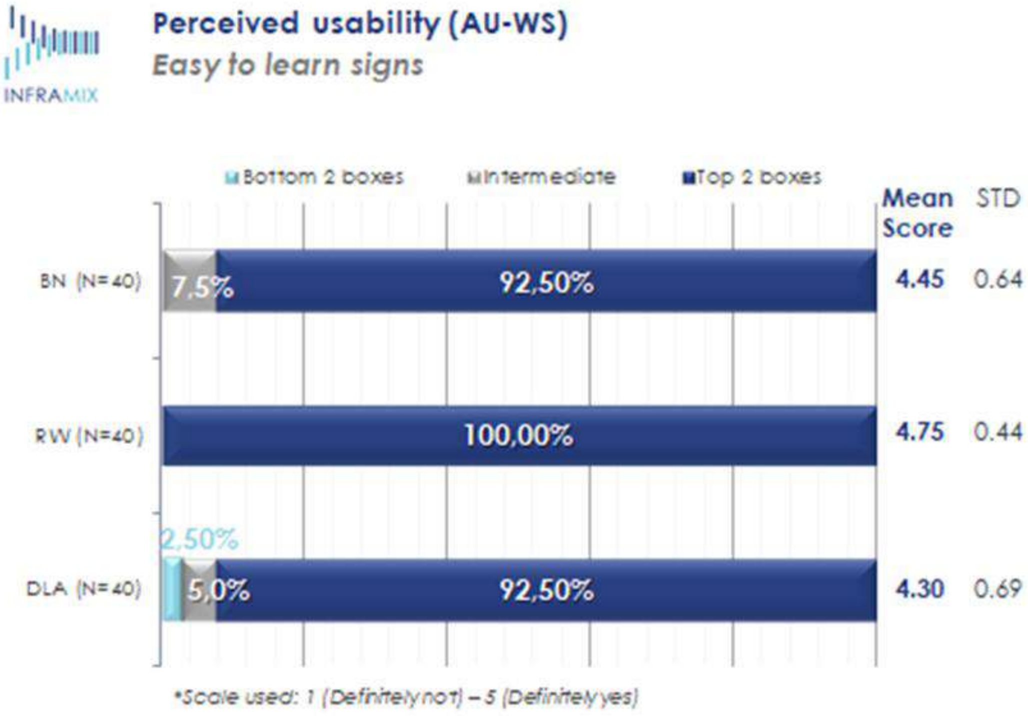
In general is increased with the real in daily life experience (not existing nowadays in ITS.



Perceived usability

Do users perceive the ITS functionalities as useful?

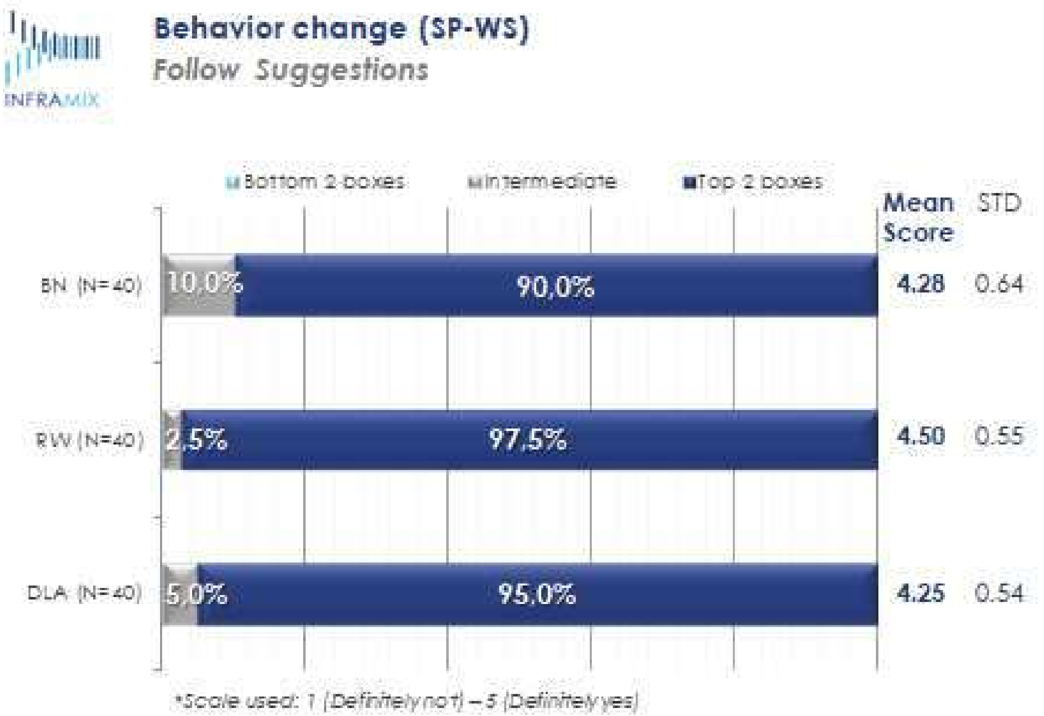
Although many innovations were seen by their inventors as useful the intended users never welcomed them. **Usability** is a pre-condition for approval.



Behaviour Change

Do users state that they would consider following the suggestions provided by the ITS?

A step forward in comparison with willingness to use because it is related to the change of driving process, actions habits and style.



Overall Results

(SP-WS)	BN		RW		DLA	
	Mean	STD	Mean	STD	Mean	STD
Willingness to use (scale used 1-5)						
Use information	4.23	0.71	4.43	0.59	4.23	0.58
Behavior change (scale used 1-5)						
Follow suggestions	4.28	0.64	4.50	0.55	4.25	0.54
Perceived usability (scale used 1-5)						
Easy to learn signs	4.13	0.83	4.41	0.72	4.26	0.64
Usefulness	4.10	0.74	4.28	0.60	3.93	0.94
Immediate reaction	4.13	0.85	4.25	0.71	4.05	0.81
Benefit	3.92	0.86	3.86	0.71	3.67	0.81
Intuitive signs	3.90	1.05	4.26	0.88	3.72	0.94
Understandable signs	3.92	1.09	4.38	0.81	3.95	0.86
Expected Impacts Results (scale used 0-10)						
Easier/intuitive interactions (DRIVERS)	7.21	1.64	7.13	1.79	6.88	1.73
Miss road sign in the in-vehicle HMI (DRIVERS)	6.89	1.71	6.90	1.67	6.42	2.00
Stress reduction (DRIVERS)	6.64	2.02	7.00	1.87	6.50	1.99
Increase comfort (DRIVERS)	6.82	1.89	6.79	1.82	6.65	1.79
Better perform daily work (TRANSPORT OPERATORS)	7.59	1.50	7.61	1.15	7.68	1.51
New incident detection ways (TRANSPORT OPERATORS)	7.15	1.65	7.46	1.39	7.28	1.82
New incident reaction ways (TRANSPORT OPERATORS)	7.87	1.34	7.77	1.22	7.90	1.37
Solve problems faster (TRANSPORT OPERATORS)	7.69	1.49	7.56	1.31	7.85	1.18
Stress reduction (TRANSPORT OPERATORS)	6.92	1.95	7.08	1.64	6.82	2.06
Expected Impacts Results (scale used 1-5)						
Traffic safety	3.95	0.99	4.40	0.63	3.93	0.62
Traffic flow/throughput	4.25	0.87	4.10	0.67	3.83	0.78
CO2 emissions	3.80	0.91	3.60	0.71	3.40	0.74

INFRAMIX

Overall Results

(SP-DM)	BN		RW		DLA	
	Mean	STD	Mean	STD	Mean	STD
Willingness to use (scale used 1-5)						
Use information	4.05	0.92	3.50	1.54	4.18	0.67
Behavior change (scale used 1-5)						
Follow suggestions	4.10	0.83	3.70	1.30	4.11	0.74
Perceived usability (scale used 1-5)						
Usefulness	4.19	1.03	3.80	1.28	4.25	0.75
Satisfying	3.62	0.92	3.70	1.38	3.86	0.65
Immediate reaction	3.62	1.12	3.70	1.38	4.11	0.50
Benefit	3.95	1.02	4.00	1.08	3.75	0.84
Easy to learn signs	4.19	0.60	4.15	1.14	4.29	0.60
Understandable signs	4.19	0.60	4.20	1.15	4.11	0.79
Correct Information	3.76	0.70	4.35	0.93	4.14	0.93
Not distracting from driving	3.38	0.97	4.10	0.79	4.04	0.64
Easier/intuitive interactions (DRIVERS)	6.62	2.13	6.10	2.55	6.89	1.77
Miss road sign in the in-vehicle HMI (DRIVERS)	7.43	2.29	7.35	2.25	7.46	1.75
Stress reduction (DRIVERS)	8.05	2.16	6.50	2.86	6.93	2.14
Increase comfort (DRIVERS)	7.71	1.82	6.95	2.48	7.39	1.62
Better perform daily work (TRANSPORT OPERATORS)	8.38	1.60	7.35	2.39	7.79	1.52
New incident detection ways (TRANSPORT OPERATORS)	7.81	2.80	6.70	3.23	7.46	2.17
New incident reaction ways (TRANSPORT OPERATORS)	7.76	2.28	7.55	2.50	7.18	2.11
Solve problems faster (TRANSPORT OPERATORS)	8.52	1.29	7.20	2.57	7.43	2.03
Traffic safety	3.95	0.80	4.25	0.91	3.96	0.69
Traffic flow/throughput	4.24	0.62	3.95	0.94	4.11	0.69
CO2 emmissions	4.14	0.96	3.50	0.95	3.71	0.81

Overall Results

(AU-WS)	BN		RW		DLA	
	Mean	STD	Mean	STD	Mean	STD
Willingness to use (scale used 1-5)						
Use information	4.38	0.70	4.55	0.64	4.38	0.70
Behavior change (scale used 1-5)						
Follow suggestions	4.30	0.76	4.33	0.66	4.18	0.71
Perceived usability (scale used 1-5)						
Easy to learn signs	4.45	0.64	4.75	0.44	4.30	0.69
Usefulness	4.23	0.73	4.40	0.67	3.88	0.85
Satisfying	4.15	0.83	4.73	0.51	4.03	0.83
Immediate reaction	4.15	0.74	4.43	0.64	3.85	0.86
Benefit	4.18	0.71	4.50	0.64	3.98	0.89
Understandable signs	4.28	0.75	4.70	0.56	3.80	1.07
Expected Impacts Results (scale used 0-10)						
Easier/intuitive interactions (DRIVERS)	7.65	1.82	6.48	2.70	7.00	2.16
Miss road sign in the in-vehicle HMI (DRIVERS)	7.35	1.73	6.78	2.50	7.00	2.16
Stress reduction (DRIVERS)	7.58	1.34	6.53	2.44	6.43	2.69
Increase comfort (DRIVERS)	7.60	1.10	6.63	2.34	6.75	2.95
Better perform daily work (TRANSPORT OPERATORS)	7.53	1.62	7.60	1.91	7.38	1.88
New incident reaction ways (TRANSPORT OPERATORS)	7.40	1.63	7.68	1.86	7.70	2.16
Solve problems faster (TRANSPORT OPERATORS)	7.44	1.85	7.73	1.78	7.48	2.12
Expected Impacts Results (scale used 1-5)						
Traffic safety	4.28	0.74	4.40	0.63	3.80	0.79
Traffic flow/throughput	4.32	0.63	4.20	0.61	3.63	1.08
CO2 emissions	4.00	0.76	3.78	0.83	3.58	0.87

Overall Results

INFRAMIX

(AU-DM)	BN		RW		DLA	
	Mean	STD	Mean	STD	Mean	STD
Willingness to use (scale used 1-5)						
Use information	4.50	0.61	4.65	0.49	4.50	0.69
Behavior change (scale used 1-5)						
Follow suggestions	4.40	0.60	4.45	0.60	4.30	0.57
Perceived usability (scale used 1-5)						
Easy to learn signs	4.05	0.76	4.55	0.51	4.40	0.88
Usefulness	4.40	0.68	4.55	0.60	4.30	0.86
Satisfying	4.35	0.59	4.15	0.59	4.00	0.73
Immediate reaction	4.25	0.55	4.40	0.50	4.30	0.66
Benefit	4.20	0.77	4.15	0.37	4.10	0.55
Intuitive signs	4.05	0.51	4.40	0.68	4.35	1.04
Understandable signs	3.95	1.05	4.50	0.83	4.25	0.85
Available in time	4.10	0.55	4.15	0.59	4.00	0.46
Enough per distance	3.95	0.69	4.15	0.75	4.00	0.73
Correct information	3.95	0.51	4.05	0.51	4.00	0.56
Not distracting from driving	4.05	0.60	4.05	0.69	3.95	0.69
Expected Impacts Results (scale used 0-10)						
Easier/intuitive interactions (DRIVERS)	7.30	1.95	7.20	2.55	6.75	2.57
Stress reduction (DRIVERS)	7.85	1.42	7.65	1.69	7.30	2.64
Increase comfort (DRIVERS)	7.60	1.47	7.45	1.57	7.20	1.91
Better perform daily work (TRANSPORT OPERATORS)	7.95	1.85	8.30	1.26	7.95	1.90
New incident reaction ways (TRANSPORT OPERATORS)	7.35	3.05	7.90	2.17	8.10	2.27
Solve problems faster (TRANSPORT OPERATORS)	8.35	1.39	8.35	1.81	7.80	2.50
Expected Impacts Results (scale used 1-5)						
Traffic safety	4.35	0.93	4.60	0.60	4.30	0.73
Traffic flow/throughput	4.40	0.88	4.40	0.68	4.05	1.00
CO_2 emissions	3.70	1.03	3.45	0.76	3.65	0.81

Conclusions

- Willingness to use/perceived usability/behaviour change: Acceptance**over 70%.**
- Drivers, passengers and road operators believe that the advanced ITS functionalities will bring positive changes in traffic conditions (safety and efficiency) but they are unsure about the specific characteristics of this improvement.
- **Promising/optimistic** results but a **gradual** upgrade of intelligent systems infrastructure is **required**.

Thank you for your attention!

Stamatis Manganiaris

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 723016.

INFRAMIX online final event

Roadmap towards fully automated transport systems

Annarita Leserri / Enide

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 723016.

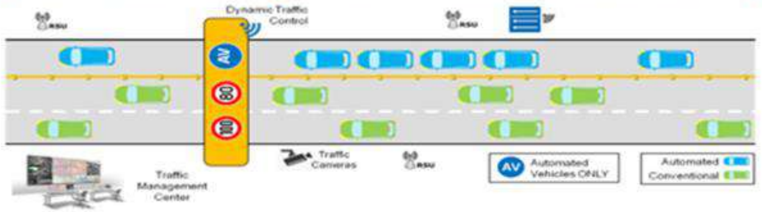
Summary

- Challenge
- Solutions
- Guidelines
- Timeline

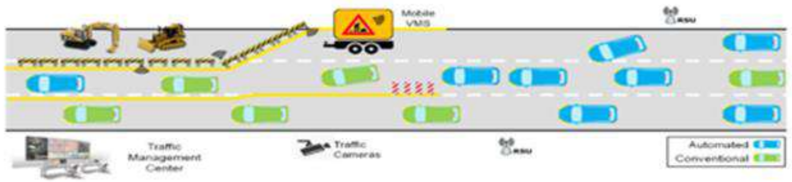
INFRAMIX challenge

We identified some challenges related to highway infrastructure management and developed them as **scenarios**.

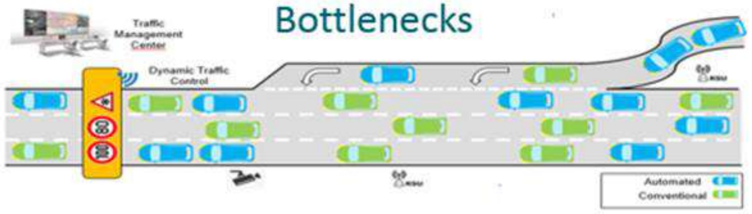
Dynamic lane assignment to automated driving



Roadworks zone



Bottlenecks



INFRAMIX solutions and outcomes

TRAFFIC MANAGEMENT MEASURES

BIDIRECTIONAL COMMUNICATION V2X

DIGITAL INFRASTRUCTURE

PHYSICAL INFRASTRUCTURE

INFRASTRUCTURE CLASSIFICATION SCHEME

SIMULATIONS AND SAFETY PERFORMANCE CRITERIA

HYBRID TESTING

USE CASES & BUSINESS MODELS

ROADMAP

How can we meet stakeholders' needs with our solutions?

INFRAMIX solutions meeting stakeholders' needs

	Industry	Infrastructure operators	Policy makers	Researchers and key influencers	General public
Traffic management measures	X	X	X	X	
Bidirectional communication V2I and I2V	X	X		X	X
Digital infrastructure	X	X		X	X
Physical infrastructure	X	X		X	X
Infrastructure classification scheme		X	X	X	
Safety performance criteria	X	X	X	X	
Use cases and business models		X		X	
Roadmap towards connected infrastructure	X	X	X	X	X

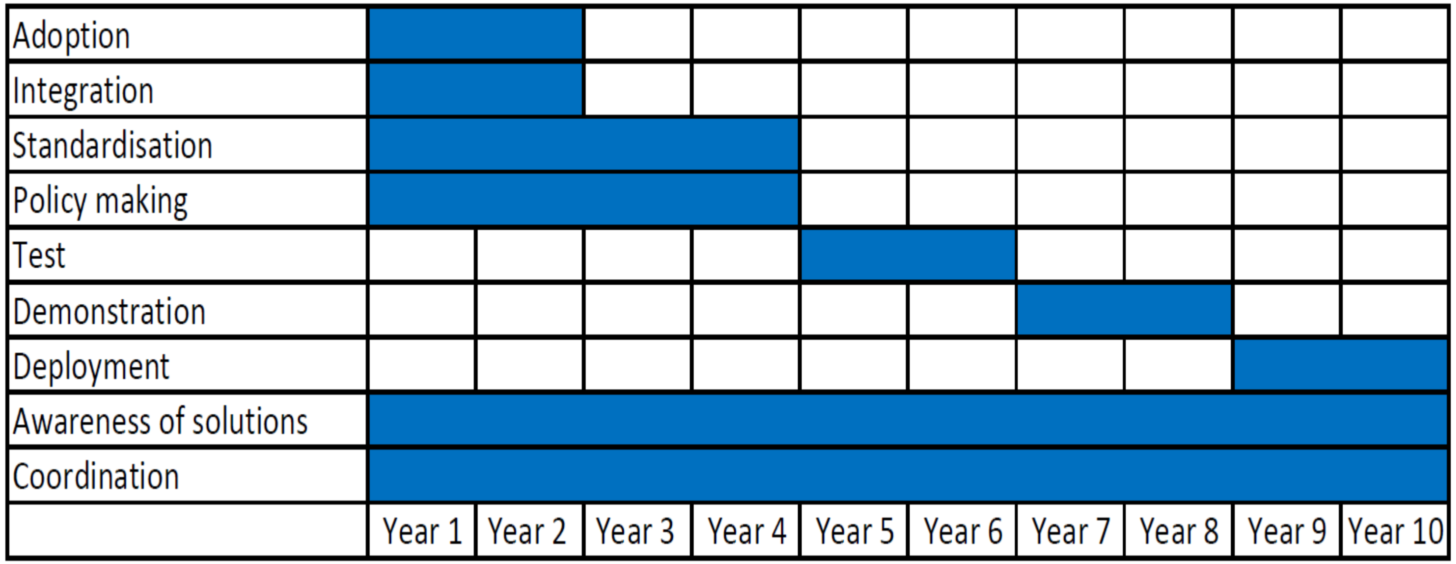
INFRAMIX Roadmap Guidelines

Stakeholder	Action needed
Industry	• Creation of new products; • Improvement of existing products; • Provision of services towards automated driving as a service; • Business relationships with third parties; • External promotion; • etc.
Infrastructure operators	• Future testing and demonstration; • Provision of new services; • Strategic decisions and investments; • Business relationships with third parties; • External promotion; • etc.
Policy makers	• Develop awareness; • Evidence-based policies and regulations; • Strategic investments; • Etc.
Researchers and key influencers	• Exploitation of algorithms, control strategies, methodologies for technical evaluation, new visual signs, ISAD; • Publication of scientific papers; • Generation of data; • Further research; • External promotion; • etc.
General public	• Develop awareness; • Users' experience feedback; • Etc.

Guidelines for stakeholder engagement

We identified several actions needed from stakeholders. INFRAMIX partners are expected to perform a leading role in implementing these actions among relevant actors.

INFRAMIX Roadmap Timeline



Timeline of activities per year of implementation

Activities required in the years to come will involve all stakeholders whose expertise could advance the implementation of INFRAMIX solutions. These activities will be implemented at least in the ten years following the end of the project in May 2020.

Recap

- Challenge: 3 traffic scenarios
- 9 solutions meeting stakeholders' needs
- Guidelines for all involved stakeholders
- Timeline of implementation

Thank you for your attention

Annarita Leserri

annarita.leserri@enide.com

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 723016.

INFRAMIX

INFRAMIX online
final conference

Road operators' and service providers' view on INFRAMIX measures

Yannick Wimmer / ASFINAG
Marko Rosenmüller / TomTom

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 723016.

ISAD Classes

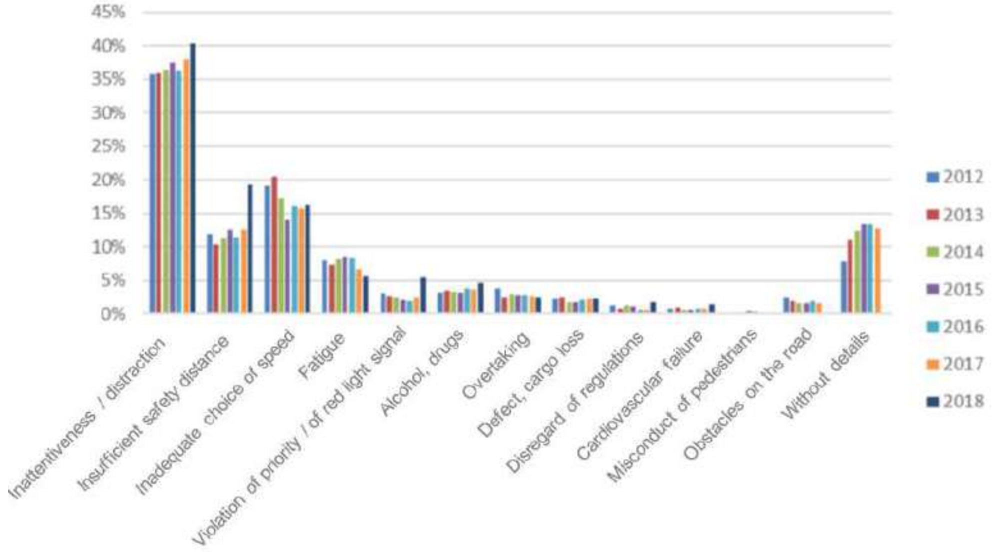
	ISAD	Name	Infrastructure side	AV side	Digtial information provided to AVs			
					Digital map with road signs	VMS warnings, incidents, weather	Microscopic traffic situations	Guidance: speed, gap, lane advice
Conventional infrastructure	E	Conventional infrastructure / no AV support		Road geometry and road signs have to be recognized by AVs on their own				
	D	Static digital information / map support	Digital map data (including static road signs) complemented by physical reference points	Traffic lights, short-term road works and VMS have to be recognized by AVs on their own				
Digital infrastructure	C	Dynamic digital information	All static and dynamic information can be provided to the AVs in digital form	AVs perceive infrastructure support data				
	B	Cooperative perception	Infrastructure is capable of perceiving microscopic traffic situations	AVs perceive infrastructure support data in real time (C-ITS Day 1)				
	A	Cooperative driving	Infrastructure is capable of perceiving vehicle trajectories and guide single AVs (or AV groups)	AVs are guided by the infrastructure in order to optimise traffic flow (C-ITS Day 2+)				

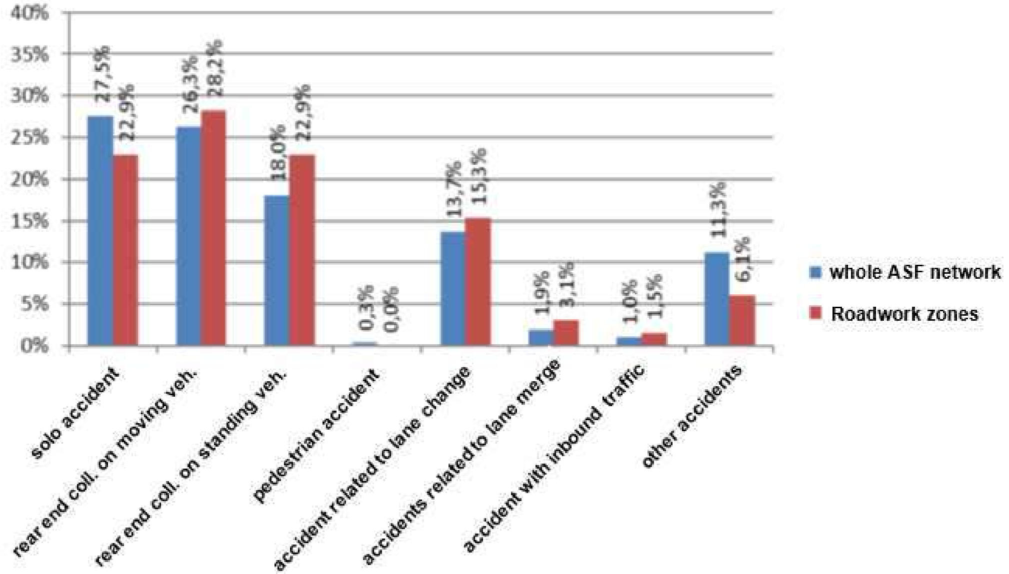
The infrastructure classification scheme can **facilitate the transition period** to higher levels of automation, indicate modularity and scalability in functionalities and services, help to **ensure safety and security**, and handle different system lifecycle integrations.

The classification **helps to understand** the capabilities of the infrastructure.

ISAD classes may be difficult to determine when not all definition prerequisites are met. Definitions may be difficult to interpret and to apply. Further detailing is necessary for OEM use (i.e. in describing individual characteristics as opposed to a one-dimensional ranking).

Safety

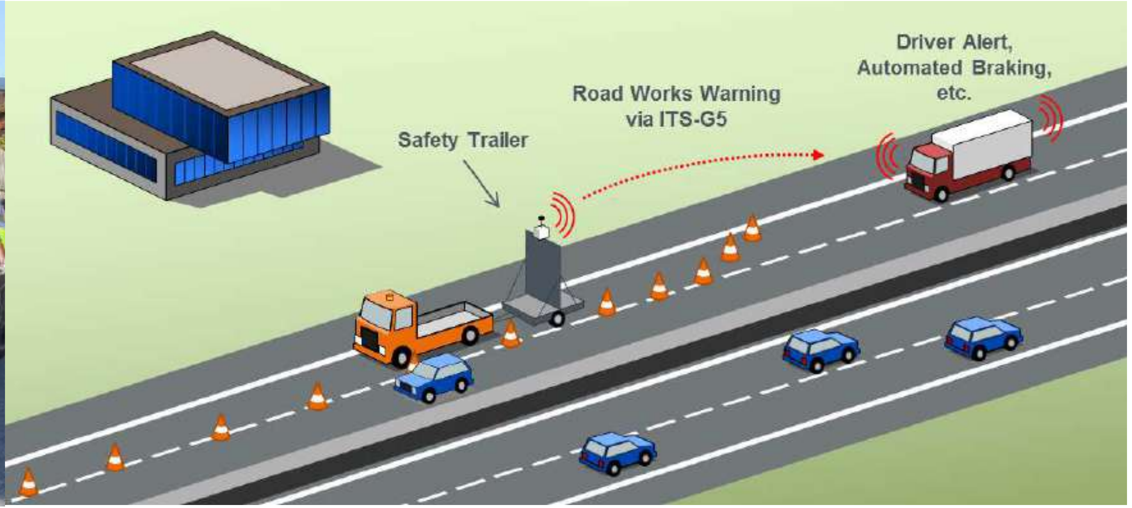




Potential of INFRAMIX message set is much broader than the 3 scenarios:

- more than 40% of the accidents are "rear end collisions", 18% are rear end collisions onto a stationary vehicle.
- ~75% of accidents are related to inattentiveness/distraction, insufficient safe distance and inadequate choice of speed.
- Roadwork zones are slightly more dangerous.

Safety



RWZ are on average more dangerous

- Rear end collision in more than 50%
- 5-10% of roadwork warning trailers are involved in such a collision every year in Austria
- -> **C-ITS Roadworks Warning (C-ITS DENM)**

HD Maps and Vehicle Horizon

- Dynamic information such as roadworks especially important for OEMs such as BMW for AD
- In INFRAMIX, lane trace sent over ITS-G5

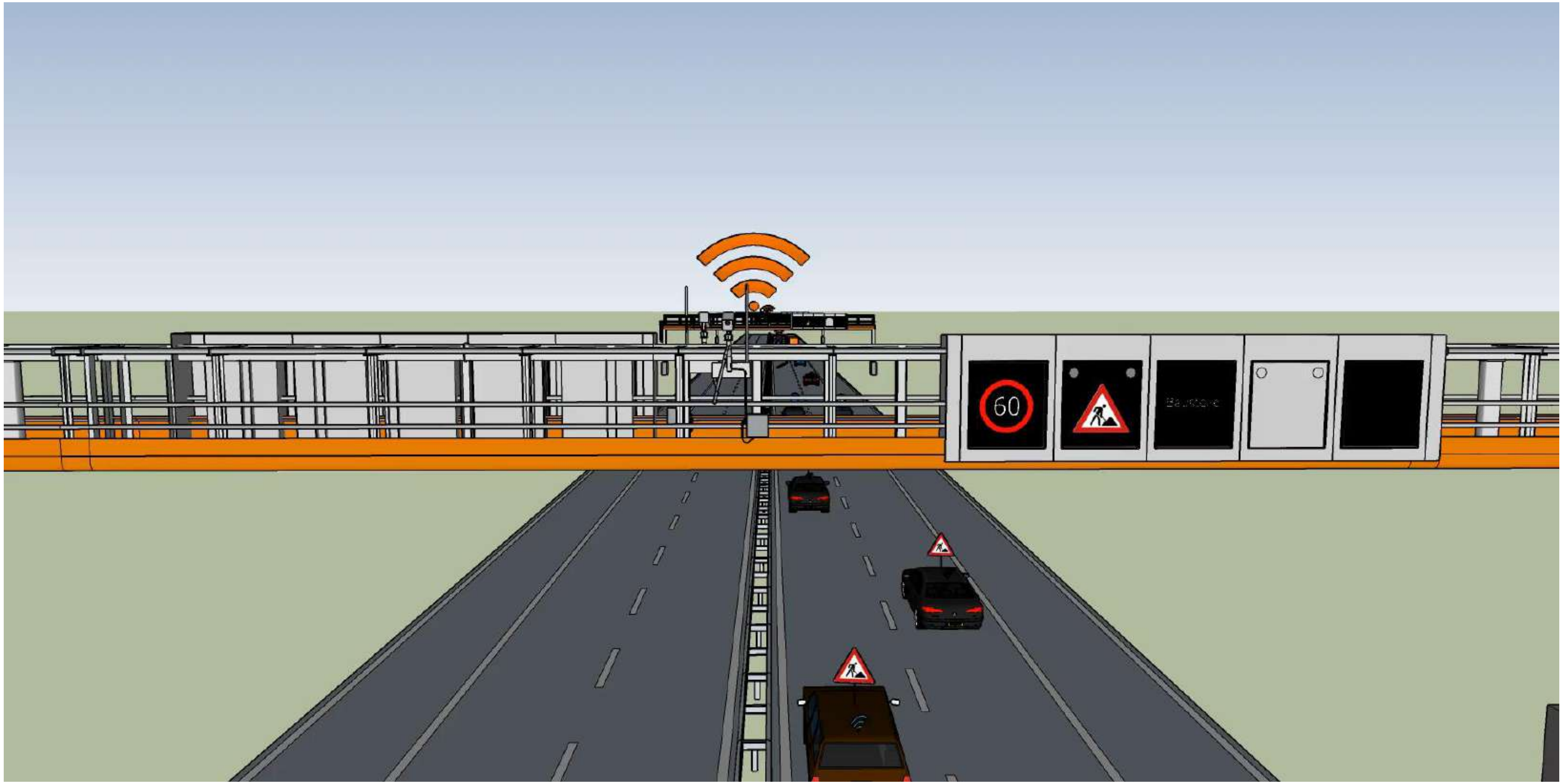
- In the future, dynamic information at lane-level integrated into TomTom HD maps

- Dynamic data to be exposed via vehicle horizon, e.g., using ADASISv3

Advice for Human Drivers

- Lane visualization required to provide lane-specific advice
  - Dedicated lane advice can be shown to human drivers if lane-level guidance is available
- Cognitive load for human drivers increases significantly
  - Additional information for each lane creates too high load
  - Special visualization needed to overcome issue, e.g., for lane change advice
- Some types of advice, such as time gap, can only be handled with assistance, such as ACC

Driving Recommendations/Commands



INFRAMIX

Driving Recommendations/Commands

Control Message	Safety	Efficiency	Remarks	Recommended
Speed limit	++	+	Works fine	Yes
Distance gap	o	++	Also works fine (cars need to have ACC feature)	Yes
Acceleration	-	o	Very little additional effect	No
Lane change	?	+	Rather "keep to lane" advice instead	No
Dedicated lane	-	-- (+ for AVs)	Benefits for AVs do not compensate for disadvantages for others	No
Roadworks	++	+	High safety potential	Yes

Traffic Control Strategies

- Not applying traffic control strategies (for higher penetration rates of AVs)
  -> will lead to considerable deterioration.
- INFRAMIX pointed out possible new control strategies to counteract these effects.
- C-ITS is a major factor in those strategies.
- Traffic control strategies do also work with a rather “sparse” RSU coverage.

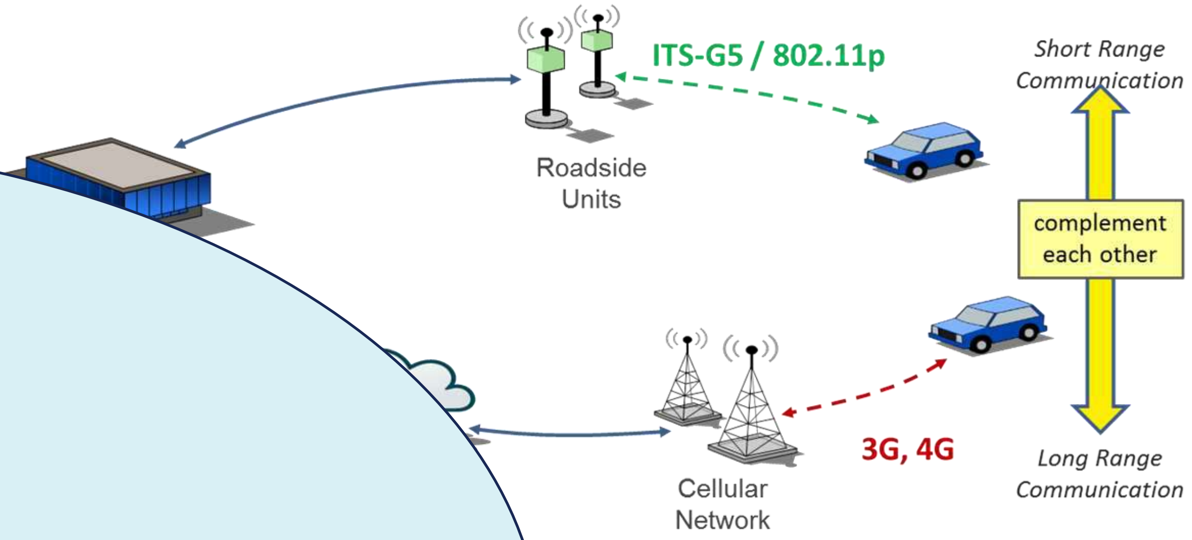
Poll

Roadmap for Spain

- Abertis Autopistas is committed to **continue exploring the results** obtained by INFRAMIX. Currently, it participates in national and European initiatives extending the bases proposed by the project; either with more use cases, such as **cross-border traffic strategies**, or **testing different communication technologies**, such as 5G.

- Abertis Autopistas does **not take a position on a specific communication technology** and works with several ones, studying technical aspects and the future role of the road operator, and pending for a national or European regulatory change.

Rollout in Austria



ASFINA

**INFRAMIX
results confirm ASFINAG‘s strategy!**

Deployment:
Austria

**175 + 325 RSUs
starting from 2021**

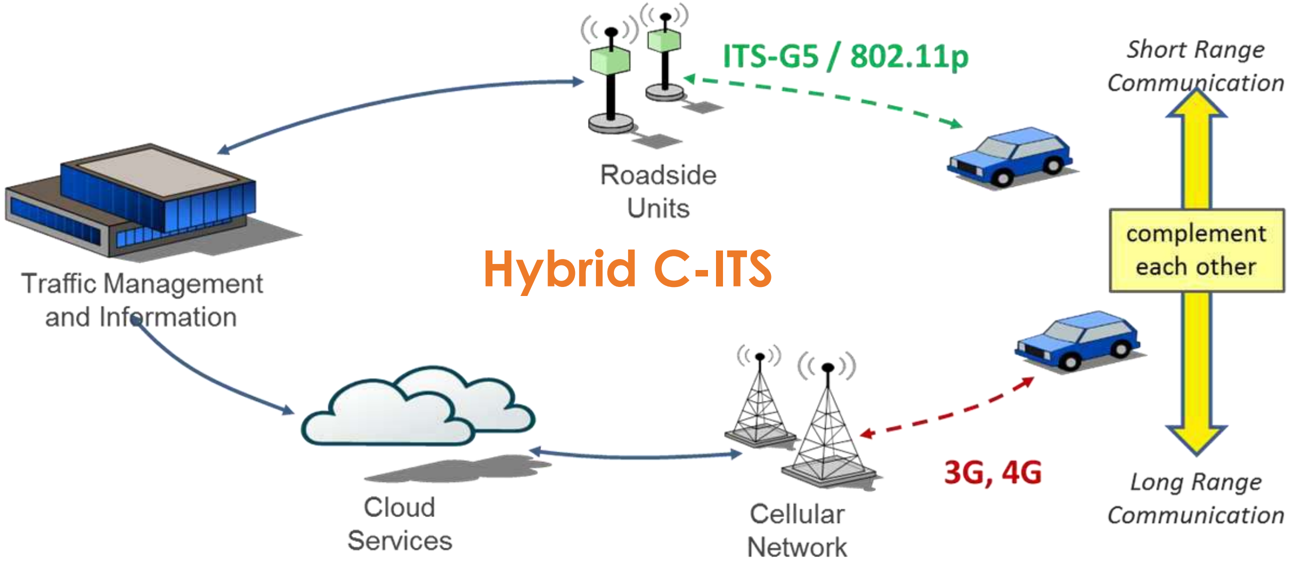
ECo-A

(Day1)
Spec (Day2)

C-Roads Spec and extensions
(Day1, Day2)

Rollout in Austria

ASFINAG C-ITS activities:

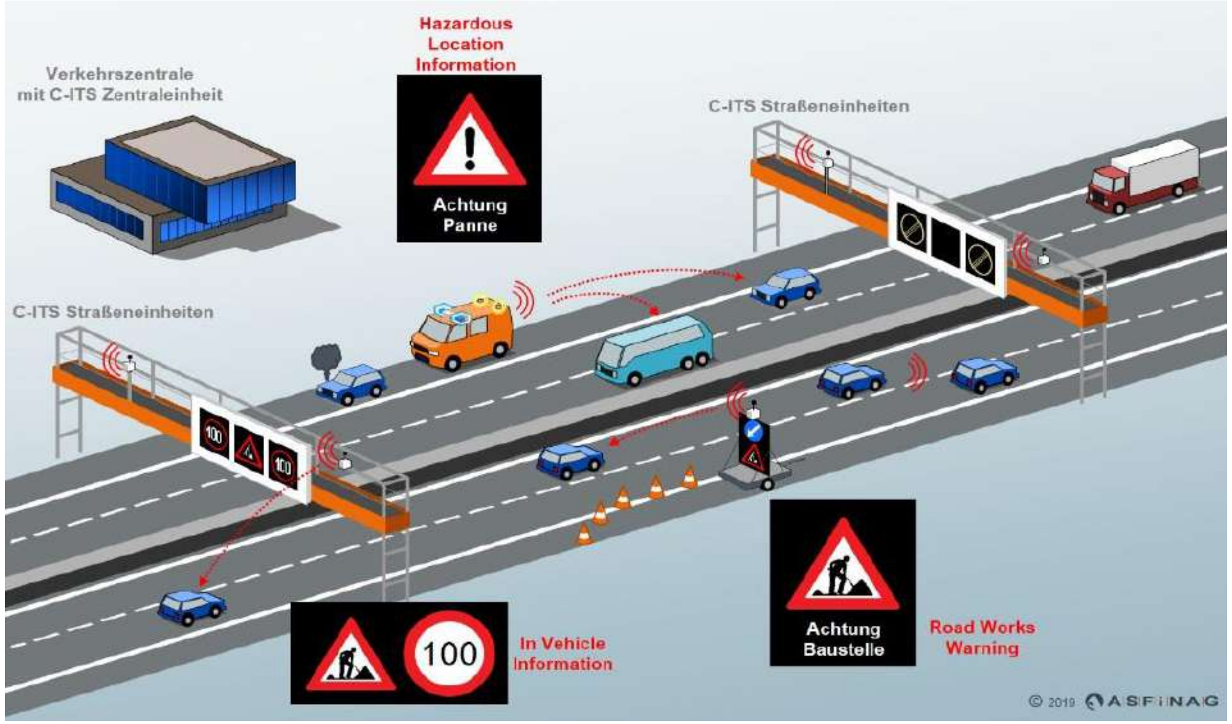


Pilot: ECo-AT	Pre-Deployment: C-Roads Pilot Austria	Deployment: Austria
25 RSUs 2015-2019	**28 RSUs** 2020	**175 + 325 RSUs** starting from 2021
ECo-AT Spec (Day1)	C-Roads Spec (Day1) ECo-AT Spec (Day2)	C-Roads Spec and extensions (Day1, Day2)

C-Roads Pilot Austria Services

Free download

Day 1 according to C-Roads Catalogue

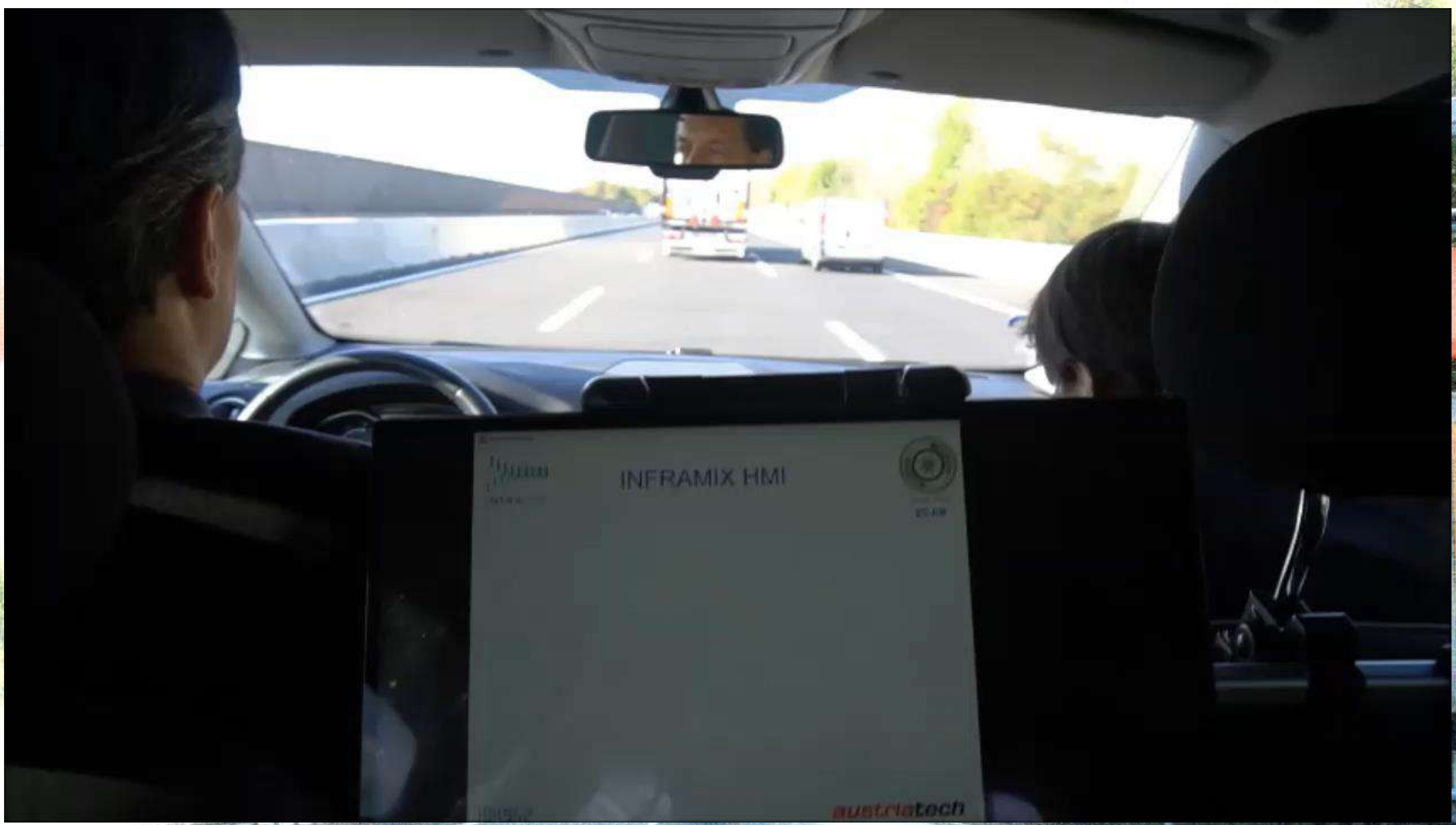


Day 2 according to ECo-AT extended Release 4.0

Use Cases C-ITS for Automated Driving
UC01: SAE level clearance for automated vehicles
UC02: Platoon support information for automated vehicles
UC03: Situation based distance gap for automated vehicles
UC04: Vehicle type and lane specific speed limit for automated vehicles
UC05: Vehicle type and lane specific speed recommendation for automated vehicles
UC06: Contextual emergency corridor information
UC07: Collective perception of objects on the road
UC08: Information about ITS-G5 equipped objects and persons on the road
UC09: Traffic situation awareness based on CAM
UC10: Long term road works warning
UC11: GNSS correction data

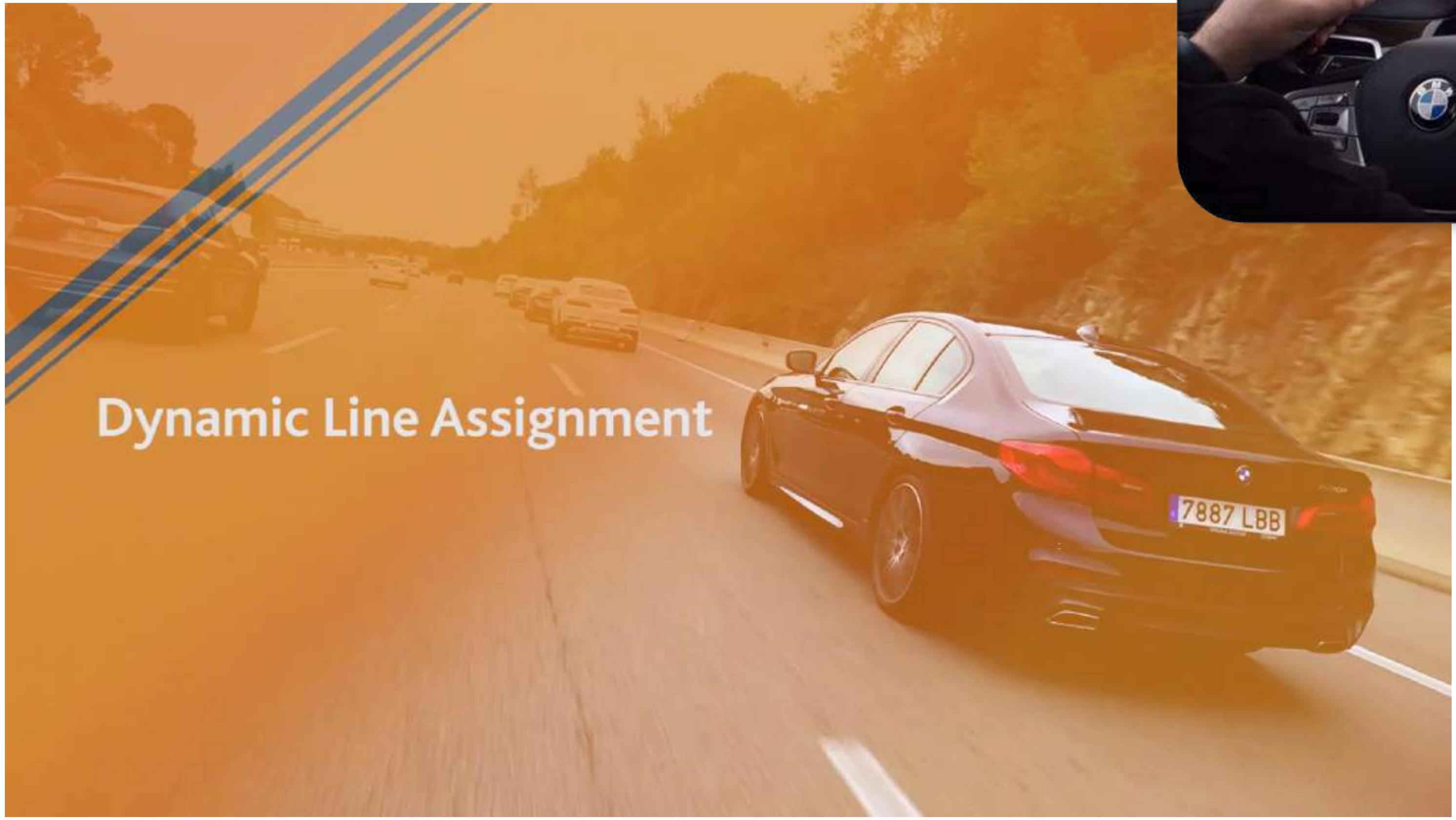
→ Running activities of harmonization and standardization of Day2 services

Demonstrators



Demonstrators

Use Case 1:
Dynamic Lane Assignment



Thank you for your attention!

Yannick Wimmer

ASFINAG

Yannick.Wimmer@asfinag.at

Marko Rosenmüller

TomTom

Marko.Rosenmueller@tomtom.com

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 723016.

European Commission

ODD and the role of infrastructure support

INFRAMIX Final Event, 26 May 2020

Tom Alkim
Directorate-General for
Research & Innovation

European Commission

HORIZON 2020

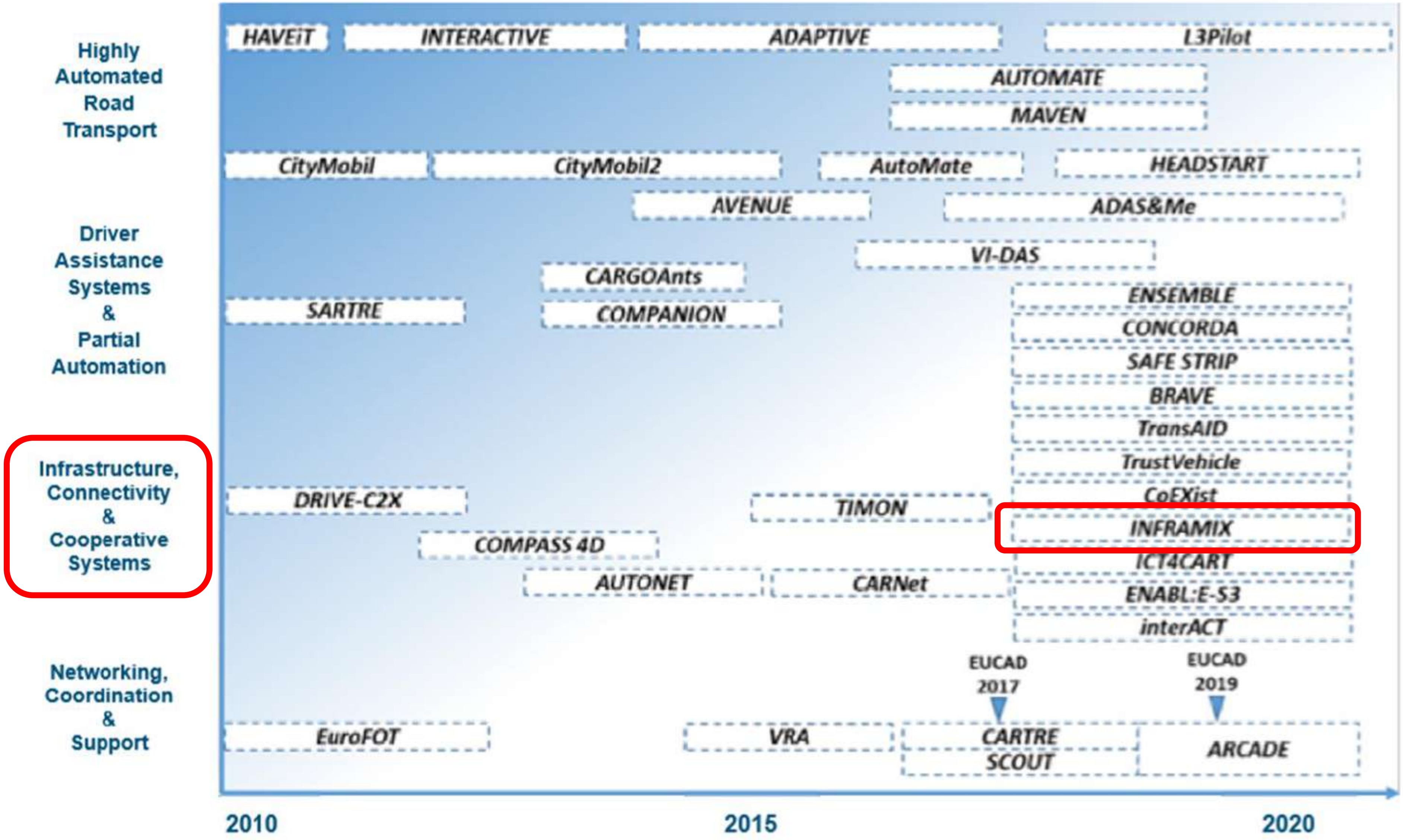
H2020 - Calls on "Automated Road Transport"

- Budget: € 300 Mio (2014-2020)
- Focus
  - Large-scale demos of automated driving systems for passenger cars, trucks and urban transport
  - Safety and end user acceptance
  - Road infrastructure to support automation
  - Traffic management solutions
  - Connectivity for automation
  - Testing and validation procedures
  - Assessment of impacts, benefits and costs of CAD systems
  - Support for cooperation and networking activities
  - Human centered design of AV

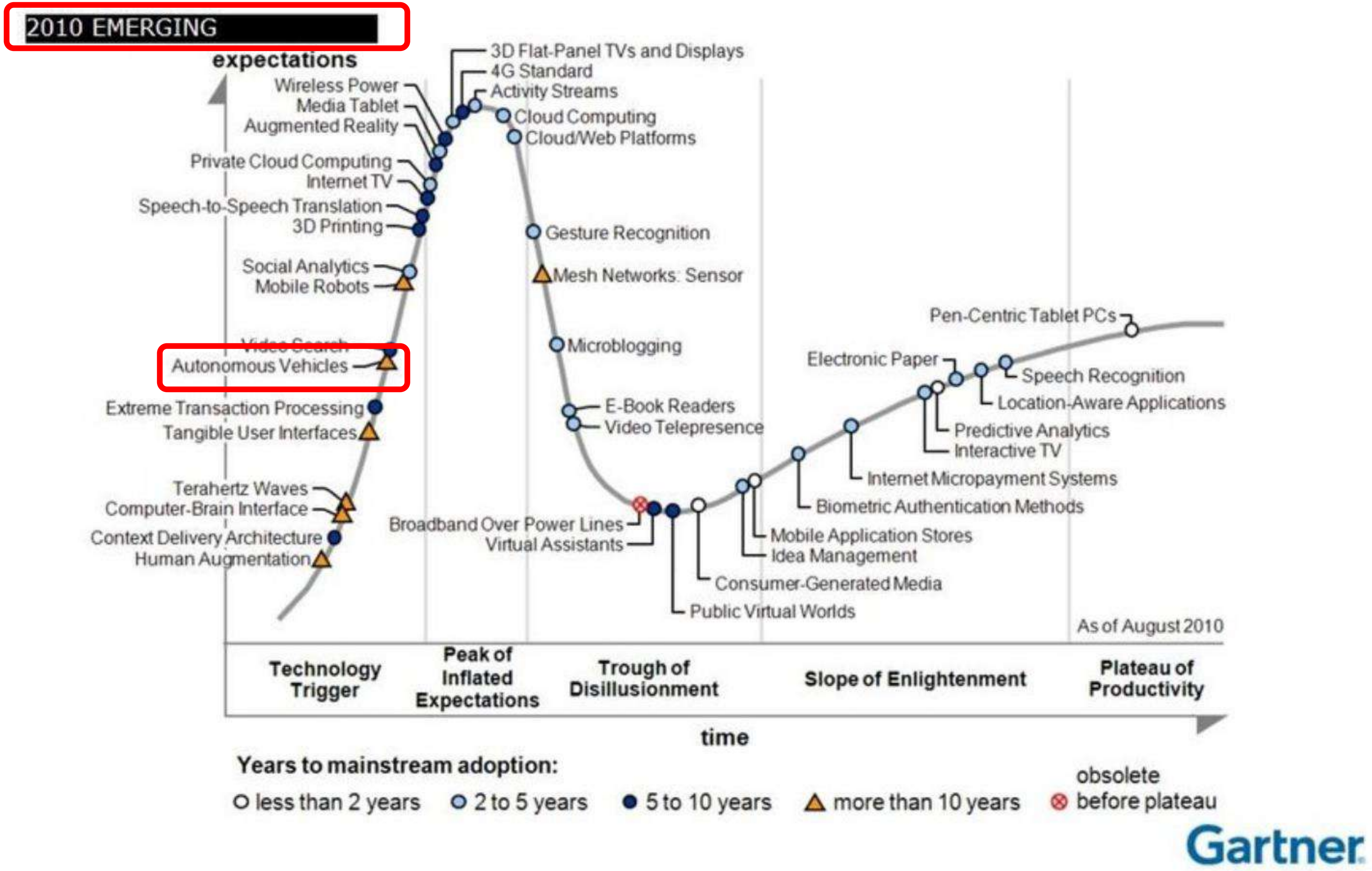
INFRAMIX

5 Calls for proposals 2016 → 2017 → 2018 → 2019 → 2020

H2020 - Calls on "Automated Road Transport"



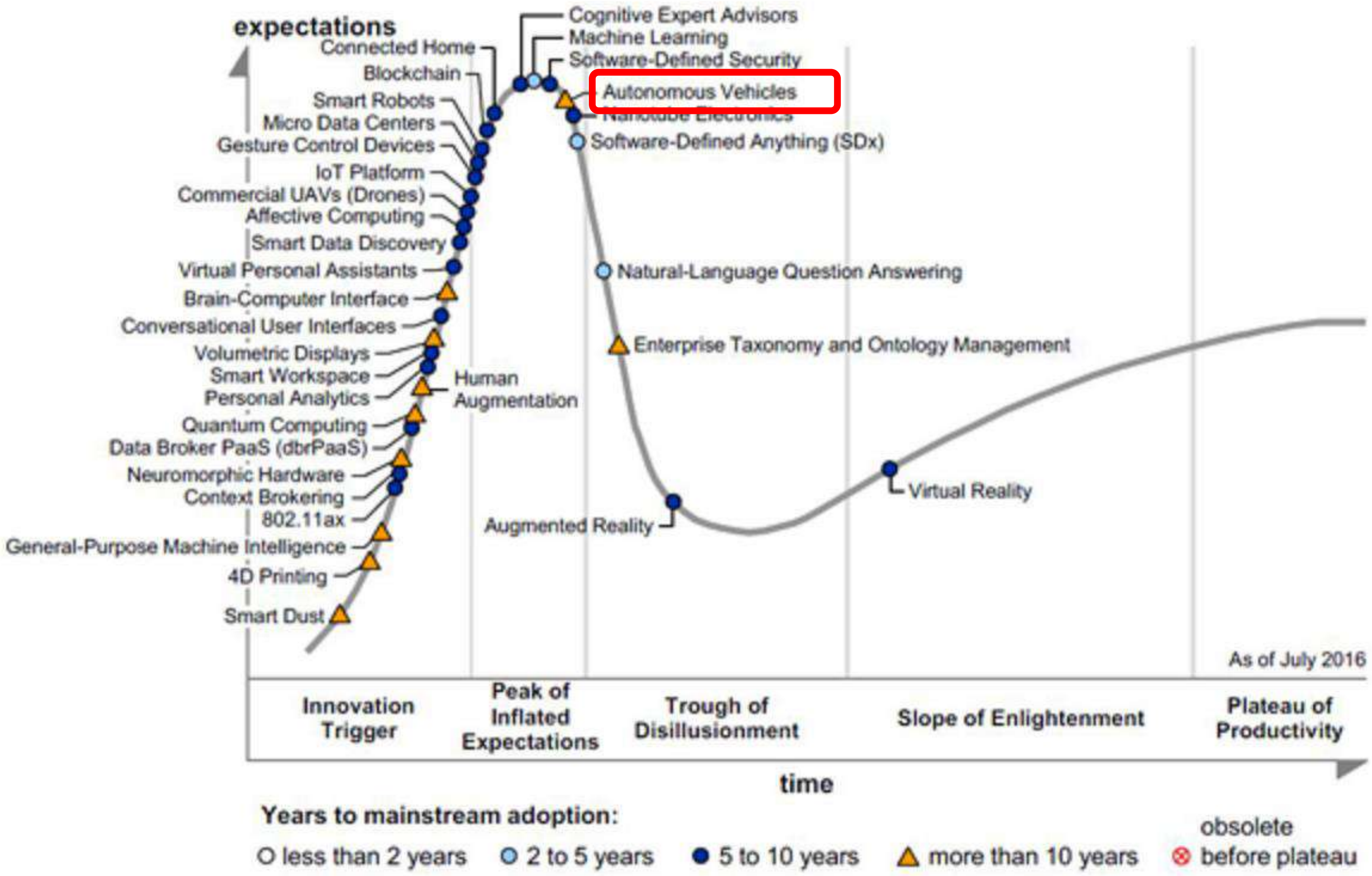
Gartner Hype Cycles 2009 - 2019



European Commission

Gartner Hype Cycles 2009 - 2019

Figure 1. Hype Cycle for Emerging Technologies, 2016



Source: Gartner (July 2016)

Gartner Hype Cycles 2009 - 2019

The single EU-wide platform on CCAM

Objectives

- develop an EU agenda for testing to better coordinate research, testing, piloting, and pre-deployment activities
- Agree on a common evaluation methodology in order to allow for comparison of results between tests
- facilitate access and exchange of data from testing
- assist the Commission in thematic areas, such as data access and exchange, road transport infrastructure, digital infrastructure, communication technology, cybersecurity, road safety, and legal frameworks, etc.
- provide advice on and support the generation of the work program for a future public private partnership on CCAM

The single EU-wide platform on CCAM

Working Groups

1. Develop an EU agenda for testing
2. Coordination and cooperation of R&I and testing activities
    - Knowledge base
    - Common evaluation methodology
    - Framework for data exchange and lessons learned
3. Physical and digital road infrastructure
4. Road Safety
5. Connectivity and digital infrastructure for CCAM
6. Cybersecurity and access to in-vehicle data linked to CCAM

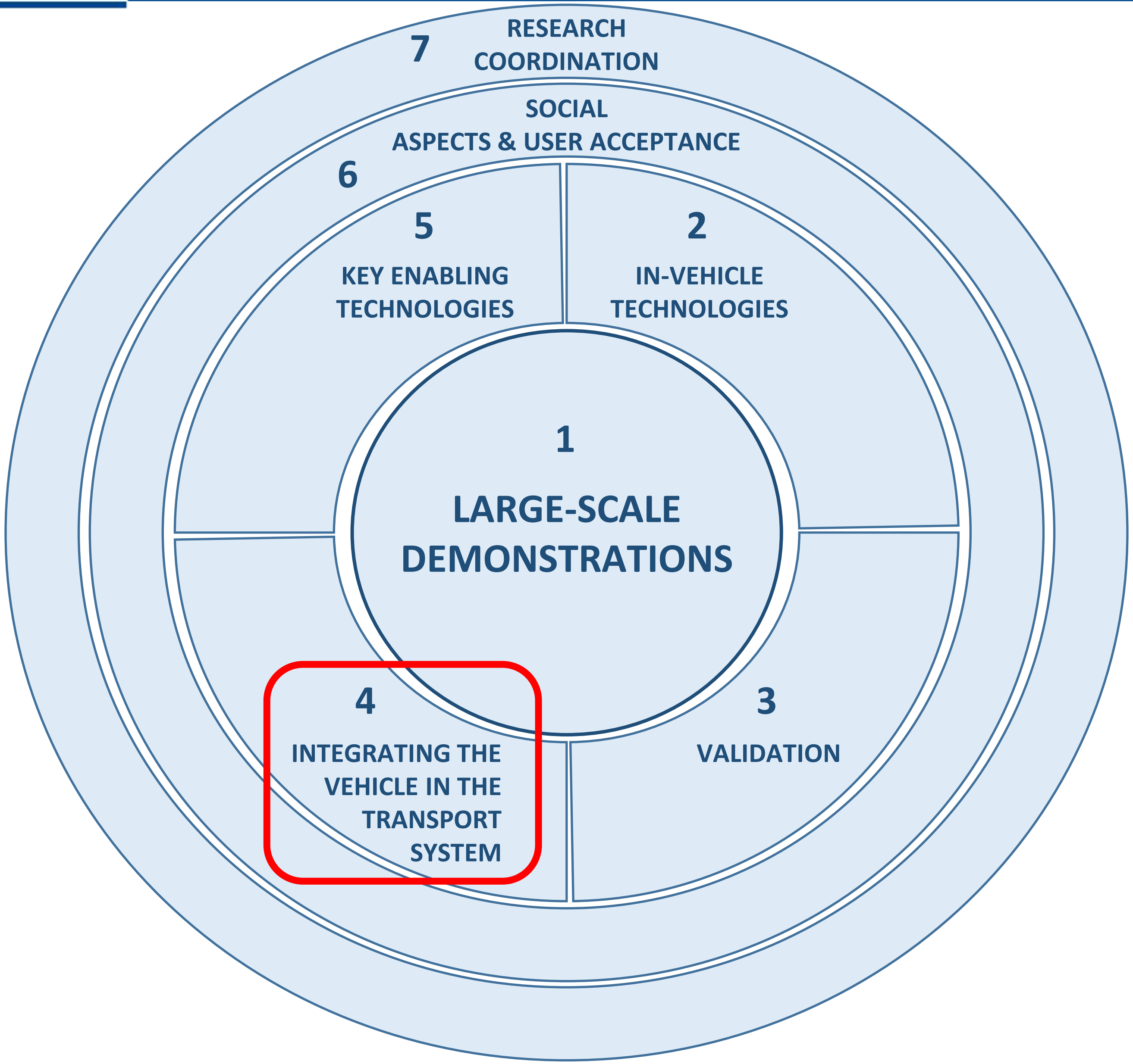
European leadership in safe and sustainable road transport through automation

- Combining **connectivity, cooperative systems and automation** will enable automated and fully orchestrated manoeuvres, bringing us closer to **Vision Zero**.
- The goal is to create more **user-centred, all-inclusive mobility**, while increasing **safety, reducing congestion** and contributing to **decarbonisation**.
- CCAM will also enable the provision of **new mobility services for passengers and goods**, fostering benefits for users and for the mobility system as a whole.

CCAM Vision and Expected Impacts for Society

- The development of CCAM shall provide benefits to **all citizens**. With full integration of CCAM in the transport system, the **expected positive impacts** for society will be:
- **Safety**: Reducing the number of road fatalities and accidents caused by human error;
- **Environment**: Reducing transport emissions and congestion by optimising capacity, smoothening traffic flow and avoiding unnecessary trips;
- **Inclusiveness**: Ensuring inclusive mobility and goods access for all; and
- **Competitiveness**: Strengthen competitiveness of European industries by technological leadership, ensuring long-term growth and jobs.

CCAM – 7 clusters



1
Shared automated mobility solutions (11)
Highly automated passenger vehicles (13)
Automated commercial/freight vehicles (14)

2
Environment perception (1)
Passive & active safety (3)
On-board decision making (4)
Human Factors requirements (6.1)

3
Validation of CCAM systems (5)
Validation of Human Factors (6.2)

4
Remote operation and surveillance (7)
Physical and digital infrastructure (8)
Connectivity / Cooperative Systems (9)
Fleet and (mixed) traffic management (12)

5
Cyber-secure electronics (2)
Artificial Intelligence (10)
Data Storage and sharing (21)

6
Societal needs analysis (15)
Socio-economic and environmental impact analysis (16)
Workforce development (22)

7
European framework for testing on public roads (17)
Data exchange platform (18)
EU-wide knowledge base (19)
Common evaluation framework (20)

ODD in the STRIA roadmap - theory

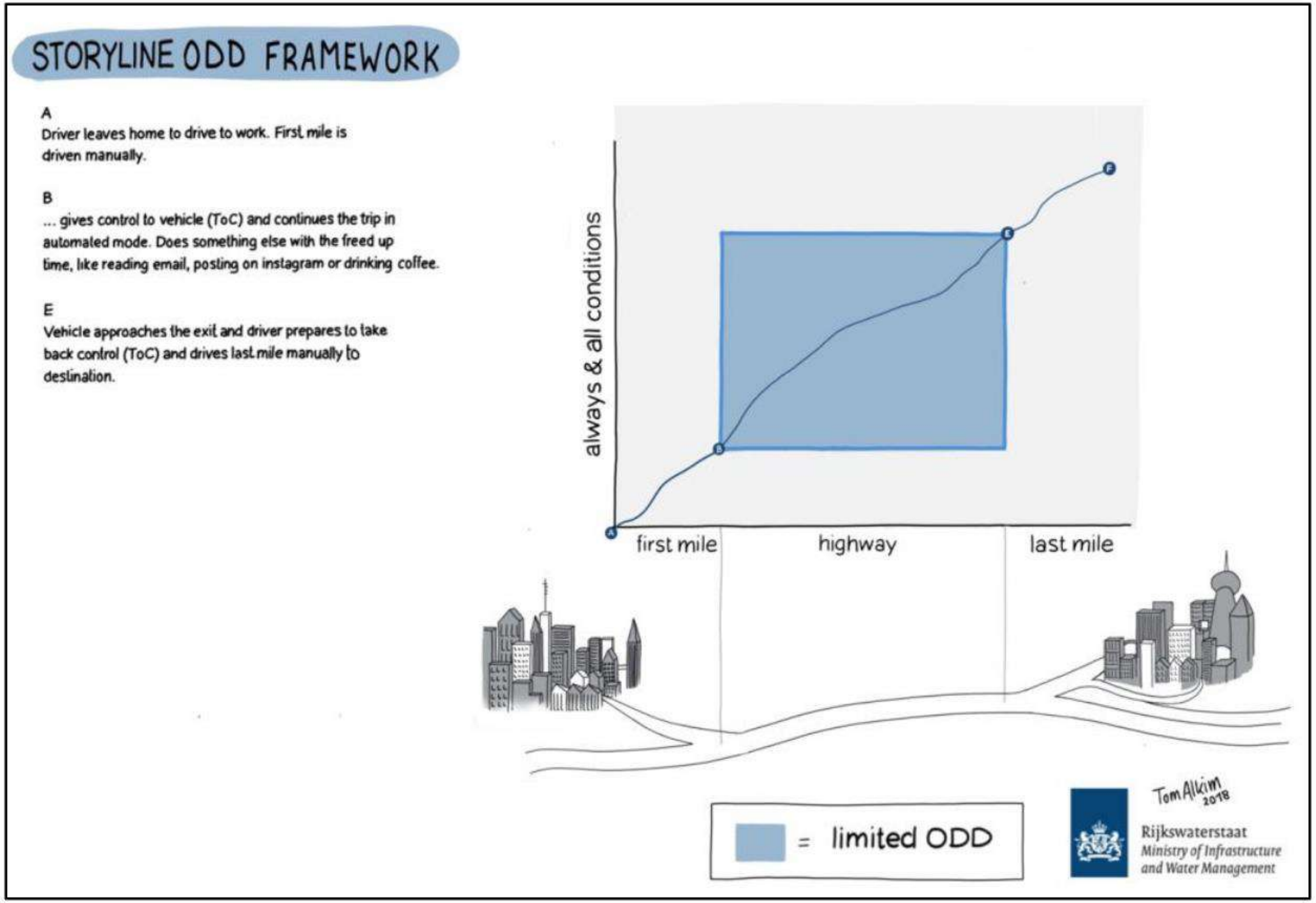


Figure 3: Visual representation of limited ODD

ODD in the STRIA roadmap - practice

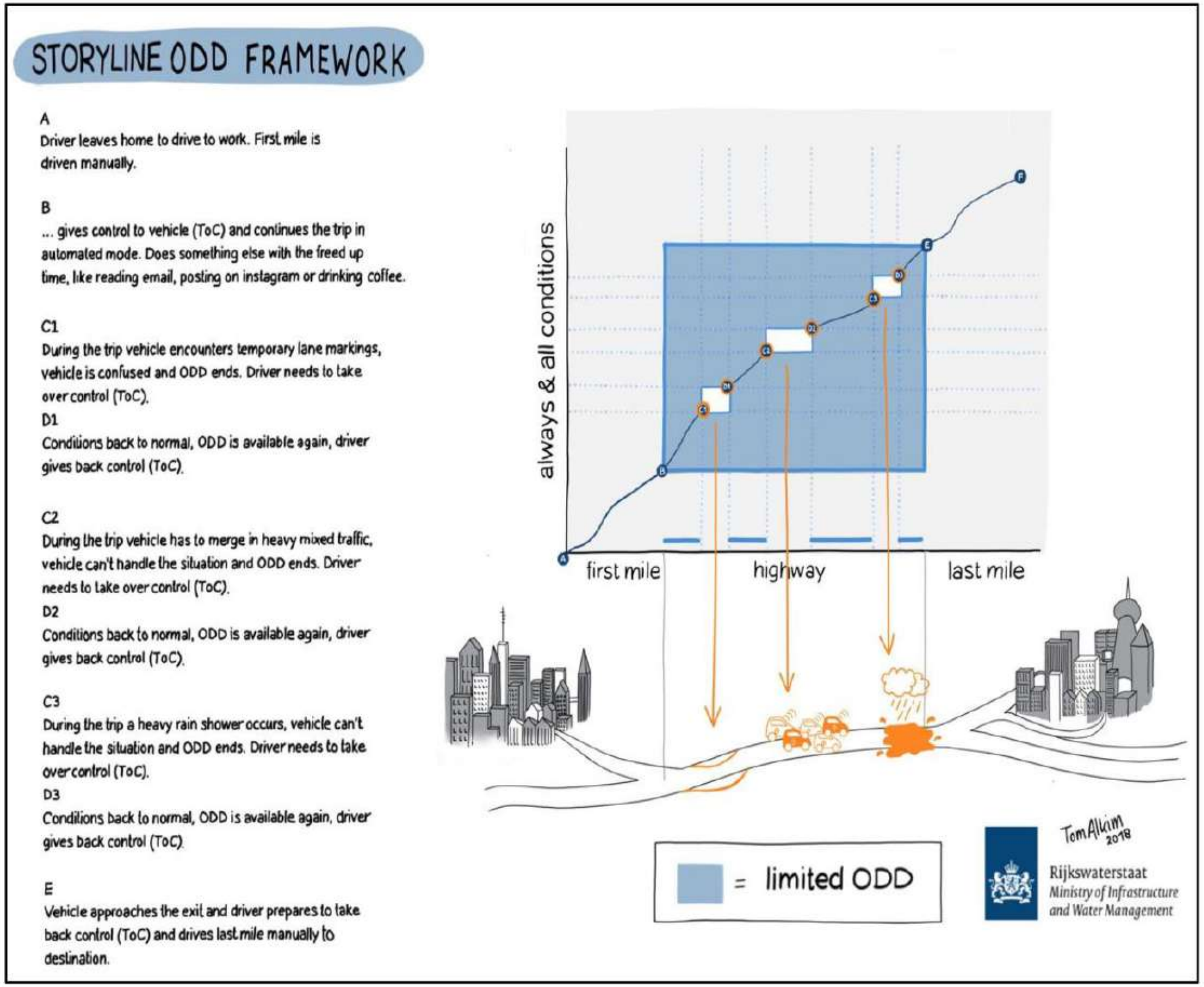


Figure 4: Visual representation of ODD in practice

ODD and ISAD

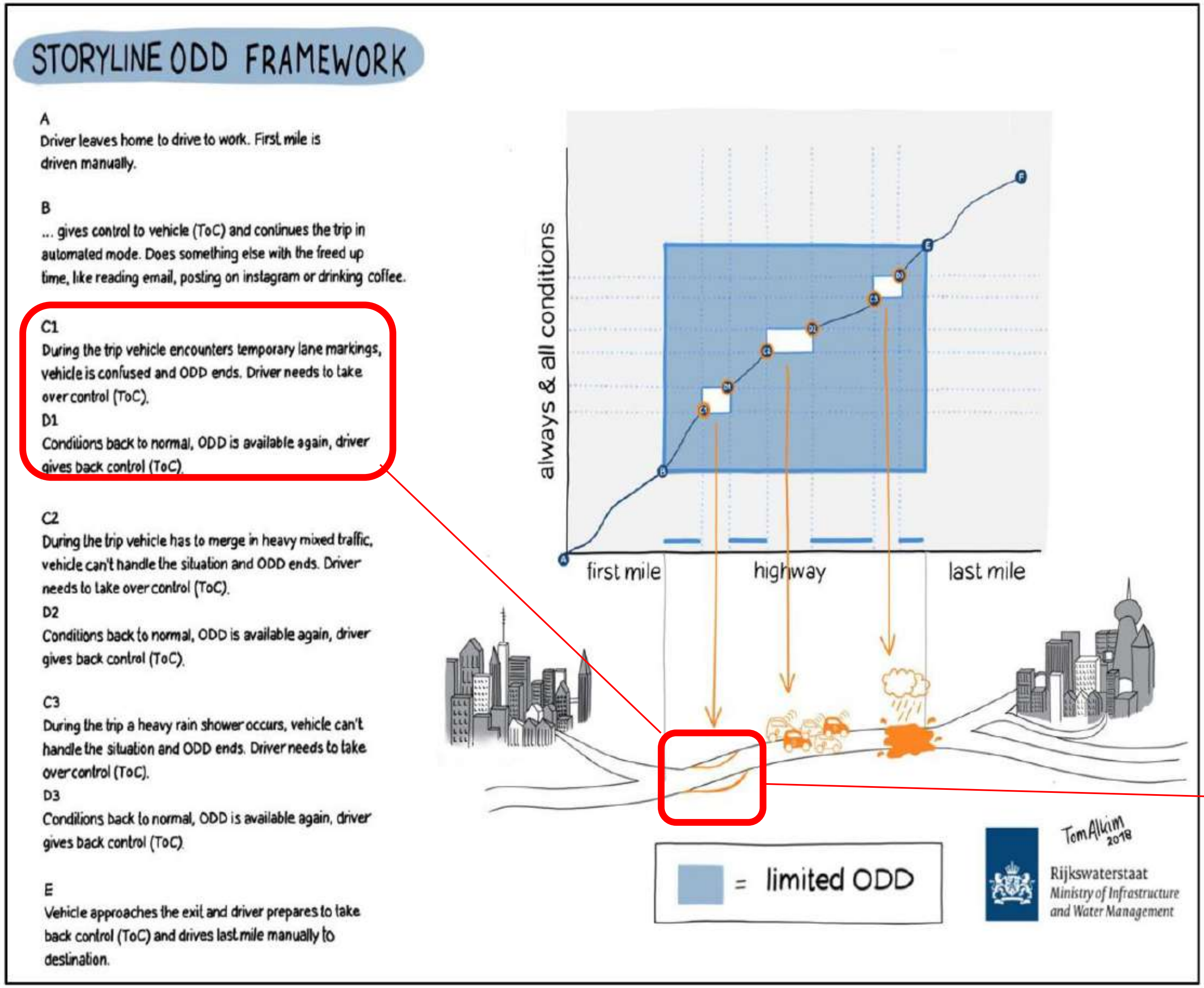
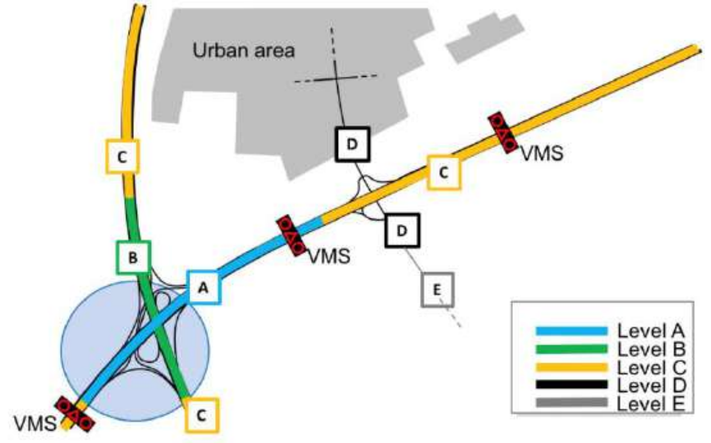


Figure 4: Visual representation of ODD in practice



ISAD levels

Thank you for your attention!

Questions?

INFRAMIX Conclusions

Martin Russ / AustriaTech

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 723016.

INFRAMIX in a Nutshell

Solutions

- Traffic control strategies
- Estimation algorithms
- Digital infra elements
- Physical infra elements

Evaluation

- Simulation – microscopic
- Simulation – submicroscopic
- Real world implementation
- Hybrid – simulation and real world

Recommen-dation

- Infrastructure classification
- Safety parameters
- Roadmap
- Exploitation plans

INFRAMIX key achievements

- Focus on **3 motorway scenarios** (bottlenecks, workzone, lane assignment)
- Infrastructure **improves efficiency and safety in mixed traffic** environments
  - New traffic control strategies
  - New evaluation toolset (microcopic, sub-microscopic, hybrid – combination of simulation and real world)
- **New Infrastructure elements** tested
  - new (C-)ITS messages,
  - link between TMCs and TSPs,
  - new physical signs
- Infrastructure support **(ISAD) classes** have been defined
- **roadmap** for the next 10 years ahead….

The future Role of Infrastructure

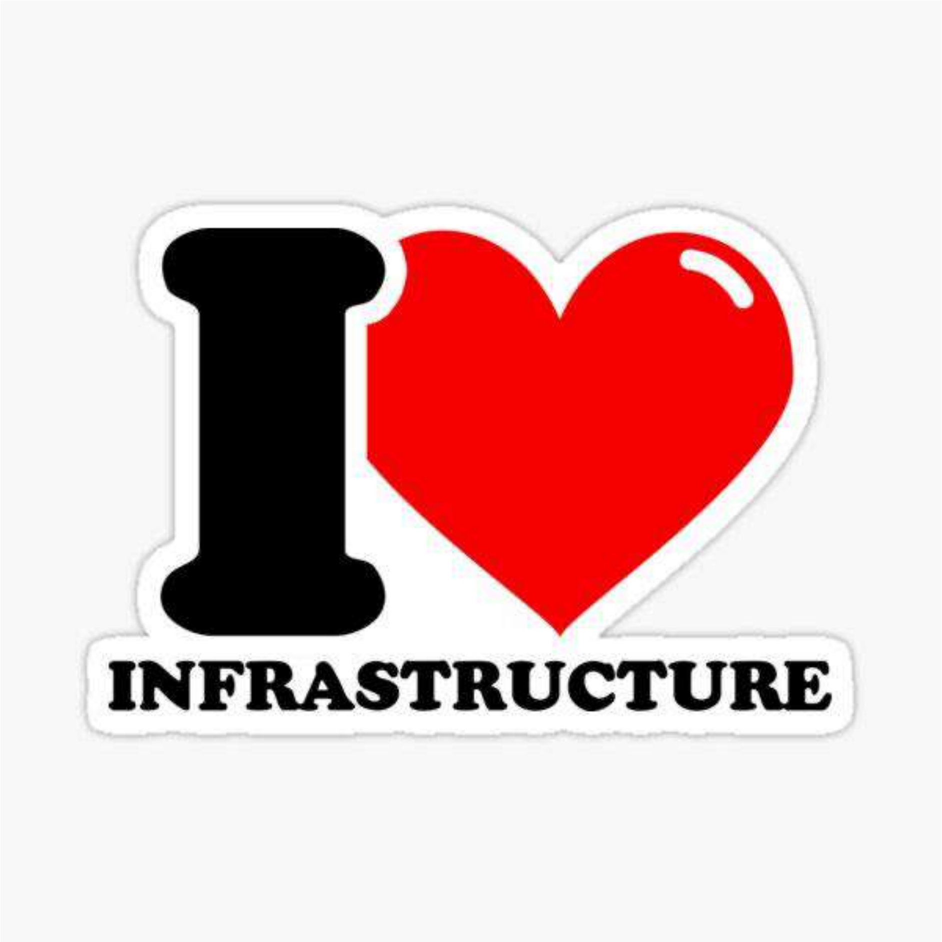
- **INFRAMIX** = one of many infrastructure related projects dealing with **“automation readiness“**
- Key platforms working on **future infra perspectives** – CEDR, ERTRAC, IRF/ERF, ASECAP, EU-EIP, ITF/OECD, Trilateral WG EU-US-JAP, CCAM Platform …on topics like:
  - Physical and digital elements
  - Data quality
  - HD maps & location referencing
  - Specific scenarios: workzones, merging, handovers,…
  - Cooperative driving & Communication infrastructures
  - Legal requirements and digital road codes
  - A future „systems approach“ defining roles of users, vehicles and infrastructure
  - New mobility services (fleet operations) and new infra functionalities
  - …..

→ **Infrastructure as a key question and domain for future research initiatives!!!**

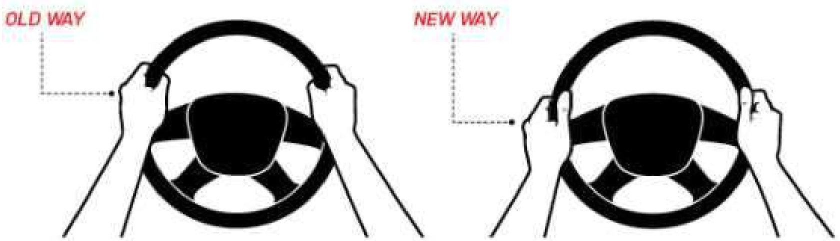
Next steps

- More **Flexibility** – different situations lead to different requirements (link to ODDs)
  - *Road type, traffic volumes, scenarios as work zone, bottleneck or transition area*
  - *Which (minimum) elements are needed to obtain the desired results?*
  - *Which data are needed (maps, positioning, ...), redundancy of elements/sensors*
- Wider perspective on **impacts & evidence**
  - *„Co-benefits“, e.g. Environmental, service-orientation, network effects*
  - *Combine with other measures to maximize the benefits of infrastructure support*
  - *Evaluate related costs & benefits*
- Integrate **legal framework**
  - *Are legal changes needed to roll out measures?*
  - *Mandatory information/advice?*
  - *Quality & trust*
- **User perspective**: further feedback on user experience – does guidance work?
- **COLLABORATION** (OEMs & Service Providers) & **„vehicle integration“**

→ **Start implementing „no regret measures“** *(along a common Vision & Strategy)*



...driving style



INFRAMIX

Martin Russ

austriatech

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 723016.