INFRAMIX overview and highlights

Martin Dirnwoeber / AustriaTech
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 efficiency (e.g. gap advice in bottlenecks) |
3 Scenarios – 3 key areas

Dynamic lane assignment to automated driving

Roadworks zone

Bottlenecks
Approach and highlights

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

Recommendation
- Infrastructure classification
- Safety parameters
- Roadmap
- 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
This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 723016.
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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

Road Operator
- Variable Message Signs
  - Traffic Management Center
  - INFRAMIX Management Center
  - ITS-G5 Road Side Units

Original Equipment Manufacturer
- OEM Vehicle Services
  - Cellular air-link
  - Cellular end-devices

Traffic Service Provider
- Traffic Service Provider
  - Cellular air-link
  - ITS-G5 end-devices

Vehicle Services
- ITS-G5 air-link

Traffic Management Center
- Sensors

Traffic Service Provider
- Cellular air-link

OEM vehicle-devices

Cellular
- ITS-G5 air-link

ITS-G5 end-devices
INFRAMIX end-to-end process

Repetitive 3-step approach:

Data provision

- Provision of traffic data

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

Evaluation & Processing

- Traffic Estimation & Traffic Control Strategies

Performed by:
- Road Operator

Distribution

- Traffic control commands

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

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Data provision

Road Operator

INFRAMIX Management Center

Sensors

Traffic Management Center

INFRAMIX Management Center

ITS-G5 Road Side Units

Original Equipment Manufacturer

OEM Vehicle Services

Cellular air-link

Cellular vehicle-devices

Traffic Service Provider

Cellular air-link

Cellular end-devices

Traffic Service Provider

ITS-G5 air-link

ITS-G5 end-devices

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
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
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Q & A
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ISAD classes

Dr. Panagiotis Lytrivis / ICCS
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
ISAD – Methodology

Creation of a high-level system architecture:
Definition of the system, its main components and associated challenges for further deployment

Group current state-of-the-art and challenges into physical-digital-operational layers (see next slide)

Categorization of the different types of information the infrastructure can provide to the vehicles & identification of the means the above information can be communicated

Creation of a gradually enhanced classification scheme where each class includes the capabilities of the previous one plus additional features

ISAD classes

Continuous improvement through workshops with experts & INFRAMIX Advisory Group (interviews, questionnaires etc.)
Traffic-management functions which facilitate the traffic flow by providing information or guidance

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

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

Operational

Road Infrastructure

Digital

Physical
**ISAD Classes**

- Incremental classes
  
  "E": typical/conventional
  
  "A": most advanced

<table>
<thead>
<tr>
<th>Level</th>
<th>Name</th>
<th>Description</th>
<th>Digital information provided to AVs</th>
</tr>
</thead>
<tbody>
<tr>
<td>E</td>
<td>Conventional infrastructure / no AV support</td>
<td>Conventional infrastructure without digital information. AVs need to recognise road geometry and road signs.</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>Static digital information / Map support</td>
<td>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.</td>
<td>X</td>
</tr>
<tr>
<td>C</td>
<td>Dynamic digital information</td>
<td>All dynamic and static infrastructure information is available in digital form and can be provided to AVs.</td>
<td>X X</td>
</tr>
<tr>
<td>B</td>
<td>Cooperative perception</td>
<td>Infrastructure is capable of perceiving microscopic traffic situations and providing this data to AVs in real-time.</td>
<td>X X X</td>
</tr>
<tr>
<td>A</td>
<td>Cooperative driving</td>
<td>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.</td>
<td>X X X X</td>
</tr>
</tbody>
</table>
Conclusions & Next steps

• 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)
     "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

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  
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ISAD classes examples

Yannick Wimmer / ASFINAG
Infrastructure can help to close ODD* gaps by providing support

*ODD: Operational design domain

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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

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<td>Digital map data (including static road signs) complemented by physical reference points</td>
<td>Traffic lights, short-term road works and VMS have to be recognized by AVs on their own</td>
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<td>AVs perceive infrastructure support data</td>
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Digital information provided to AVs:
- Digital map with road signs
- VMS warnings
- Intersection weather
- Microscopic traffic situation
- Guidance: speed, gap, lane advice
**ISAD Classification Scheme (Carreras et al. 2018)**

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Digital information provided to AVs:
- Road geometry and road signs
- VMS warnings, short-term traffic situations
- Microscopic traffic situation
- Guidance: speed, gap, lane advice

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#### Digital information provided to AVs
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- VMS warnings, variable message signs
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- Guidance: speed, gap time advice
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Examples of C-ITS Use Cases

[Diagram showing various traffic warning scenarios]

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Preliminary Austrian ISAD classification
Thank you for your attention!

Yannick Wimmer
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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

- 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

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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)

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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

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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 \( \rho_{cr} \).

• 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)

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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)

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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 the 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
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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.

- Infrastructure
- Estimation/Control
- Digital Map
- Traffic/Vehicle Modelling
- Communication

Interfaces to Estimation/Control
Co-Simulation with VSimRTI

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

INFRA MIX Co-Simulation Environment
powered by VSimRTI

Federation Management  Time Management  Interaction Management
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

[Graph showing data on speeds and capacity drop on segment 30]
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

No Control  Full VMS deployment  Few VMS deployment
Evaluating the VSL Controller (1)

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

![Travel Delay Improvement Chart]

Penetration Rate (CV - CCV - AV)

- Few VMS
- Full VMS

26/5/2020

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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)
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
This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 723016.
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Martin Rudigier/Virtual Vehicle
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 simulation

Microscopic traffic flow

Infra-structure

C2X Comm.

Digital road

Static Environment

Functional sensors

Automated driving-fct.

Vehicle dynamics

Microscopic simulation

VSimRTI
V2X Simulation Runtime Infrastructure

Submicroscopic simulation

ICOS
Submicroscopic simulation

Vehicle Dynamics
- driving status
- position
- velocity
- brake, gas, steering angle

Driving Function
- vehicle position
- infrastructure information

Static Environment
- lane layout, signs
- position, velocity, ... of relevant road users

Dynamic Data
- ITS-G5
- DENM, IVIM

Vehicle Sensor
- position, velocity, ... of relevant road users

VSimRTI
- SUMO, SNS, VMS, C2X

Fraunhofer FOKUS

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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:

<table>
<thead>
<tr>
<th>Level of Service</th>
<th>Flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOS A</td>
<td>1580</td>
</tr>
<tr>
<td>LOS B</td>
<td>3065</td>
</tr>
<tr>
<td>LOS C</td>
<td>4410</td>
</tr>
<tr>
<td>LOS E</td>
<td>5180</td>
</tr>
</tbody>
</table>

Vehicle types:

<table>
<thead>
<tr>
<th>Vehicle Type</th>
<th>Part of the flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional</td>
<td>64.5%</td>
</tr>
<tr>
<td>Automated</td>
<td>21.2%</td>
</tr>
<tr>
<td>Motorcycles</td>
<td>2.3%</td>
</tr>
<tr>
<td>Trucks</td>
<td>4.7%</td>
</tr>
<tr>
<td>Trailers</td>
<td>6.9%</td>
</tr>
</tbody>
</table>
Bottleneck onramp

- VuT (Vehicle under Test) starts from 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 vs Baseline vs Measure I vs Measure II

<table>
<thead>
<tr>
<th></th>
<th>Demanded</th>
<th>Baseline</th>
<th>Measure I</th>
<th>Measure II</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOS A</td>
<td>1580</td>
<td>1603</td>
<td>1612</td>
<td>1609</td>
</tr>
<tr>
<td>LOS B</td>
<td>3065</td>
<td>3051</td>
<td>3059</td>
<td>3053</td>
</tr>
<tr>
<td>LOS C</td>
<td>4410</td>
<td>4397</td>
<td>4414</td>
<td>4368</td>
</tr>
<tr>
<td>LOS E</td>
<td>5180</td>
<td>4952</td>
<td>5008</td>
<td>4735</td>
</tr>
</tbody>
</table>

### Baseline vs Measure I vs Measure II

<table>
<thead>
<tr>
<th></th>
<th>Baseline</th>
<th>Measure I</th>
<th>Measure II</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOS A</td>
<td>VuT</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>LOS B</td>
<td>VuT</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>LOS C</td>
<td>VuT</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>LOS E</td>
<td>VuT</td>
<td>7</td>
<td>2</td>
</tr>
</tbody>
</table>
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

<table>
<thead>
<tr>
<th>Demanded</th>
<th>Baseline</th>
<th>Measure I</th>
<th>Measure II</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow</td>
<td>Flow</td>
<td>Flow</td>
<td>Flow</td>
</tr>
<tr>
<td>veh/h</td>
<td>veh/h</td>
<td>veh/h</td>
<td>veh/h</td>
</tr>
<tr>
<td>LOS A</td>
<td>1580</td>
<td>1593</td>
<td>1584</td>
</tr>
<tr>
<td>LOS B</td>
<td>3065</td>
<td>2995</td>
<td>2977</td>
</tr>
<tr>
<td>LOS C</td>
<td>4410</td>
<td>3995</td>
<td>4000</td>
</tr>
<tr>
<td>LOS E</td>
<td>5180</td>
<td>4567</td>
<td>4573</td>
</tr>
</tbody>
</table>
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 recognizes with its own sensors the roadworks zone

Measure
• The VuT is informed via a DENM about the upcoming roadwork zone and can early start a lane change manoeuvre to merge into the 2 remaining lanes.
## Roadworks zone

<table>
<thead>
<tr>
<th></th>
<th><strong>Traffic flow, Baseline</strong></th>
<th></th>
<th><strong>Traffic flow, Measure</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Deviation</td>
<td>Min</td>
</tr>
<tr>
<td></td>
<td>veh/h</td>
<td>veh/h</td>
<td>veh/h</td>
</tr>
<tr>
<td><strong>LOS_A</strong></td>
<td>1637</td>
<td>418</td>
<td>420</td>
</tr>
<tr>
<td><strong>LOS_B</strong></td>
<td>2910</td>
<td>473.2</td>
<td>1402</td>
</tr>
<tr>
<td><strong>LOS_C</strong></td>
<td>3350</td>
<td>511.5</td>
<td>2340</td>
</tr>
<tr>
<td><strong>LOS_E</strong></td>
<td>3485</td>
<td>478.3</td>
<td>1620</td>
</tr>
</tbody>
</table>
### Baseline vs Measure

<table>
<thead>
<tr>
<th></th>
<th>Baseline</th>
<th>Measure</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Num. stopped</td>
<td>Num. Merged</td>
</tr>
<tr>
<td>LOS A</td>
<td>3</td>
<td>34</td>
</tr>
<tr>
<td>LOS B</td>
<td>3</td>
<td>26</td>
</tr>
<tr>
<td>LOS C</td>
<td>3</td>
<td>26</td>
</tr>
<tr>
<td>LOS E</td>
<td>3</td>
<td>35</td>
</tr>
</tbody>
</table>
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

\[ KPI_{TTC} = \int_0^\infty \zeta(TTC). (c_0(TTC) - c_1(TTC))dTTC \]

\[ \zeta(TTC) = \begin{cases} 1 & \text{if} \ TTC \leq TTC_{Th} \\ 0 & \text{if} \ TTC > TTC_{Th} \end{cases} \]

<table>
<thead>
<tr>
<th>SC3UC3, Bottleneck, Onramp</th>
<th>LOS A</th>
<th>LOS B</th>
<th>LOS C</th>
<th>LOS E</th>
</tr>
</thead>
<tbody>
<tr>
<td>KPI_{TTC,3, Speed Advice}</td>
<td>-52.8 %</td>
<td>-1.2 %</td>
<td>-14.4 %</td>
<td>6.6 %</td>
</tr>
<tr>
<td>KPI_{TTC,3, Lane Change Advice}</td>
<td>22.1 %</td>
<td>29.2 %</td>
<td>-2.7 %</td>
<td>4.8 %</td>
</tr>
</tbody>
</table>
Brake rate as Safety KPI

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

### SC3UC3, Bottleneck, Onramp, Speed Advice

<table>
<thead>
<tr>
<th>LOS</th>
<th>C_B (%)</th>
<th>LOS B (%)</th>
<th>LOS C (%)</th>
<th>LOS E (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0.88</td>
<td>2.05</td>
<td>2.90</td>
<td>3.00</td>
</tr>
<tr>
<td>B</td>
<td>0.86</td>
<td>0.89</td>
<td>1.96</td>
<td>2.57</td>
</tr>
<tr>
<td>KPI_{BR, Speed Advice}</td>
<td>2.7%</td>
<td>56.5%</td>
<td>32.3%</td>
<td>14.3%</td>
</tr>
</tbody>
</table>

### SC3UC3, Bottleneck, Onramp, Lane Change Advice

<table>
<thead>
<tr>
<th>LOS</th>
<th>C_B (%)</th>
<th>LOS B (%)</th>
<th>LOS C (%)</th>
<th>LOS E (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0.88</td>
<td>2.05</td>
<td>2.90</td>
<td>3.00</td>
</tr>
<tr>
<td>B</td>
<td>9.14</td>
<td>17.06</td>
<td>20.08</td>
<td>14.91</td>
</tr>
<tr>
<td>KPI_{BR, Lane Change Advice}</td>
<td>-932%</td>
<td>-733%</td>
<td>-592%</td>
<td>-397%</td>
</tr>
</tbody>
</table>
Hybrid Testing:
A Vehicle-in-the-Loop Methodology for Evaluating Automated Driving Functions in Virtual Traffic

Dr. Selim Solmaz / Virtual Vehicle
Hybrid Testing Concept
- 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

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

Stamatis Manganiaris, ICCS
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
  o Dynamic Lane Assignment
  o Roadworks
  o Bottlenecks (on-ramps, lane drops, tunnels etc.)
• Digital questionnaires, paper questionnaires, videos, passengers' experience in demonstrations
### Evaluation Methodology

**Research categories**

<table>
<thead>
<tr>
<th>Users’ appreciation factor</th>
<th>Research question</th>
<th>$S1_U1$</th>
<th>$S1_U2$</th>
<th>$S1_U3$</th>
<th>$S2_U1$</th>
<th>$S2_U2$</th>
<th>$S3_U1$</th>
<th>$S3_U2$</th>
<th>$S3_U3$</th>
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<td>x</td>
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<td>RQ3.3 Intuitiveness</td>
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<td>x</td>
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<td>RQ3.4 Understandability</td>
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<td>RQ3.5 Timing and number of signs</td>
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<td>RQ3.6 Correct information</td>
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<td>RQ3.7 No distraction</td>
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<td>RQ3.8 Immediate Reaction</td>
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<td>RQ3.9 Potential benefit</td>
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</tbody>
</table>
Evaluation Methodology

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

• Top 2 box + Bottom 2 box methodology was followed:
  o The top 2 box score is the sum of percentages for the top two highest points on satisfaction, appreciation or awareness.
  o 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)
  o Scenario 1  28
  o Scenario 2  20
  o 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.
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**

<table>
<thead>
<tr>
<th>willngness to use (scale used 1-5)</th>
<th>BN Mean</th>
<th>STD</th>
<th>RW Mean</th>
<th>STD</th>
<th>DLA Mean</th>
<th>STD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Use information</td>
<td>4.23</td>
<td>0.71</td>
<td>4.43</td>
<td>0.59</td>
<td>4.23</td>
<td>0.58</td>
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<table>
<thead>
<tr>
<th>behavior change (scale used 1-5)</th>
<th>BN Mean</th>
<th>STD</th>
<th>RW Mean</th>
<th>STD</th>
<th>DLA Mean</th>
<th>STD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Follow suggestions</td>
<td>4.28</td>
<td>0.64</td>
<td>4.50</td>
<td>0.55</td>
<td>4.25</td>
<td>0.54</td>
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<table>
<thead>
<tr>
<th>perceived usability (scale used 1-5)</th>
<th>BN Mean</th>
<th>STD</th>
<th>RW Mean</th>
<th>STD</th>
<th>DLA Mean</th>
<th>STD</th>
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</thead>
<tbody>
<tr>
<td>Easy to learn signs</td>
<td>4.13</td>
<td>0.83</td>
<td>4.41</td>
<td>0.72</td>
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<td>0.94</td>
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<td>0.71</td>
<td>4.05</td>
<td>0.81</td>
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<td>Benefit</td>
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<td>3.86</td>
<td>0.71</td>
<td>3.67</td>
<td>0.81</td>
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<tr>
<td>Intuitive signs</td>
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<td>1.05</td>
<td>4.26</td>
<td>0.88</td>
<td>3.72</td>
<td>0.94</td>
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<td>1.09</td>
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<td>0.86</td>
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<table>
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<th>RW Mean</th>
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</thead>
<tbody>
<tr>
<td>Easier/intuitive interactions (DRIVERS)</td>
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<td>7.13</td>
<td>1.79</td>
<td>6.88</td>
<td>1.73</td>
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<tr>
<td>Miss road sign in the in-vehicle HMI (DRIVERS)</td>
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<td>Increase comfort (DRIVERS)</td>
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<td>1.89</td>
<td>6.79</td>
<td>1.82</td>
<td>6.65</td>
<td>1.79</td>
</tr>
<tr>
<td>Better perform daily work (TRANSPORT OPERATORS)</td>
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<td>1.50</td>
<td>7.61</td>
<td>1.15</td>
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<td>7.77</td>
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<td>Solve problems faster (TRANSPORT OPERATORS)</td>
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<table>
<thead>
<tr>
<th>expected impacts results (scale used 1-5)</th>
<th>BN Mean</th>
<th>STD</th>
<th>RW Mean</th>
<th>STD</th>
<th>DLA Mean</th>
<th>STD</th>
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</thead>
<tbody>
<tr>
<td>Traffic safety</td>
<td>3.95</td>
<td>0.99</td>
<td>4.40</td>
<td>0.63</td>
<td>3.93</td>
<td>0.62</td>
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<tr>
<td>Traffic flow/throughput</td>
<td>4.25</td>
<td>0.87</td>
<td>4.10</td>
<td>0.67</td>
<td>3.83</td>
<td>0.78</td>
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<td>CO2 emissions</td>
<td>3.80</td>
<td>0.91</td>
<td>3.60</td>
<td>0.71</td>
<td>3.40</td>
<td>0.74</td>
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## Overall Results

<table>
<thead>
<tr>
<th>Willingness to use (scale used 1-5)</th>
<th>BN</th>
<th>RW</th>
<th>DLA</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Use information</strong></td>
<td>4.05 0.92</td>
<td>3.50 1.54</td>
<td>4.18 0.67</td>
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<table>
<thead>
<tr>
<th>Behavior change (scale used 1-5)</th>
<th>BN</th>
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<th>DLA</th>
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<tbody>
<tr>
<td><strong>Follow suggestions</strong></td>
<td>4.10 0.83</td>
<td>3.70 1.30</td>
<td>4.11 0.74</td>
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<table>
<thead>
<tr>
<th>Perceived usability (scale used 1-5)</th>
<th>BN</th>
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<th>DLA</th>
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<tbody>
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<td>3.80 1.28</td>
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<tr>
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<td>3.62 0.92</td>
<td>3.70 1.38</td>
<td>3.86 0.65</td>
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<td><strong>Immediate reaction</strong></td>
<td>3.62 1.12</td>
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<td>4.00 1.08</td>
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<td>4.29 0.60</td>
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<tr>
<td><strong>Understandable signs</strong></td>
<td>4.19 0.60</td>
<td>4.20 1.15</td>
<td>4.11 0.79</td>
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<tr>
<td><strong>Correct Information</strong></td>
<td>3.76 0.70</td>
<td>4.35 0.93</td>
<td>4.14 0.93</td>
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<tr>
<td><strong>Not distracting from driving</strong></td>
<td>3.38 0.97</td>
<td>4.10 0.79</td>
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<table>
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<th>Easier/intuitive interactions (DRIVERS)</th>
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<th>DLA</th>
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<tr>
<td><strong>Easier/intuitive interactions (DRIVERS)</strong></td>
<td>6.62 2.13</td>
<td>6.10 2.55</td>
<td>6.89 1.77</td>
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<tr>
<td><strong>Miss road sign in the in-vehicle HMI (DRIVERS)</strong></td>
<td>7.43 2.29</td>
<td>7.35 2.25</td>
<td>7.46 1.75</td>
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<td><strong>Stress reduction (DRIVERS)</strong></td>
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<td>6.93 2.14</td>
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<tr>
<td><strong>Increase comfort (DRIVERS)</strong></td>
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<td>6.95 2.48</td>
<td>7.39 1.62</td>
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<tr>
<td><strong>Better perform daily work (TRANSPORT OPERATORS)</strong></td>
<td>8.38 1.60</td>
<td>7.35 2.39</td>
<td>7.79 1.52</td>
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<td><strong>New incident detection ways (TRANSPORT OPERATORS)</strong></td>
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<td>6.70 3.23</td>
<td>7.46 2.17</td>
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<tr>
<td><strong>New incident reaction ways (TRANSPORT OPERATORS)</strong></td>
<td>7.76 2.28</td>
<td>7.55 2.50</td>
<td>7.18 2.11</td>
</tr>
<tr>
<td><strong>Solve problems faster (TRANSPORT OPERATORS)</strong></td>
<td>8.52 1.29</td>
<td>7.20 2.57</td>
<td>7.43 2.03</td>
</tr>
</tbody>
</table>

| 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 emissions                        | 4.14 0.96  | 3.50 0.95  | 3.71 0.81  |
## Overall Results

### Willingness to use (scale used 1-5)

<table>
<thead>
<tr>
<th></th>
<th>BN</th>
<th>RW</th>
<th>DLA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Use information</td>
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<td>4.38</td>
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### Behavior change (scale used 1-5)

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<tr>
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</tr>
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<tbody>
<tr>
<td>Follow suggestions</td>
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<td>4.33</td>
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### Perceived usability (scale used 1-5)

<table>
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<th>BN</th>
<th>RW</th>
<th>DLA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Easy to learn signs</td>
<td>4.45</td>
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<td>Usefulness</td>
<td>4.23</td>
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<tr>
<td>Satisfying</td>
<td>4.15</td>
<td>4.73</td>
<td>4.03</td>
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<tr>
<td>Immediate reaction</td>
<td>4.15</td>
<td>4.43</td>
<td>3.85</td>
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<tr>
<td>Benefit</td>
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<tr>
<td>Understandable signs</td>
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### Expected Impacts Results (scale used 0-10)

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<tr>
<td>Easier/intuitive interactions (DRIVERS)</td>
<td>7.65</td>
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<td>Miss road sign in the in-vehicle HMI (DRIVERS)</td>
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<td>6.78</td>
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<tr>
<td>Stress reduction (DRIVERS)</td>
<td>7.58</td>
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<td>6.43</td>
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<tr>
<td>Increase comfort (DRIVERS)</td>
<td>7.60</td>
<td>6.63</td>
<td>6.75</td>
</tr>
<tr>
<td>Better perform daily work (TRANSPORT OPERATORS)</td>
<td>7.53</td>
<td>7.60</td>
<td>7.38</td>
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<tr>
<td>New incident reaction ways (TRANSPORT OPERATORS)</td>
<td>7.40</td>
<td>7.68</td>
<td>7.70</td>
</tr>
<tr>
<td>Solve problems faster (TRANSPORT OPERATORS)</td>
<td>7.44</td>
<td>7.73</td>
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### Expected Impacts Results (scale used 1-5)

<table>
<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td>Traffic safety</td>
<td>4.28</td>
<td>4.40</td>
<td>3.80</td>
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<tr>
<td>Traffic flow/throughput</td>
<td>4.32</td>
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<td>CO2 emissions</td>
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<td>3.58</td>
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## Overall Results

<table>
<thead>
<tr>
<th>Willingness to use (scale used 1-5)</th>
<th>BN</th>
<th>RW</th>
<th>DLA</th>
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<tbody>
<tr>
<td>Use information</td>
<td>Mean</td>
<td>STD</td>
<td>Mean</td>
</tr>
<tr>
<td>Use information</td>
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<th>Behavior change (scale used 1-5)</th>
<th>BN</th>
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<tbody>
<tr>
<td>Follow suggestions</td>
<td>Mean</td>
<td>STD</td>
<td>Mean</td>
</tr>
<tr>
<td>Follow suggestions</td>
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<table>
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<th>Perceived usability (scale used 1-5)</th>
<th>BN</th>
<th>RW</th>
<th>DLA</th>
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<tbody>
<tr>
<td>Easy to learn signs</td>
<td>Mean</td>
<td>STD</td>
<td>Mean</td>
</tr>
<tr>
<td>Usefulness</td>
<td>4.05</td>
<td>0.76</td>
<td>4.55</td>
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<tr>
<td>Satisfying</td>
<td>4.40</td>
<td>0.68</td>
<td>4.55</td>
</tr>
<tr>
<td>Immediate reaction</td>
<td>4.25</td>
<td>0.55</td>
<td>4.40</td>
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<td>Benefit</td>
<td>4.20</td>
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<td>4.15</td>
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<tr>
<td>Intuitive signs</td>
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<td>Understandable signs</td>
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<td>Available in time</td>
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<tr>
<td>Enough per distance</td>
<td>3.95</td>
<td>0.69</td>
<td>4.15</td>
</tr>
<tr>
<td>Correct information</td>
<td>3.95</td>
<td>0.51</td>
<td>4.05</td>
</tr>
<tr>
<td>Not distracting from driving</td>
<td>4.05</td>
<td>0.60</td>
<td>4.05</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Expected Impacts Results (scale used 0-10)</th>
<th>BN</th>
<th>RW</th>
<th>DLA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Easier/intuitive interactions (DRIVERS)</td>
<td>Mean</td>
<td>STD</td>
<td>Mean</td>
</tr>
<tr>
<td>Easier/intuitive interactions (DRIVERS)</td>
<td>7.30</td>
<td>1.95</td>
<td>7.20</td>
</tr>
<tr>
<td>Stress reduction (DRIVERS)</td>
<td>7.85</td>
<td>1.42</td>
<td>7.65</td>
</tr>
<tr>
<td>Increase comfort (DRIVERS)</td>
<td>7.60</td>
<td>1.47</td>
<td>7.45</td>
</tr>
<tr>
<td>Better perform daily work (TRANSPORT OPERATORS)</td>
<td>Mean</td>
<td>STD</td>
<td>Mean</td>
</tr>
<tr>
<td>Better perform daily work (TRANSPORT OPERATORS)</td>
<td>7.95</td>
<td>1.85</td>
<td>8.30</td>
</tr>
<tr>
<td>New incident reaction ways (TRANSPORT OPERATORS)</td>
<td>Mean</td>
<td>STD</td>
<td>Mean</td>
</tr>
<tr>
<td>New incident reaction ways (TRANSPORT OPERATORS)</td>
<td>7.35</td>
<td>3.05</td>
<td>7.90</td>
</tr>
<tr>
<td>Solve problems faster (TRANSPORT OPERATORS)</td>
<td>Mean</td>
<td>STD</td>
<td>Mean</td>
</tr>
<tr>
<td>Solve problems faster (TRANSPORT OPERATORS)</td>
<td>8.35</td>
<td>1.39</td>
<td>8.35</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Expected Impacts Results (scale used 1-5)</th>
<th>BN</th>
<th>RW</th>
<th>DLA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traffic safety</td>
<td>Mean</td>
<td>STD</td>
<td>Mean</td>
</tr>
<tr>
<td>Traffic safety</td>
<td>4.35</td>
<td>0.93</td>
<td>4.60</td>
</tr>
<tr>
<td>Traffic flow/throughput</td>
<td>4.40</td>
<td>0.88</td>
<td>4.40</td>
</tr>
<tr>
<td>CO2 emissions</td>
<td>Mean</td>
<td>STD</td>
<td>Mean</td>
</tr>
<tr>
<td>CO2 emissions</td>
<td>3.70</td>
<td>1.03</td>
<td>3.45</td>
</tr>
</tbody>
</table>
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
INFRAMIX online
final event

Roadmap towards fully automated transport systems

Annarita Leserri / Enide
Summary

• Challenge
• Solutions
• Guidelines
• Timeline
We identified some challenges related to highway infrastructure management and developed them as scenarios.
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

<table>
<thead>
<tr>
<th></th>
<th>Industry</th>
<th>Infrastructure operators</th>
<th>Policy makers</th>
<th>Researchers and key influencers</th>
<th>General public</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traffic management measures</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Bidirectional communication V2I and I2V</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Digital infrastructure</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Physical infrastructure</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Infrastructure classification scheme</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Safety performance criteria</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Use cases and business models</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Roadmap towards connected infrastructure</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
</tbody>
</table>
INFRAMIX Roadmap Guidelines

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

<table>
<thead>
<tr>
<th>Stakeholder</th>
<th>Action needed</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Industry</strong></td>
<td>• 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.</td>
</tr>
<tr>
<td><strong>Infrastructure operators</strong></td>
<td>• Future testing and demonstration; • Provision of new services; • Strategic decisions and investments; • Business relationships with third parties; • External promotion; • etc.</td>
</tr>
<tr>
<td><strong>Policy makers</strong></td>
<td>• Develop awareness; • Evidence-based policies and regulations; • Strategic investments; • Etc.</td>
</tr>
<tr>
<td><strong>Researchers and key influencers</strong></td>
<td>• 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.</td>
</tr>
<tr>
<td><strong>General public</strong></td>
<td>• Develop awareness; • Users’ experience feedback; • Etc.</td>
</tr>
</tbody>
</table>
## 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
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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.
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
- \[\rightarrow\] **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
### Driving Recommendations/Commands

<table>
<thead>
<tr>
<th>Control Message</th>
<th>Safety</th>
<th>Efficiency</th>
<th>Remarks</th>
<th>Recommended</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed limit</td>
<td>++</td>
<td>+</td>
<td>Works fine</td>
<td>Yes</td>
</tr>
<tr>
<td>Distance gap</td>
<td>O</td>
<td>++</td>
<td>Also works fine (cars need to have ACC feature)</td>
<td>Yes</td>
</tr>
<tr>
<td>Acceleration</td>
<td>-</td>
<td>O</td>
<td>Very little additional effect</td>
<td>No</td>
</tr>
<tr>
<td>Lane change</td>
<td>?</td>
<td>+</td>
<td>Rather “keep to lane” advice instead</td>
<td>No</td>
</tr>
<tr>
<td>Dedicated lane</td>
<td>-</td>
<td>--</td>
<td>Benefits for AVs do not compensate for disadvantages for others</td>
<td>No</td>
</tr>
<tr>
<td>Roadworks</td>
<td>++</td>
<td>+</td>
<td>High safety potential</td>
<td>Yes</td>
</tr>
</tbody>
</table>
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.
INFRAMIX results confirm ASFINAG’s strategy!
Rollout in Austria

ASFINAG C-ITS activities:

Pilot: ECo-AT

- 25 RSUs (2015-2019)
- ECo-AT Spec (Day1)

Pre-Deployment: C-Roads Pilot Austria

- 28 RSUs (2020)
- C-Roads Spec (Day1, Day2)

Deployment: Austria

- 175 + 325 RSUs starting from 2021
- C-Roads Spec and extensions (Day1, Day2)
C-Roads Pilot Austria Services

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

26/5/2020 INFRAMIX final online conference
Demonstrators
Use Case 1: Dynamic Lane Assignment
Thank you for your attention!

Yannick Wimmer
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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.
ODD and the role of infrastructure support

INFRAMIX Final Event, 26 May 2020

Tom Alkim
Directorate-General for Research & Innovation
European Commission
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

H2020 - Calls on "Automated Road Transport"
Figure 1. Hype Cycle for Emerging Technologies 2016

Gartner Hype Cycles 2009 - 2019
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
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. Large-scale demonstrations
   - Shared automated mobility solutions (11)
   - Highly automated passenger vehicles (13)
   - Automated commercial/freight vehicles (14)

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

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

4. Integrating the vehicle in the transport system
   - Remote operation and surveillance (7)
   - Physical and digital infrastructure (8)
   - Connectivity / Cooperative Systems (9)
   - Fleet and (mixed) traffic management (12)

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

6. Social aspects & user acceptance
   - Societal needs analysis (15)
   - Socio-economic and environmental impact analysis (16)
   - Workforce development (22)

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

A. Driver leaves home to drive to work. First mile is driven manually.

B. ... gives control to vehicle (ToC) and continues the trip in automated mode. Does something else with the freed up time, like reading email, posting on Instagram or drinking coffee.

E. Vehicle approaches the exit and driver prepares to take back control (ToC) and drives last mile manually to destination.

Figure 3: Visual representation of limited ODD
ODD in the STRIA roadmap - practice

Figure 4: Visual representation of ODD in practice
ODD and ISAD

STORYLINE ODD FRAMEWORK

A
Driver leaves home to drive to work. First mile is driven manually.

B
... gives control to vehicle (TsC) and continues the trip in automated mode. Does something else with the freed up time, like reading email, posting on Instagram or drinking coffee.

C1
- During the trip vehicle encounters temporary lane markings, vehicle is confused and ODD ends. Driver needs to take over control (TrC).
- Conditions back to normal, ODD is available again, driver gives back control (TtC).

C2
- During the trip vehicle has to merge into heavy mixed traffic, vehicle can’t handle the situation and ODD ends. Driver needs to take over control (TrC).
- Conditions back to normal, ODD is available again, driver gives back control (TtC).

C3
- During the trip a heavy rain shower occurs, vehicle can’t handle the situation and ODD ends. Driver needs to take over control (TrC).
- Conditions back to normal, ODD is available again, driver gives back control (TtC).

C4
- Vehicle approaches the exit and driver prepares to take back control (TtC) and drives last mile manually to destination.

always & all conditions

first mile
highway
last mile

= limited ODD

ISAD levels

Figure 4: Visual representation of ODD in practice
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

Recommendation
- Infrastructure classification
- Safety parameters
- Roadmap
- Exploitation plans

26/5/2020
INFRAMIX final online conference
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 (microscopic, 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
This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 723016.

Martin Russ