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CARTRE Webinar Series (**VIII**):

'Key performance indicator (KPIs) and assessment of impacts of automated driving'

28 March 2018

CARTRE and SCOUT are funded by the European Union Horizon 2020 Work Programme

Introduction: CAD Initiative and Webinar Series

CARTRE
Coordination of Automated Road Transport Deployment for Europe

- **Connected Automated Driving**: Joint Initiative by two European projects (CARTRE, SCOUT)
- **Partnership**: 30 Partners and around 40 associated partners from research, industry and authorities
- **Project Goal**: Bundle European and national actions to accelerate deployment of automated driving
- **Webinar Series**: Present existing CAD projects and explore global issues in automated driving research

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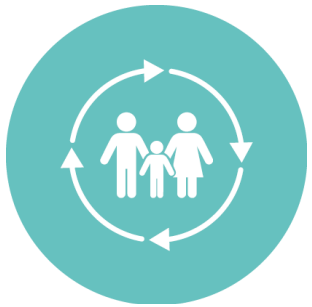
Introduction: CAD Activities in Europe and Beyond

Annual Conference	Digital Knowledgebase	Strategic Guidance
Position Paper Development	Data Sharing and Evaluation	Stakeholder Network

Introduction: Thematic Interest Groups

Connectivity



Socio-Economic Sustainability

Industrial Production

Human Factors

Big Data and AI

Infrastructure

In-Vehicle Enablers

Safety Validation

Policy and Regulation

New Business Models

Users and Society

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Agenda

CARTRE
Coordination of Automated Road Transport Deployment for Europe

13:00-13:05	Introduction and agenda of the webinar, Satu Innamaa/VTT
13:05-13:15	Trilateral Impact Assessment Framework, Satu Innamaa/VTT
13:15-13:25	Trilateral KPI Survey results, Satu Innamaa/VTT
13:25-13:40	Safety impact assessment for automated driving as in AdaptIVe project, Adrian Zlocki/ika
13:40-13:45	Outlook to safety impact assessment methodology for the ongoing L3Pilot project, Adrian Zlocki/ika
13:45-14:00	Questions and answers

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Trilateral Impact Assessment Framework

Satu Innamaa/VTT

Trilateral activity for building the framework

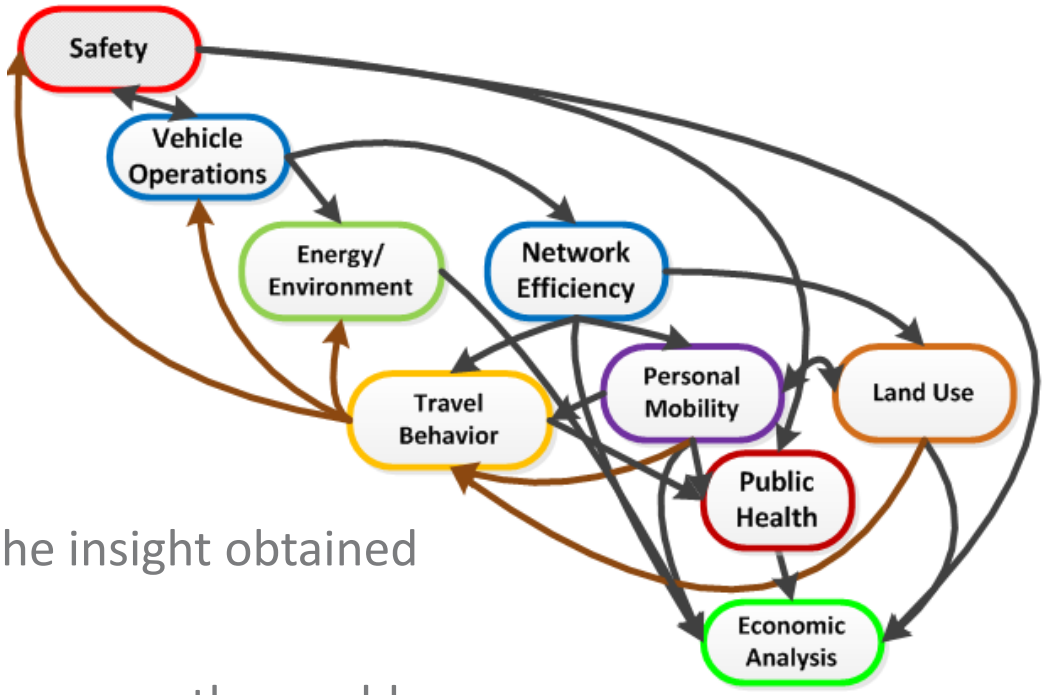
- Cooperation between Europe, US and Japan in ART WG
- Subgroup for impact assessment
  - Formed in 2015
  - 40+ members
- Objective:

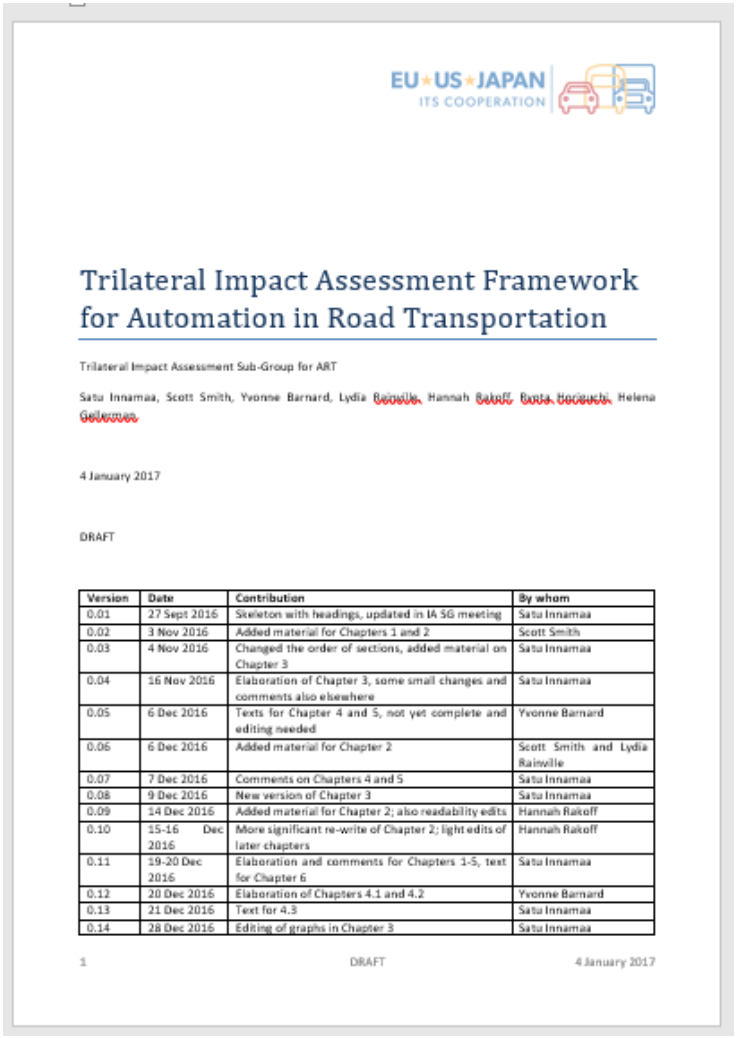
  > "Harmonization of the high-level evaluation framework for assessing the impact of automation in road transportation"

- High-level framework intended for FOT designers, policy makers and those making impact assessment of ART

Motivation

- Potential impacts of automation are far reaching and complex
  - High expectations on what connected and automated vehicles shall be able to contribute to several societal goals
- Field tests are expensive
- International harmonization
  - Design tests and studies to maximize the insight obtained
  - Enable meta-analysis
  - Can arrange complementary evaluation across the world
  - Make better use of each other's findings
  - Exchange best practices





EU★US★JAPAN
ITS COOPERATION

Trilateral Impact Assessment Framework for Automation in Road Transportation

Trilateral Impact Assessment Sub-Group for ART

Satu Innamaa, Scott Smith, Yvonne Barnard, Lydia Rainville, Hannah Rakoff, Ryota Horiguchi, Helena Gellerman

4 January 2017

DRAFT

Version	Date	Contribution	By whom
0.01	27 Sept 2016	Skeleton with headings, updated in IA SG meeting	Satu Innamaa
0.02	3 Nov 2016	Added material for Chapters 1 and 2	Scott Smith
0.03	4 Nov 2016	Changed the order of sections, added material on Chapter 3	Satu Innamaa
0.04	16 Nov 2016	Elaboration of Chapter 3, some small changes and comments also elsewhere	Satu Innamaa
0.05	6 Dec 2016	Texts for Chapter 4 and 5, not yet complete and editing needed	Yvonne Barnard
0.06	6 Dec 2016	Added material for Chapter 2	Scott Smith and Lydia Rainville
0.07	7 Dec 2016	Comments on Chapters 4 and 5	Satu Innamaa
0.08	9 Dec 2016	New version of Chapter 3	Satu Innamaa
0.09	14 Dec 2016	Added material for Chapter 2; also readability edits	Hannah Rakoff
0.10	15-16 Dec 2016	More significant re-write of Chapter 2; light edits of later chapters	Hannah Rakoff
0.11	19-20 Dec 2016	Elaboration and comments for Chapters 1-5, text for Chapter 6	Satu Innamaa
0.12	20 Dec 2016	Elaboration of Chapters 4.1 and 4.2	Yvonne Barnard
0.13	21 Dec 2016	Text for 4.3	Satu Innamaa
0.14	28 Dec 2016	Editing of graphs in Chapter 3	Satu Innamaa

1 DRAFT 4 January 2017

Contents

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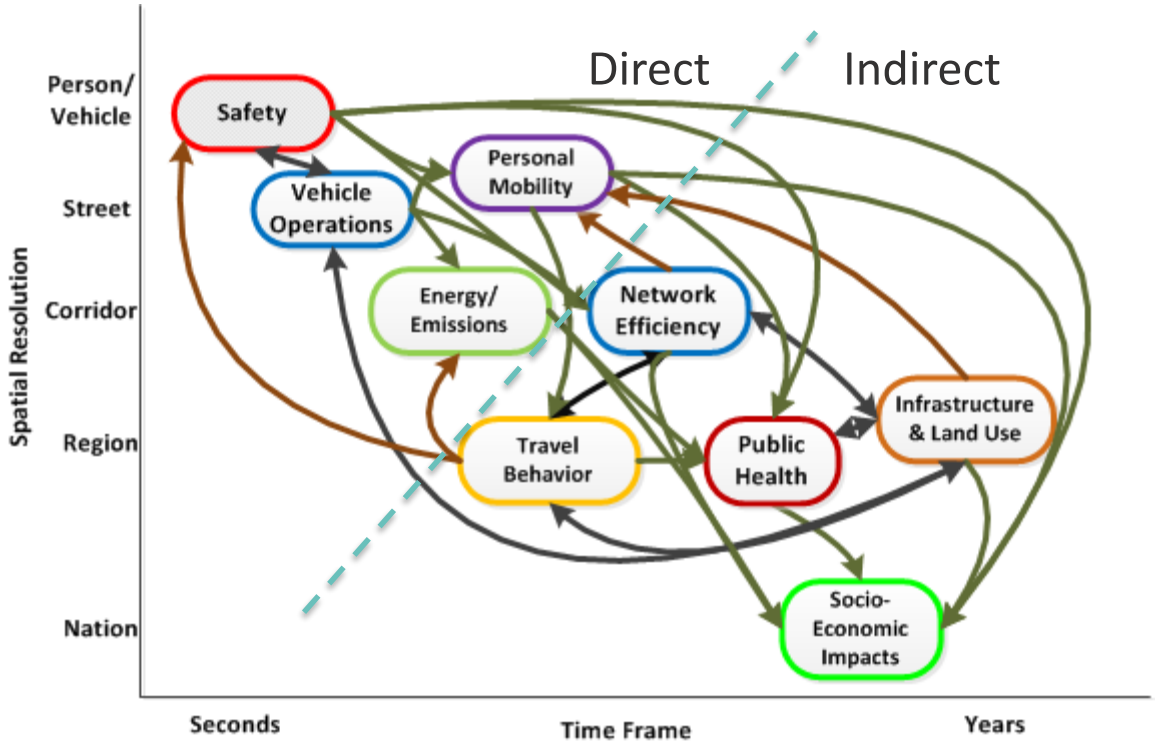
System and Impact Classification

- Direct & indirect impacts
- Definition and KPIs
  - KPIs being updated based on survey
- System and design domain



Impact Mechanisms

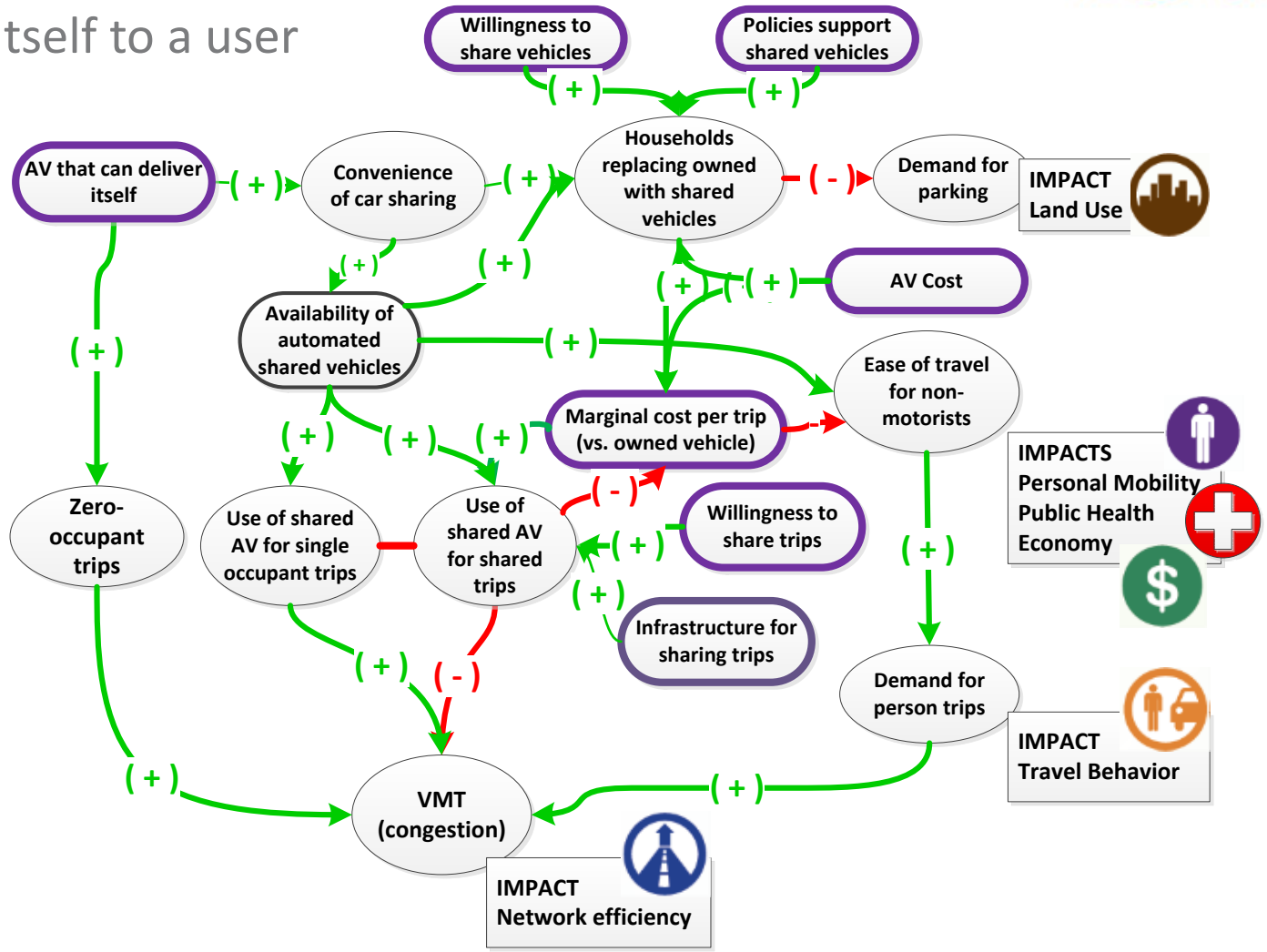
The potential impact mechanisms defined for ART to ensure that assessment covers systematically

- the intended and unintended
- direct and indirect
- short-term and long-term

impacts of both AV-users and non-users.

It is recommended that these mechanisms be identified for all impact areas, although, not all of them could be assessed.

AV that can deliver itself to a user

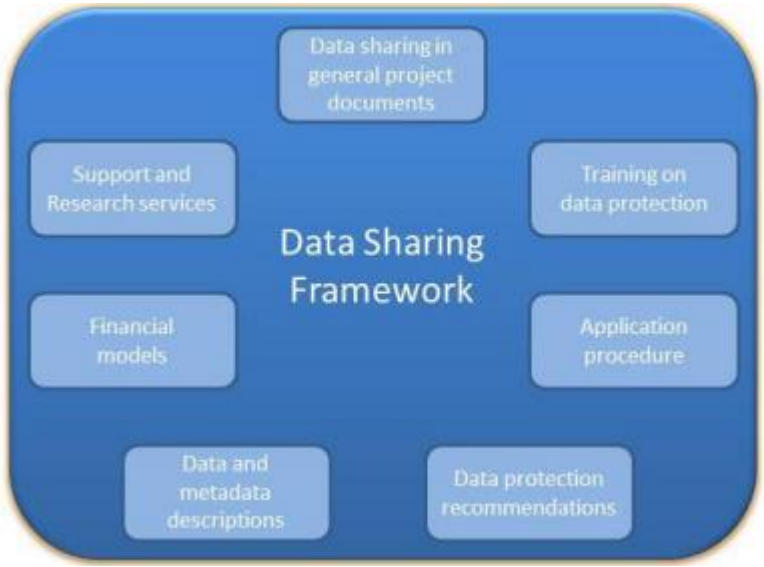


Recommendations for experimental procedure

- Basics for setting the study design
  - Recommendations in line with the FESTA V
- Special for ART
  - It will not always be possible to test AVs in a naturalistic environment
    → Use of controlled testing and simulation discussed
  - Many (first) AD studies will be performed utilising prototype vehicles, whose performance may not be the same as in the planned production vehicle

Recommendations for Data Sharing

- Reasons for data sharing discussed
  - References to RDE and FOT-Net's Data Sharing Framework
- Obstacles for data sharing and their solutions
  - Competitive information
  - Privacy-sensitive data
  - Different legal and ethical conditions
  - Not always easily-accessible
  - Storing, maintaining and opening data after a project has a cost
- Common dataset needs to be agreed within 1-2 years



Framework document available

Framework draft 1.0 (4 Jan 2017):
https://connectedautomateddriving.eu/wp-content/uploads/2017/05/Trilateral_IA_Framework_Draft_v1.0.pdf

Updated version to be published
in April 2018!

Trilateral KPI Survey Results

Satu Innamaa/VTT

Introduction

- To be able to provide recommendations on the most important key performance indicators (KPIs) for measuring and expressing the impacts, the Trilateral Impact Assessment subgroup conducted an international survey
  - The survey was open for answers from June to November 2017
  - In total, 77 answers were obtained from EU, US and Japan
  - 56% represented research organizations, 18% policy makers or authority and 14% automotive or other industry
- The resulting recommendations on KPIs will be provided in version 2.0 of the Trilateral Impact Assessment Framework which will be published in April 2018

Structure of survey

- Region and sector
- Impact areas of interest
  - Vehicle operations / automated vehicles
  - Use of automated driving
  - Safety
  - Energy or environment
  - Personal mobility
  - Travel behavior
  - Network efficiency
  - Asset management
  - Costs
  - Public health
  - Land use
  - Economic impacts
- Vehicle type that they would assume when answering the questions: automated passenger car, shuttle bus/pod, truck or mixed traffic including VRUs
- Automation level: SAE 1-2, SAE 3 and SAE 4-5
- Rating for KPIs for areas they had indicated having expertise in
  - Scale is from 0 = 'not at all important' to 6 = 'extremely important', N/A = 'not applicable'
- Additional KPIs

Example of results: Vehicle operations

KPI	Rating	N
Number of instances where the driver must take manual control / 1000 km or miles	5.69	29
Mean and maximum duration of the transfer of control between operator/driver and vehicle (when requested by the vehicle)	5.63	30
Mean and maximum duration of the transfer of control between operator/driver and vehicle (turning automated driving system on/off, manual overrule)	5.03	29
Number of emergency decelerations per 1000 km or miles	4.97	32
Mean and minimum time-headway to the vehicle in front in car following situations	4.75	32
Minimum accepted gap at intersections or in lane changes	4.70	30
Mean and minimum distance to the vehicle in front in car following situations (headway 5 s or less)	4.63	32
Mean and maximum longitudinal acceleration and deceleration	4.48	31

Note: Only part of result table

Example of results: KPIs by SAE level

KPI	SAE 1-2		SAE 3		SAE 4-5	
	Rating	N	Rating	N	Rating	N
Number of instances where the driver must take manual control / 1000 km or miles	5.33	6	5.86	7	5.75	16
Mean and maximum duration of the transfer of control between operator/driver and vehicle (when requested by the vehicle)	5.33	6	6.00	7	5.59	17
Mean and maximum duration of the transfer of control between operator/driver and vehicle (turning automated driving system on/off, manual overrule)	5.17	6	5.29	7	4.88	16
Number of emergency decelerations per 1000 km or miles	4.50	6	5.00	8	5.11	18
Mean and minimum time-headway to the vehicle in front in car following situations	4.50	6	4.88	8	4.78	18

Note: Only part of result table

Example of results: KPIs by vehicle type

KPI	Automated passenger car		Mixed traffic	
	Rating	N	Rating	N
Number of instances where the driver must take manual control / 1000 km or miles	5.64	14	5.75	12
Mean and maximum duration of the transfer of control between operator/driver and vehicle (when requested by the vehicle)	5.69	16	5.67	12
Mean and maximum duration of the transfer of control between operator/driver and vehicle (turning automated driving system on/off, manual overrule)	5.07	15	5.00	12
Number of emergency decelerations per 1000 km or miles	4.94	16	5.08	13

Note: Only part of result table

Discussion

- None of the KPIs received very low ratings
  - This is most likely due to having a large expert group selecting the KPIs for the survey and dropping irrelevant KPIs during survey design
  - As the impacts of automation are still partly unknown, the experts are interested in many potential impacts
- In order not to have too long a list of alternative KPIs to rate, some KPIs were not precisely defined
  - They will need additional work on making them unambiguous before use in practice
- Recommendations and a full list of potential KPIs (a KPI repository) will be added to version 2.0 of Trilateral impact assessment framework (expected in April 2018)

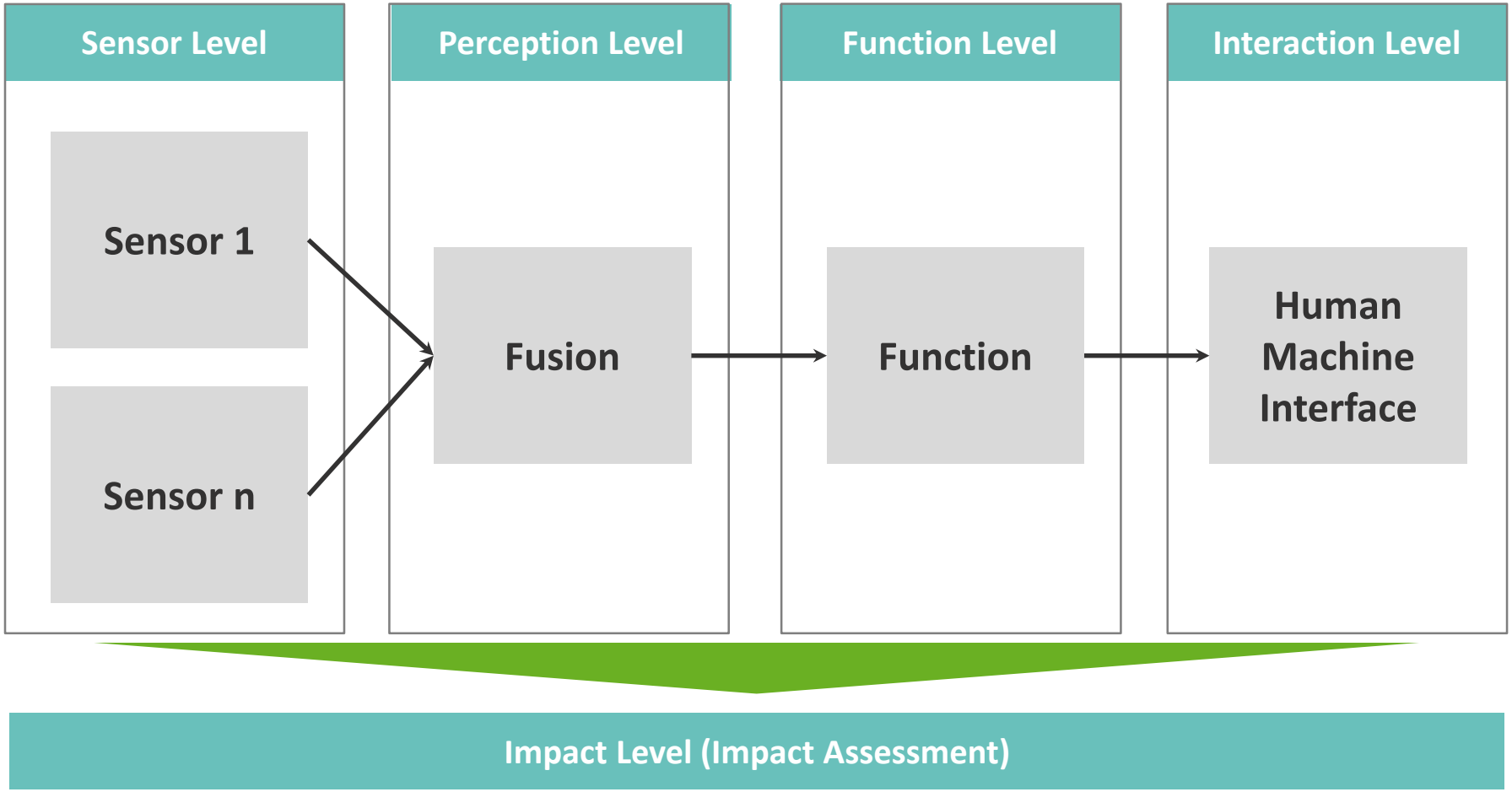
Full results available

Innamaa, S & Kuisma, S (2018). Key performance indicators for assessing the impacts of automation in road transportation: Results of the Trilateral key performance indicator survey. Research Report VTT-R- 01054-18, VTT.
https://connectedautomateddriving.eu/wp-content/uploads/2018/03/KPIS-for-Assessing-Impact-CAD_VTT.pdf

Safety impact assessment for automated driving as in AdaptIVe project

Adrian Zlocki/ika

Evaluation Methodology
Determination of Test Level



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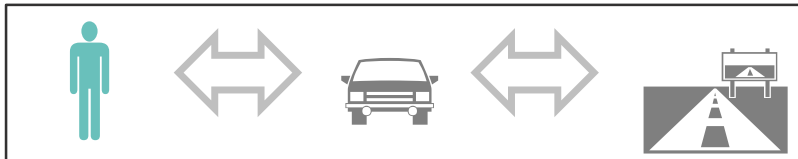
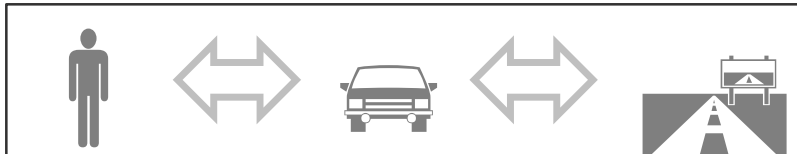
Evaluation Methodology
Different Methodologies

Methods	DRIVER VEHICLE ENVIRONMENT	
Field Operational Test		+ trajectory & interaction 1:1 perceptible - reproducibility limited - relevant situations occur rarely - extensive effort
Controlled Field		+ trajectory & HMI quite well perceptible o reproducibility - situation space limited - high effort
Dynamic Driving Simulator		+ trajectory & HMI well perceptible + reproducibility + critical situations possible o medium effort
Simulation		- trajectory bad perceptible o interaction limited perceptible + reproducibility + low effort

REAL

Increase of validity

VIRTUAL

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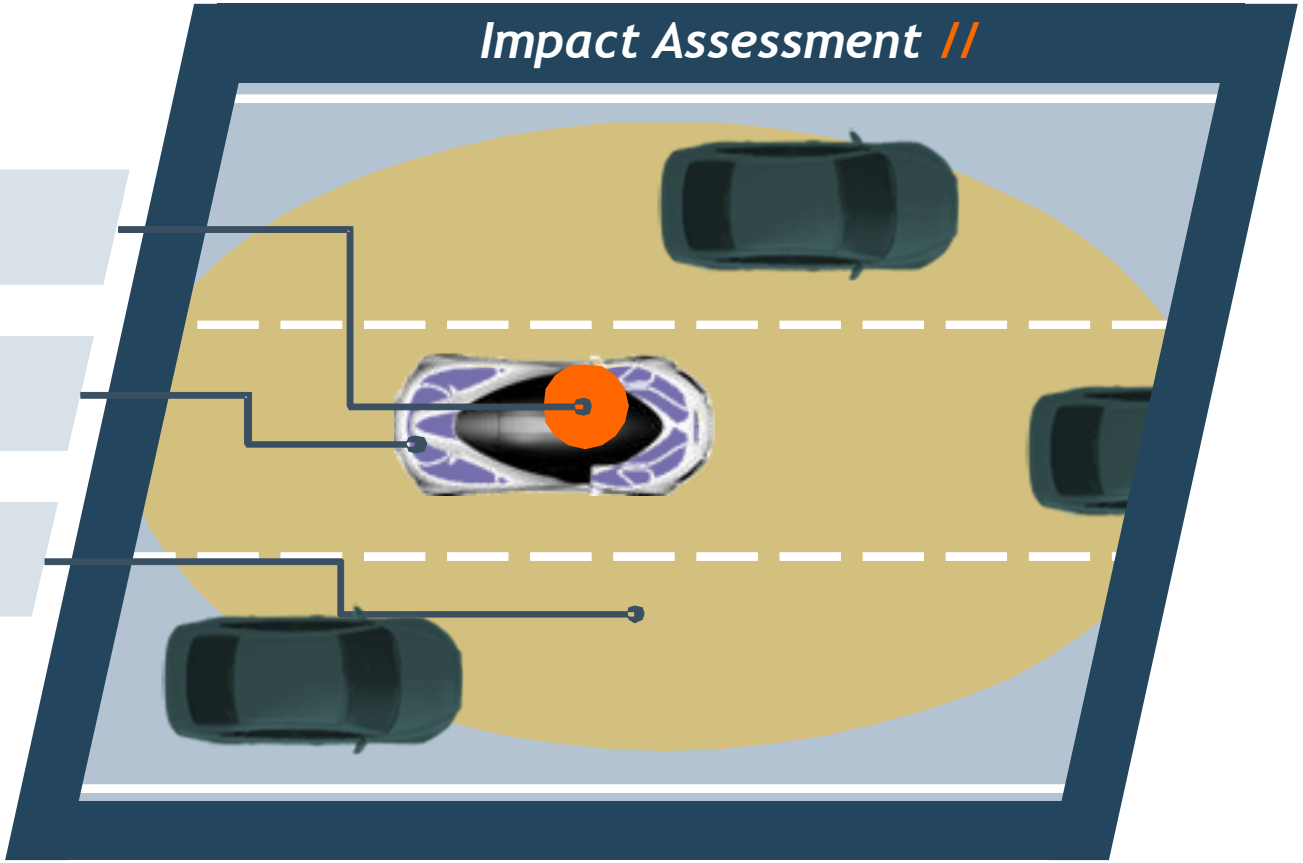
Evaluation of AdaptIVe Functions

User-Related Assessment //

Technical Assessment //

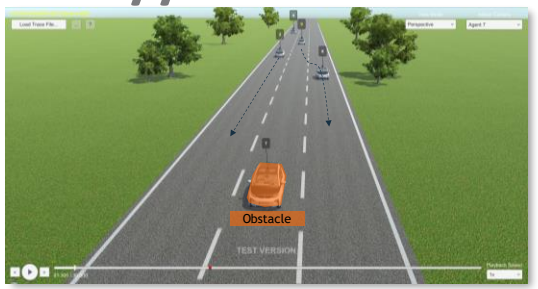
In-Traffic Behaviour Assessment //



// Real-traffic

// Test track

// Simulations



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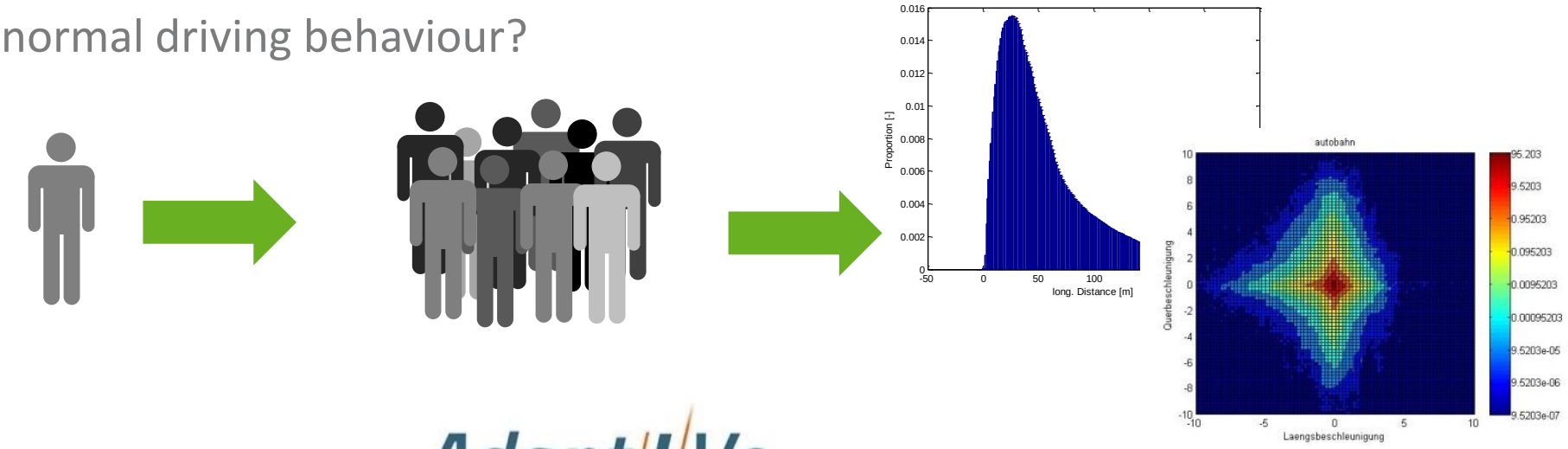
Adapt!Ve

Baseline for Assessment of Automated Driving

- Description of the baseline for the evaluation
  - Objectives of automated driving functions
    - Objective is a collision free traffic
    - Operation in mixed traffic conditions (→ not disturbing normal traffic)

    →The functions have to be operated within range of normal driver behaviour

  - What is normal driving behaviour?



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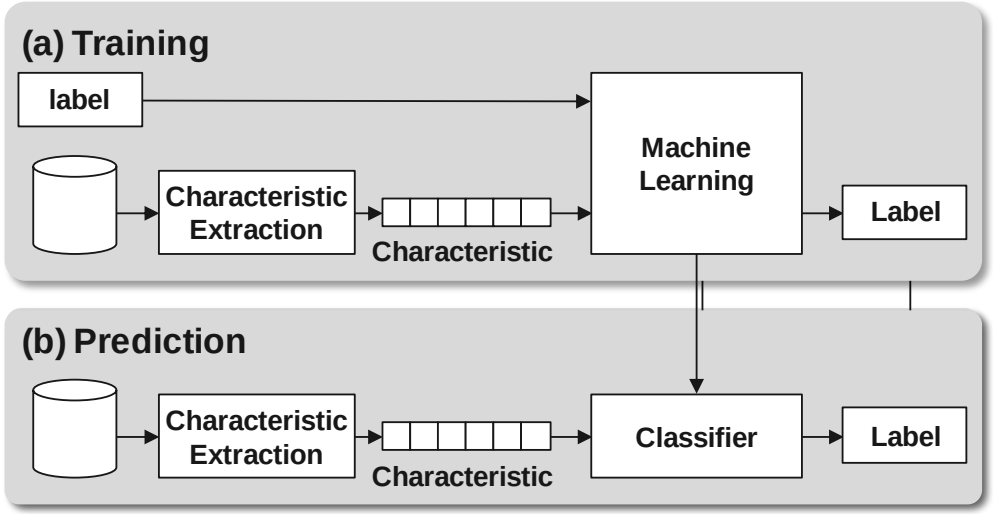
Adapt!/Ve

March 28, 2018

Analysis of Automated Driving Field Test Data
Scenario Classification of Real-World Data

- **Rule-based Clasification**
  Benmimoun (2011)
  - Offline classification
  - Uses decision trees parameterized by hand
  - No easy adaptation, no consideration of time series
- **Machine-learning based Classification**
  Reichel (2010), Roesener (2016)
  - Proficient using of Machine Learning Techniques
  - Partial automated
  - Choice of classifier based on expert knowledge

► Machine learning techniques provide an efficient & automated data clustering



Reichel (2010), Roesener (2016)

Available Literature:

- ika PhD thesis: M. Benmimoun 2015
- Paper @ ITSC 2016: C. Rösener, F. Fahrenkrog, A. Uhlig, L.;
  A Scenario-Based Assessment Approach for Automated Driving by Using Time Series Classification of Human-Driving Behaviour,
  ITSC 2016, Brasilia, 01.11.2016 - 04.11.2016

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Testing Automated Driving in Field Tests
Scenario-based Assessment of Automated Driving

Data Source

Demonstrator Function

Reference: FOT

Classification of Scenarios

Classification of Scenarios

Classifier Scenario 1

Classifier Scenario 2

Classifier Scenario x

PIs

Scenario-based Assessment

Assessment

Calculation of:
- Derived Measures
- Performance Indicators

Δ Frequency (Scenario)

Δ Effect (Scenario)

► **Human driving** as a **baseline**

► Classification of scenarios by using **time series classification algorithms (Hidden Markov Models)**

► Assessment of **Δfrequency** and **Δeffect** induced by system in **scenario**

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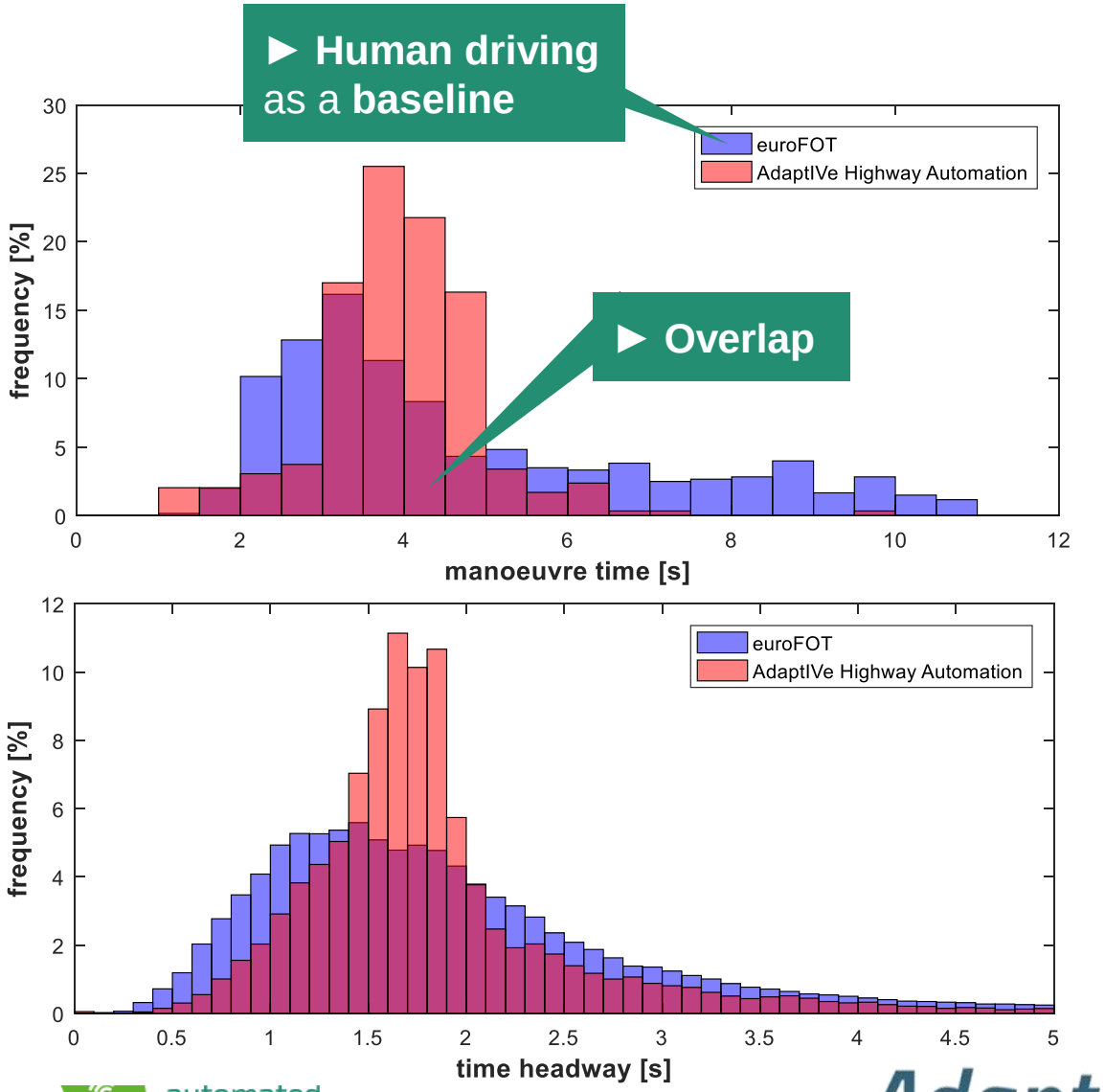
AdaptIVe

Technical Assessment – Example Results for Highway



The **AdaptIVe Highway-Chauffeur is** showing a **control capability similar to human driving** from euroFOT. Two results stand out:

- Top figure: **duration** of **lane change** is much **more uniform** with automation
- Bottom figure: **time headway** in **vehicle following** shows **much less variability** with automation

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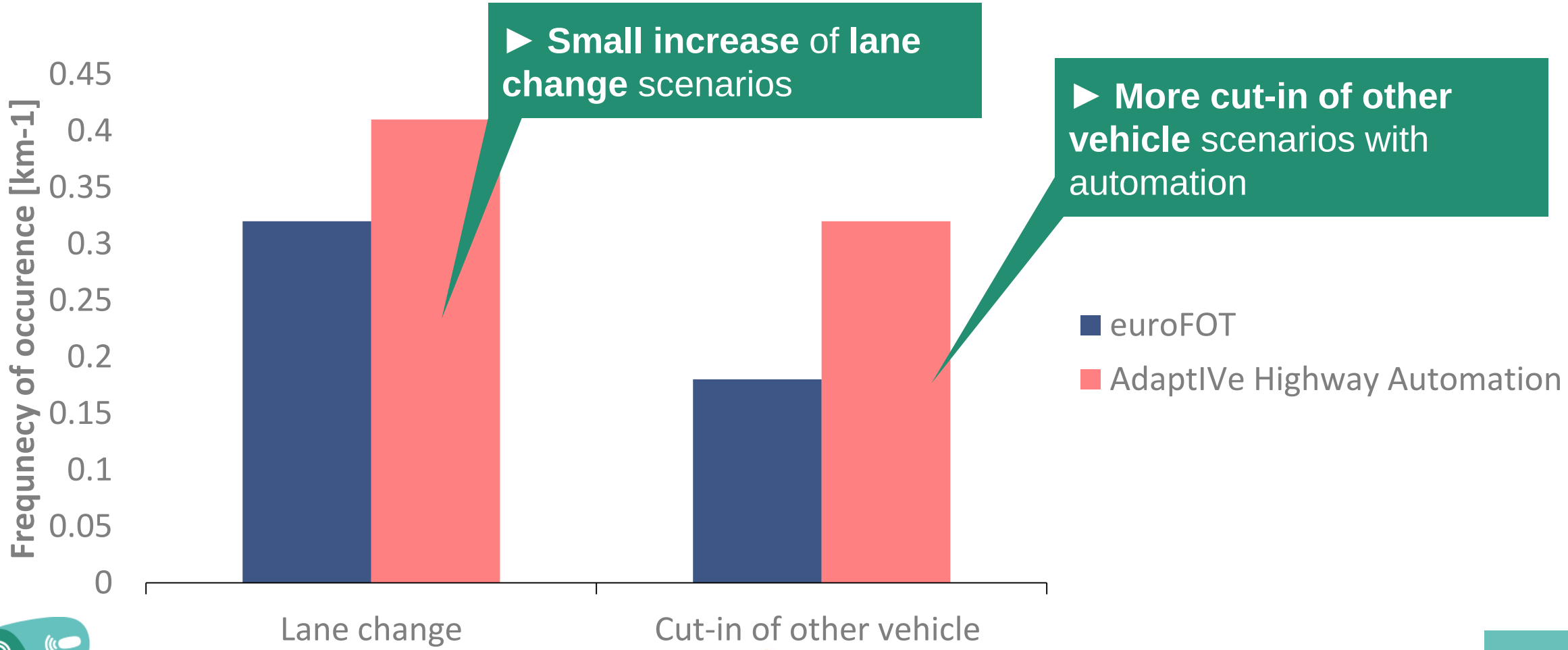
AdaptIVe

Application of Method – Frequencies for Highway



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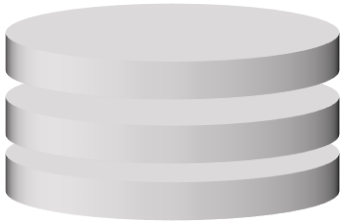
AdaptIVe

Safety Impact Assessment - Methodology



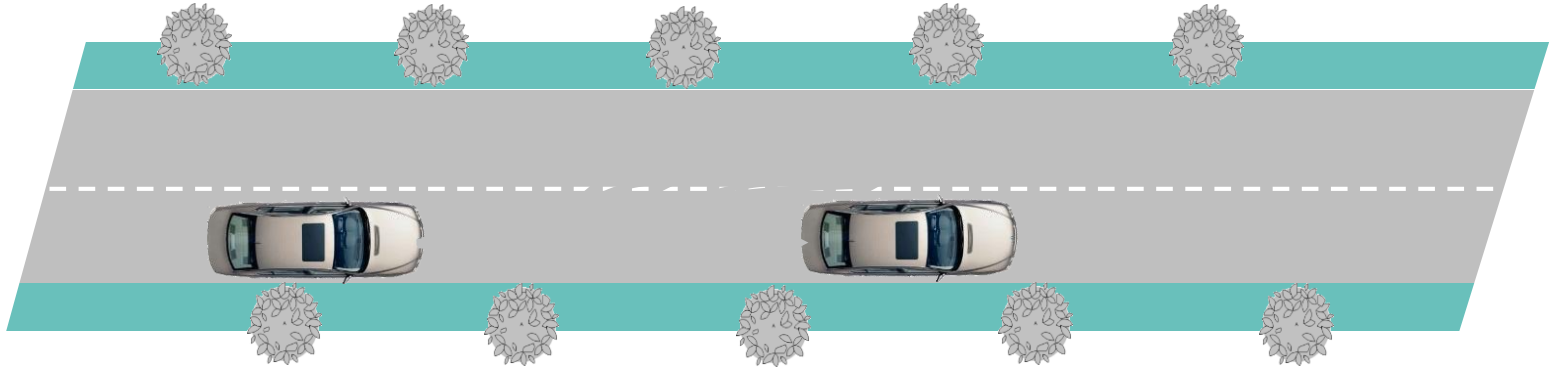
Accident data (e.g. GIDAS) / Critical situations (FOT)

Description of function

Simulation of traffic scenarios

Top-Scenario

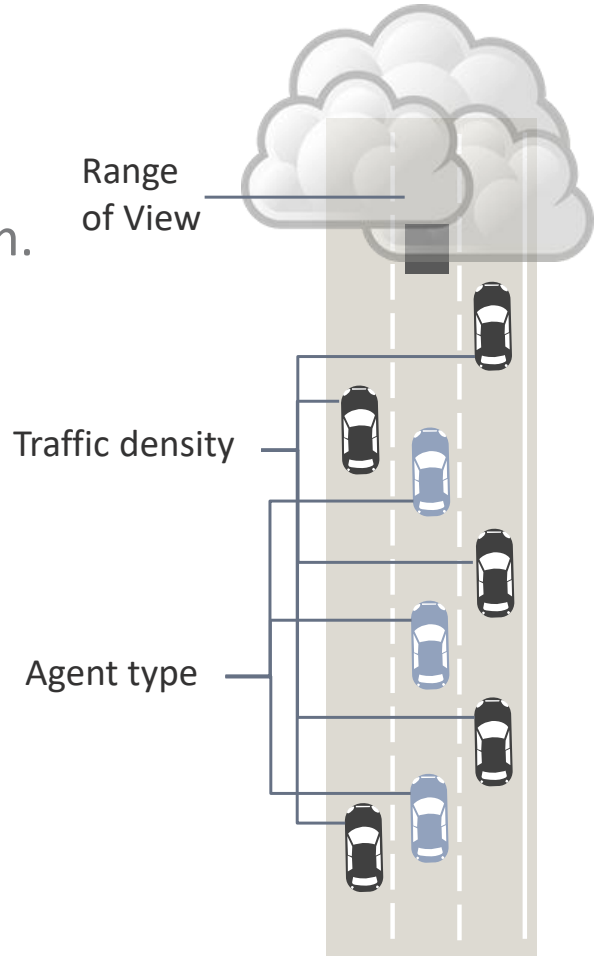
Simulation of driving scenarios



Safety Impact Assessment – Example Obstacle in Lane

Setup of the scenario:

- Three lane motorway of length of 4 km
- The obstacle is placed in the central driving lane at a position of s_x = 350 m. Positon can be adjusted via GUI in order to be able to place the obstacle also in a curve
- The surrounding traffic is generated by means of stochastic approaches (start position & characteristics of the driver)
- The first three vehicles that approach the obstacle are considered as the “relevant vehicles”
- The relevant vehicles are either driven by the automated driving function or manually (SCM-driver model)
- Variation of parameters



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Adapt!/Ve

Safety Impact Assessment – Limitation of Study

Aspect that limit the analysis:

- Situations (→ transition of control) with potential negative effects are not considered
- Effects along the penetration rate are not considered, however will limit the overall effect
- Usage is not considered → function is not necessarily used although it is available
- Available data → currently, the relevant and available data set (detailed accident data & NDS and FOT data) is quite limited

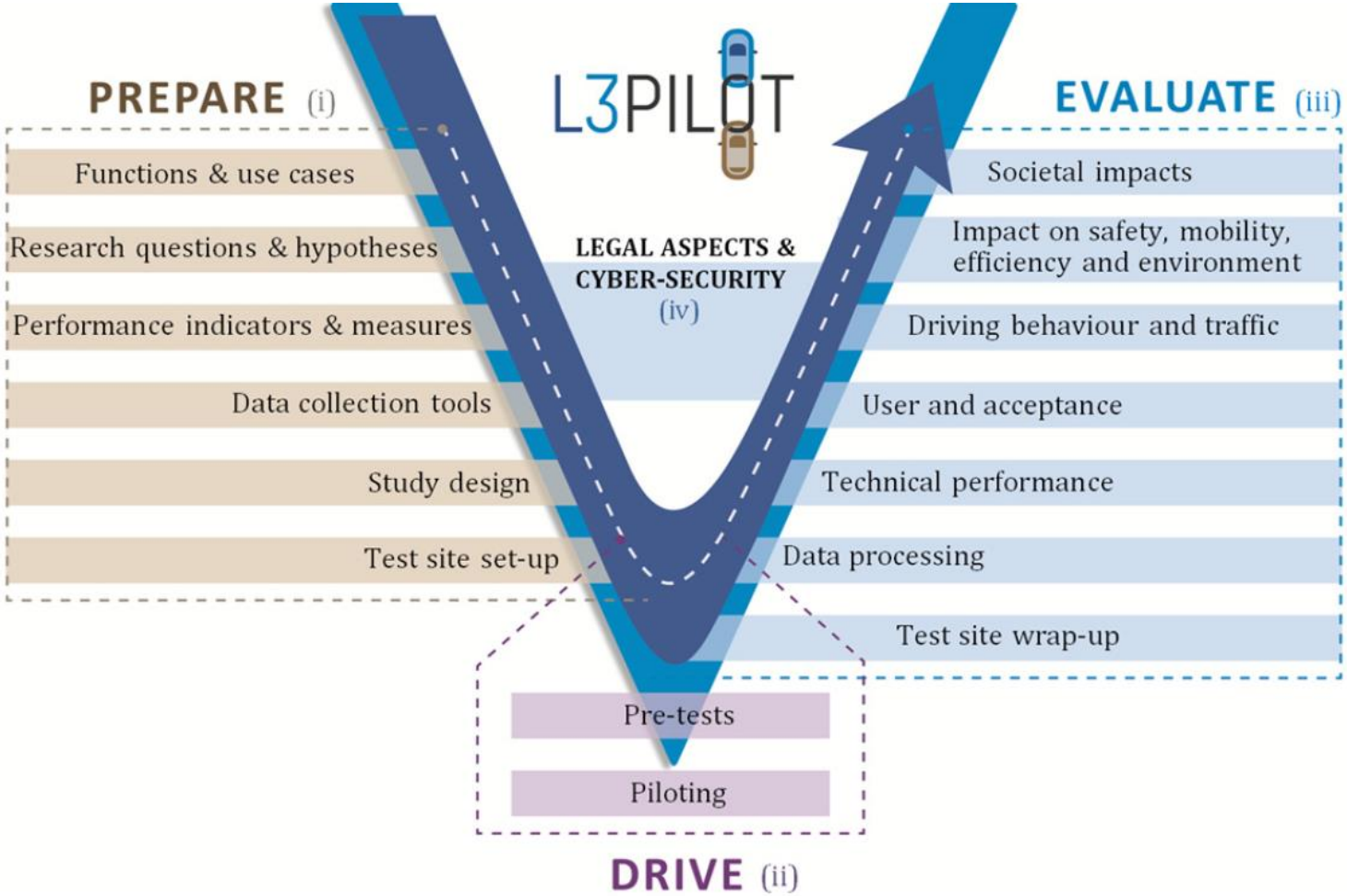
Outlook to safety impact assessment methodology for the ongoing L3Pilot project

Adrian Zlocki/ika

Piloting Automated Driving on European Roads
L3Pilot – Real World Data for Impact Assessment

- Large-scale Level 3 piloting
- 1,000 test drivers,100 vehicles in 11 European countries
- EC funded in Horizon 2020
- 34 partner
- Budget: 68 € Mio., Funding: 36 € Mio.

- Website: **http://www.l3pilot.eu**



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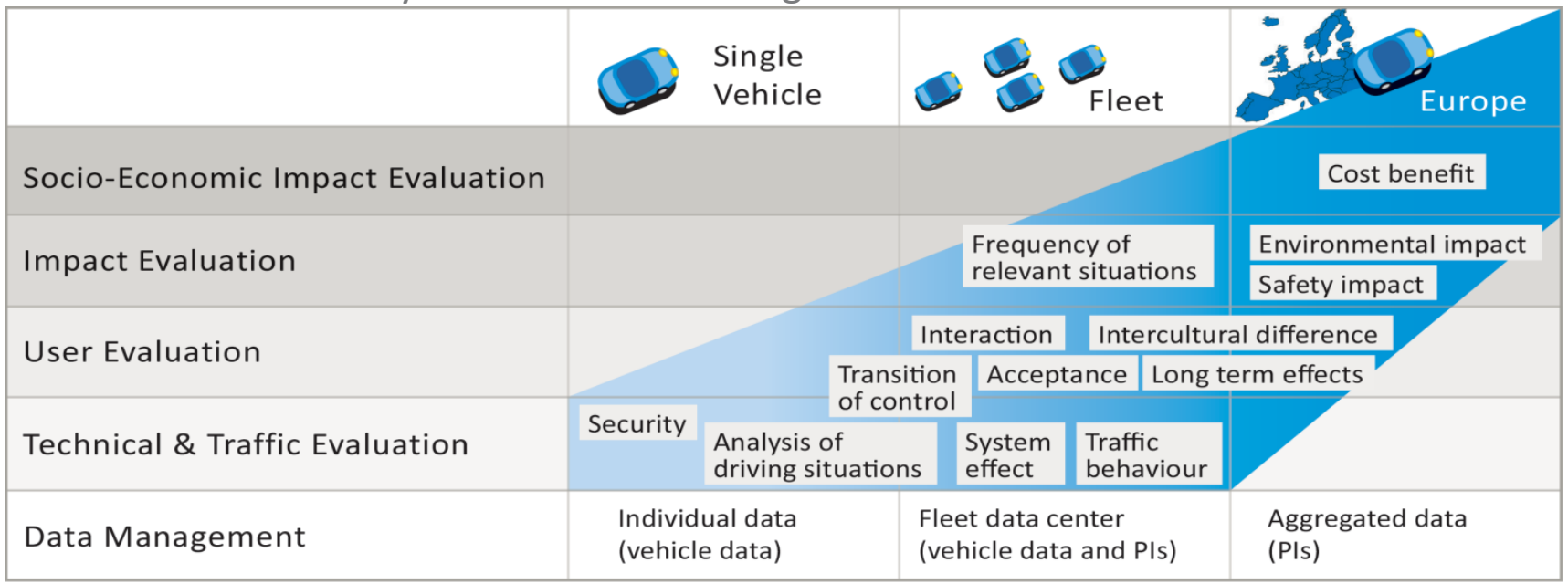
L3Pilot SP “Evaluation”
Impact Assessment is Evaluation Scope

- Objectives:
  - Overall evaluation of automated driving function with respect to the influence on technical, user & acceptance and driving & travel behavior aspects.
  - Assessment of long-term effects of automated driving on user attitudes and acceptance.
  - Investigation of interactions between different traffic participants in different automation modes.
  - Assessment of the readiness and reliability of automated driving functions.



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Questions & Answers

Questions & Answers Session

Conclusion: Stay in touch with us

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- **Get involved**: CARTRE builds a diverse expert network across Europe and beyond
  - Revisit the recording of this session and further material: www.connectedautomateddriving.eu/webinars
  - Share your thoughts and opinions on Twitter: @Europe_CAD
  - Subscribe to our newsletter: www.connectedautomateddriving.eu/news
  - Become an associated partner to the project: partnership@connectedautomateddriving.eu

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Thank you!

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CARTRE and SCOUT are funded by the European Union Horizon 2020 Work Programme