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Automated Driving Applications and Technologies for Intelligent Vehicles

A Comprehensive Evaluation Methodology for Automated Driving

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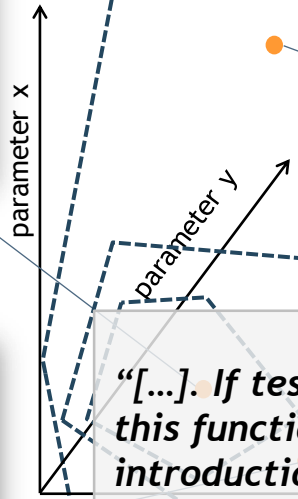
// Bottleneck for the Introduction of Automated Driving?

ACC (*SAE Level 1*)

Source: Audi (2013)

Motorway Automation (*SAE Level 3*)

Source: BMW (2015)



Urban Robot Taxi (*SAE Level 4*)

Source: Google (2015)

"[…]. If testing and assessment methods cannot keep pace with this functional growth, they will become the bottleneck of the introduction of advanced DAS to the market."

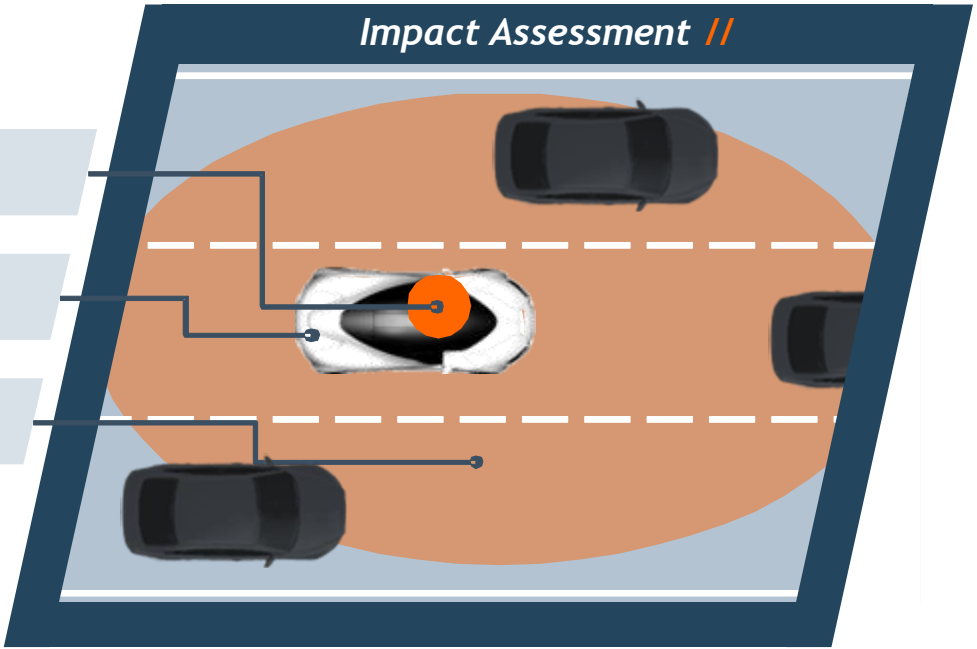
(„Three Decades of Driver Assistance Systems", UNI-DAS, IEEE ITS Magazine, 2014).

// Evaluation of AdaptIVe functions

User-Related Assessment //

Technical Assessment //

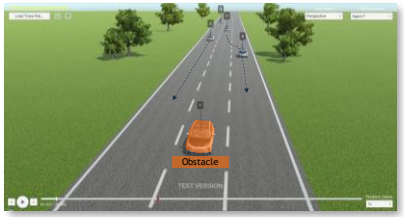
In-Traffic Behaviour Assessment //



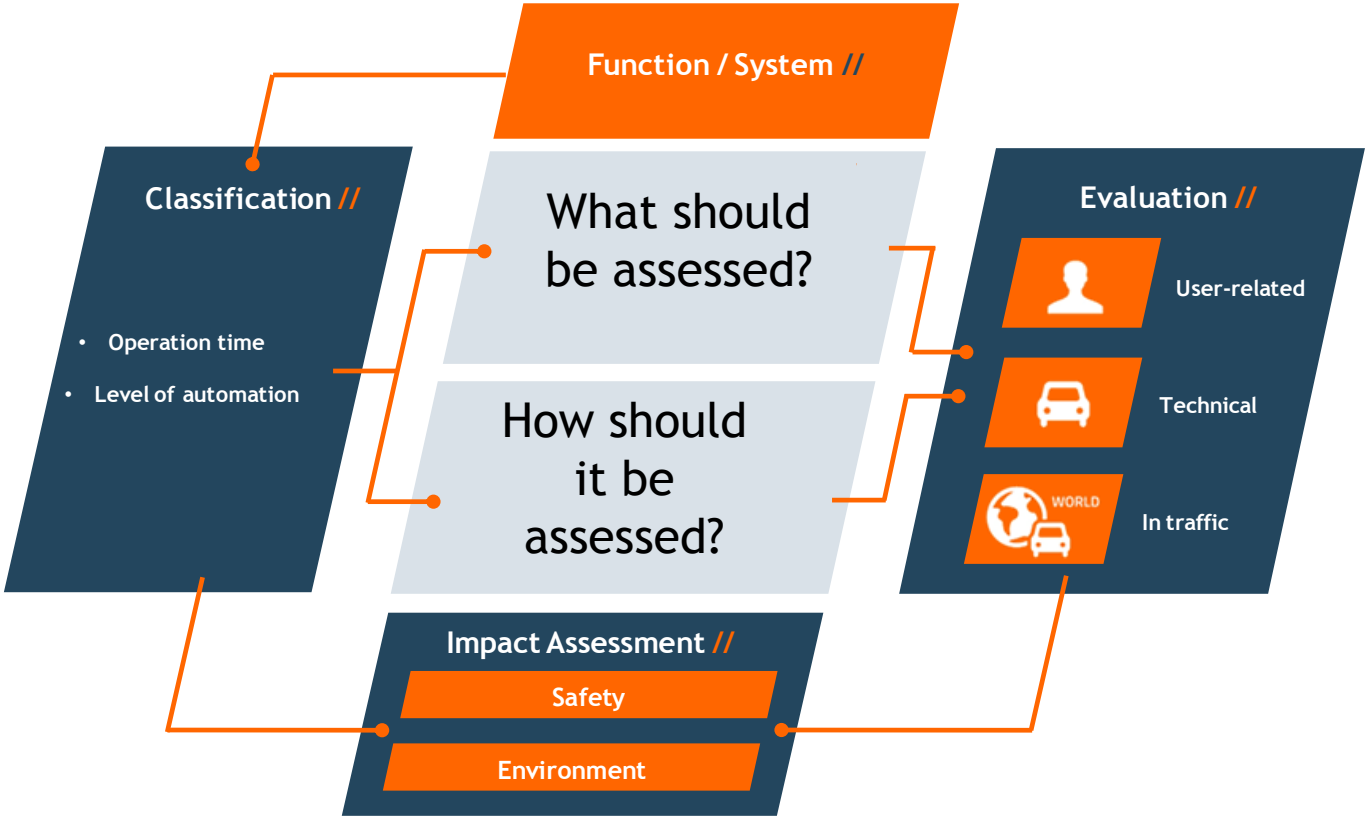
// Real-traffic

// Test track

// Simulations



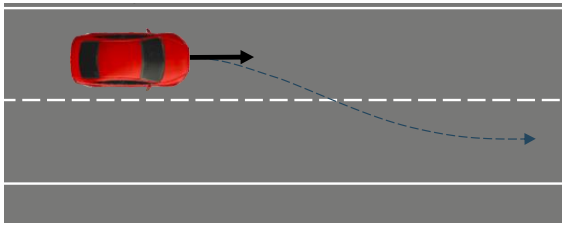
// Evaluation Approach in AdaptIVe



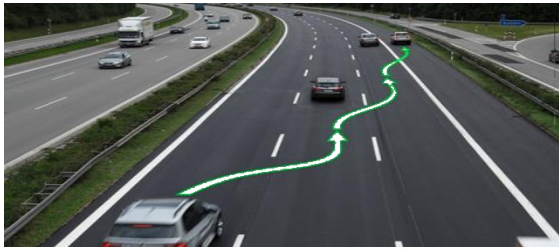
// Definitions for Evaluation

- **Traffic Scenario**: A traffic scenario describes **a larger traffic context**, which includes different (not pre-defined) driving scenarios.

- **Driving Scenario**: A driving scenario is the **abstraction and the general description of a driving situation** without any specification of the parameters of the driving situation.



- **Driving Situation**: A driving situation is **a specific driving manoeuvre** (e.g. a concrete lane change with defined parameters).



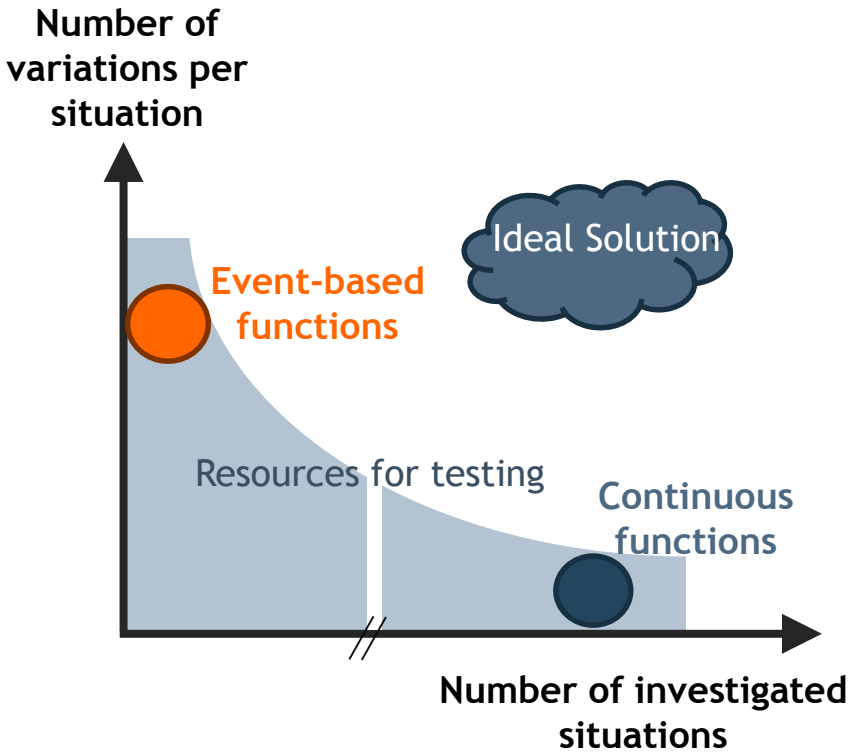
// Classification of Automated Driving Functions

- Classification by operation time:
  - **Event based operating**
    - Function that is only active for a short period in time (typically vehicle stands still at the end or the automated driving ends)
    - Examples: Parking, Minimum Risk Manoeuvres

  - **Continuously operating**
    - Function that is active for a longer period in time (typically vehicle is still moving at the end of an manoeuvre respectively automated driving is continued)
    - Example: Highway Pilot

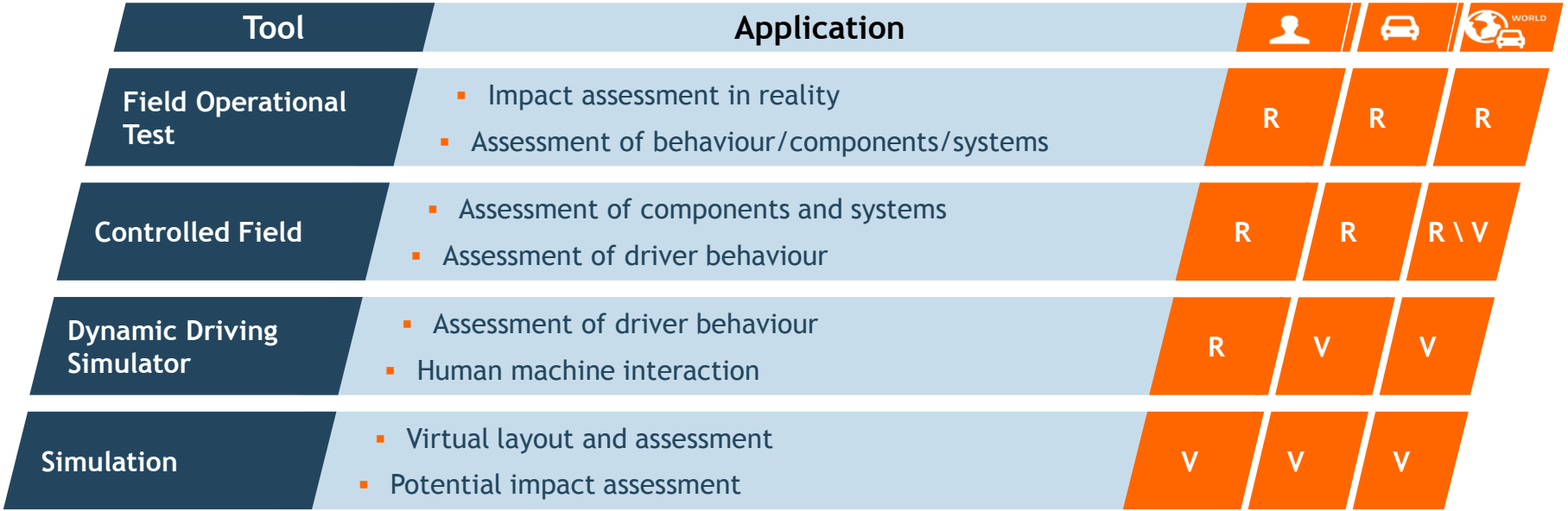
//How to limit the test amount?

- Different approaches for **event-based** and **continuously operation functions:**
  - **Event-based functions:** similar approaches as in previous research project e.g. interactIVe
  - **Continuously operating functions:** small field test on public road in order to assess the function in many different situations



//Evaluation Tools

- Which tool should be applied for which type of assessment?



R: real, V: virtual

// Evaluation Tools in AdaptIVe

- Identification of an appropriate evaluation methodology for the technical, user-related, in-traffic behaviour and impact assessment

Tool	Technical	User-related	In-traffic	Impact			
Field Operational Test	Yes Continously	Yes	(Yes)	No	R	R	R
Controlled Field	Yes Event-based	Yes	No	No	R	R	R \ V
Dynamic Driving Simulator	No	Yes	No	No	R	V	V
Simulation	No	No	Yes	Yes	V	V	V

//Technical Assessment

Event-based//

1. **Defining evaluation scope**
   - Definition of research questions, hypotheses & indicators
2. **Planning of assessment**
   - Analyse system description and adaption of hypotheses
   - Planning of test cases
   - (Risk assessment)
3. **Tests in controlled field**
   - Number of test variations
   - Logging of test data
4. **Assessment of tests**
   - Analysis of hypotheses based on test data & indicators

Continuous//

1. **Defining evaluation scope**
   - Definition of research questions, hypotheses & indicators
2. **Planning of assessment**
   - Analyse system description and adaption of hypotheses
   - Planning of test cases and test route
   - Definition evaluation criteria (distributions & boundaries)
   - Risk assessment
3. **Pre-/component tests in controlled field**
   - Basic tests of functionality
   - Sensor tests
4. **Tests in real traffic**
   - Test route and test amount to be determined
5. **Assessment of tests**
   - Analysis of hypotheses based on test data & indicators

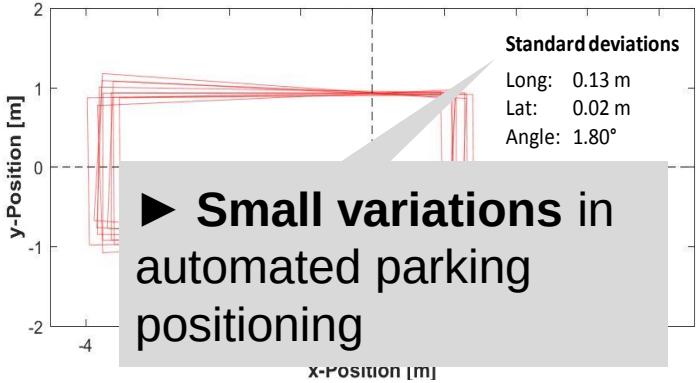
// Technical Assessment
Event-based

// Technical Assessment

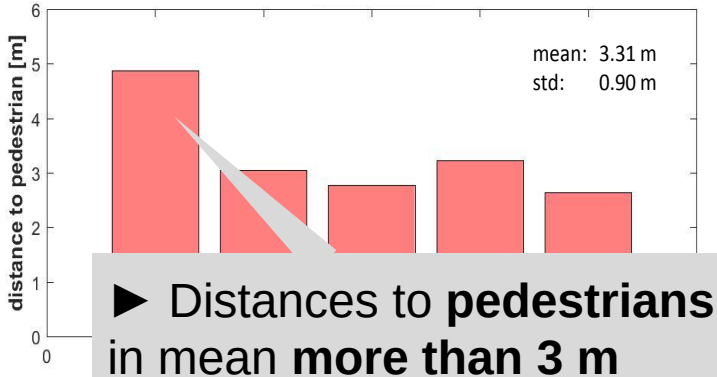
- For assessment of event-based automated driving functions, **classical use-case based testing** was conducted.
- **Five repetitions** per **test case** were conducted.
- Tests executed in a **closed environment.**

// Technical Assessment

- **Close distance functions** can be evaluated by **classical use-case based testing**.
- It turned out that close distance functions are providing **accurate positioning in parking applications**.
- Safe **distances to pedestrians were kept** in all test cases.



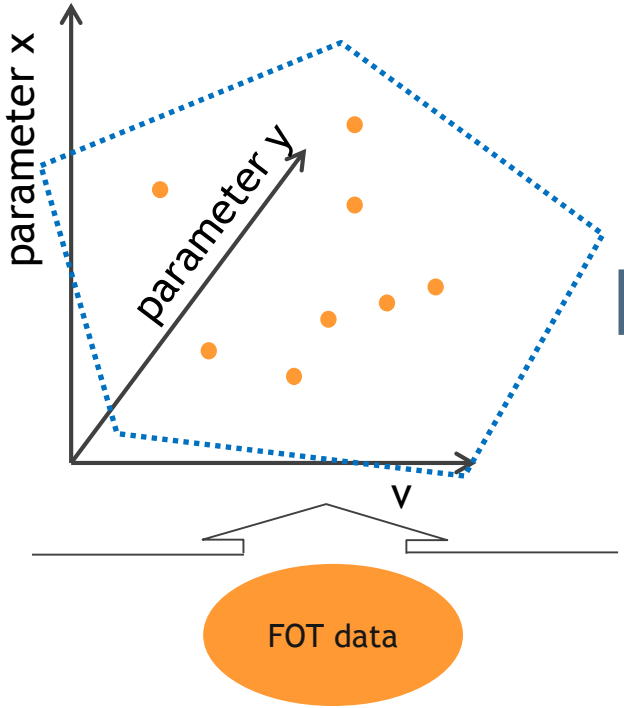
► **Small variations** in automated parking positioning

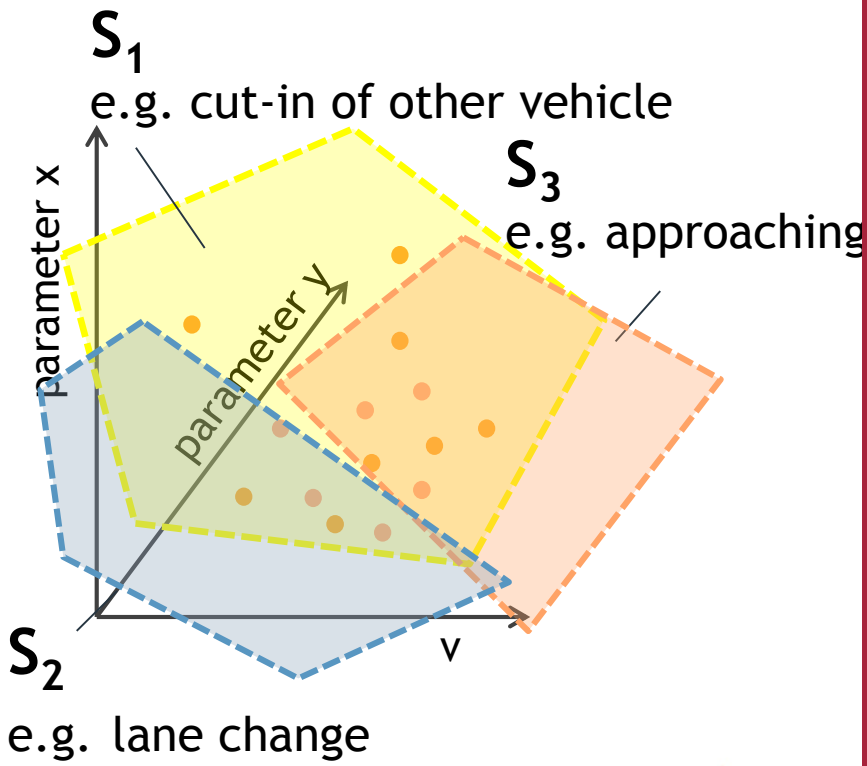


► Distances to **pedestrians** in mean **more than 3 m**

// Technical Assessment
Continuous operating

//Scenario Classification of Real-world data

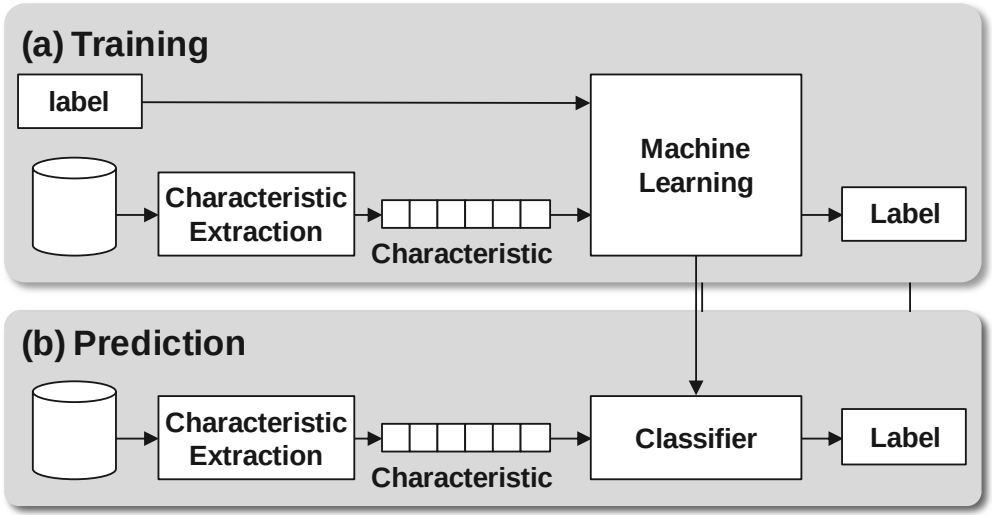




// Scenario Classification of Real-world data

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

▶ **Machine learning techniques provide an efficent & automated data clustering**

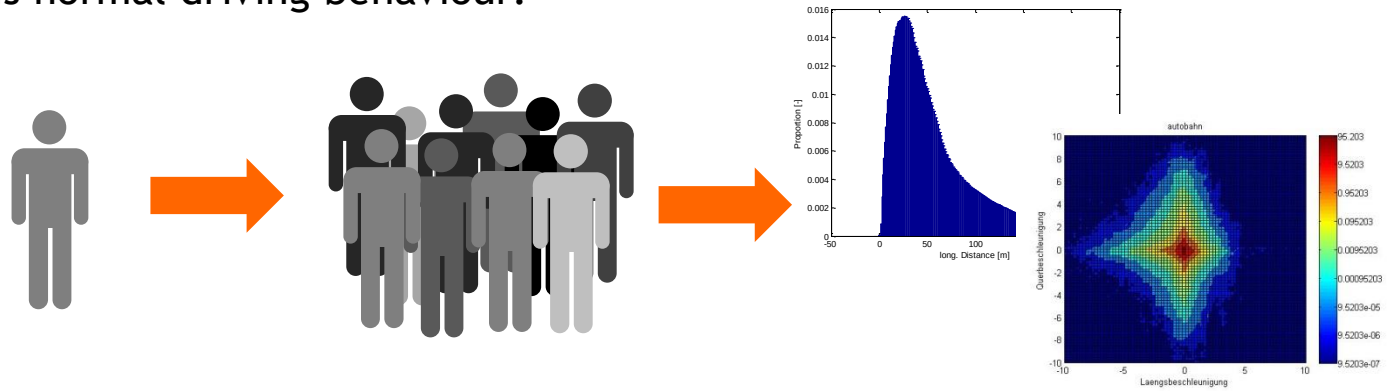


Reichel (2010), Roesener (2016)

// Baseline for Assessment of Automated Driving

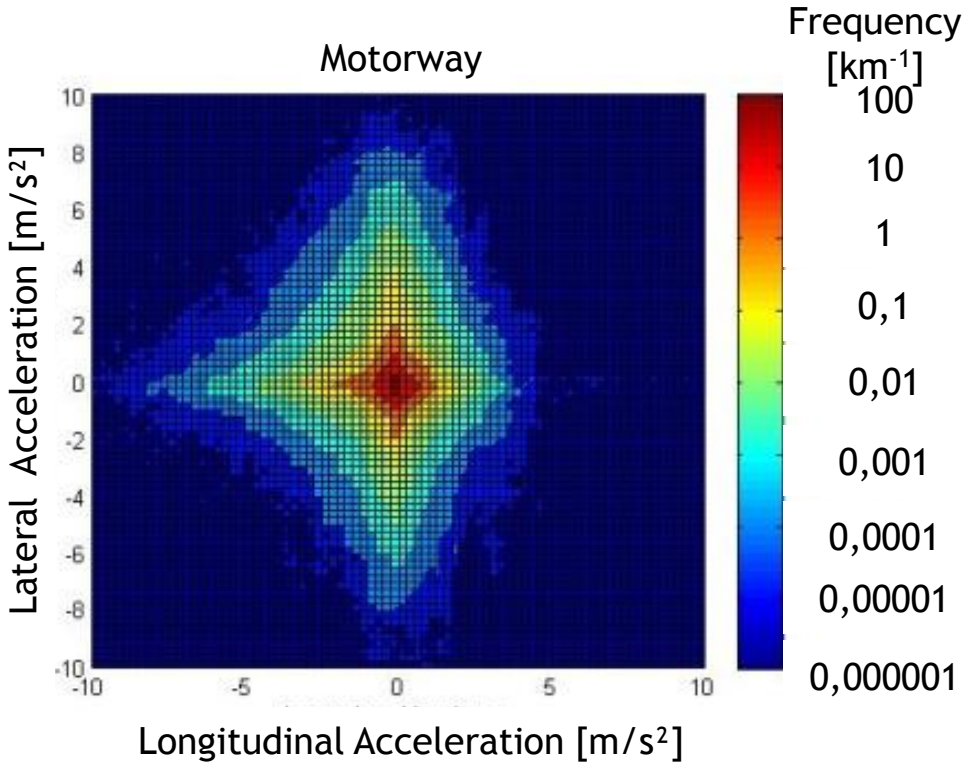
- Description of the baseline for the evaluation
  - Objectives of automated driving functions
    - Objective is a collision free traffic
    - Operation in mixed traffic conditions (→ not disturbing normal traffic)

    → The functions have to be operated within range of normal driver behaviour
  - What is normal driving behaviour?



// Baseline for Assessment of Automated Driving

- Analysis of **euroFOT data**
- Plot displayed: Acceleration during normal driving
- Data from 98 vehicles
- Motorway, rural roads and urban roads



//Scenario-based Assessment of Automated Driving

Data Source//

AdaptIVe demonstrator

Reference: euroFOT

► **Human driving** as a **baseline**

Classification of Scenarios//

Classifier Scenario 1

Classifier Scenario 2

Classifier Scenario x

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

PIs

Scenario-based Assessment//

Assessment//

Calculation of:

- Derived Measures
- Performance Indicators

Δ Frequency (Scenario)

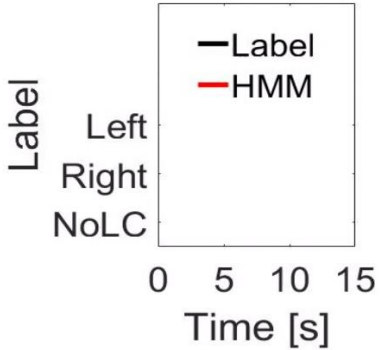
Δ Effect (Scenario)

► Assessment of Δ**frequency** and Δ**effect** induced by system in **scenario**

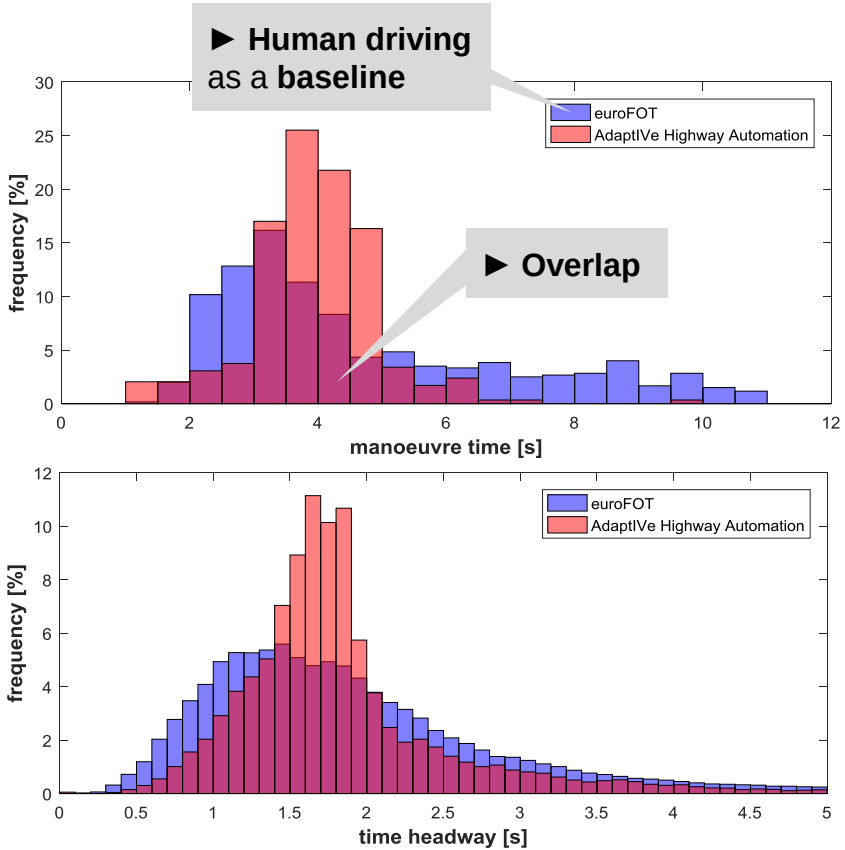
// Scenario Classification – Scenario „Lane Change“

Scenario:

No Lane Change, 99.8%



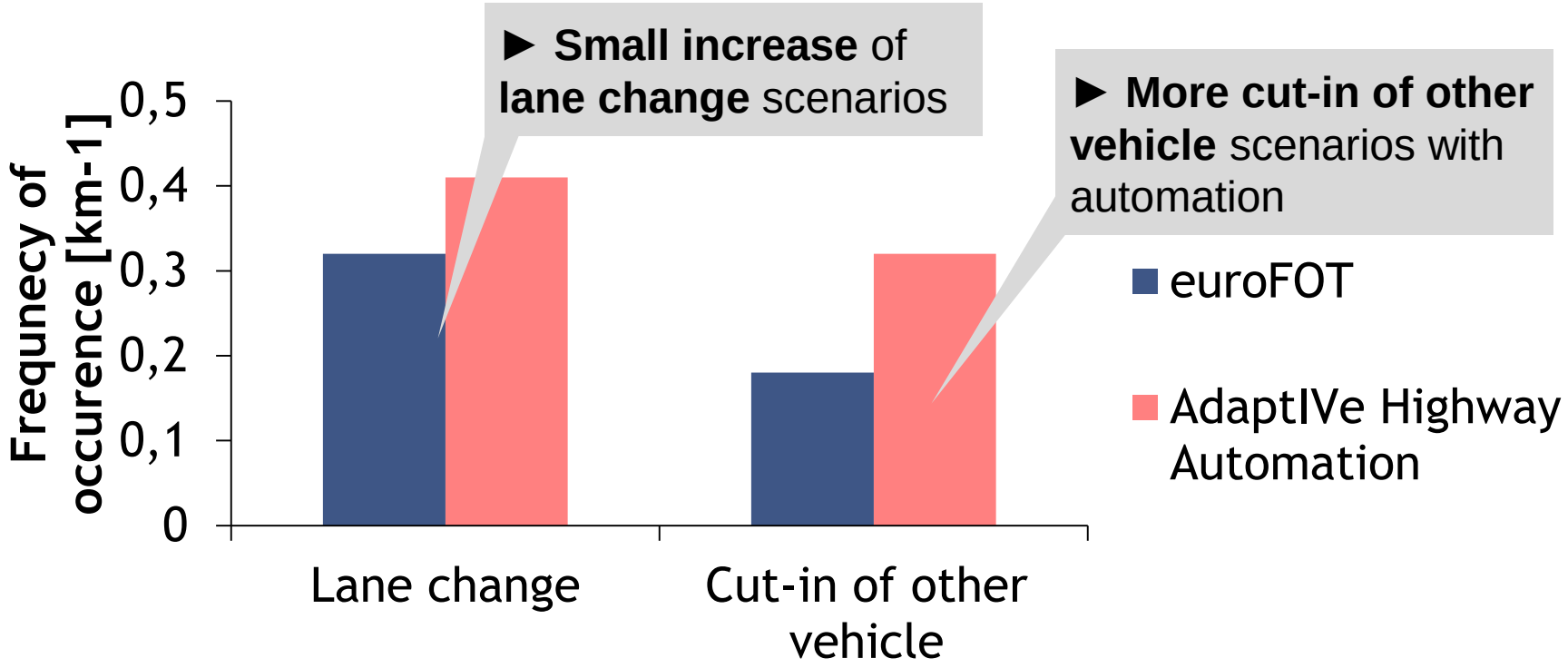
// Technical Assessment - Results



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

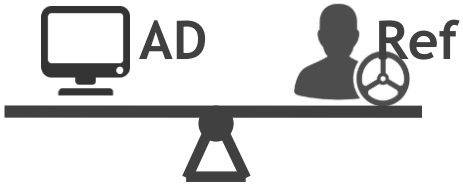
- Top figure: **duration** of **lane change** is much **more uniform** with automation
- Bottom figure: **time headway** in **vehicle following** shows **much less variability** with automation

// Application of Method – Frequencies



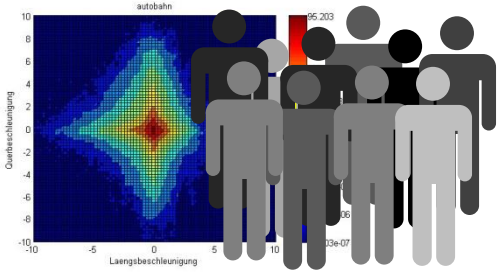
//Summary

- The **baseline** for assessment of automated driving should be **human driving behaviour**



- Automated driving functions **are showing less variability in driving behaviour** (headway keeping, lane changing) **compared to human driving.**

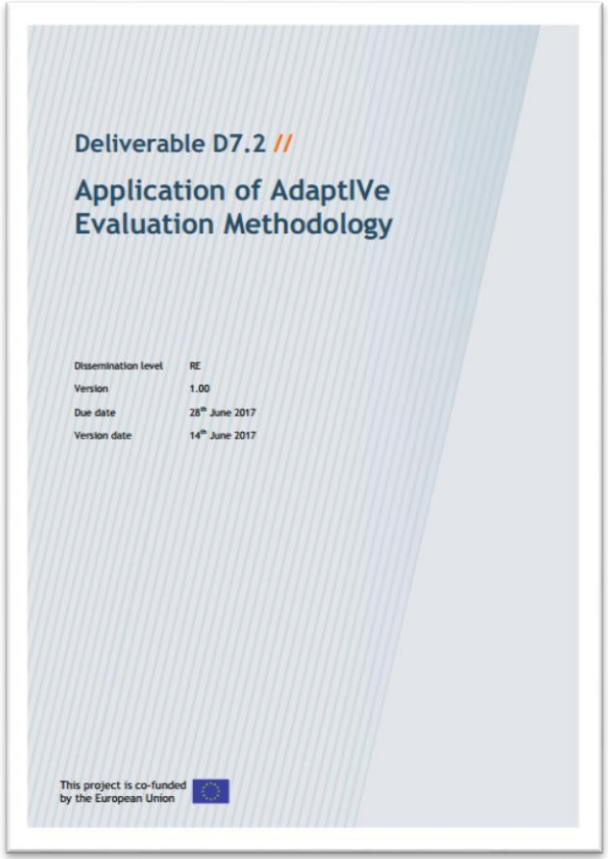
- Automated driving is leading to a **change in frequency of occurence of relevant scenarios** due a **different driving behaviour compared to humans.**



// Deliverable D7.2

- Methodology and Results are provided in Deliverable D7.2 „Application of AdaptIVe Evaluation Methodology“

- Many thanks to all, who have contributed to the assessments:
  - András Várhélyi, Erwin de Gelder, Jan Sauerbier, Felix Fahrenkrog and Pablo Mejuto



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Automated Driving Applications and Technologies for Intelligent Vehicles

Thank you.

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