



# Functional Testing of Automated Driving on Highways

Methodology and Test-Case Identification on the way towards approval

Holger Znamiec, TU Braunschweig – Institute of Automotive Engineering

Gefördert durch:



Bundesministerium  
für Wirtschaft  
und Energie

aufgrund eines Beschlusses  
des Deutschen Bundestages

# Agenda

INTRODUCTION

METHODOLOGY

TERMINOLOGY AND TEST-CASE IDENTIFICATION

TOOLS FOR TEST EXECUTION

RESULTS AND SUMMARY

# Agenda

INTRODUCTION

METHODOLOGY

TERMINOLOGY AND TEST-CASE IDENTIFICATION

TOOLS FOR TEST EXECUTION

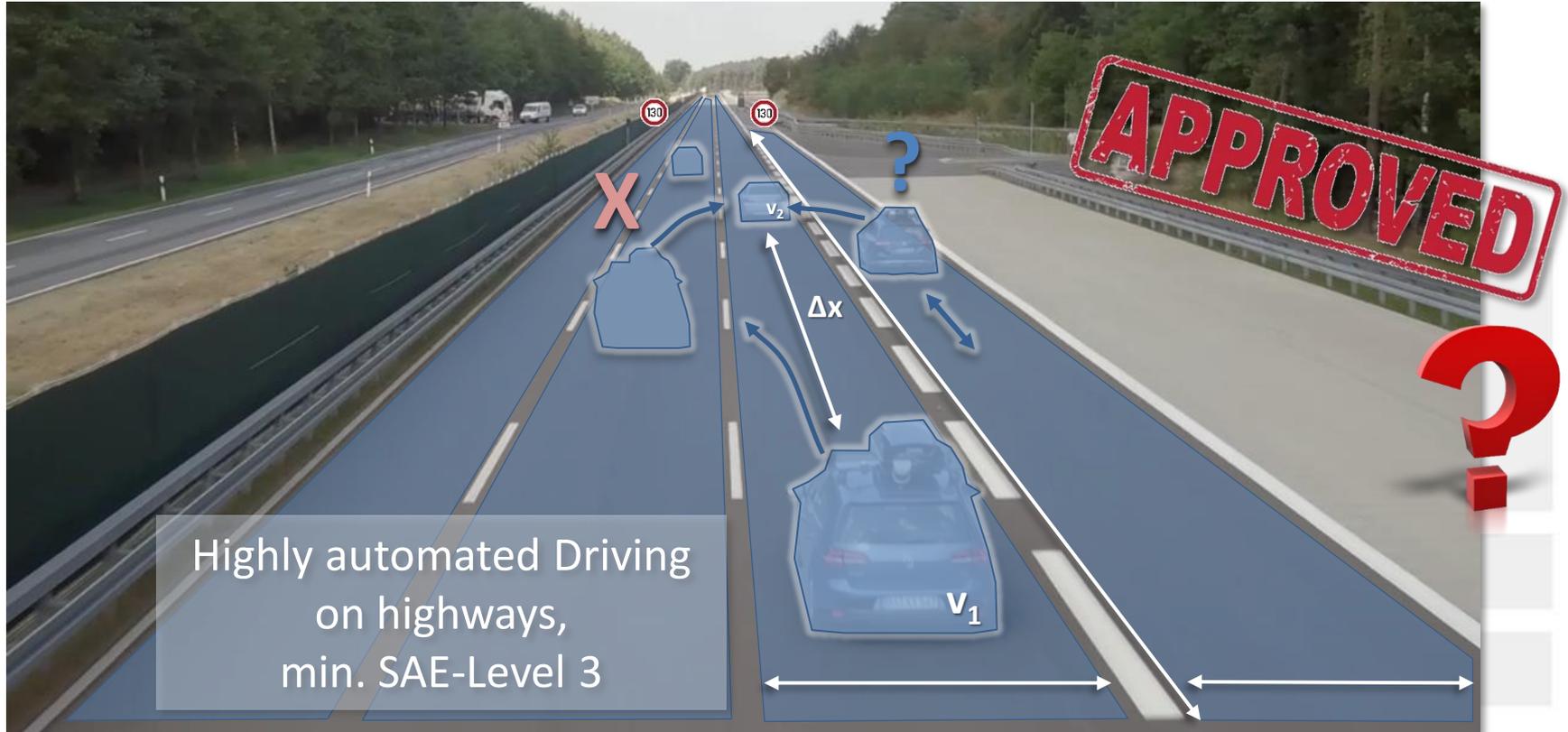
SUMMARY



# Introduction



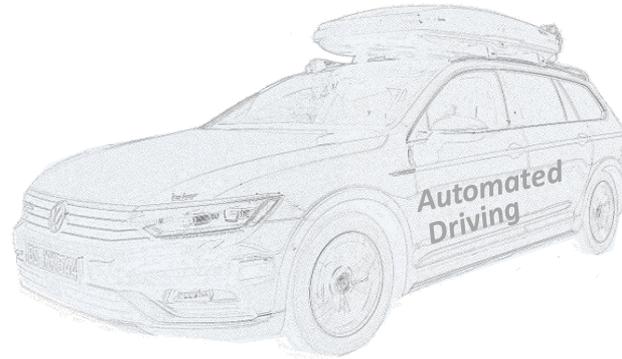
# Challenges of Testing



# Objective

Highly automated Driving  
on highways,  
min. SAE-Level 3

addresses  
multidimensional  
environmental  
parameterspace



- Definition of **relevant parameters**
- Identification of **representative parameter specifications**
- Requirements on **Test Process**  
(Test Environments, Execution, Efficiency,...)

**Qualification of the System in representative Test-Cases**

# Agenda

INTRODUCTION

**METHODOLOGY**

TERMINOLOGY AND TEST-CASE IDENTIFICATION

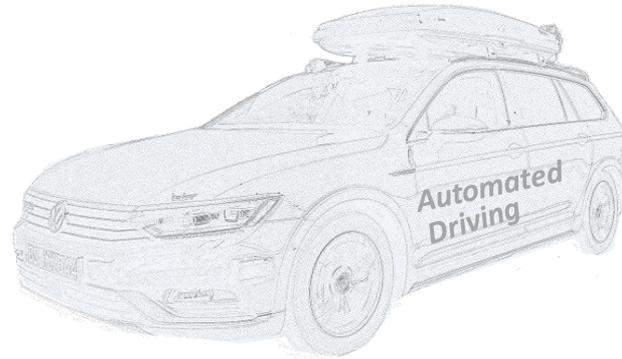
TOOLS FOR TEST EXECUTION

SUMMARY

# Approach

highly automated Driving  
on highways,  
min. SAE-Level 3

addresses  
multidimensional  
environmental  
parameterspace

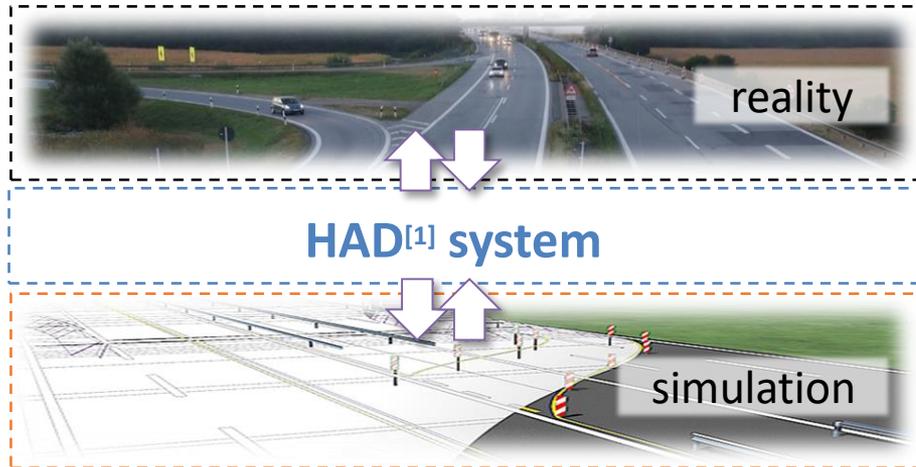


- Definition of **relevant parameters**
- Identification of **representative parameter specifications**
- Requirements on **Test Process**  
(Test Environments, Execution, Efficiency,...)

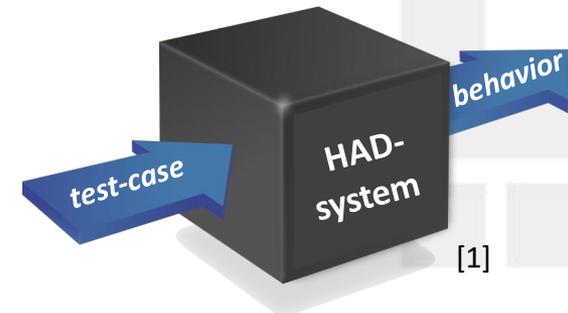
**Qualification of the System in representative Test-Cases**

## Qualification of the System in representative Test-Cases

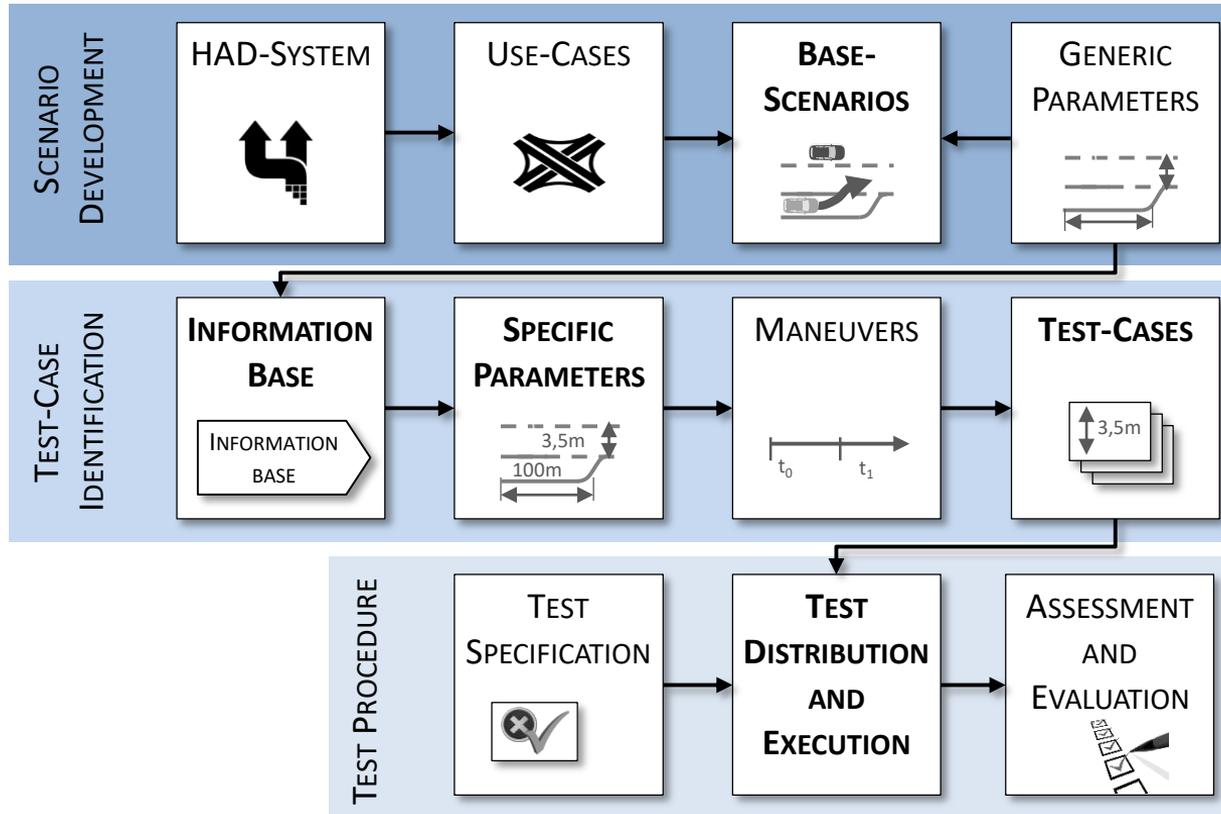
### I.) Scenario-Based Testing



### II.) Black-Box-Testing



# Overall Methodology



# Agenda

INTRODUCTION

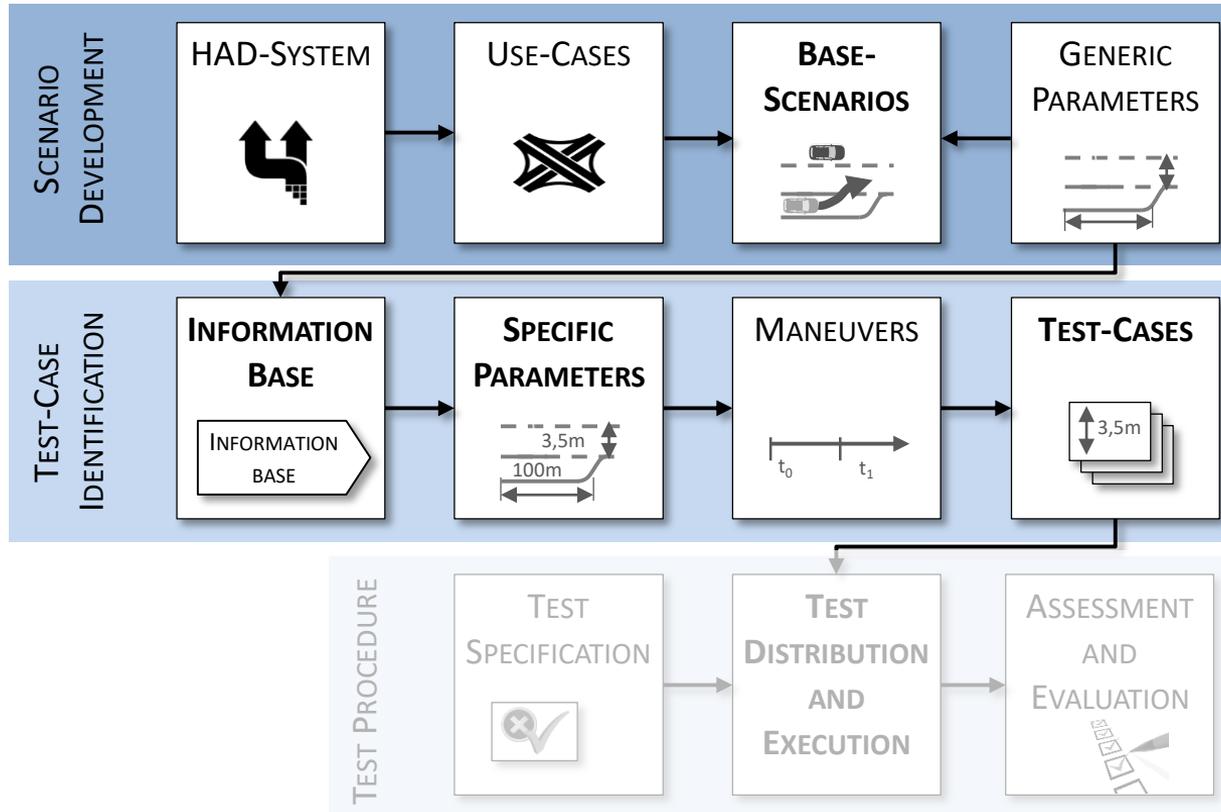
METHODOLOGY

**TERMINOLOGY AND TEST-CASE IDENTIFICATION**

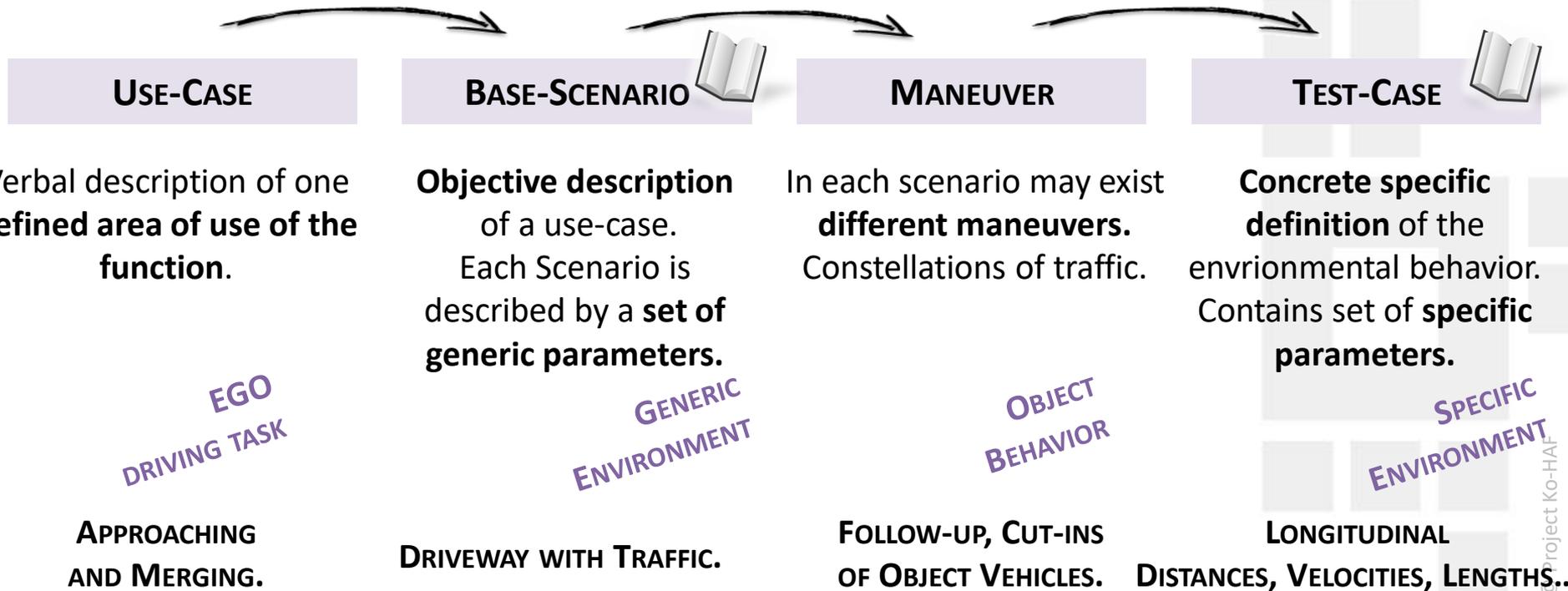
TOOLS FOR TEST EXECUTION

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# Terminology and Test-Case Identification



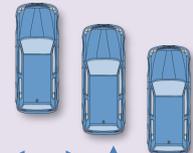
# Terminology



# Scenario Description

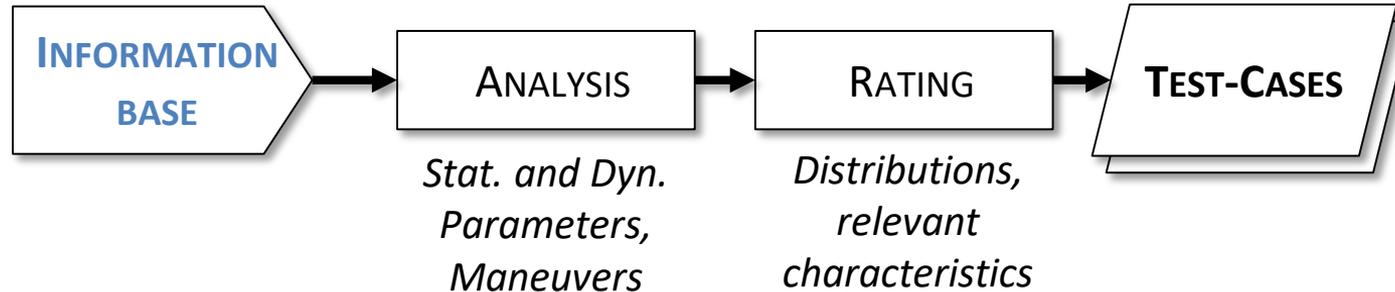
Scenario Catalog



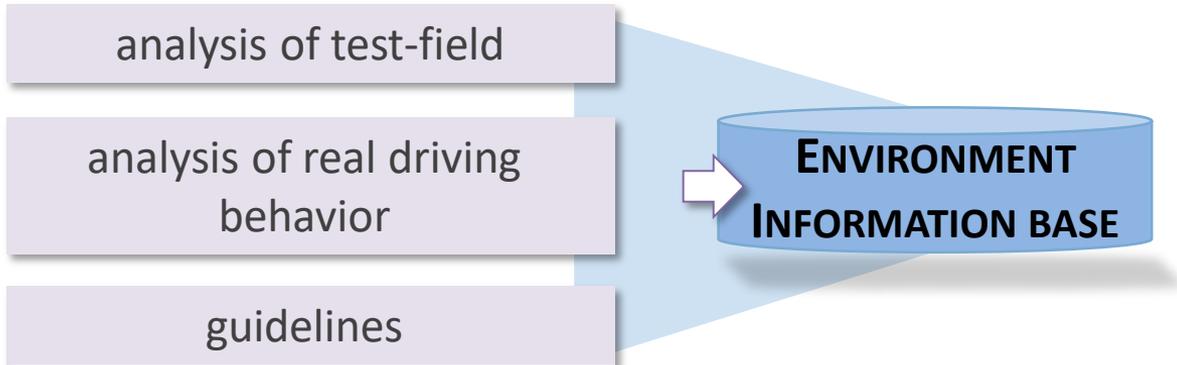
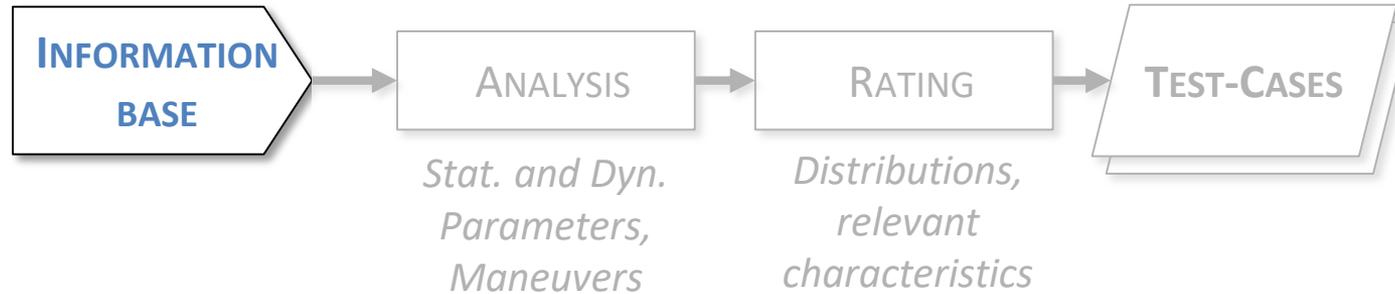
Base-Scenarios	Scenery elements	maneuvers	dynamic parameters	static Parameters
<i>driveway</i>	ramps		traffic:	accl.-lane:
<i>exit</i>	accl. lane			
<i>intersections</i>	driving lanes		...	...
<i>constructions</i>	merging lanes		...	...
<i>Hazard. zones</i>	...	...	...	...

# Test-Case Identification

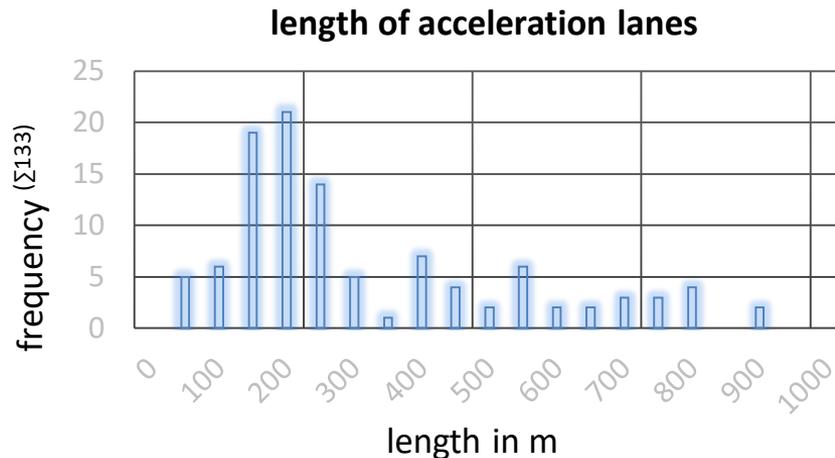
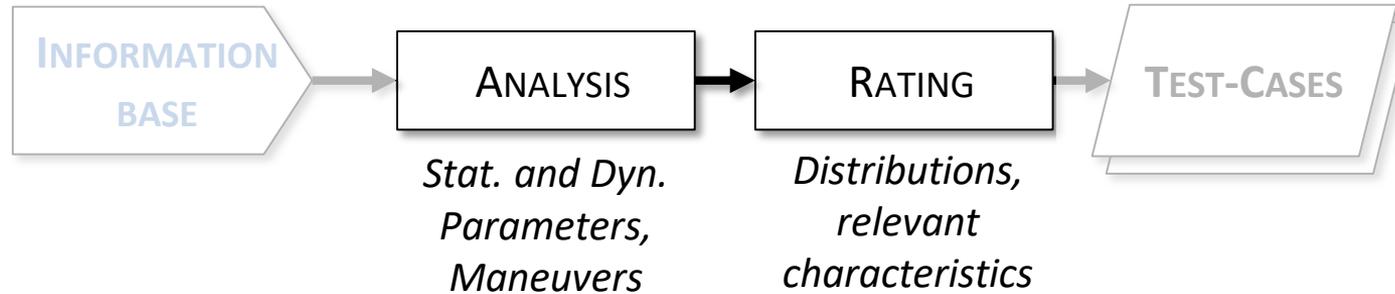
- Developed process for the specification of representative
- Test-cases towards approval of HAD-systems
- Extract the relevant specifications from different information bases



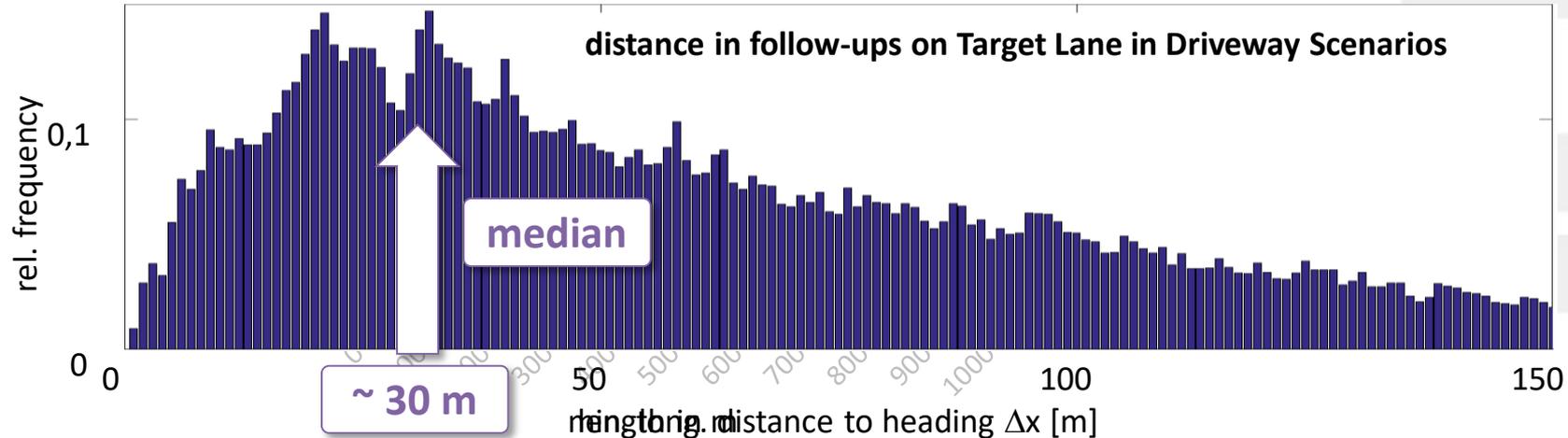
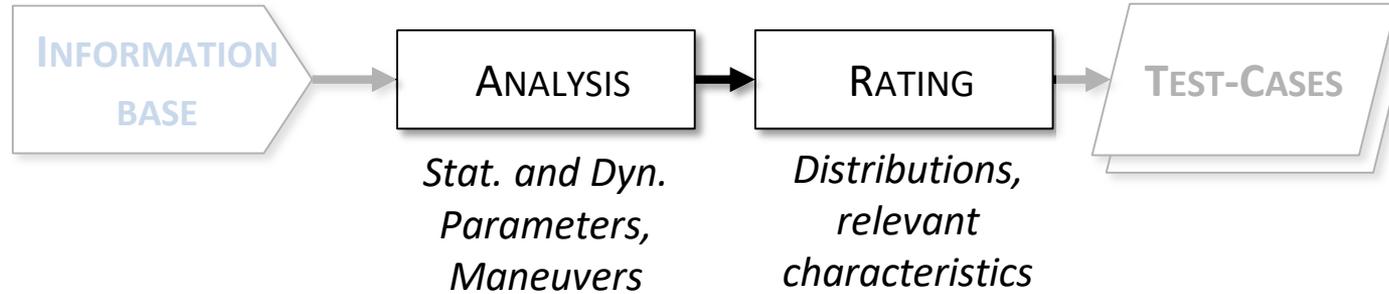
# Test-Case Identification



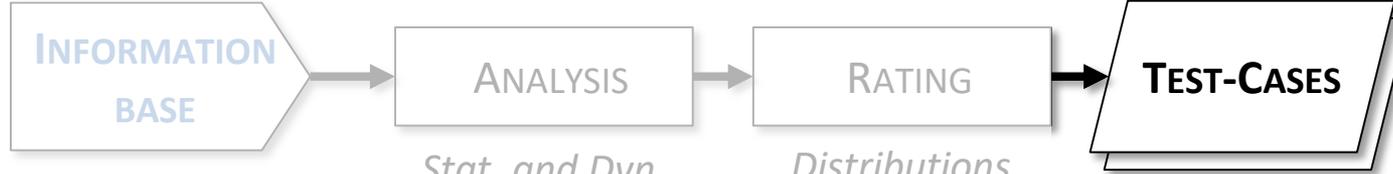
# Test-Case Identification



# Test-Case Identification



# Test-Case Identification



*Stat. and Dyn.  
Parameters,  
Maneuvers*

*Distributions,*

Analysis of all  
**function-relevant  
environmental parameters**



**Test-Case Catalog**

AP5 Absicherung - Erprobung und Validierung  
UAP5.2 Testprozedur  
**Testkatalog**

TF-ID	Typ	Rahmenbedingung		Beschreibung	Wert
TK_1.1.3	1.1	Testfall		Auffahrt ohne Vorausfahrenden in ausreichend große Lücke	
TK_1.1.3	1.1.1	Szenarie Element	Rampe		
TK_1.1.3	1.1.2	Szenarie Element	Beschleunigungssteifen		
TK_1.1.3	1.1.3	Szenarie Element	Durchgehender Fahrstreifen		
TK_1.1.3	1.1.4	Szenarie Element	Verkehrsregelung		
TK_1.1.3	1.1.5	Dynamisches Element	Verkehr		
TK_1.1.3	1.1.5.1	Dyn. Rahmenbedingung	Verkehr	Anzahl Targets	2
TK_1.1.3	1.1.5.2	Sequenz	Verkehr	Egofahrzeu	
TK_1.1.3	1.1.5.2.1	Testschritt	Verkehr	Initialwer	Startspur
TK_1.1.3	1.1.5.2.2	Testschritt	Verkehr	Initialwer	Startpunkt
TK_1.1.3	1.1.5.2.3	Testschritt	Verkehr	Initialwer	Funktion
TK_1.1.3	1.1.5.2.4	Testschritt	Verkehr	Initialwer	Geschwindigkeit
TK_1.1.3	1.1.5.2.5	Testschritt	Verkehr	Zielwert	Spurwechsel
TK_1.1.3	1.1.5.2.6	Testschritt	Verkehr	Initialwer	Endpunkt
TK_1.1.3	1.1.5.3	Sequenz	Verkehr	Target 1	
TK_1.1.3	1.1.5.3.1	Testschritt	Verkehr	Target 1	Initialwer
TK_1.1.3	1.1.5.3.2	Testschritt	Verkehr	Target 1	Initialwer
TK_1.1.3	1.1.5.3.3	Testschritt	Verkehr	Target 1	Initialwer
TK_1.1.3	1.1.5.3.4	Testschritt	Verkehr	Target 1	Zustand
TK_1.1.3	1.1.5.4	Sequenz	Verkehr	Target 2	
TK_1.1.3	1.1.5.4.1	Testschritt	Verkehr	Target 2	Initialwer
TK_1.1.3	1.1.5.4.2	Testschritt	Verkehr	Target 2	Initialwer
TK_1.1.3	1.1.5.4.3	Testschritt	Verkehr	Target 2	Initialwer
TK_1.1.3	1.1.5.4.4	Testschritt	Verkehr	Target 2	Zustand

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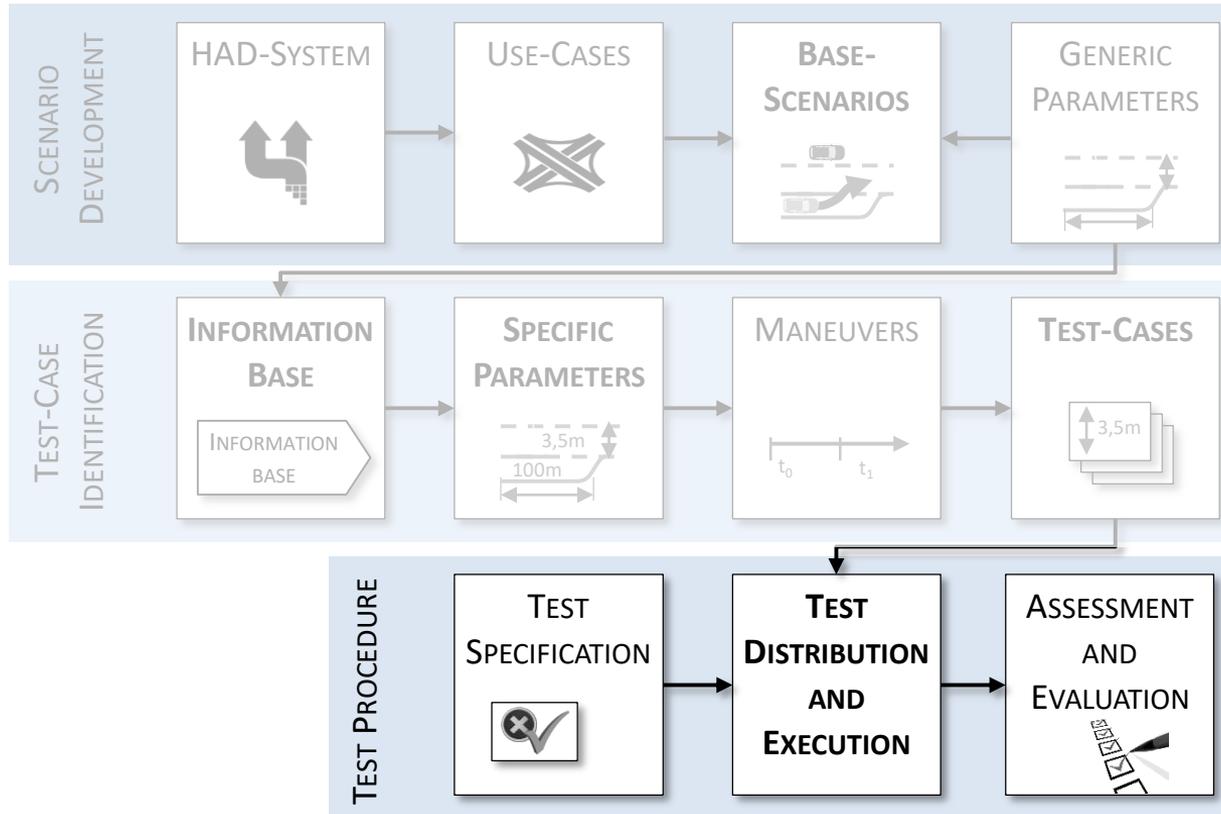
TERMINOLOGY AND TEST-CASE IDENTIFICATION

TOOLS FOR TEST EXECUTION

SUMMARY



# Overall Methodology



# Test-Case Assignment Tool



Test-Case Catalog

TEST-CASES

ASSIGNMENT

SIMULATION-  
FRAMEWORK



PROVING  
GROUND



PUBLIC ROAD,  
TEST FIELD



ASSESSMENT

# Testmanager

## Task:

- **monitoring** of real driven test-cases
- giving **test instructions**
- (**controlling** of object vehicles)
- ... for reproducible test executions

## Maneuvers:

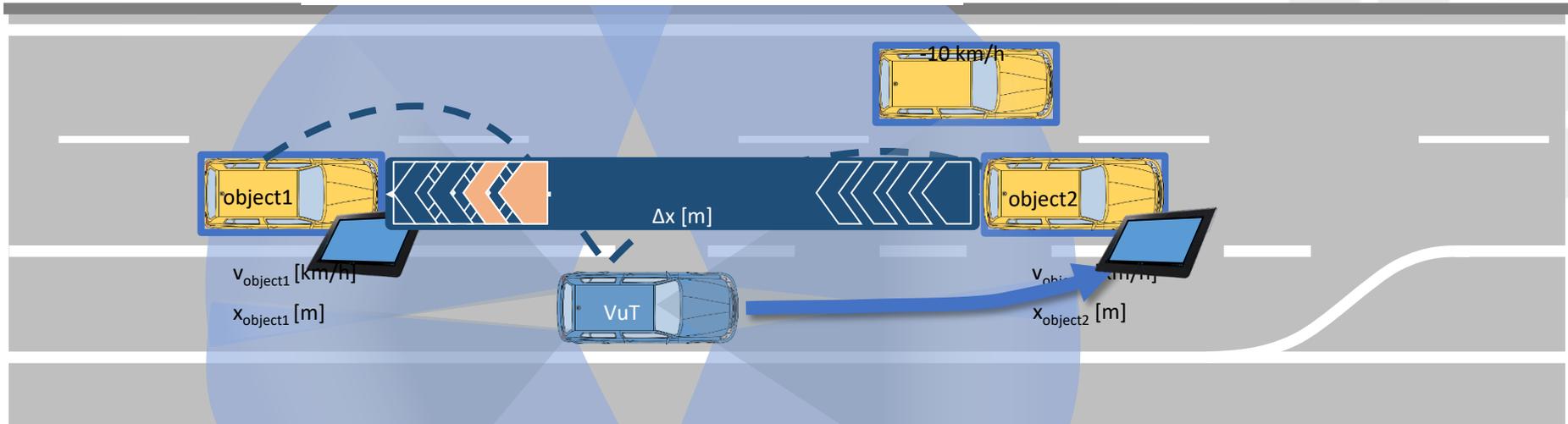
- merging
- lane changes
- overtaking

## Usage:

- proving grounds

instructions

$v_{\text{target, object2}}$  [ reduce speed ! ]



based on **high-precise 360° lidar** sensors,  
**wlan communication**

# Testmanager

## Task:

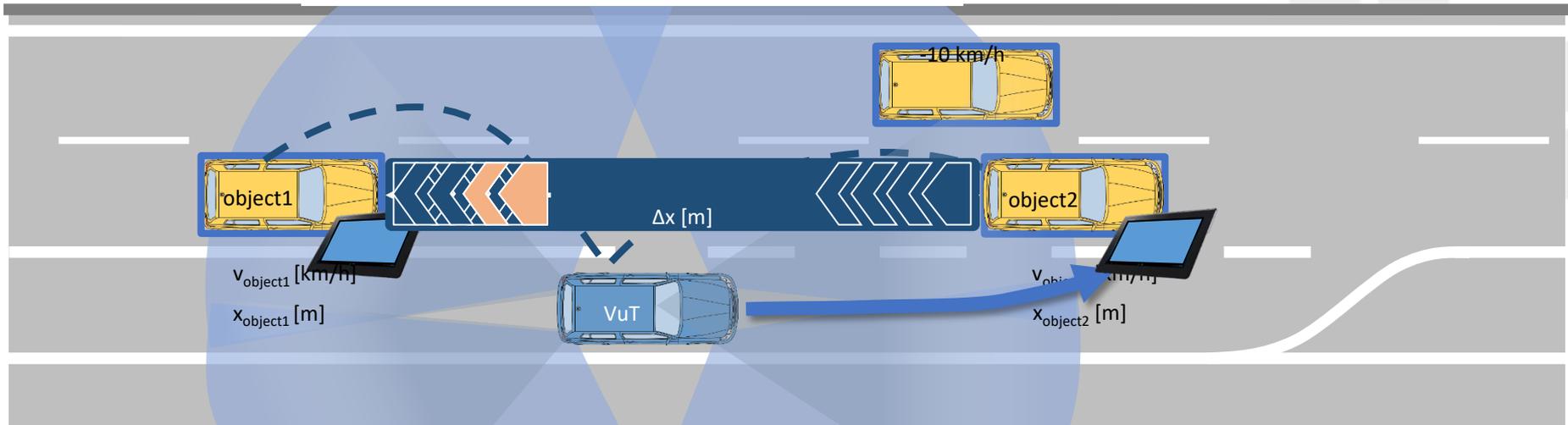
- **monitoring** of real driven test-cases
  - giving **test instructions**
  - (**controlling** of object vehicles)
- ... for reproducible test executions

## Maneuvers:

- merging
- lane changes
- overtaking

## Usage:

- proving grounds instructions



based on **high-precise 360° lidar** sensors,  
**wlan communication**

# Testmanager

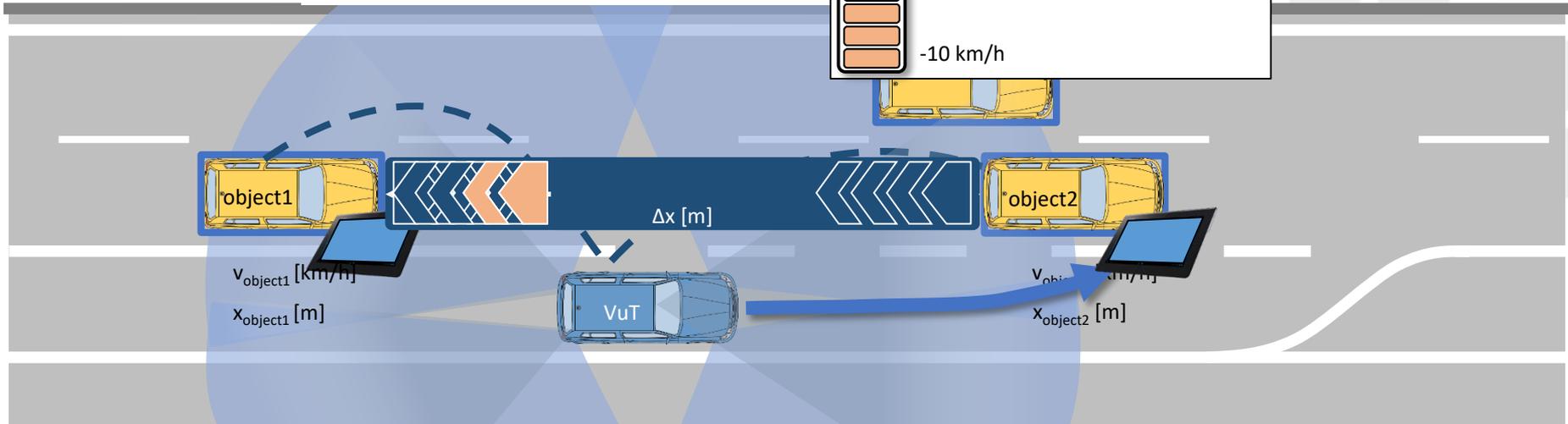
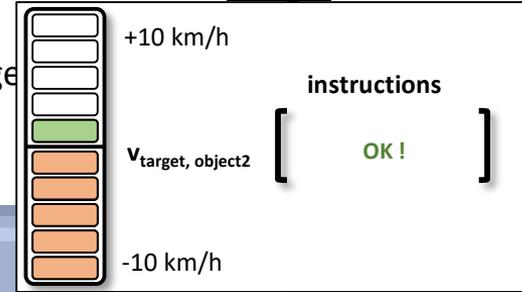
## Task:

- **monitoring** of real driven test-cases
- giving **test instructions**
- (**controlling** of object vehicles)
- ... for reproducible test executions

## Maneuvers:

- merging
- lane change
- overtaking

## Usage:



based on **high-precise 360° lidar** sensors,  
**wlan communication**

# Testmanager

Testmanager | Object 1 | Object 2 | Test Cases | View

Stop Main Test
Start
Reset

Testmanager

Current Checkpoint

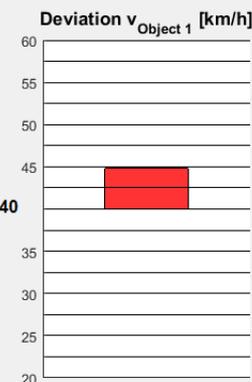
**Object 1**

Maneuver: Lane Keeping

Target Velocity [km/h] 40

Deviation Target Velocity Not OK

Deviation  $v_{\text{Object 1}}$  [km/h]



Target 40

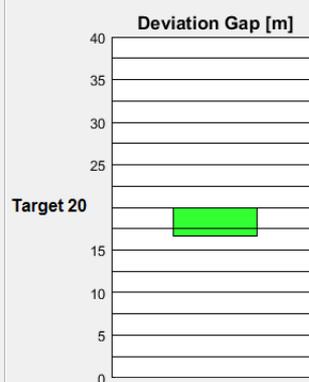
Driven Distance

Driven Distance [m] 242.3

Target Gap

Deviation Target Gap OK

Deviation Gap [m]



Target 20

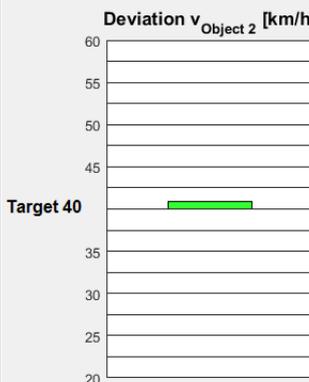
**Object 2**

Maneuver: Lane Keeping

Target Velocity [km/h] 40

Deviation Target Velocity OK

Deviation  $v_{\text{Object 2}}$  [km/h]



Target 40

Quality-Index

Quality-Index-Velocity	Current	Average
Velocity Object 1	12%	12%
Velocity Object 2	3%	8%

Quality-Index Gap	Current	Average
Deviation Gap	17%	17%

Quality-Index Total	Value
Quality-Index Total	12.3%

Offline

Time: 00:17 / 00:34

Next Check Points

Next Check Point in: 255 m

Object 1:	Value
Velocity	50
Maneuver	Lane Keeping

Object 2:	Value
Velocity	46
Maneuver	Lane Change Left

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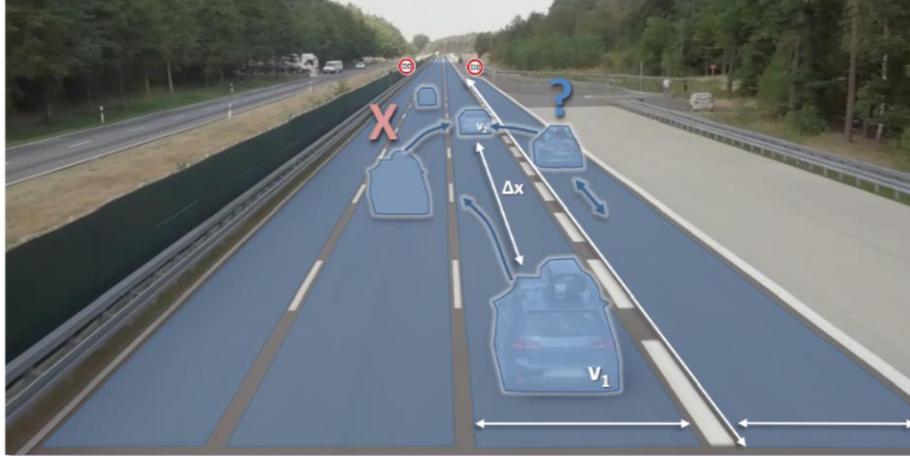
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# Summary

## Challenges of Testing



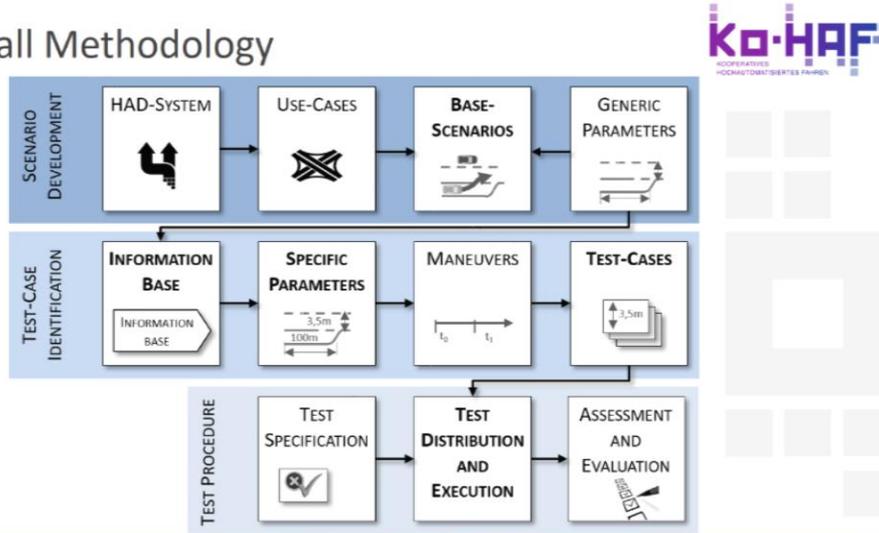
September 19th & 20th, 2018

Ko-HAF – Functional Testing of Automated Driving on Highways

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# Summary

## Overall Methodology



September 19th & 20th, 2018

Ko-HAF – Functional Testing of Automated Driving on Highways

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# Summary

## Test-Case Identification



Analysis of all **function-relevant environmental parameters.**



Test-Case Catalog

**Ko-HAF** KOOPERATIVES HOCHAUTOMATISIERTES FAHREN

APR Abklärung - Erhebung und Validierung  
LAMP 2 Testscenarior  
Testkatalog

TT-ID	Typ	Rahmenbedingung	Bedingung	Beschreibung	Wert
TC-1.1.1	1.1	Testfall		Manöver ohne Verkehrsszenen in ausreichend großer Lücke	
TC-1.1.2	1.1.1	Statische Element	Manöver		
TC-1.1.3	1.1.1	Statische Element	Manöver		
TC-1.1.4	1.1.1	Statische Element	Manöver		
TC-1.1.5	1.1.1	Statische Element	Manöver		
TC-1.1.6	1.1.1	Statische Element	Manöver		
TC-1.1.7	1.1.1	Statische Element	Manöver		
TC-1.1.8	1.1.1	Statische Element	Manöver		
TC-1.1.9	1.1.1	Statische Element	Manöver		
TC-1.1.10	1.1.1	Statische Element	Manöver		
TC-1.1.11	1.1.1	Statische Element	Manöver		
TC-1.1.12	1.1.1	Statische Element	Manöver		
TC-1.1.13	1.1.1	Statische Element	Manöver		
TC-1.1.14	1.1.1	Statische Element	Manöver		
TC-1.1.15	1.1.1	Statische Element	Manöver		
TC-1.1.16	1.1.1	Statische Element	Manöver		
TC-1.1.17	1.1.1	Statische Element	Manöver		
TC-1.1.18	1.1.1	Statische Element	Manöver		
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TC-1.1.44	1.1.1	Statische Element	Manöver		
TC-1.1.45	1.1.1	Statische Element	Manöver		
TC-1.1.46	1.1.1	Statische Element	Manöver		
TC-1.1.47	1.1.1	Statische Element	Manöver		
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TC-1.1.49	1.1.1	Statische Element	Manöver		
TC-1.1.50	1.1.1	Statische Element	Manöver		

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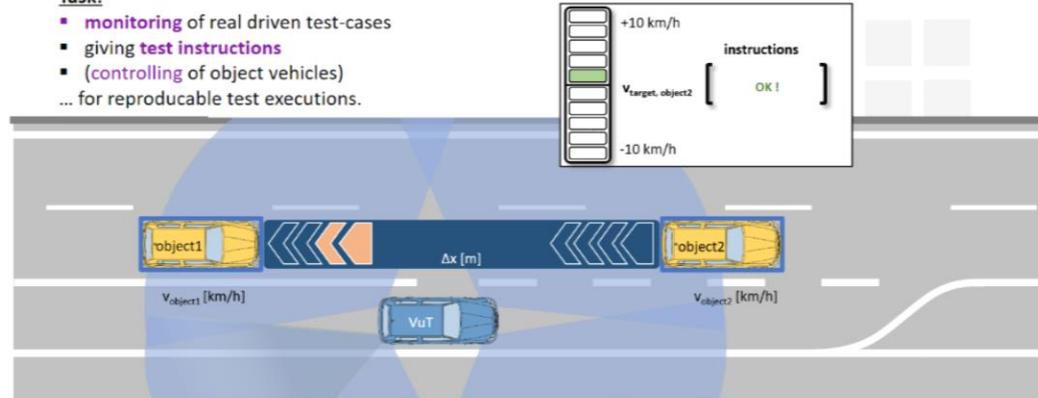
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# Summary

## Testmanager

### Task:

- **monitoring** of real driven test-cases
- giving **test instructions**
- (**controlling** of object vehicles)
- ... for reproducible test executions.



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und Energie

aufgrund eines Beschlusses  
des Deutschen Bundestages

# Sources

[1] - <https://dir.indiamart.com/impcat/black-box-testing-service.html>

