Automated and Connected Vehicles – Integrated Tool-Chains for Development and Test

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Institute of Transportation Systems

German Aerospace Center

- Research branches
  - Aeronautics / Space / Transport / Energy
  - Safety / Digitalization

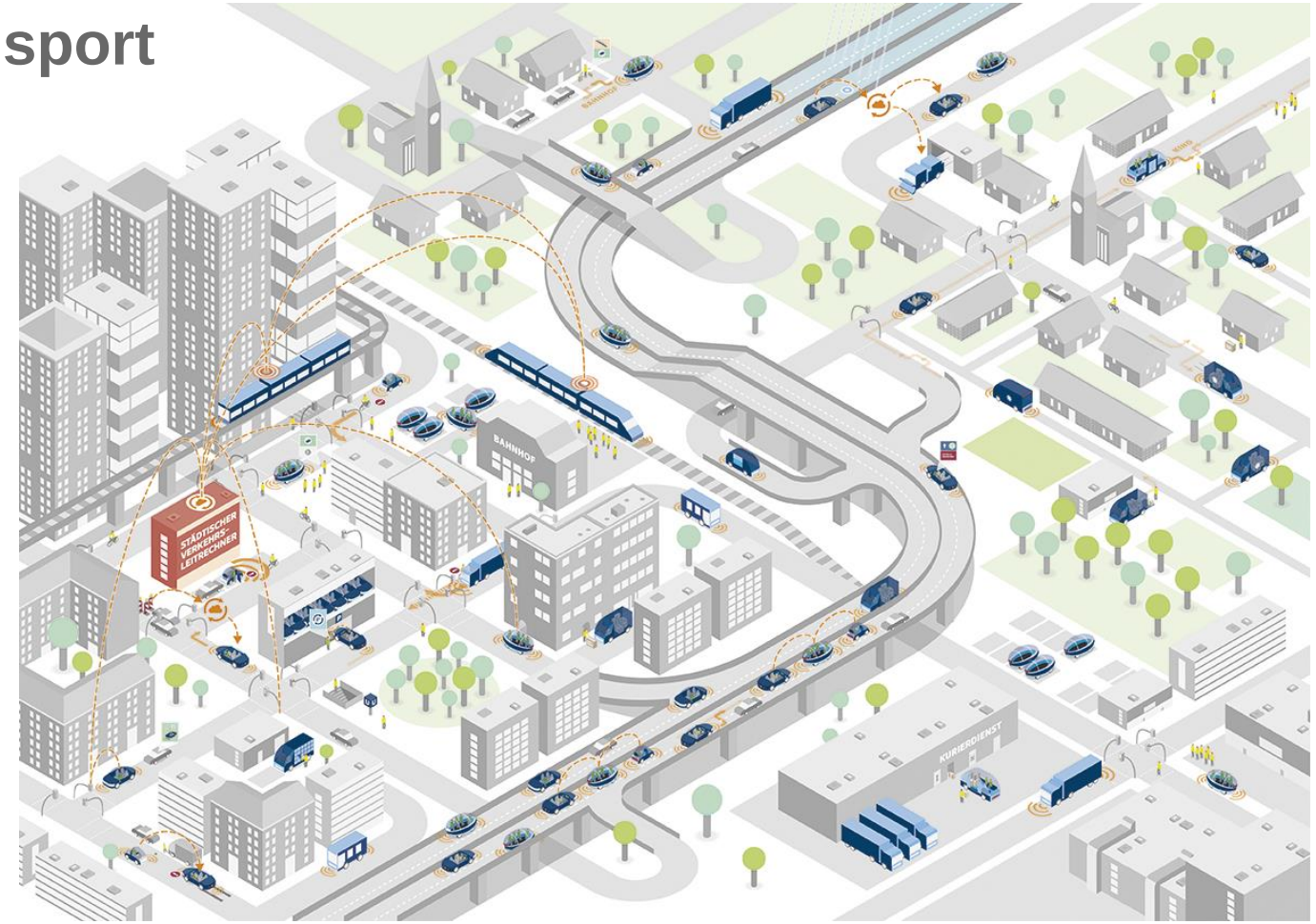
- Around 8.600 employees working in 47 research institutes and facilities at 26 sites in Germany

  Offices in Brussels, Paris, Washington, and Tokyo

German Aerospace Center – Transport

(High Level Goals)

- Green → environment-oriented traffic management, alternative drive trains …
- Smart → automated & connected driving, intelligent traffic infrastructure, intermodal transport chains, new business models ...
- User Friendly → human-centered design, intuitive interaction, high level of comfort, affordable products/services ...
- Reliable → safe, secure, robust, highly available ...
- Systemic Approach → interactions between land use ↔ city planning ↔ traffic planning and management ↔ technologies ↔ humans and society …



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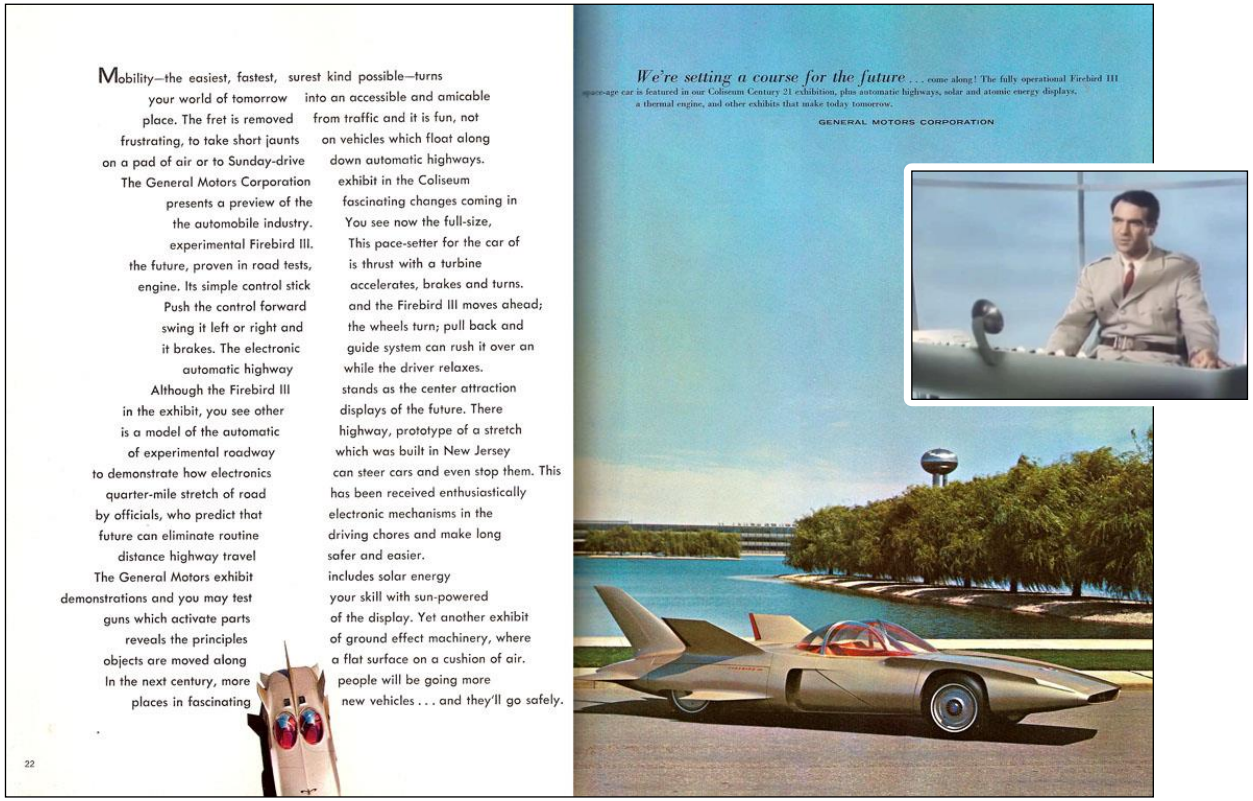
Automated and Connected Driving – Motivation (1/3)

- The mobility of the future should be
  - safe / secure / clean / efficient / comfortable
- In particular, automated and connected vehicles will significantly help to
  - improve traffic flow
  - reduce occurrence of critical situations
  - optimize the handling of planned and unplanned incidences
  - relieve pressure on drivers and environment
  - generate added value & stimulate innovative business models



- As the market penetration, the degree of automation, and the level of interconnection rises, the benefits that can be derived from these developments will also increase.

Automated and Connected Driving – Motivation (2/3)

- The mobility of the future should be
  - safe / secure / clean / efficient / comfortable
- In particular, automated and connected vehicles will significantly help to
  - improve traffic flow
  - reduce occurrence of critical situations
  - optimize the handling of planned and unplanned incidences
  - relieve pressure on drivers and environment
  - generate added value & stimulate innovative business models

- As the market penetration, the degree of automation, and the level of interconnection rises, the benefits that can be derived from these developments will also increase.

Automated and Connected Driving – Motivation (3/3)

- The mobility of the future should be
  - safe / secure / clean / efficient / comfortable
- In particular, automated and connected vehicles will significantly help to
  - improve traffic flow
  - reduce occurrence of critical situations
  - optimize the handling of planned and unplanned incidences
  - relieve pressure on drivers and environment
  - generate added value & stimulate innovative business models

- As the market penetration, the degree of automation, and the level of interconnection rises, the benefits that can be derived from these developments will also increase.

Automated and Connected Driving – Levels of Automation

Summary of Levels of Driving Automation for On-Road Vehicles

This table summarizes SAE International's levels of *driving* automation for on-road vehicles. Information Report J3016 provides full definitions for these levels and for the italicized terms used therein. The levels are descriptive rather than normative and technical rather than legal. Elements indicate minimum rather than maximum capabilities for each level. "System" refers to the driver assistance system, combination of driver assistance systems, or *automated driving system*, as appropriate.

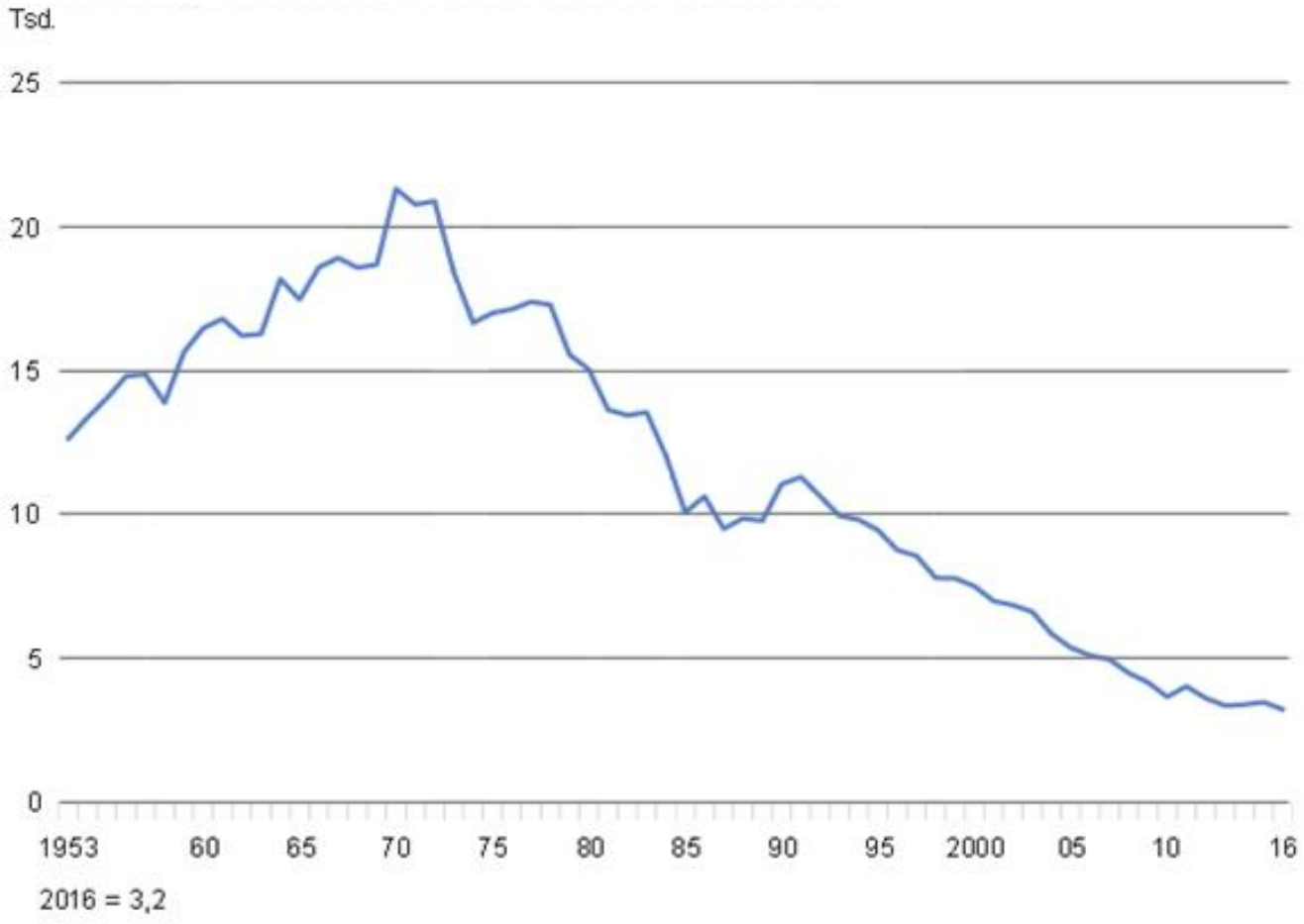
The table also shows how SAE's levels definitively correspond to those developed by the Germany Federal Highway Research Institute (BASt) and approximately correspond to those described by the US National Highway Traffic Safety Administration (NHTSA) in its "Preliminary Statement of Policy Concerning Automated Vehicles" of May 30, 2013.

Level	Name	Narrative definition	Execution of steering and acceleration/ deceleration	Monitoring of driving environment	Fallback performance of *dynamic driving task*	System capability (*driving modes*)	BASt level	NHTSA level
Human driver **monitors the driving environment**								
0	**No Automation**	the full-time performance by the *human driver* of all aspects of the *dynamic driving task*, even when enhanced by warning or intervention systems	Human driver	Human driver	Human driver	n/a	Driver only	0
1	**Driver Assistance**	the *driving mode*-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	Human driver and system	Human driver	Human driver	Some driving modes	Assisted	1
2	**Partial Automation**	the *driving mode*-specific execution by one or more driver assistance systems of both steering and acceleration/deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	**System**	Human driver	Human driver	Some driving modes	Partially automated	2
Automated driving system **("system") monitors the driving environment**								
3	**Conditional Automation**	the *driving mode*-specific performance by an *automated driving system* of all aspects of the *dynamic driving task* with the expectation that the *human driver* will respond appropriately to a *request to intervene*	System	**System**	Human driver	Some driving modes	Highly automated	3
4	**High Automation**	the *driving mode*-specific performance by an *automated driving system* of all aspects of the *dynamic driving task*, even if a *human driver* does not respond appropriately to a *request to intervene*	System	System	**System**	Some driving modes	Fully automated	3/4
5	**Full Automation**	the full-time performance by an *automated driving system* of all aspects of the *dynamic driving task* under all roadway and environmental conditions that can be managed by a *human driver*	System	System	System	**All driving modes**	-	

Automated and Connected Driving – current Status regarding Road Safety (1/2)

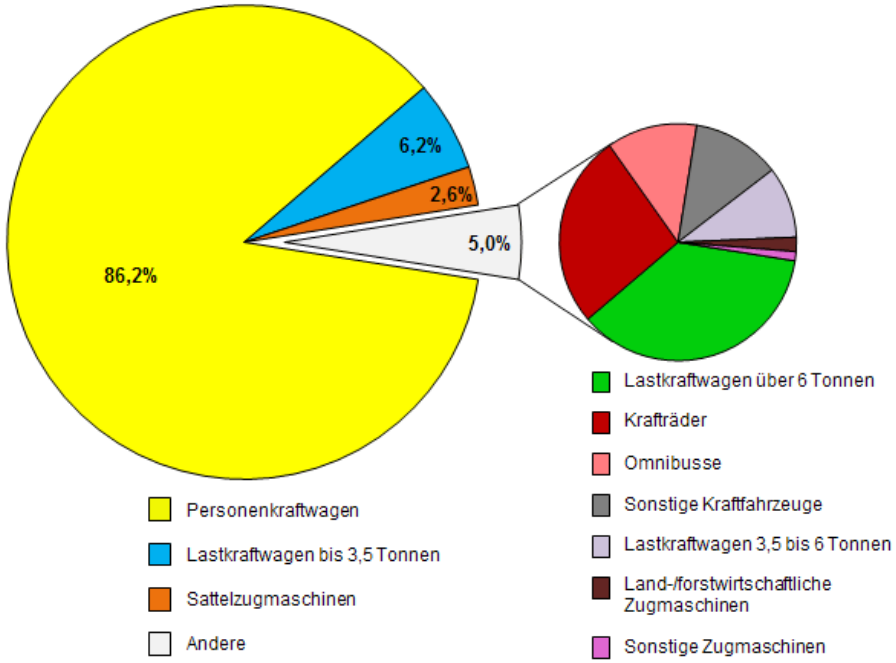
– Reduction of critical events ⟶ raise safety

Number of Death in Road Traffic (1953 ... 2016):



The annual total mileage of vehicles registered in Germany increased to more than 725 billion kilometers in 2016.

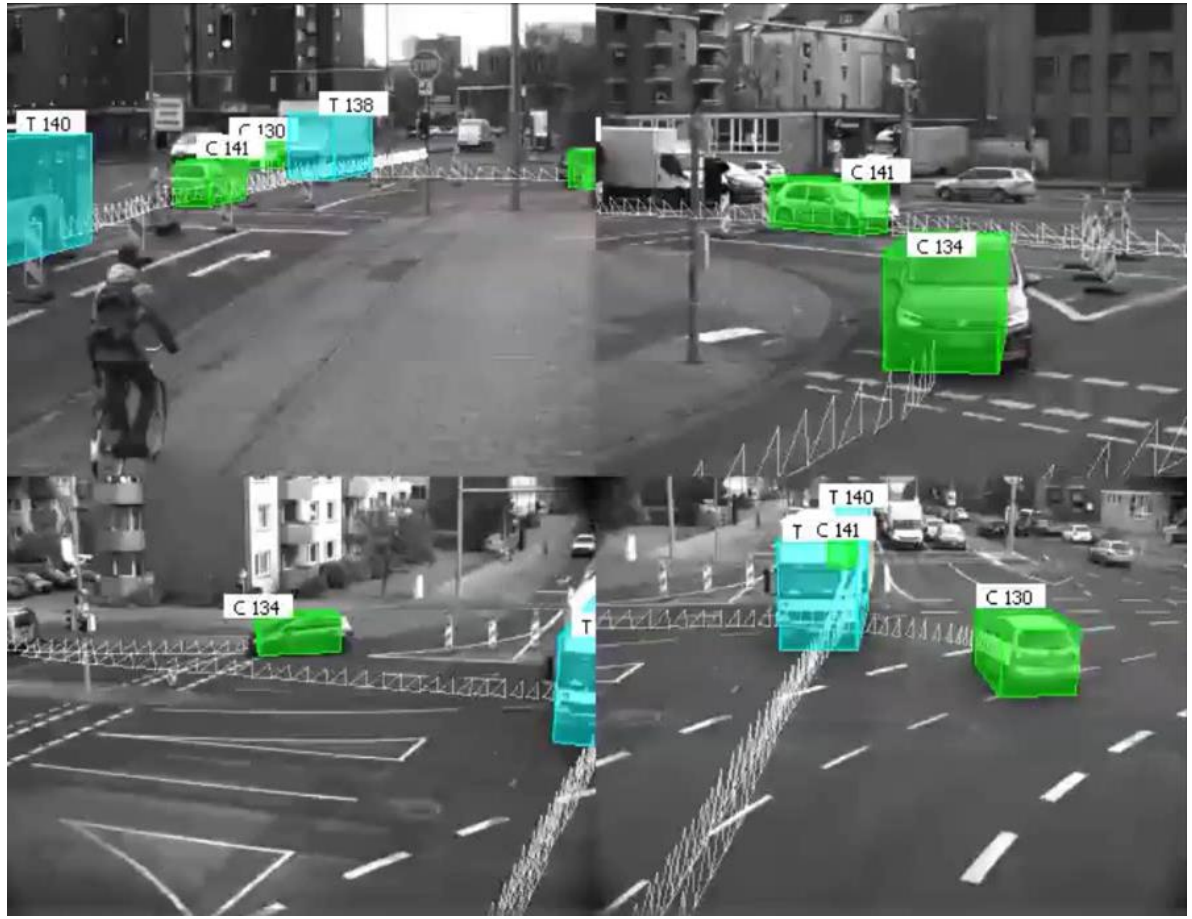
Total mileage broken down by vehicle type in 2016:



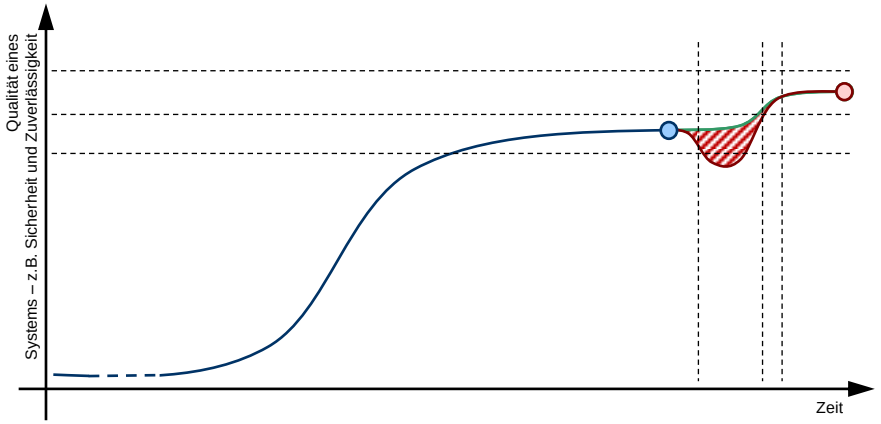
Anzahl der im Straßenverkehr Getöteten – vgl. Statistisches Bundesamt (2017)
Jährliche Gesamtfahrleistung – vgl. Kraftfahrtbundesamt (2017)

Automated and Connected Driving – current Status regarding Road Safety (2/2)

– Reduction of critical events → raise safety



– Automated and connected driving is complicated and inherently complex
  – advanced technologies & functionalities
  – complex environments (e.g. urban areas), traffic systems (e.g. an intelligent traffic infrastructure, communication technologies and backend systems), traffic scenarios
  – users and other traffic participants (in particular cyclists and pedestrians)
  – normative and non-normative behavior

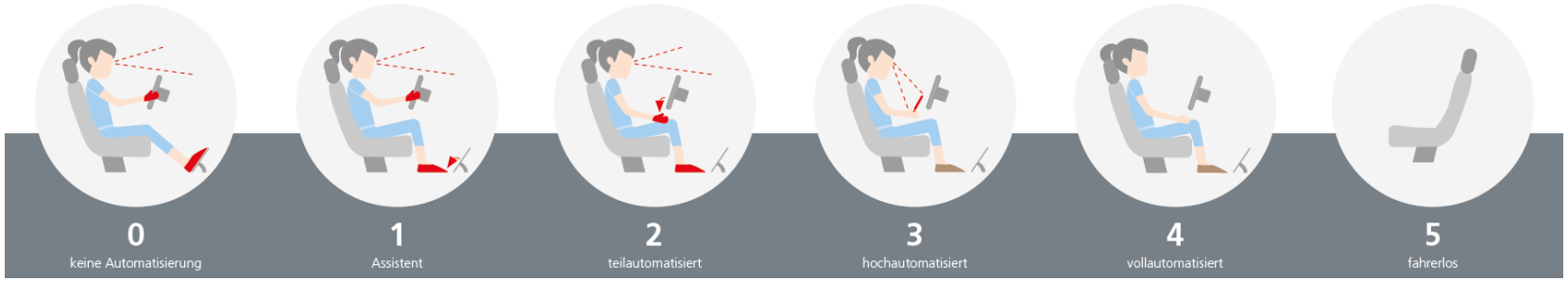


Automated and Connected Driving – Development Strategy

– Automated vehicles – levels of automation, implementation procedures and deployment
→ Evolutionary vs. 1-Shot Approach

Evolutionary approach → generally aims on a successively growing scope of functions in all areas with comparable traffic situations or conditions (for example Highway-Chauffeur = Highway-Chauffeur on all motorways in Europe or worldwide)

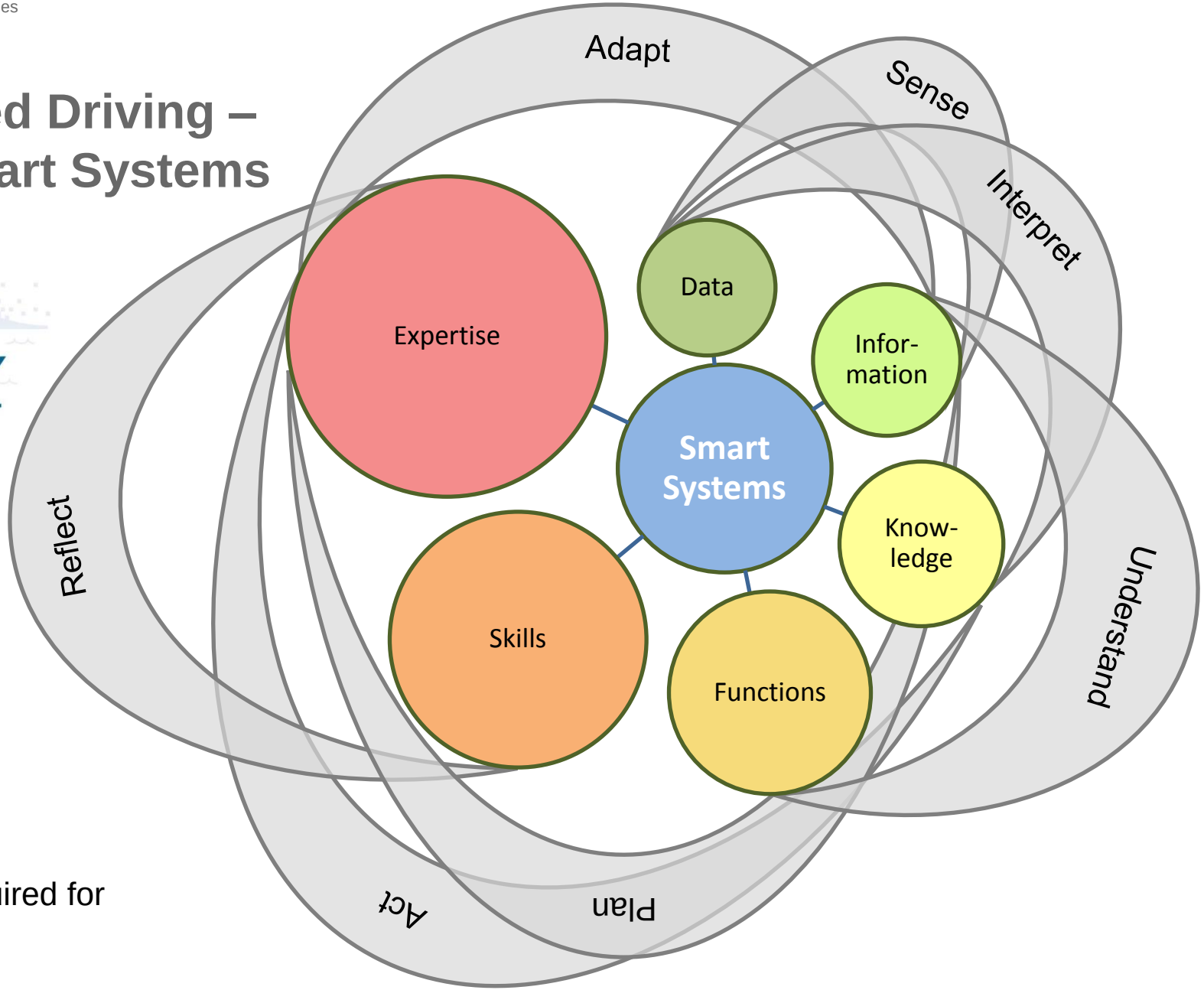
1-Shot-Approach→ generally targeting full functionality for selected areas (e.g., automated taxi = automated taxi in Los Angeles)



Automated and Connected Driving – from Technologies to Smart Systems

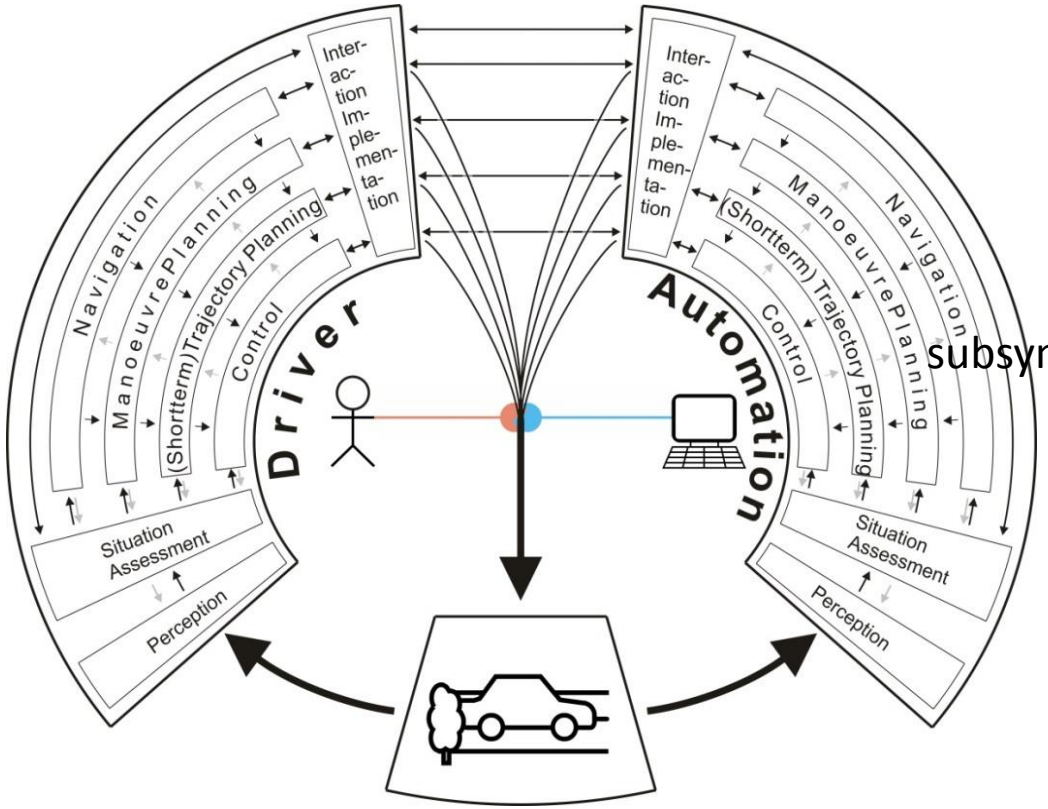
Abbildung: www.intelligente-welt.de

- Considering just technologies isn't sufficient
- Inter- and transdisciplinary research is necessary
- Differentiation of "intelligence levels" required
  - differentiation is essential for societal discourse …
  - which "intelligence level" is required for which function?



Automated and Connected Driving – from Technologies to Smart Systems

Artificial Intelligence & Machine Learning



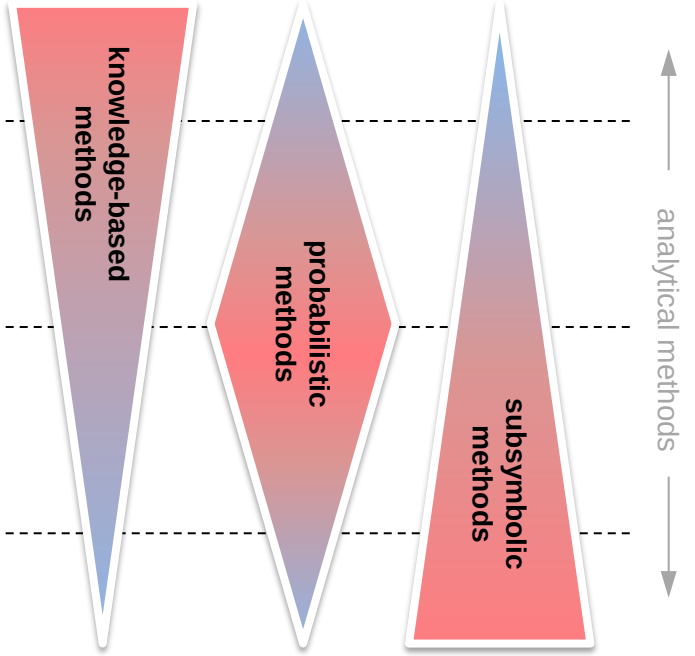
mission level

strategic level
(navigation)

subsymbolic methods

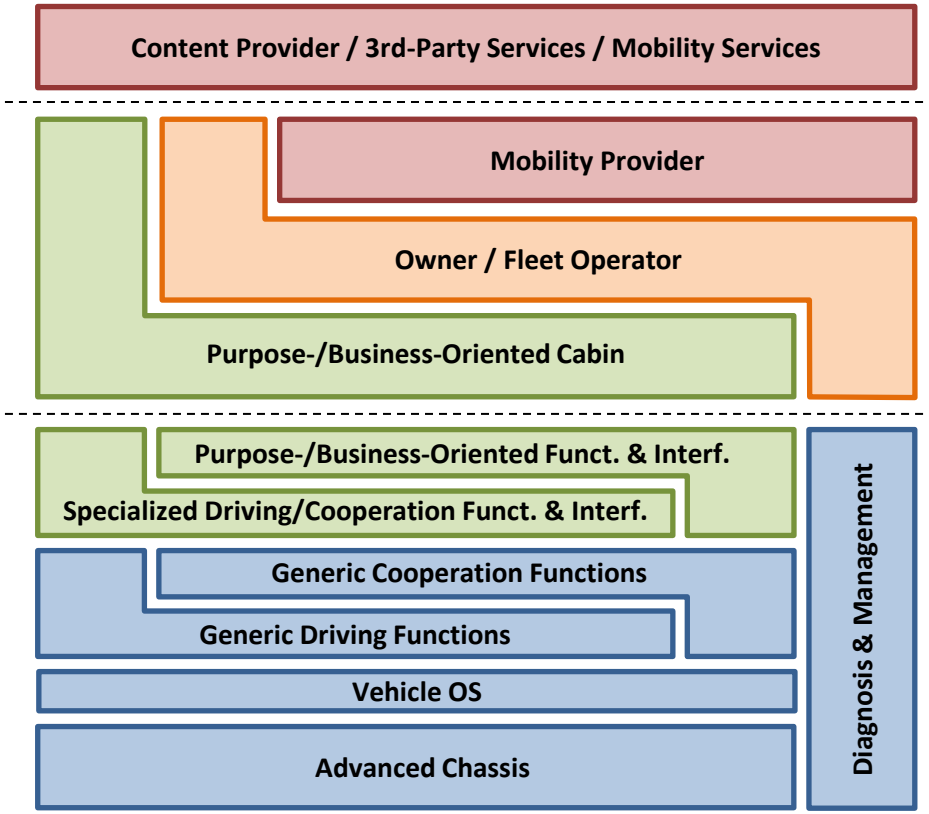
tactical level
(maneuver / trajectory planning)

reactive level
(operation / control)



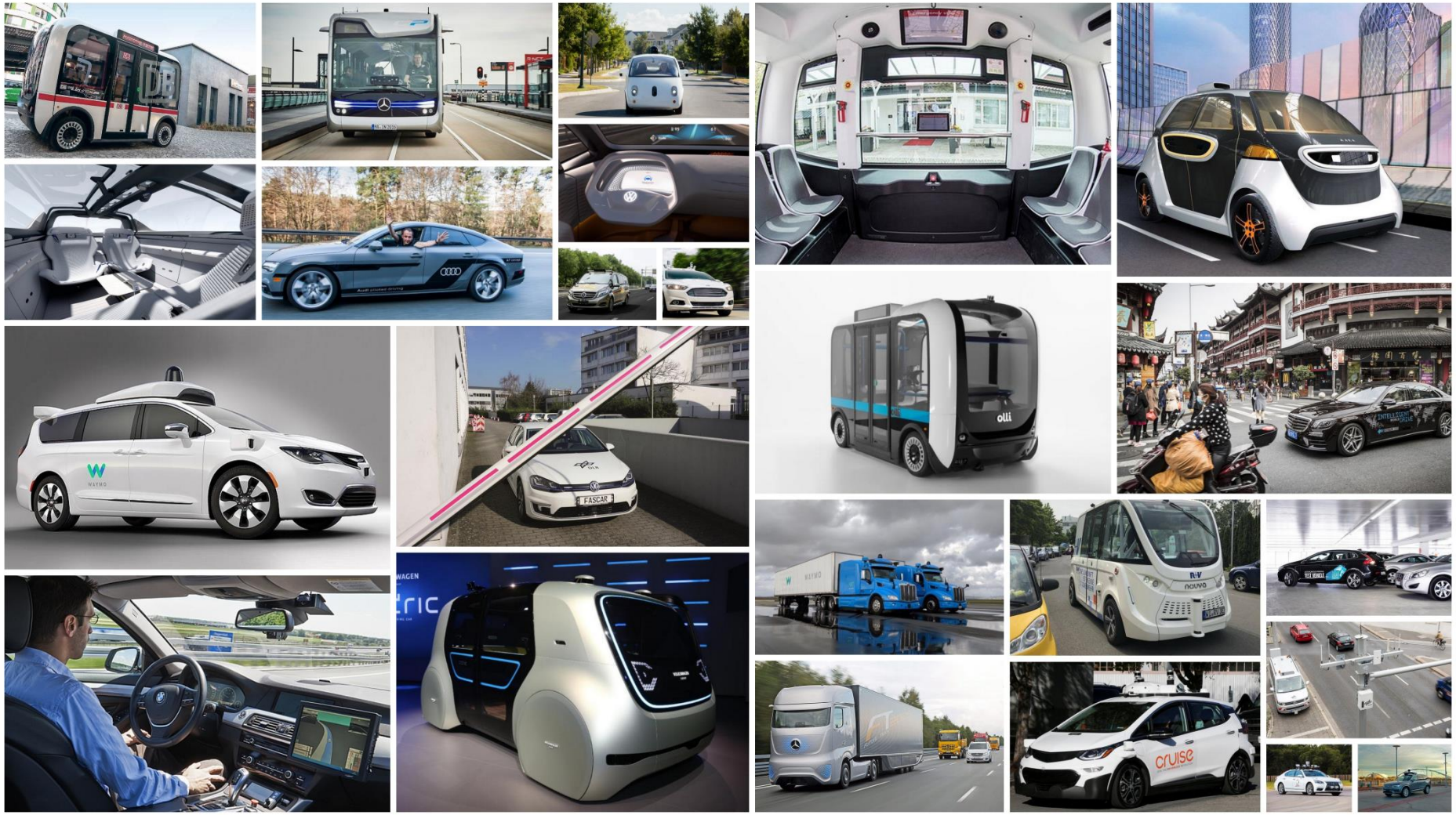
Automated and Connected Driving – a wide Range of additional Topics

- Separation of hard- and software
- Reduction of the number of ECUs / OBUs → new generation of ECUs
- Conventional software components and AI-based functions
- Over-the-Air Software-Updates / Continuous Integration
- New basic functions in automated and connected vehicles
  - repositories (vehicles / background systems)
  - service orientation → distributed functions
  - orchestration of services and dynamic re-orchestration
  - physical / virtual redundancy in hard- and software
  - execution environments (especially monitoring / diagnosis)
  - secure networks and Block Chain technology
- Use of state-of-the-art programming paradigms and model-based software or system development
- Digital Twins – e.g. model- and simulation-based development and testing



The current Traffic System could also be Transformed …

Prototypes / Pilots



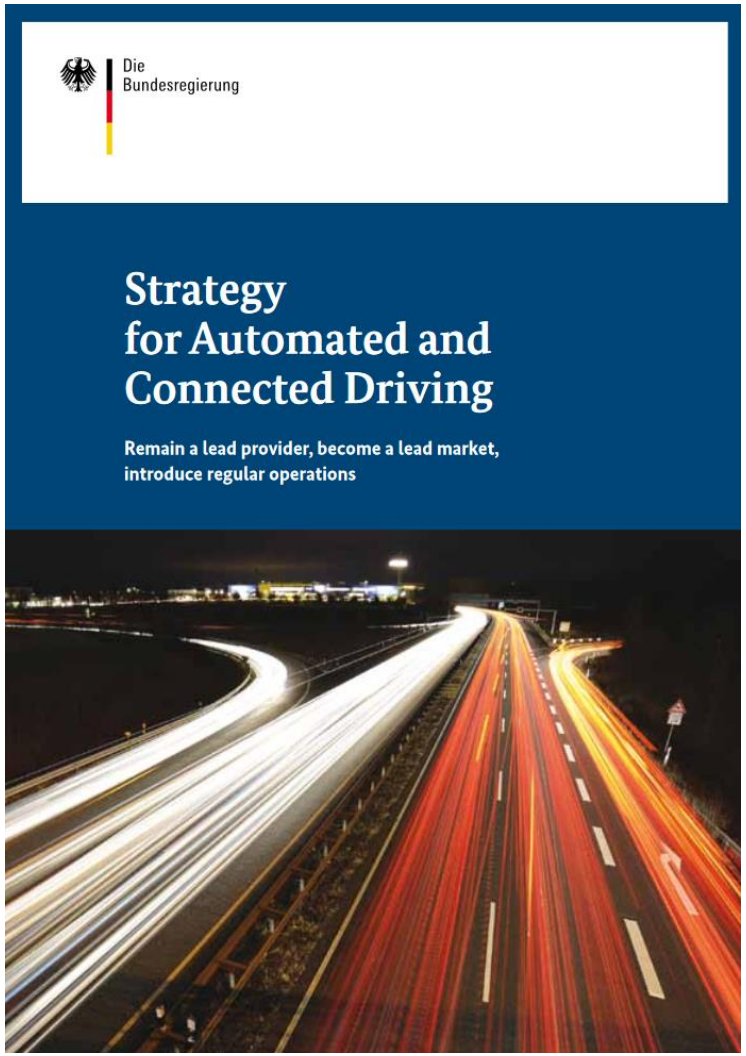
Strategic Framework

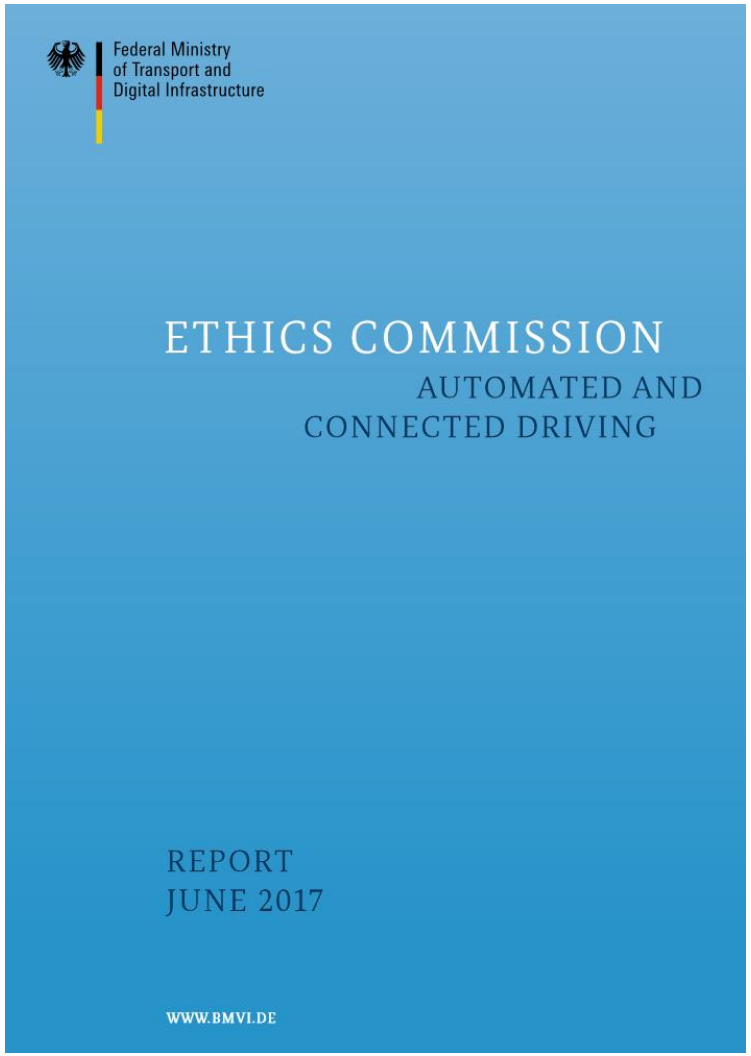
The Federal Government is committed to creating an regulatory framework as well as the necessary conditions for the introduction of automated and connected vehicles.

In 2013, the Federal Ministry of Transport and Digital Infrastructure established the **“Automated Driving” Round Table**.

The “Automated Driving” Round Table an advisory body that enables a close exchange of ideas and experience among stakeholders from industry, academia, associations and public administration.

Furthermore, it pools the required know-how in such a way that a broad-based societal consensus can be achieved on all relevant aspects of automated and connected driving.





On 20 June 2017, the **Ethics Commission on Automated and Connected Driving** presented its report, including 20 ethical rules. The work started at the end of 2016 and the commission was chaired by Prof. Udo Di Fabio, a former judge at the German Federal Constitutional Court.

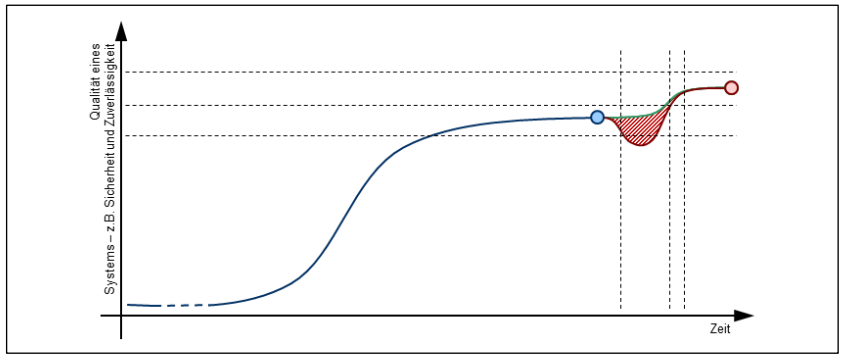
The Commission includes distinguished experts from academia, society, the automotive industry and the digital technology sector.

PEGASUS

Methods for the Assessment of Highly Automated Driving Function

What level of performance is expected of an automated vehicle?

How can we verify that it achieves the desired performance consistently?



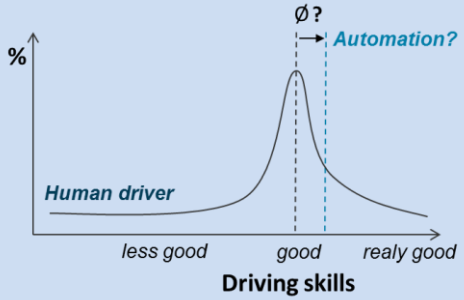
PEGASUS = **P**rojekt zur **E**tablierung von **g**enerell **a**kzeptierten Gütekriterien, Werkzeugen und Methoden sowie **S**zenarien **u**nd **S**ituationen zur Freigabe hochautomatisierter Fahrfunktionen

PEGASUS

Methods for the Assessment of Highly Automated Driving Function

Scenario Analysis & Quality Measures

- What human capacity does the application require?



- What about technical capacity?
- Is it sufficiently accepted?
- Which criteria and measures can be deducted from it?

Implementation Process

- Which tools, methods and processes are necessary?

Testing

- How can complete-ness of relevant test runs be ensured?
- What do the criteria and measures for these test runs look like?
- What can be tested in labs or in simulation? What must be tested on proving grounds, what must be tested on the road?

Reflection of Results & Embedding

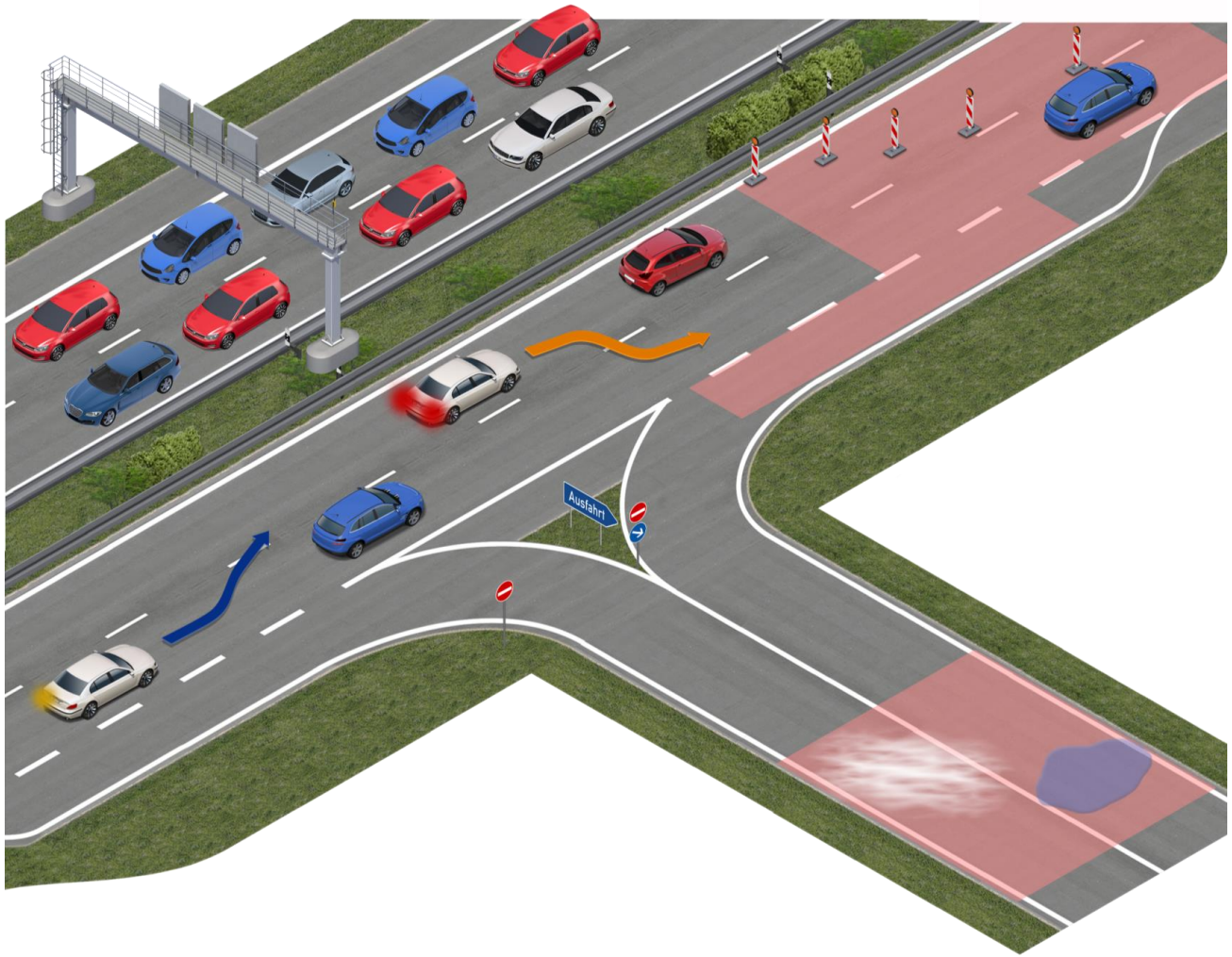
- Is the concept sustainable?
- How can the PEGASUS-Partners embed the results?

PEGASUS

Methods for the Assessment of Highly Automated Driving Function

- Highway-Chauffeur (level 3)
- Motorways or motorway-like roads including appropriate lane markings
- Driving in speed-range from 0 to 130 km/h
- lane changes
- automated follow-up driving in traffic jams (stop-and-go)
- automated emergency braking as well as automated collision avoidance

- Not covered by the function (e.g.)
  - construction sites
  - merging or leaving
  - extreme weather conditions



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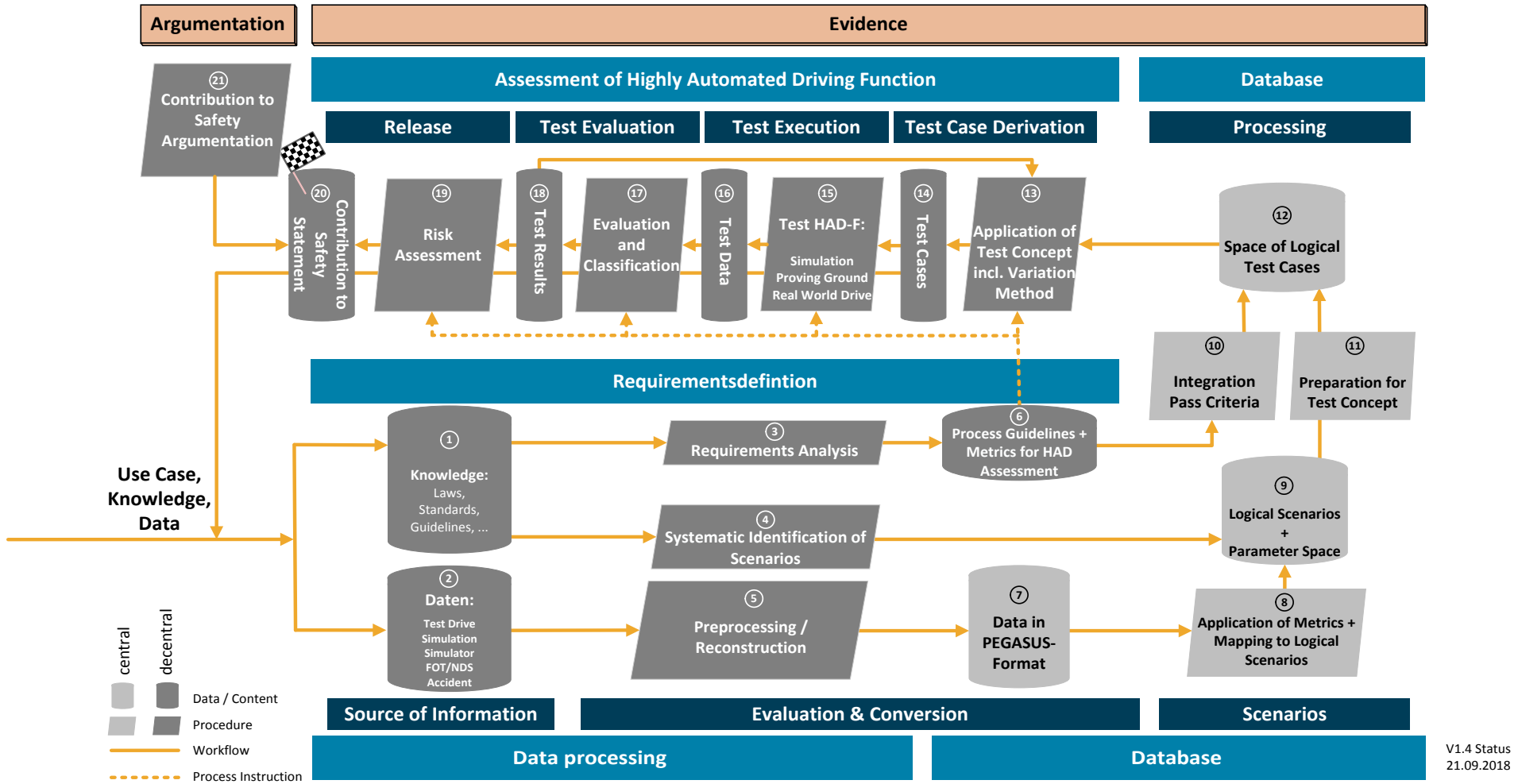
Methods for the Assessment of Highly Automated Driving Function

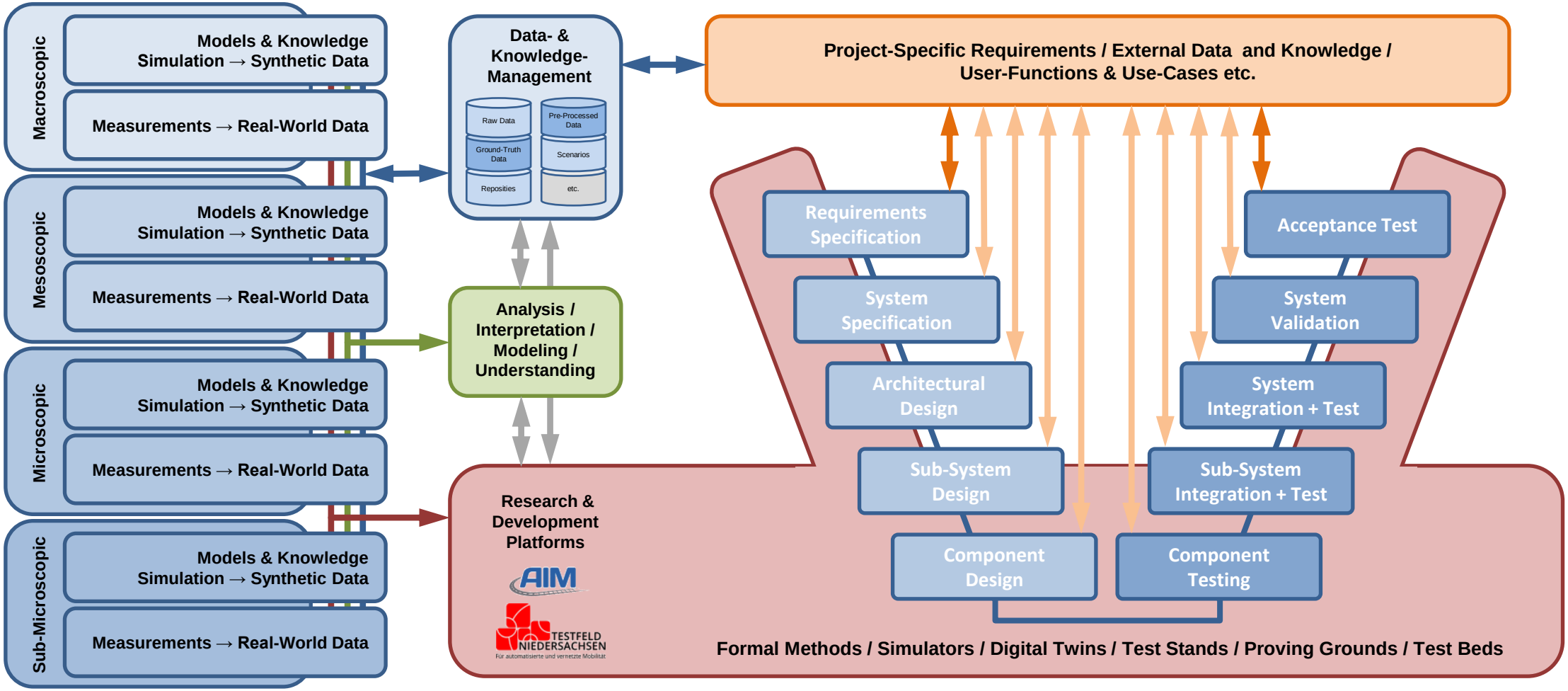


V1.4 Status
21.09.2018

PEGASUS = **P**rojekt zur **E**tablierung von **g**enerell **a**kzeptierten Gütekriterien, Werkzeugen und Methoden sowie **S**zenarien **u**nd **S**ituationen zur Freigabe hochautomatisierter Fahrfunktionen

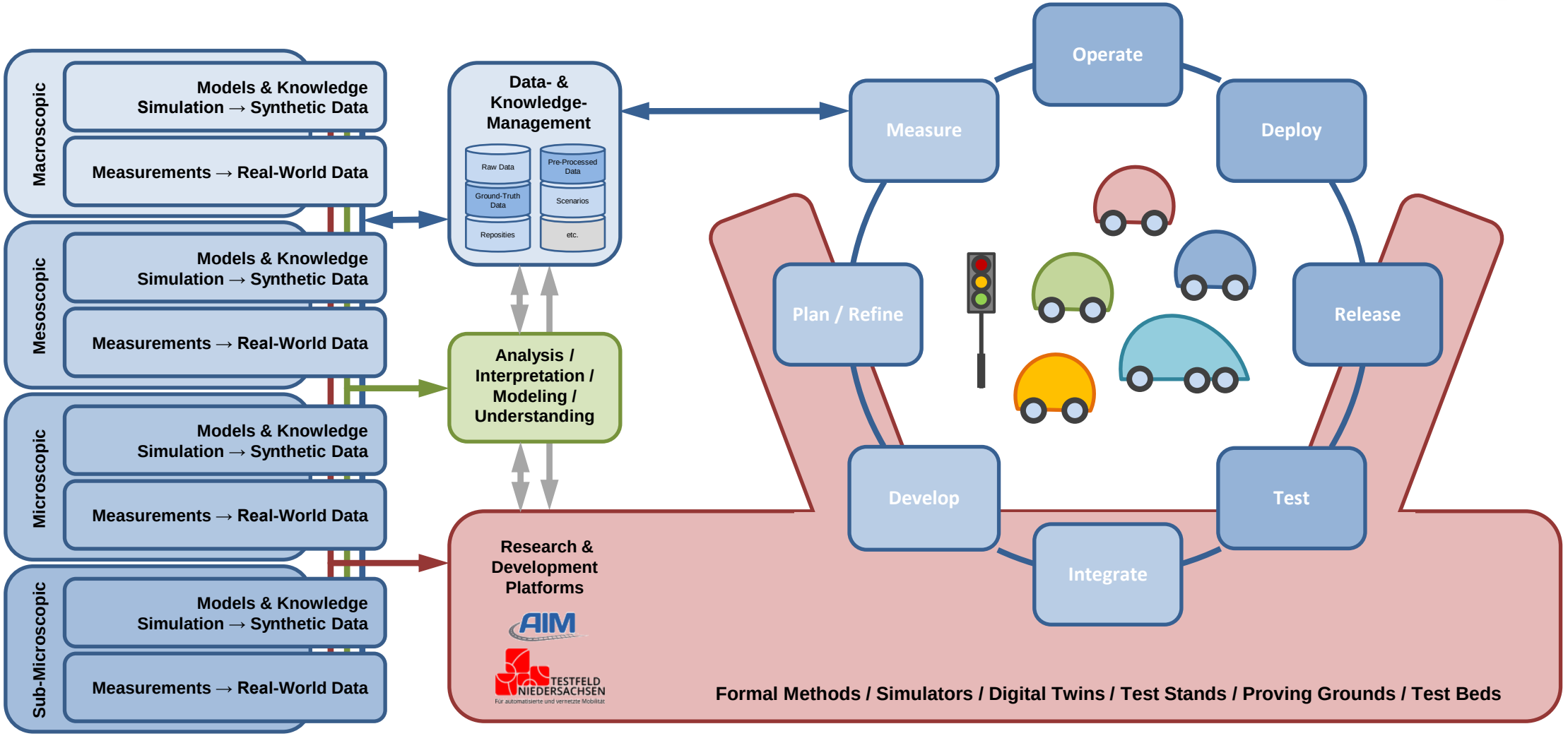
Integrated Tool-Chains (1/2)

e.g. at the German Aerospace Center



Integrated Tool-Chains (2/2)

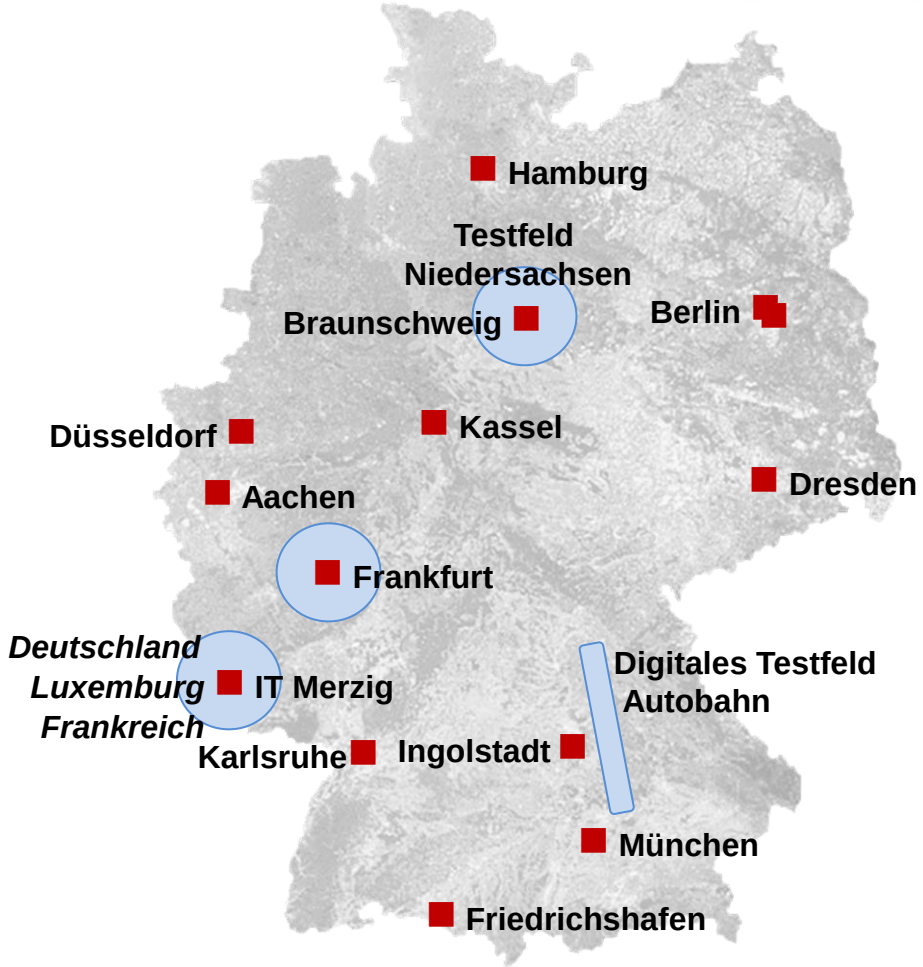
e.g. at the German Aerospace Center



Test Beds for Automated and Connected Driving & Intelligent Mobility

- Test beds on highways, other relevant road types for inter-urban connections, and urban areas (in german)
  - Digitales Testfeld Autobahn (A9)
  - Berlin (SAFARI | Diginet-PS)
  - Braunschweig (AIM)
  - Dresden
  - Düsseldorf
  - Hamburg
  - Ingolstadt
  - Kassel
  - München
  - Testfeld Niedersachsen (mainly A2, A7, A39, A395)
  - Frankfurt (in particular, DRIVE-Testfeld)
  - Transnationally test bed Deutschland | Frankreich | Luxemburg

Other implementations of test beds in Friedrichshafen, Merzig, Karlsruhe, and Aachen etc.



AIM = Application-Platform Intelligent Mobility

Test Beds for Automated and Connected Driving & Intelligent Mobility – Use-Cases

- Different categories – for example

• Determination of requirements and refinement / understand the system	**Exploration**
• Design of functions • Development of functions • Demonstration of functions	**Feasibility | solution finding and synthesis | exploration**

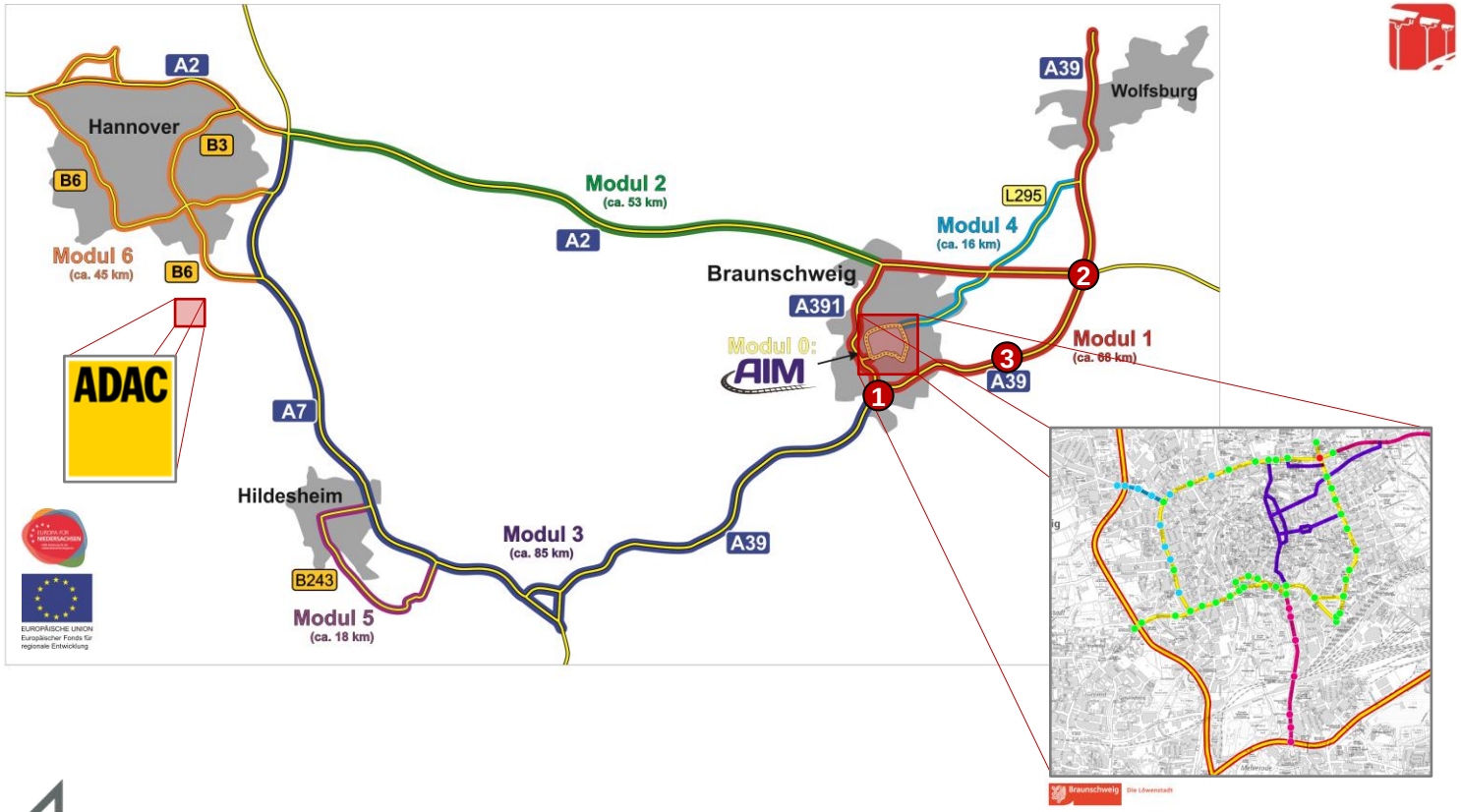
• Assessment
  • test
  • effect
  • acceptance
	Verification und Validation | interoperability

• Reference implementations and pilots	**Standardization | system migration**
• Information (politics / society)	**Information | communication**

Application-Platform Intelligent Mobility & Test Bed Lower Saxony

Integrated Tool-Chains (1/3)

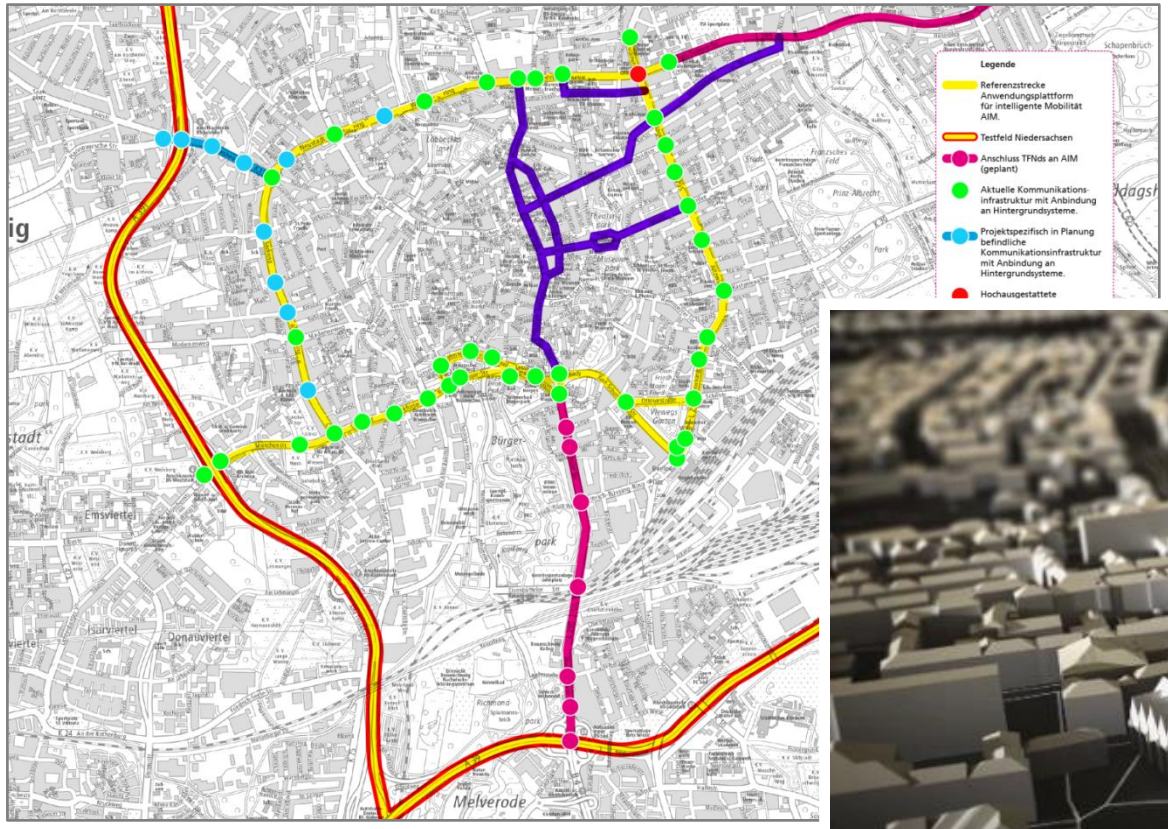
Approximately 280 km of different types of roads will extend AIM – with a focus on highways. Technical components of the Test Bed Lower Saxony are based on established AIM-Components. The integrated use of AIM and Test Bed Lower Saxony will be possible.



- **Camera-Based Detection** – anonymized detection of traffic objects and their trajectories → ground truth
- **Communication** – V2X via WiFi 802.11p and Cellular
- **Maps** – highly accurate and up to date maps for vehicles and various simulation-purposes
- **Scenarios and Models** – parametrizations and (sub-) models for the construction of (ecologically) valid simulations
- **Interfaces to Traffic Infrastructure and traffic-related Databases** – e.g. connection to the traffic management
- **Backend-System** – data management and delivery of online services
- **Cadastre** – in particular, documentation of the test field status / quality

Application-Platform Intelligent Mobility & Test Bed Lower Saxony

Integrated Tool-Chains (2/3)

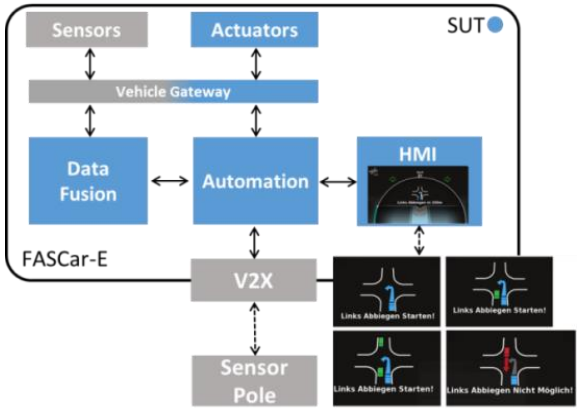


Application-Platform Intelligent Mobility & Test Bed Lower Saxony

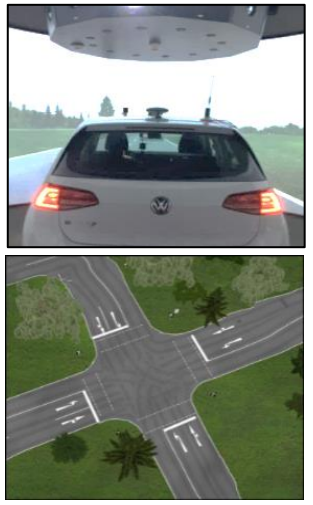
Integrated Tool-Chains (3/3)

Proving Ground

System Under Test (SUT)



Simulation

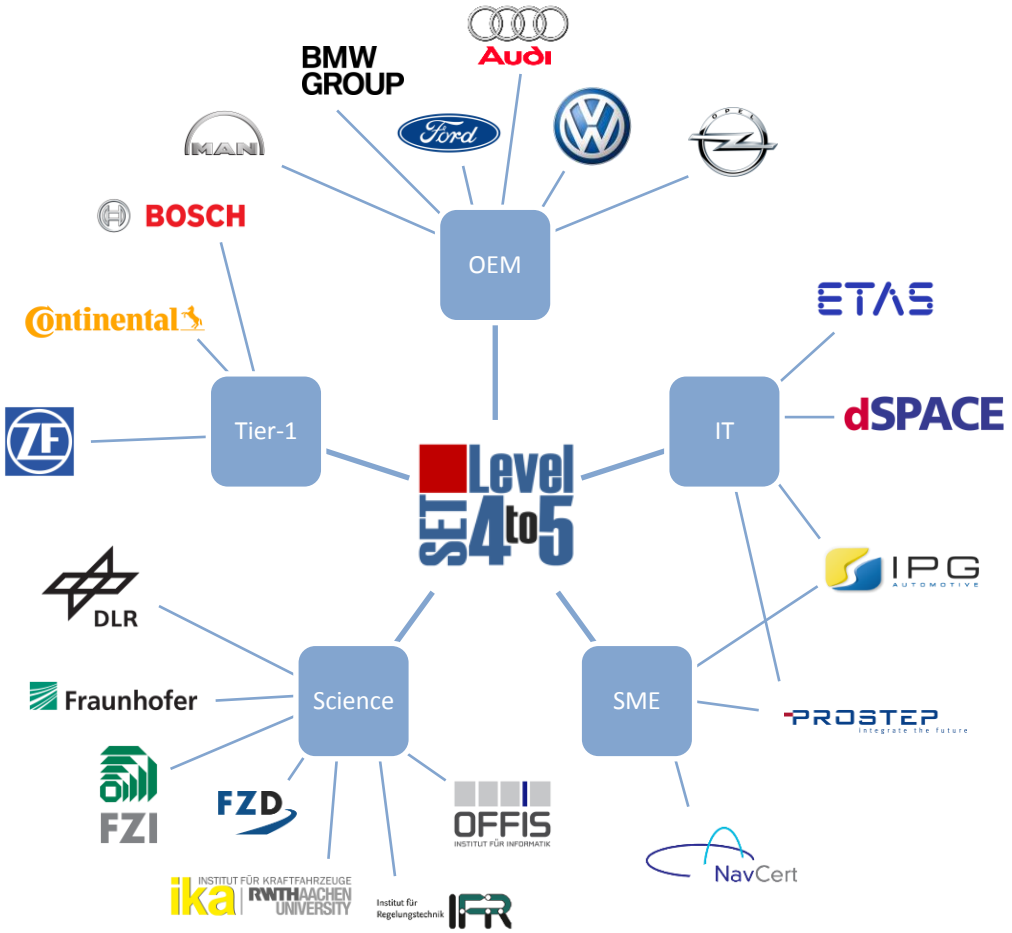


Simulation-Based Tools (1/2)

SET Level 4to5 – Simulationsbasiertes Entwickeln und Testen von Level 4 und 5 Systemen – Coordination BMW | DLR

- Simulation will be an essential tool in the context of
  - determination of requirements and their refinement
  - development of functions and training/learning
  - adaption of functions
  - assessment and test
  - homologation

- Heterogeneous user groups define a broad catalog of requirements for simulation-based tools

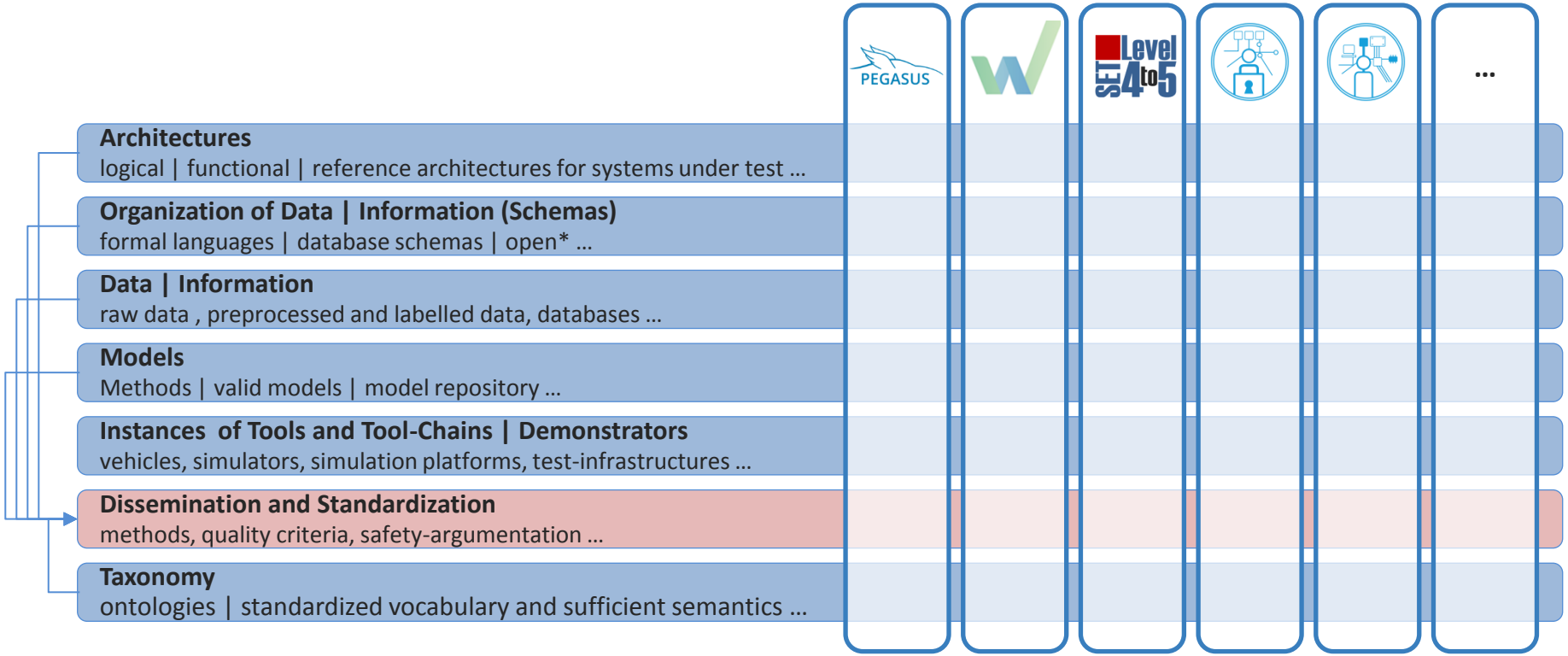


Simulation-Based Tools (2/2)

SET Level 4to5 – Simulationsbasiertes Entwickeln und Testen von Level 4 und 5 Systemen – Coordination BMW | DLR

- Expected results
  - platform for system exploration and testing as a service
  - handling of level 4 and 5 vehicles in urban traffic situations
  - generic services – open | flexible | adaptable | extensible
  - Adaptation and configuration with little effort | ease of use
  - Traceablity is guaranteed
  - homologation can be supported
- Standardization of results is seen as essential → ASAM
  - openDRIVE (PEGASUS)
  - openSCENARIO (PEGSUS)
- Building block of a project-ecosystem focusing on test | homologation

Overall Coordination of Lighthouse Projects | Standardization



Thank You for Your Attention…

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