

Testing and Validation for the Commercialization of Autonomous Driving

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- 01** **Introduction**
- 02** **Testing and Validation Strategy**
- 03** **Reference Systems**
- 04** **Conclusion**

01

Introduction

Why autonomous driving needs reliable validation.

GeneSys in Brief

1996

Founded in
Offenburg, Germany

30 years

Measurement and
testing expertise

Global

Automotive and
mobility projects



Core and business fields

Automotive testing

ADMA ground truth: vehicle dynamics, ADAS and AD testing —
largest segment

Tunneling & navigation

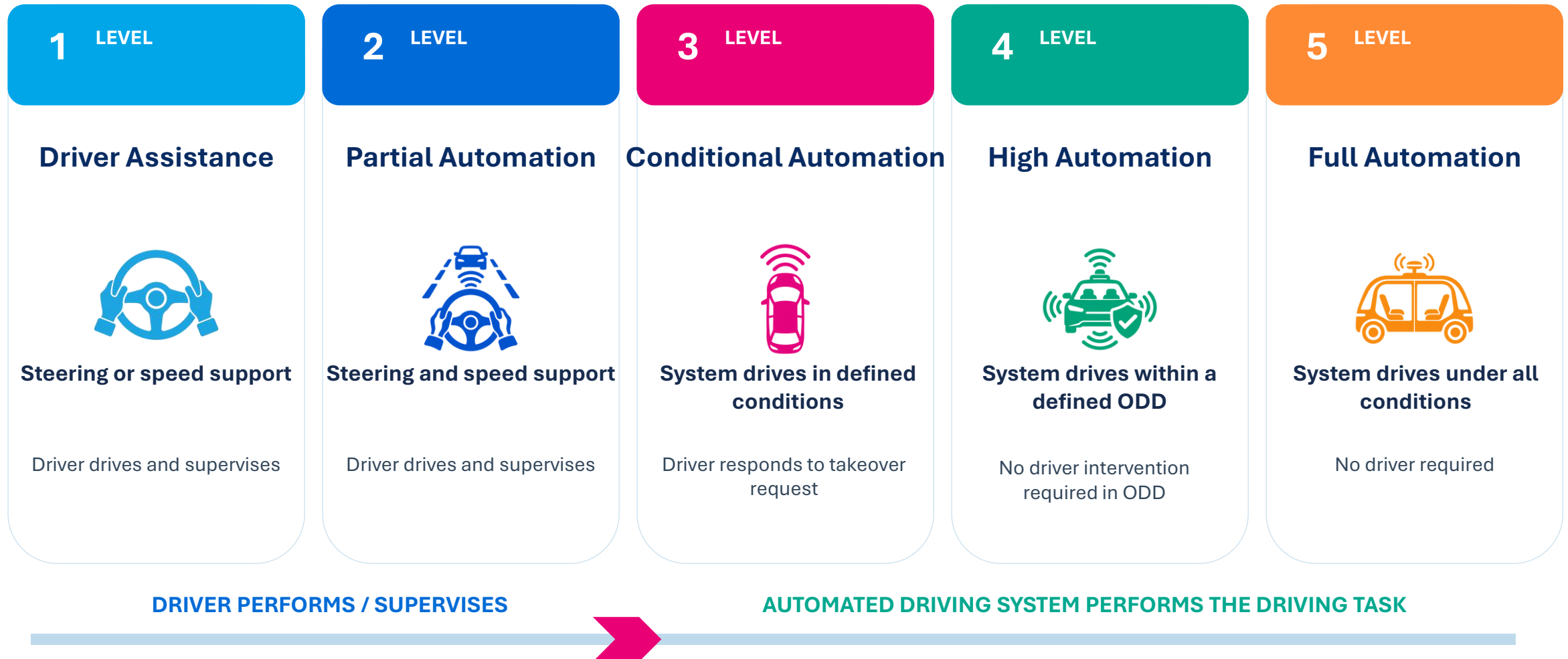
Inertial and LASER-based navigation and positioning for tunnel
boring machines

Industrial image processing

Automated optical inline inspection in production



SAE Levels 1 to 5: Who is Driving?



Automated Driving Already in Regular Service

Level 3 stays limited to motorways - Level 4 runs commercially in narrow operating domains.

Level 3 - private cars

Germany: Mercedes, BMW - motorways up to 130 km/h (UN R157)

USA: Mercedes - certified in Nevada since 2023

Japan: Honda - world's first type approval in 2020

China: ZF, Horizon - series launch announced for 2026

Korea: Genesis G90 - launches with L2+ instead of L3



Level 4 - robotaxi

USA: Waymo - over 500,000 paid rides per week, 14 cities

China: Apollo Go - over 22 million rides; Pony.ai over 1,700 vehicles

Korea: Seoul - first L4 taxi service planned for Nov 2026

Japan: Waymo, Nihon Kotsu - Tokyo launch announced for 2027



Level 4 - people mover

Switzerland: national L4 shuttle regulation since 2025

Germany: Holon - nationwide test permit, safety driver (AFGBV)

Norway: Ruter, Holo - Oslo pilot with ID. Buzz AD from 2026

France: Navya - 450 shuttle deployments in 30+ countries



Level 4 - freight and last mile

USA: Aurora - over 100,000 driverless truck miles in Texas

USA: Bot Auto - first humanless freight run, April 2026

USA: Einride - driverless on Texas highways since March 2026

USA, UK: Starship - over 9 million sidewalk deliveries, 270+ sites



Trend 2026: Mercedes and BMW have announced the withdrawal of their Level 3 offerings - the limit is the business case, not the technology.

Regulatory Framework

Safety and engineering standards



ISO 26262:2018 – functional safety
ISO 21448:2022 – SOTIF, safety of the intended functionality
ISO/SAE 21434:2021 – cybersecurity engineering
ISO 34501:2022 – ADS test scenario vocabulary
ISO 34502:2022 – scenario-based safety evaluation
ISO 34503:2023 – operational design domain specification
ISO 22133:2026 – test-object monitoring and control
ISO 19206 series – targets and test devices for active-safety testing
SAE J3016 – automation level definitions

Approval and market requirements



UNECE R157 – automated lane keeping systems
UNECE R155 / R156 – cybersecurity and software updates
UNECE R171 DCAS – driver control assistance systems
EU 2022/1426 – requirements for automated driving systems
MOLIT Level 3 safety standard
German AFGVB – Level 4 operation approval
Euro, US, CN, K NCAP – consumer assessment protocols
FMVSS (NHTSA) – US vehicle safety standards
FMVSS No. 127 – automatic emergency braking (from MY 2029)
KMOVSS – Korean vehicle safety standards

Standards define the required evidence; testing and reference systems make it measurable.

02

Testing and Validation Strategy

Combining virtual and physical testing for scalable evidence.

Safeguarding ADAS and AD Functions

No single method proves safety - the evidence comes from the combination.

Scenario-based testing

Functional, logical and concrete scenarios derived from ODD analysis;
ISO 34501 to 34504.



Simulation and X-in-the-loop

SiL, HiL, DiL and ViL for high coverage, repeatability and early fault injection.



Proving ground and road

Controlled manoeuvres with test targets plus real traffic complexity on public roads.



Statistical and formal proof

Field data, residual-risk assessment per SOTIF and a documented safety case.



Coverage, realism and statistical relevance can only be achieved together.

One Strategy, Different Test Environments



Simulation / Lab Testing

High coverage, repeatability

Proving Ground

Controlled scenarios, artificial environment

Public Road

Real operating complexity

No single environment is sufficient.

Simulation Moves the Test Earlier

SiL

Software

Algorithms and software only
No target hardware needed
Massively parallel testing



HiL

Hardware

Real ECUs or components
Stimulated sensor signals
Fault injection in real time



DiL

Driver

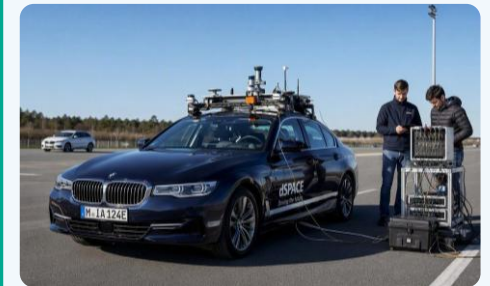
Real driver at the wheel
Simulated vehicle
Simulated environment
Takeover and HMI behaviour



ViL

Vehicle

Complete vehicle, real track
Simulated environment
Stimulated sensors or ECUs



Increasing scalability ←

Increasing physical realism →

Simulation Is Powerful, but Not Self-Sufficient

What simulation provides



Repeatability



Large scenario coverage



Safe testing of critical cases



Early availability



Efficient regression testing

What must be demonstrated in reality



Model validity



Sensor behavior



Environmental complexity



System integration



Transfer to physical behavior

Simulation results are only as reliable as the models and assumptions behind them.

Proving Grounds Deliver Controlled Reality



Controlled

Defined conditions and scenarios

Repeatable

Comparable test runs

Safe

Critical maneuvers under control

Measurable

Precise reference data

Public Roads Add the Unexpected



Natural Road Users

Unscripted behavior in real traffic

Real Infrastructure

Roads, signs and markings as built

Weather and Lighting

Changing environmental conditions

Unexpected Combinations

Rare and unplanned situations

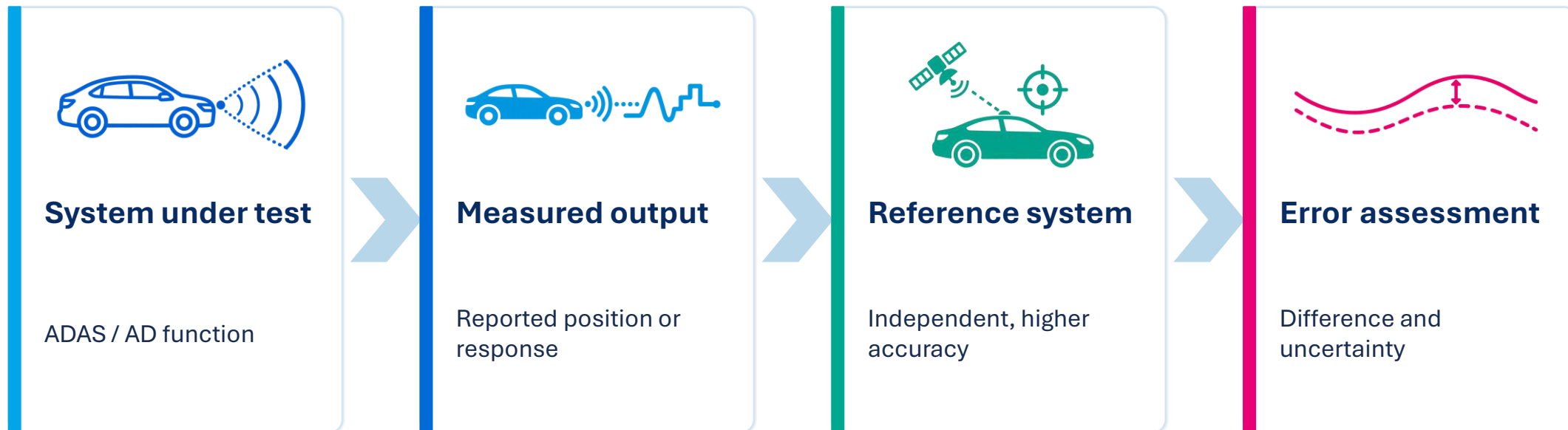
But realism without reliable reference data is not enough.

03

Reference Systems

Objective assessment starts with an independent reference.

Reference Systems Make Performance Measurable



The Reference must be independent, time-synchronized and sufficiently more accurate than the system under test.

Ground-Truth with GNSS and Inertial Measurement



Inputs

- GNSS
- Inertial sensors (accelerometer, gyro)
- Vehicle or auxiliary signals



Kalman Filter

Real-time sensor fusion



Outputs

- Acceleration and angular rate
- Position and velocity
- Roll, pitch, yaw and heading angle

Highend Navigation Solution



GYROSCOPES
ROTATION



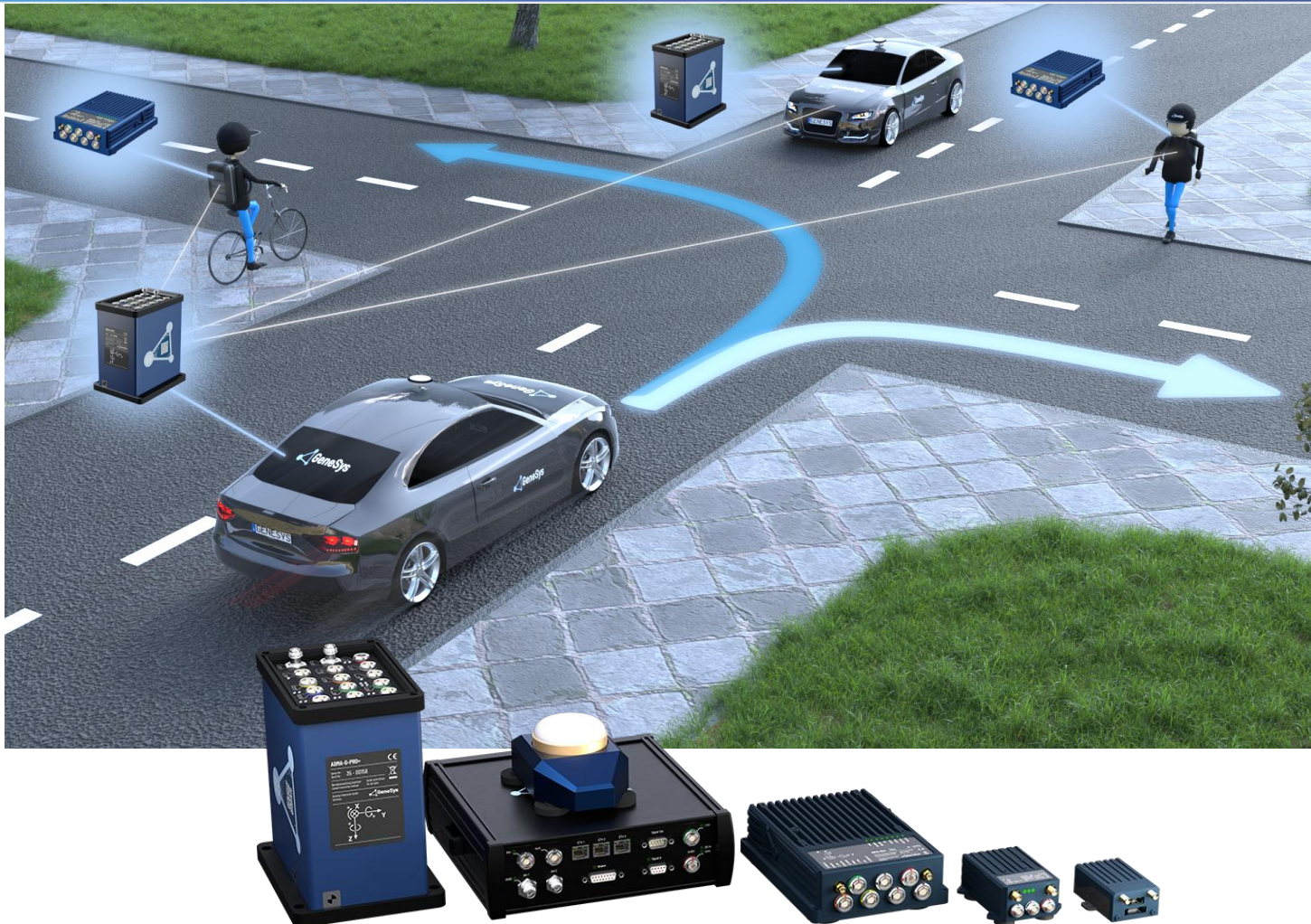
ACCELEROMETERS
MOTION



GNSS-RECEIVER
ABSOLUTE POSITION



Different ADMA Models for Different Requirements



Requirements

Every application has its own demands on dynamics, installation space and integration.

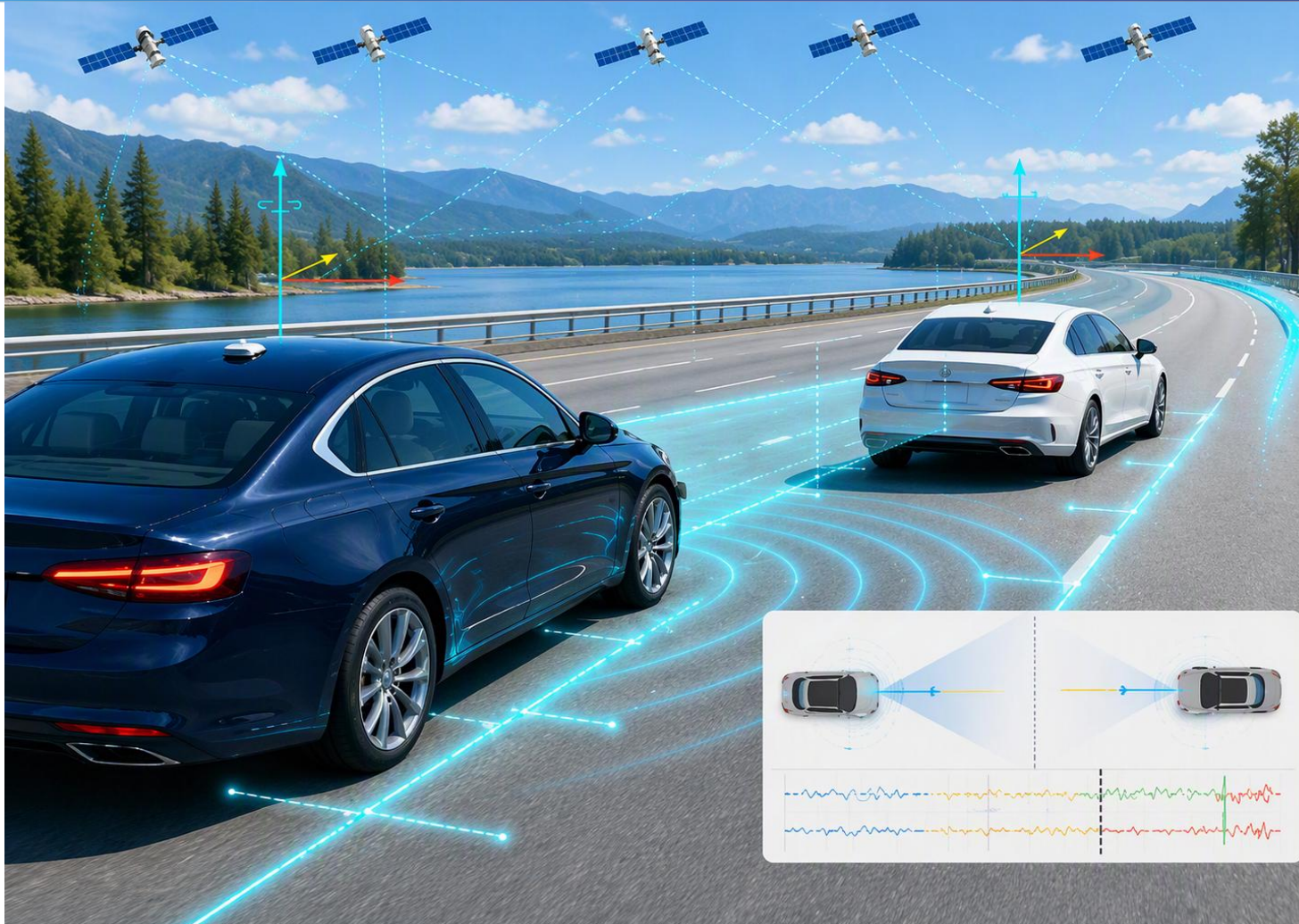
Accuracies

The model range scales from highest reference accuracy to compact measurement solutions.

The Right Fit

Together we find the ADMA model that matches your use case.

ADAS Testing Requires Relative Ground Truth



Relative distance

Relative speed

Relative heading

Synchronized motion in Real-time

Typical applications

Car to car: ACC • AEB • cut-in / cut-out • lane-change scenarios

Car to line: LDW • LKS control behavior assessment

Key Components for ADAS Testing



Driving robots

Steering, accelerator and brake control



Moving-target platforms

Overrunable carriers for soft targets



VRU dummies

Pedestrian, cyclist and motorcycle targets



Control station & software

Scenario control and live monitoring



Motion pack (GNSS/INS)

Position, speed and orientation



Communication network

Wireless links between test objects

AI-generated illustrations — equipment categories, not specific products.

Key Components for ADAS Testing



Validation Does Not End with Vehicle Motion



Visual warnings

Icons, telltales and display messages

Acoustic warnings

Onset, duration and sequence

Time correlation

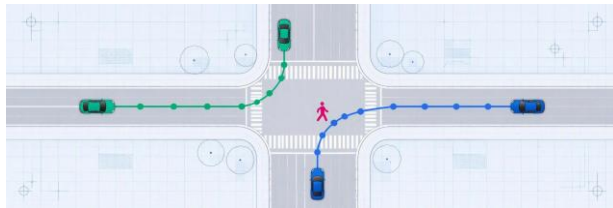
Link HMI events to vehicle behavior

SensorX turns driver/passenger information into objective, synchronized measurement data.

From Test Scenario to Objective Result

Define scenario

Vehicles, trajectories and trigger conditions. Edge case identification



 ASAM OpenSCENARIO & OpenDRIVE,
IPG Scenario Editor

Measure

Simulate

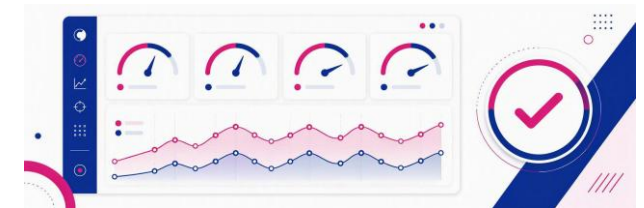
Time-synchronized motion and system response.



 IPG CarMaker, dSPACE ASM/AURELION,
Vector CANape, ETAS INCA,
GeneSys ADMA & SensorX,
Driving robots and soft targets from 4a
ABD, Humanetics, Stähle

Assess

KPI definition and evaluation: reaction time, deviation and safety margin



 MdynamiX MXeval,
Vector CAN-OE

reproducible evidence instead of subjective impressions builds confidence for commercialization.

Key Performance Indicators for ADAS and AD

KPI area	Representative metrics
 Perception & sensors	Precision / recall / F1, false detections, track loss / ID switches Object position / velocity error, lane boundary error
 ADAS functions	LKA: lateral error ACC: gap / speed error AEB: impact speed / TTC Parking: success rate, minimum clearance, manoeuvre time
 Automated driving	Trajectory tracking error, goal completion, rule violations Conflict resolution time, critical situations
 Safety & fallback	Critical event / dangerous failure rates, safe-stop success Minimum TTC / PET, L3 takeover success and completion time
 Ride comfort	Longitudinal / lateral acceleration, jerk Unnecessary braking, passenger comfort rating
 ODD & test coverage	Scenario, ODD, requirement and code coverage Weather, lighting, road classes and regions within a defined test space
 L4/L5 operation	Collisions, critical events and disengagements per distance Mean distance between failures / disengagements

KPIs definition: What to measure and what counts as a pass.

Selected references: Euro NCAP, nuScenes, ISO 34502, UNECE, de Gelder et al. (2025), Ronchi et al. (2026). Details in notes.

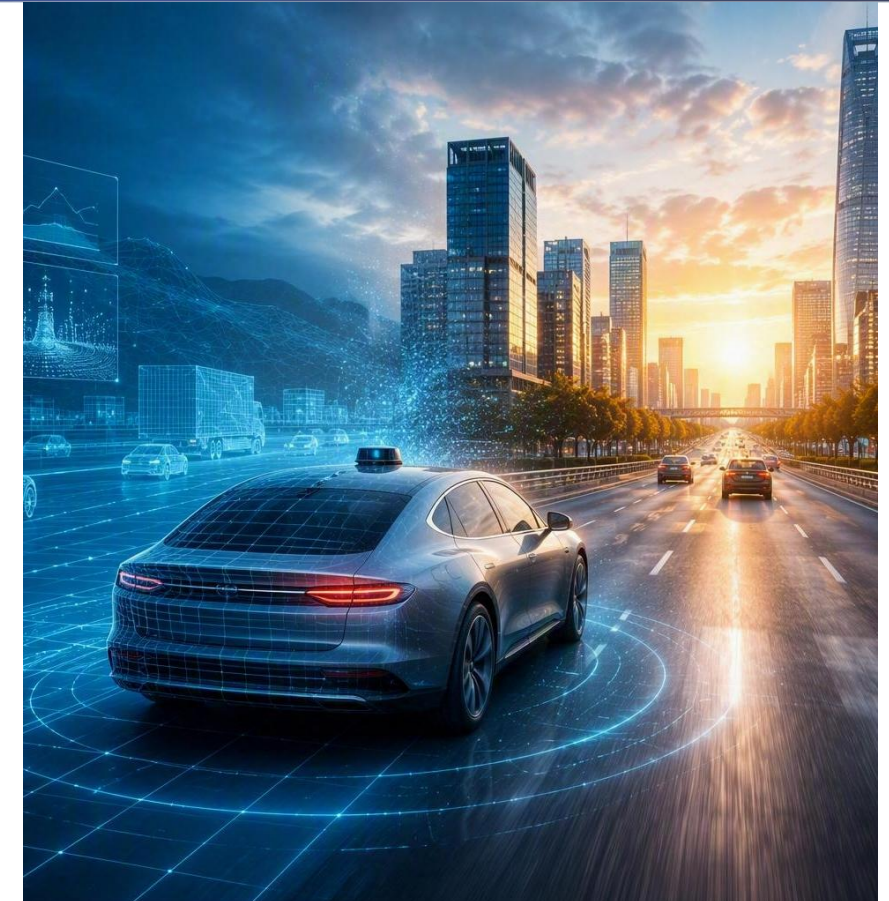
04

Conclusion

From reliable measurement to commercial readiness.

Four Takeaways

- 1 **Scenario definition must match the intended operating domain.**
- 2 **Simulation, track and road tests provide complementary evidence.**
- 3 **Synchronized reference makes motion and HMI responses measurable.**
- 4 **Release decisions need defined KPIs and thresholds for reaction time and safety margins.**



Independent reference measurements provide reproducible evidence for a credible safety case.

Thank you

Questions and Discussion

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