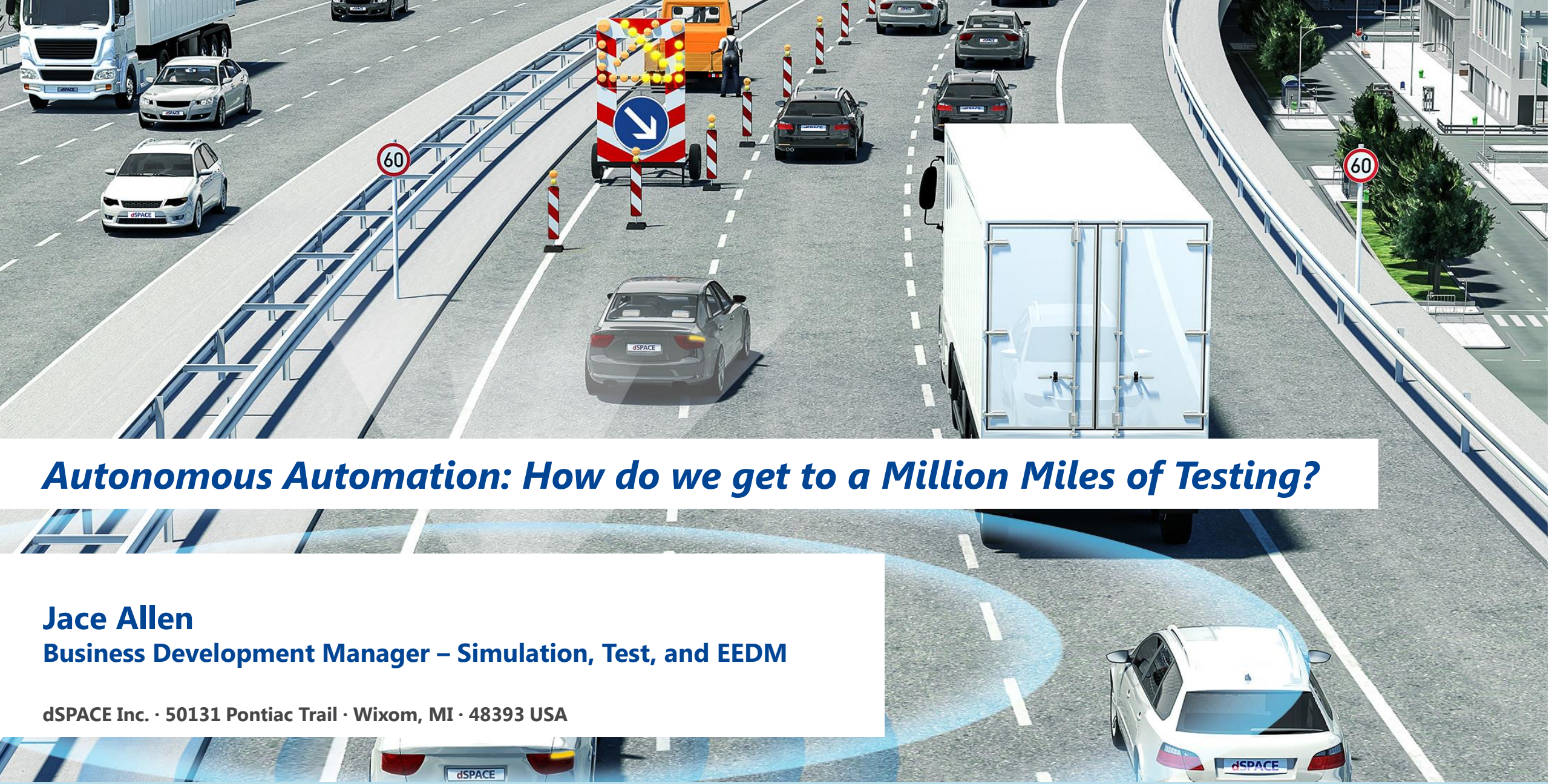


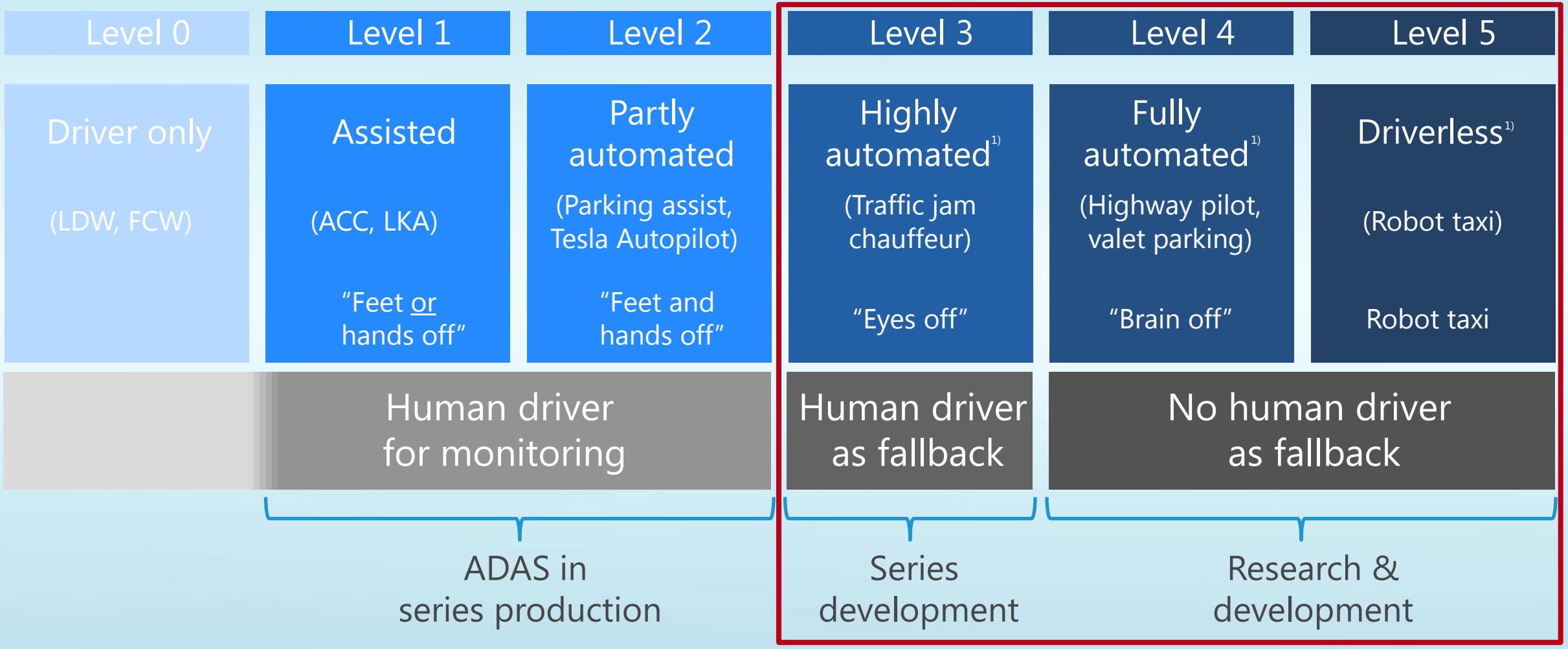
Autonomous Automation: How do we get to a Million Miles of Testing?

Jace Allen

Business Development Manager – Simulation, Test, and EEDM

dSPACE Inc. · 50131 Pontiac Trail · Wixom, MI · 48393 USA

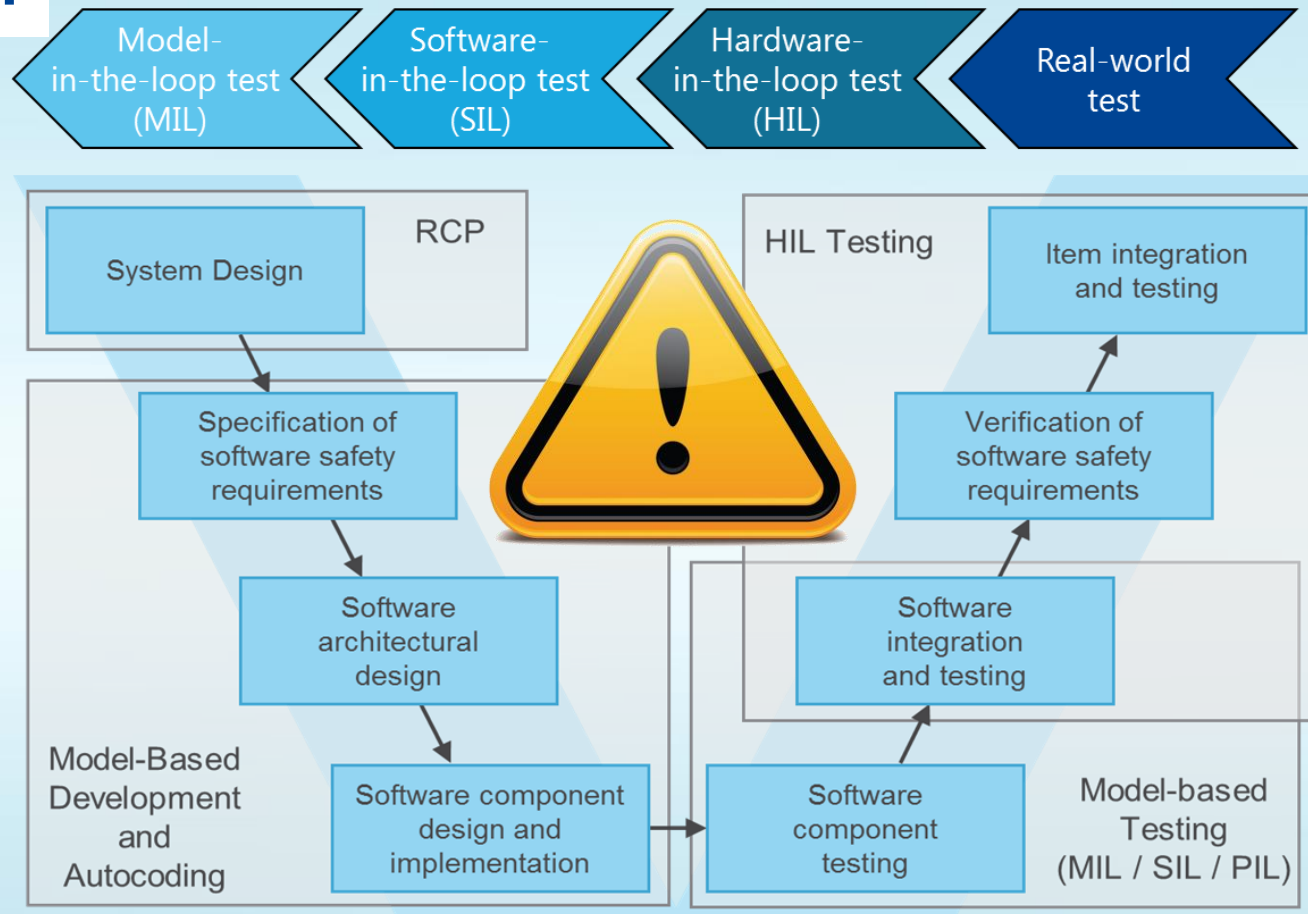
Trends – The vision of autonomous driving becomes reality …



1) Automation levels according to German Association of the Automotive Industry (VDA)

Validate System Behavior with Simulation

- MBD Testing = Simulation at <u>All Levels</u>
- Advantages of simulation: reproducibility, test beyond performance/endurance limits and dangerous situations
- ISO 26262 recommends MIL/SIL/HIL simulation for conducting the software safety requirements verification
- What changes with testing Autonomous Vehicles?



KEY ISO26262 References

- Testing of safety requirements needs to be planned, specified, executed, evaluated and documented in a systematic manner (8-9.2)
- MIL, SIL, HIL testing and simulation recommended for Software Unit Testing (6-9), Software Integration Testing (6-10), Verification of Software Safety Requirements (6-11) and Item Integration and Testing (4-8)

ISO 26262

Challenges – Changing validation process

- Vehicle, driver, sensors
- Road, road networks
- Traffic, roadside structures
- Environmental conditions (weather, …)
- Driving maneuvers
- …

Traffic scenarios
(critical, representative, …)
Scenario databases, …

Data & test management
Models, parameters, tests, test results, …

Support of open file formats and standards

Automated test execution, test evaluation and control

- Defined scenarios
- Stochastic parameter variation
- Test control to detect critical scenarios based on metrics and evaluation criteria

Requirements-based testing not sufficient

Virtual test drives – MIL/SIL simulation

Virtual test drives – HIL simulation

Real test drives

Virtual ECUs

PC cluster

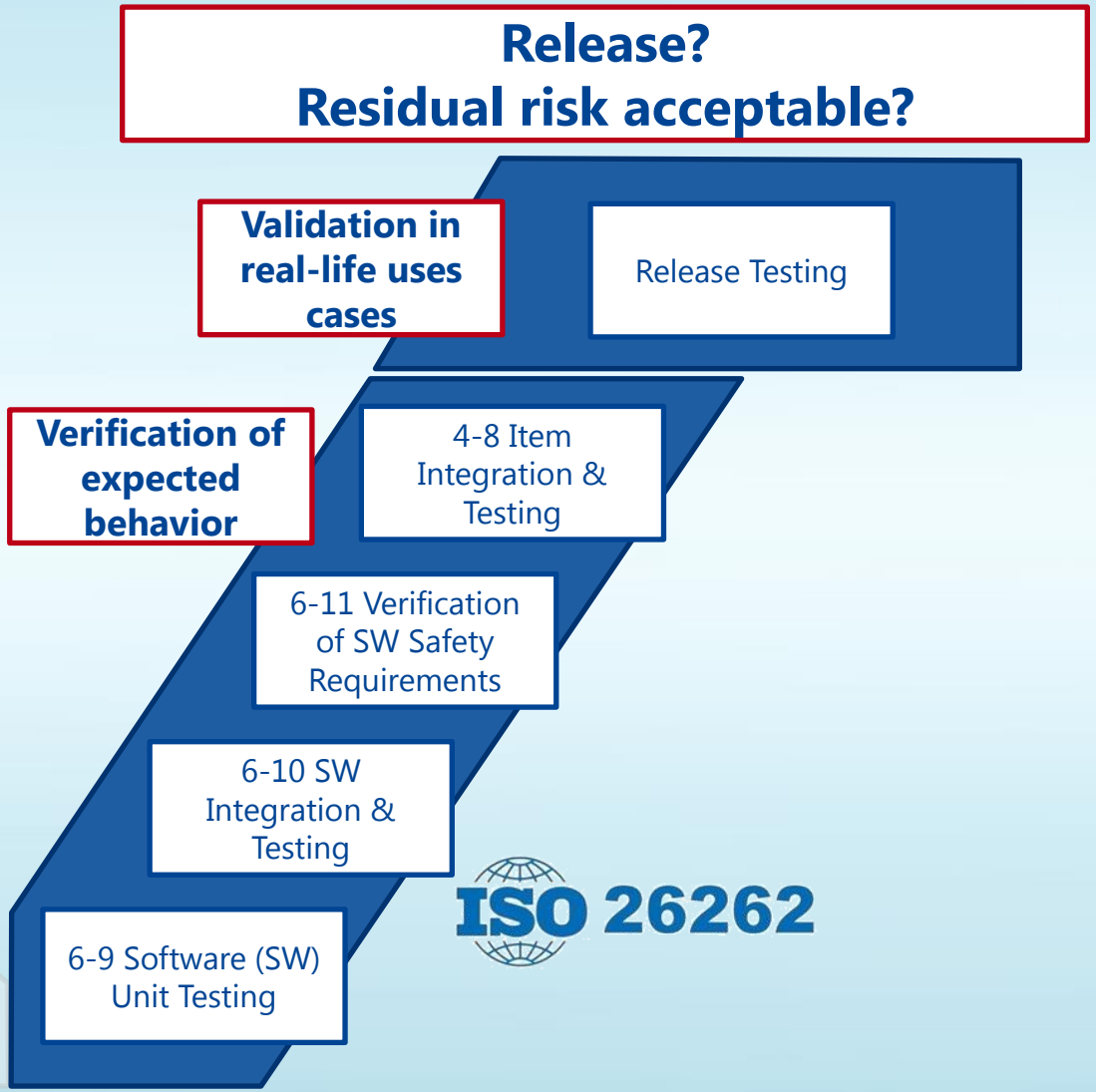
Real ECUs

Sensing the Environment?

- Acceptable level of system safety?
- Reducing unreasonable risk

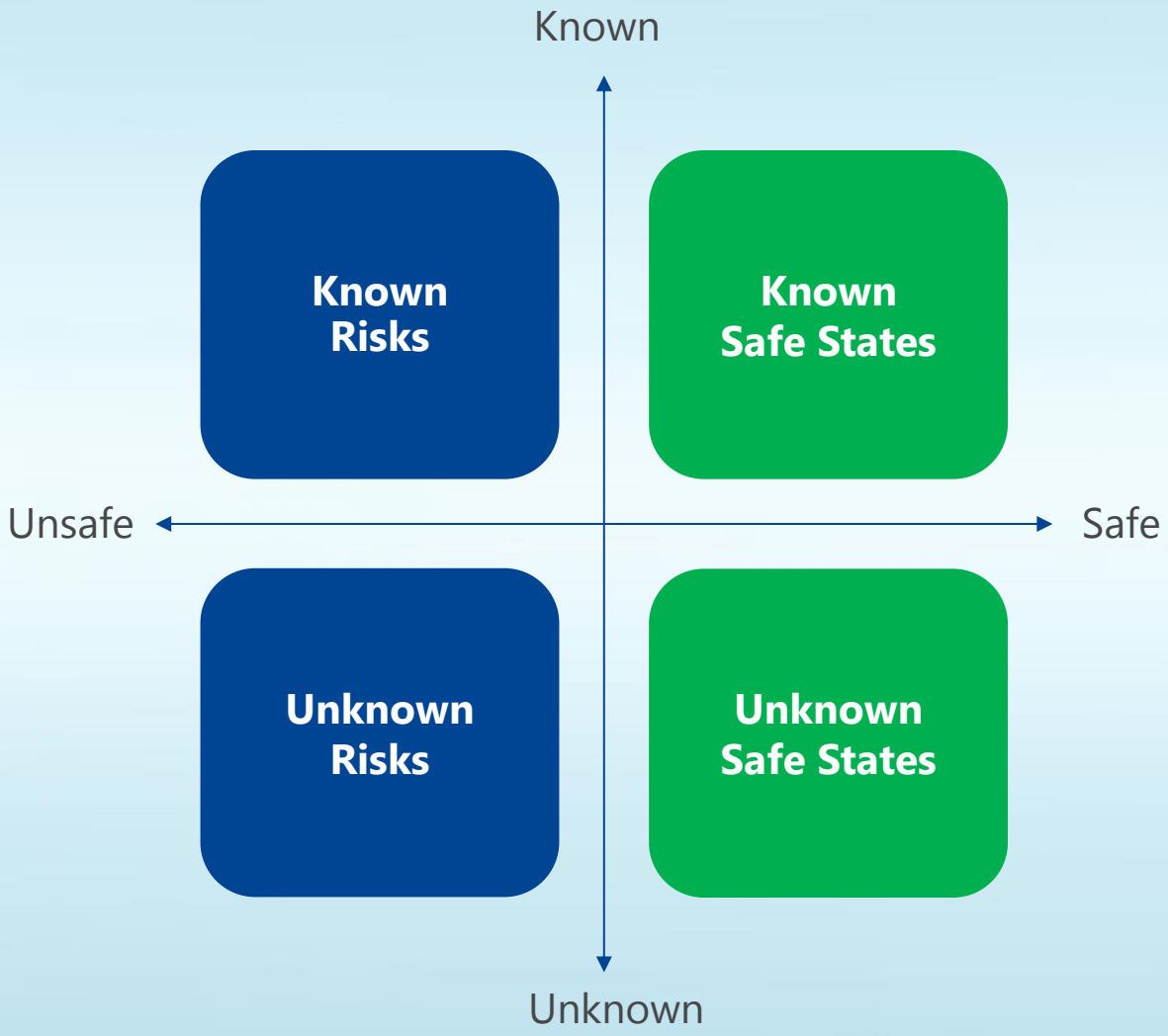
- If the system senses the environment hazards are caused by the environment – OR -
  - In contrast to faults coming from the software or hardware
  - Insufficient sensors or the inability of machine learning algorithms to comprehend the situation

- **Verifying the expected behavior with regard to influences from the environment**
- **Validating the functionalities in real-life use cases**



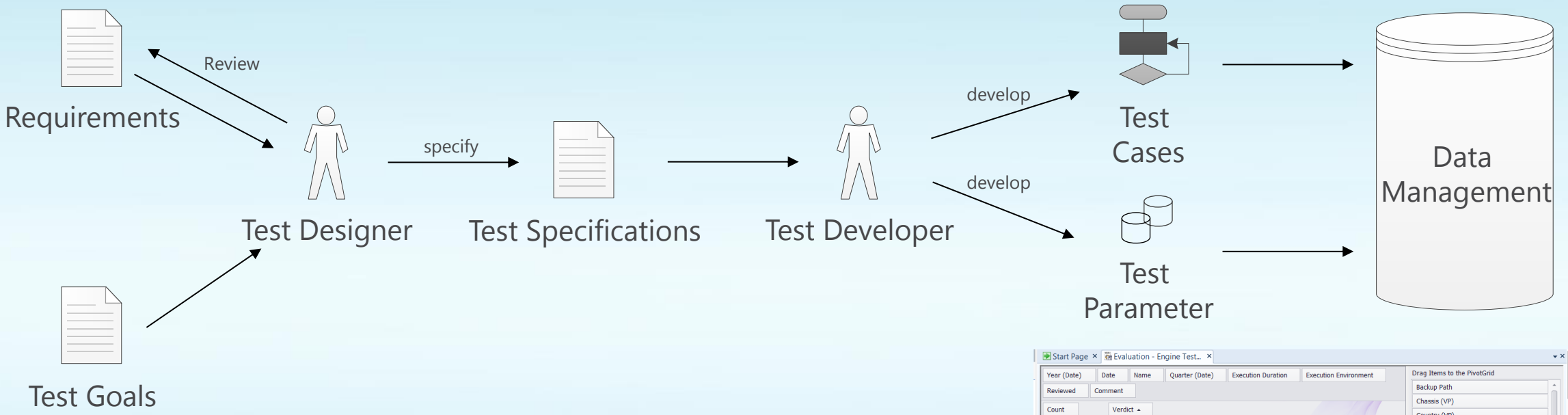
Evaluation of the residual risk

- Evaluating known risks by requirements-based testing
- To evaluate the residual risk you have to validate the Unknown Risks



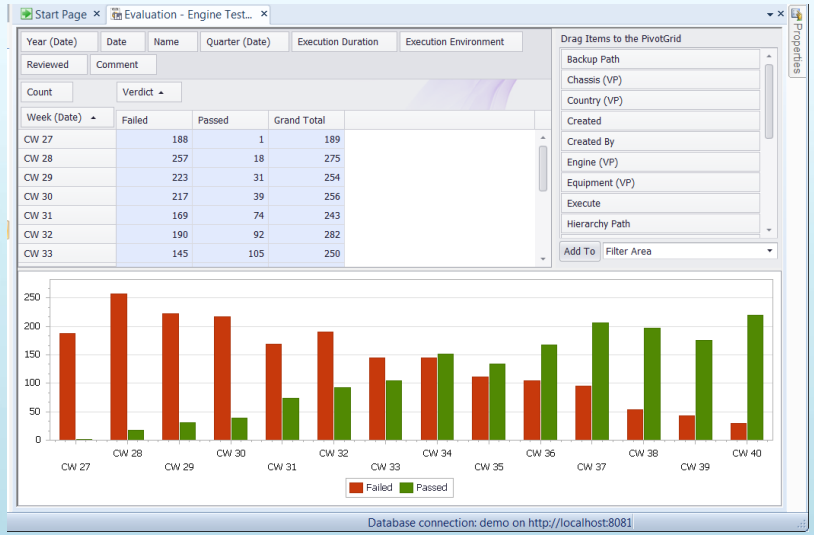
- **Evaluation of the residual risk demands a suitable combination of testing approaches**
  - **Requirements-based testing**
  - **Scenario-based testing**

Verifying the Known Risks

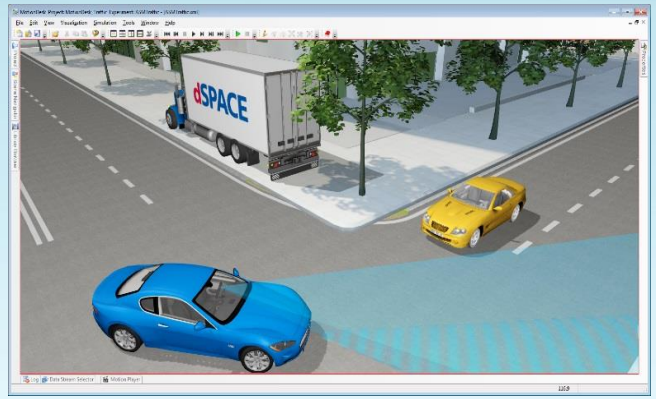


- Bidirectional traceability from requirement to test case
- Test coverage metrics are established
- Software tools supporting static and dynamic testing
- The ISO 26262 has to be considered

- **But what changes to evaluate the Unknown Risks?**



Validating the Unknown Risks



Top Level Requirements

specify

Test Designer

Logical Scenario

Test Developer

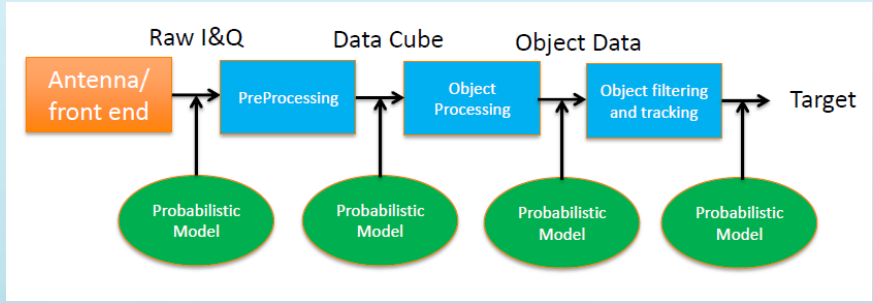
develop

Simulation Scenarios

Use Cases

Scenario Parameters

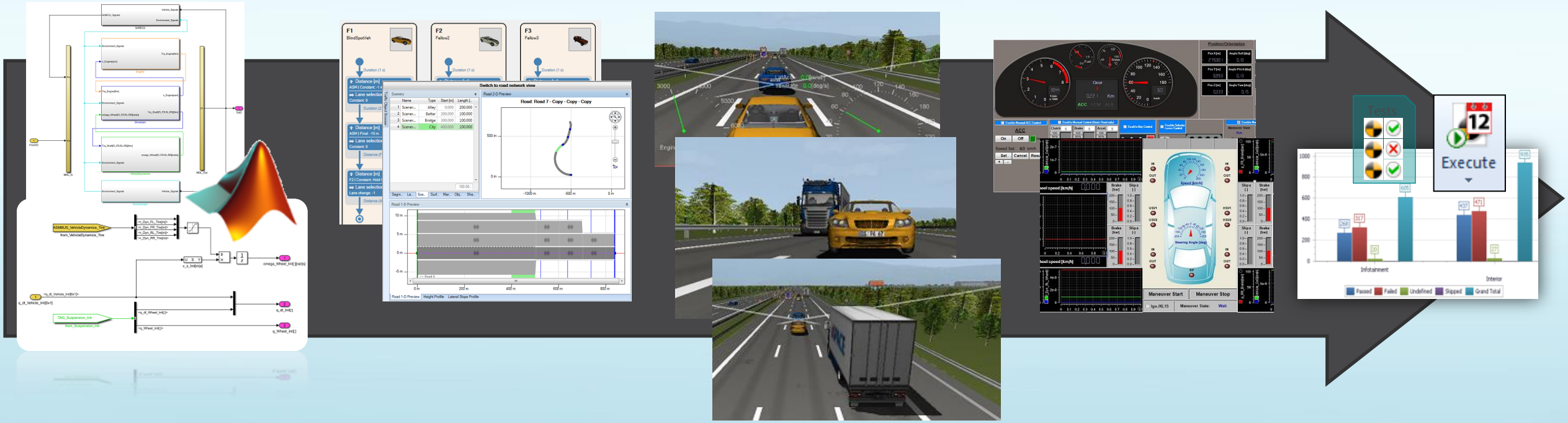
Utilize probabilistic approaches to expand scenario coverage and automate test development



ADAS/AV TESTING TECHNOLOGY

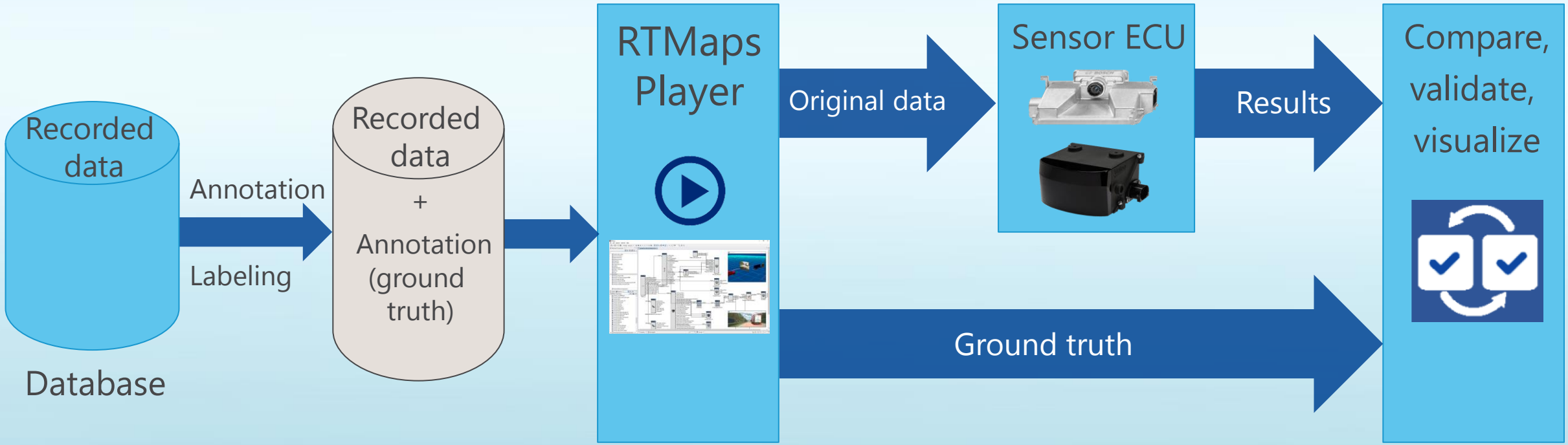
dSPACE Solutions: A Powerful Simulation Toolchain

Simulate Models → **Test Scenarios** → **Visualize Maneuvers** → **Control & Experiment** → **Test Management**

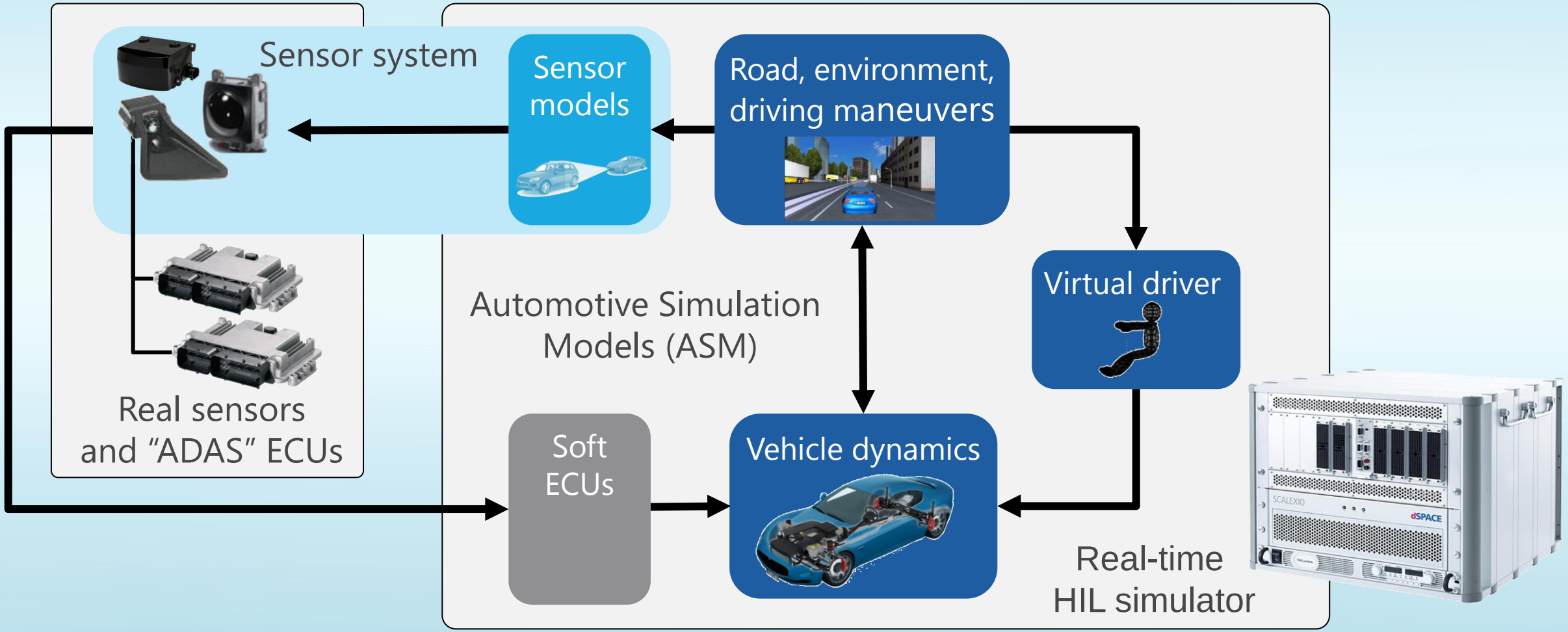


Open-Loop Data Play Back Tests

Validation of camera and lidar ECUs – Playing back recorded data



Closed-loop HIL Simulation



Automotive Simulation Models (ASM)

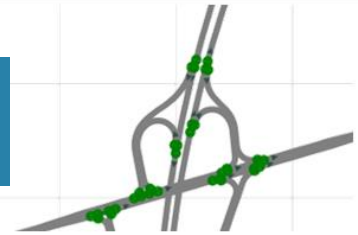
Vehicle Dynamics

Vehicle simulation
- Vehicle Dynamics
- Drivetrain
- Soft-ECU network
- Driver model
- Maneuver

Traffic Objects
- Vehicles, pedestrians
- Traffic signs
- Parking vehicles

Traffic

Environment

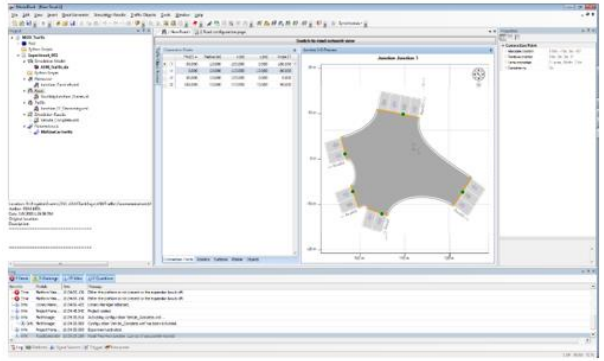


Road networks
- Roads and intersections
- Lane support
- Artifical/ real world roads
- Road import
- Roadside obstacles

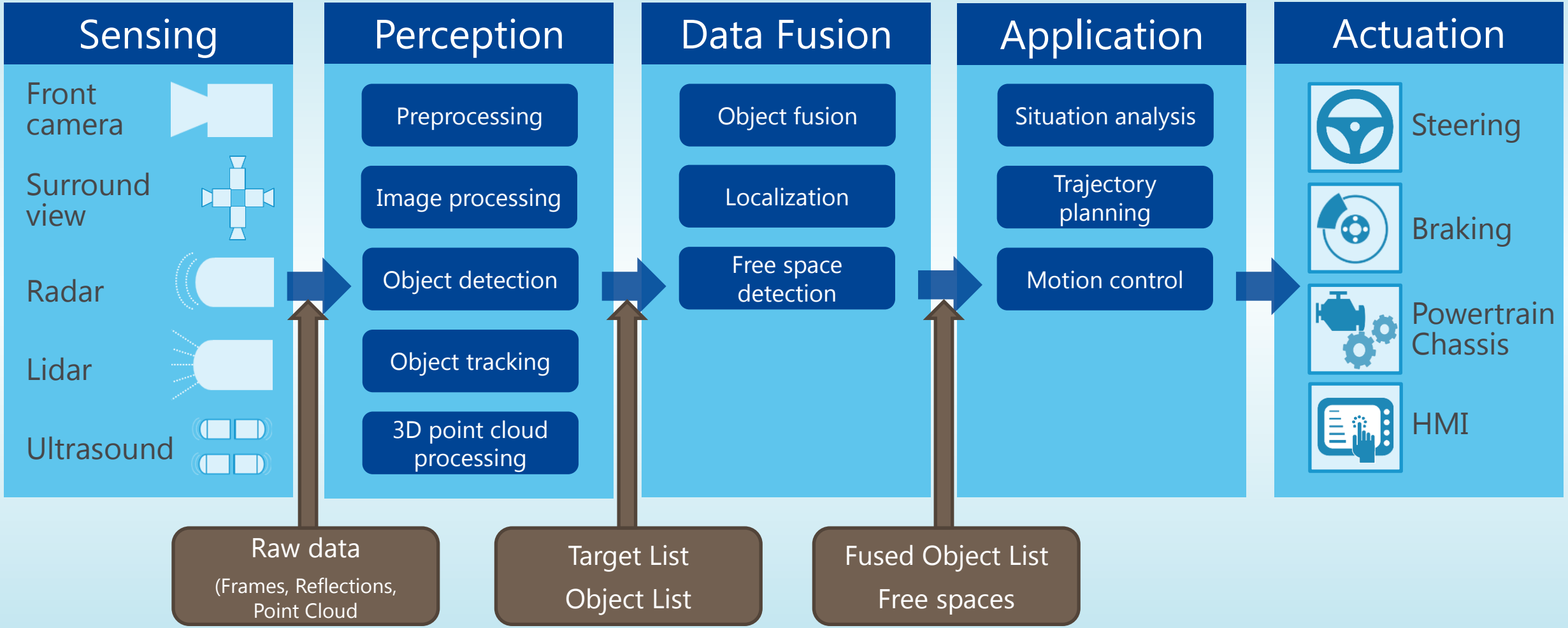
Traffic Sensors
- 2-D/3-D sensors
- Camera, radar, lidar
- Traffic sign recognition
- Object list simulation

MotionDesk
Animation

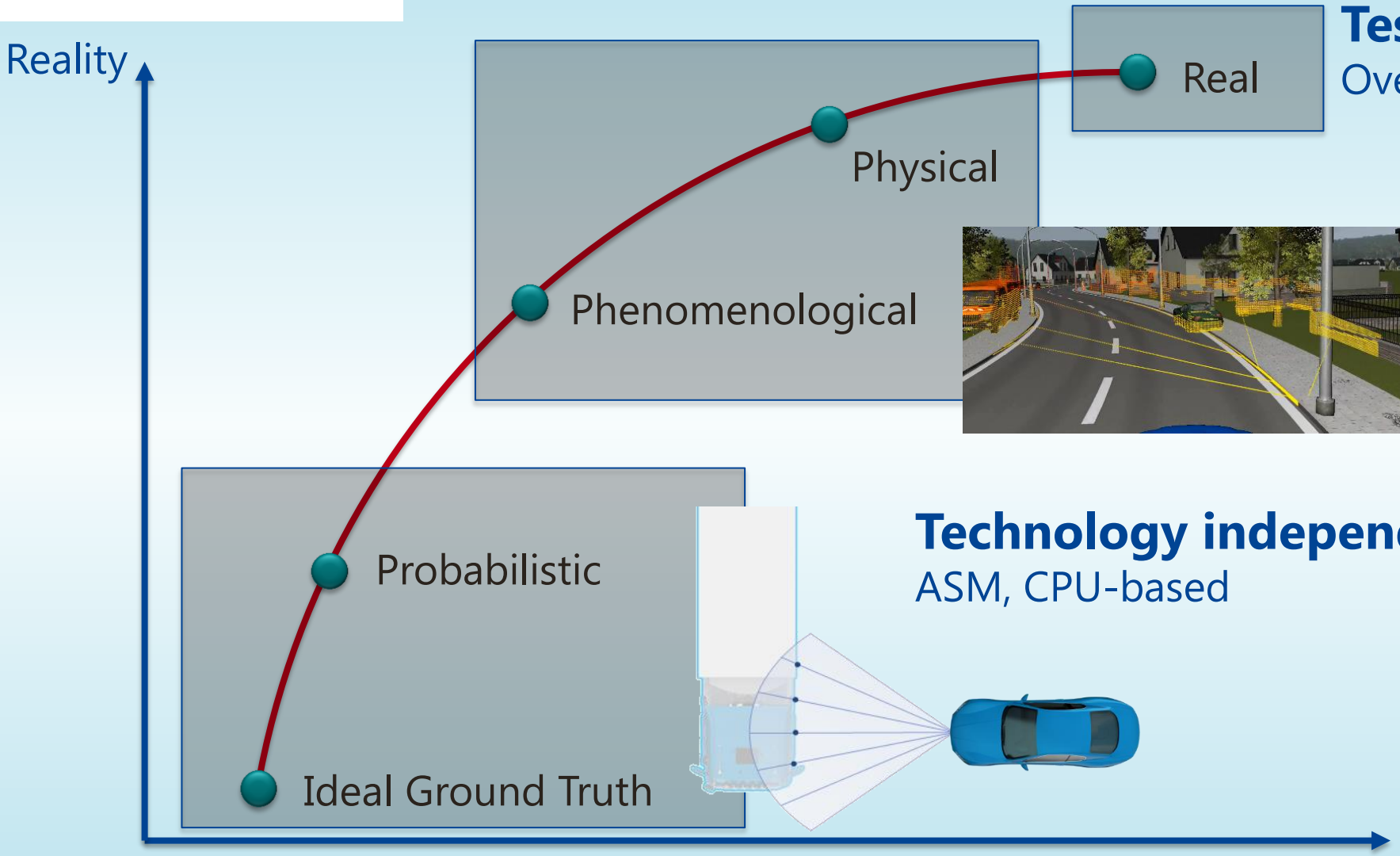
ModelDesk
Parameterization



Testing autonomous driving – Sensor model architecture



Sensor Models



Test Bench
Over the air (OTA)

Physics-based models
MotionDesk, GPU-based

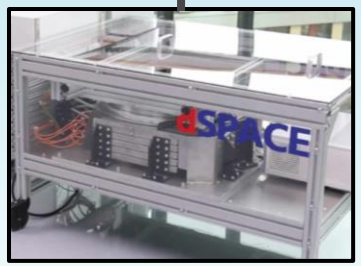
Technology independent models
ASM, CPU-based

Simulation over-the-air (OTA): Overview

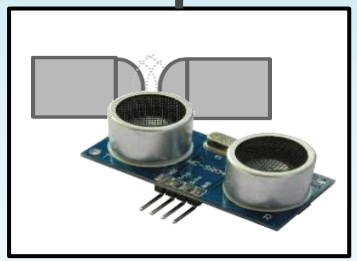
HDMI, ETH

- Scene generation
- Vehicle models
- Sensor simulation

Cinema Setup

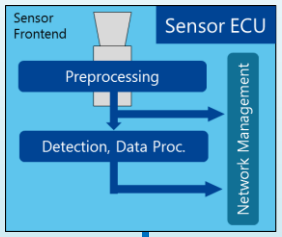


Automotive Radar Scene Generator

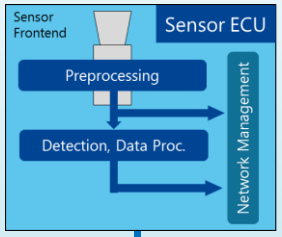


UltrasonicSensorSimulation (USS)

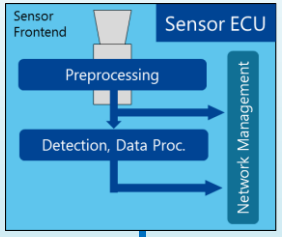
Camera



Radar



Ultrasonic



Vehicle network
(CAN, ETH, FLX, etc.)

ADAS Domain Controller

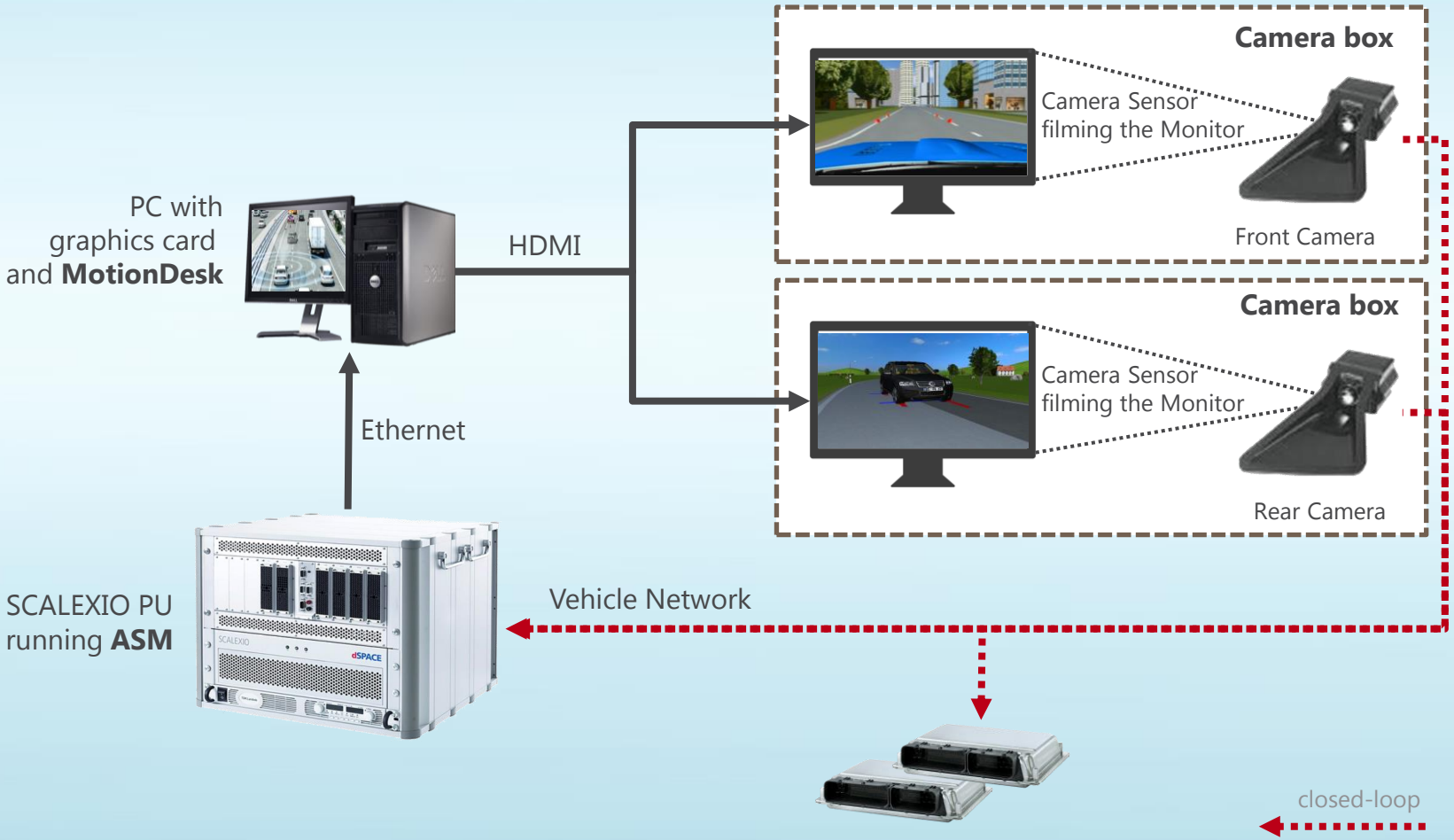
Simulation over-the-air (OTA): Camera

Typical applications:

- Lane departure warning
- Lane keeping assist
- Traffic sign recognition

Benefits:

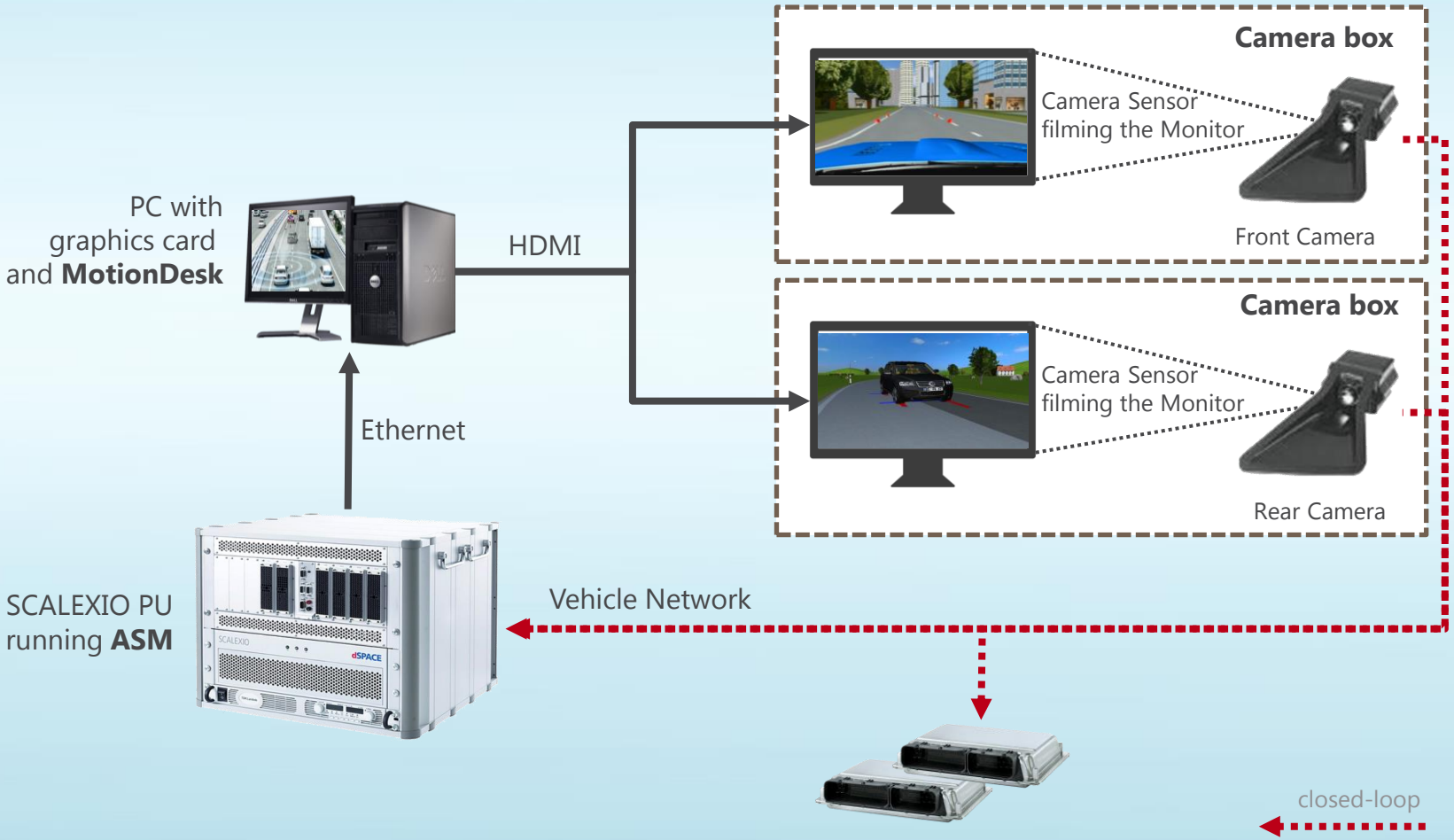
- Original, non-modified ECU
- Easy to configure
- Cost efficient



Simulation over-the-air (OTA): Camera

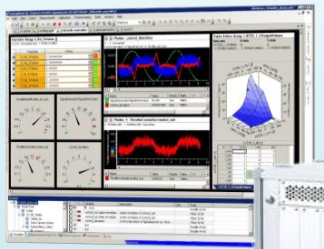
Challenges:

- Limited contrast by monitor (night, glare conditions)
- Distortion caused by lenses (e.g. fish eye)
- Complex setup with stereo or multiple cameras
- Dirt within the optical path
- Pixel errors

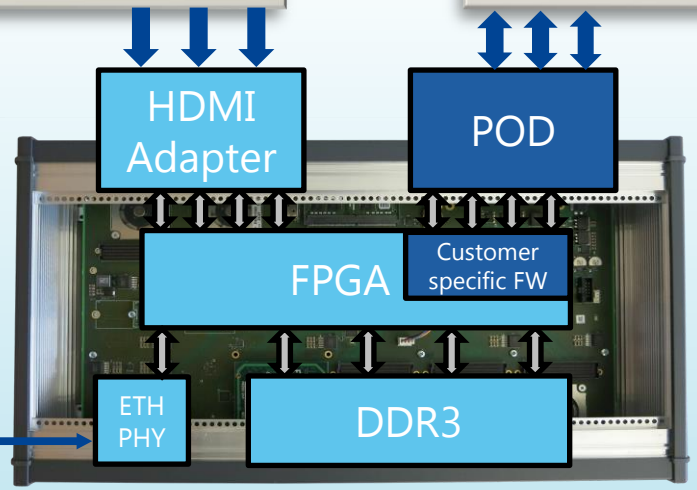


Closed-loop HIL testing of multiple camera based systems

Configuration/
Automation



- ROI adjustment
- Exposure control
- Monochrome sensor
- Failure insertion

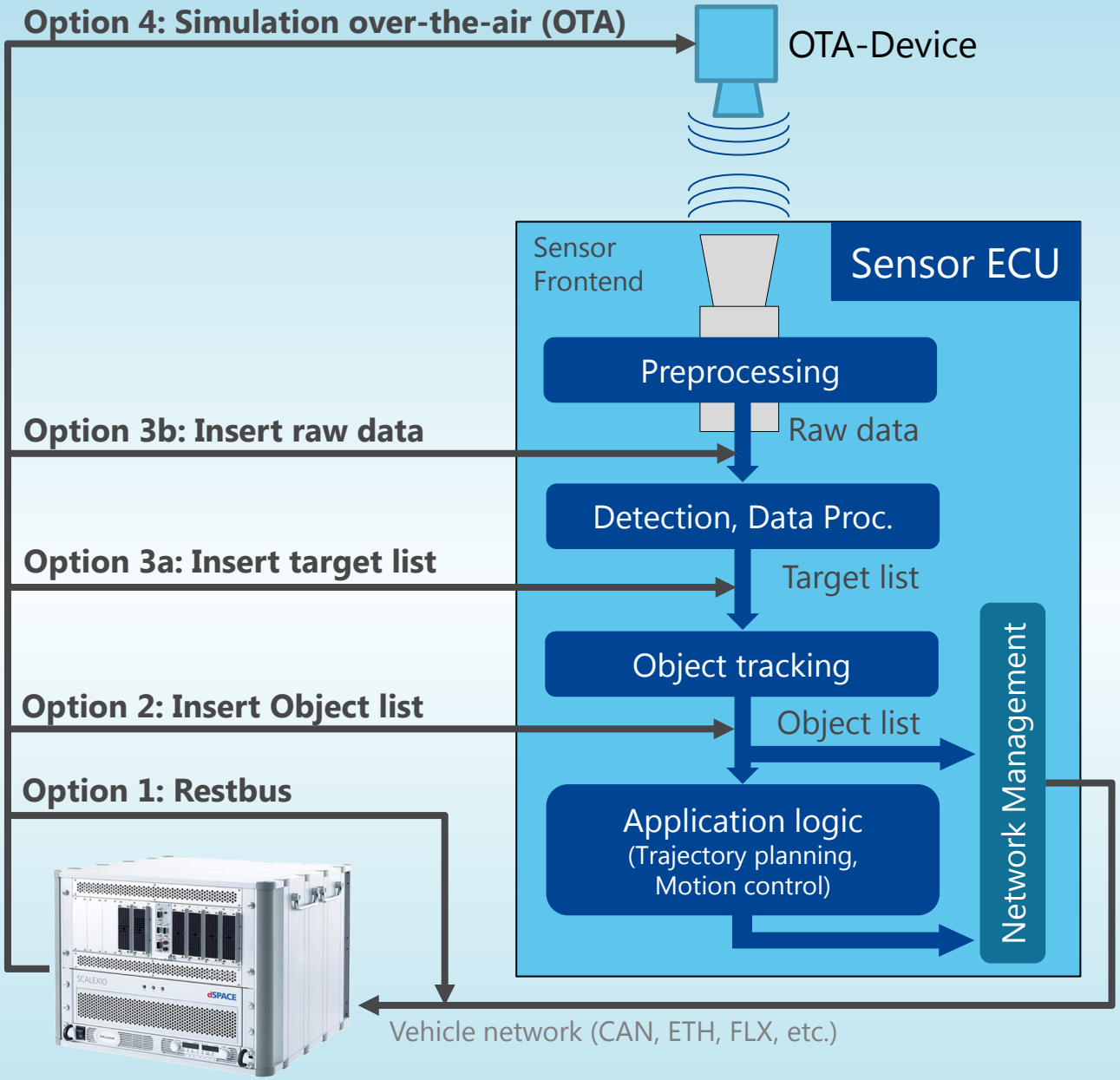


Environment sensor
interface unit

ROI: Region of interest

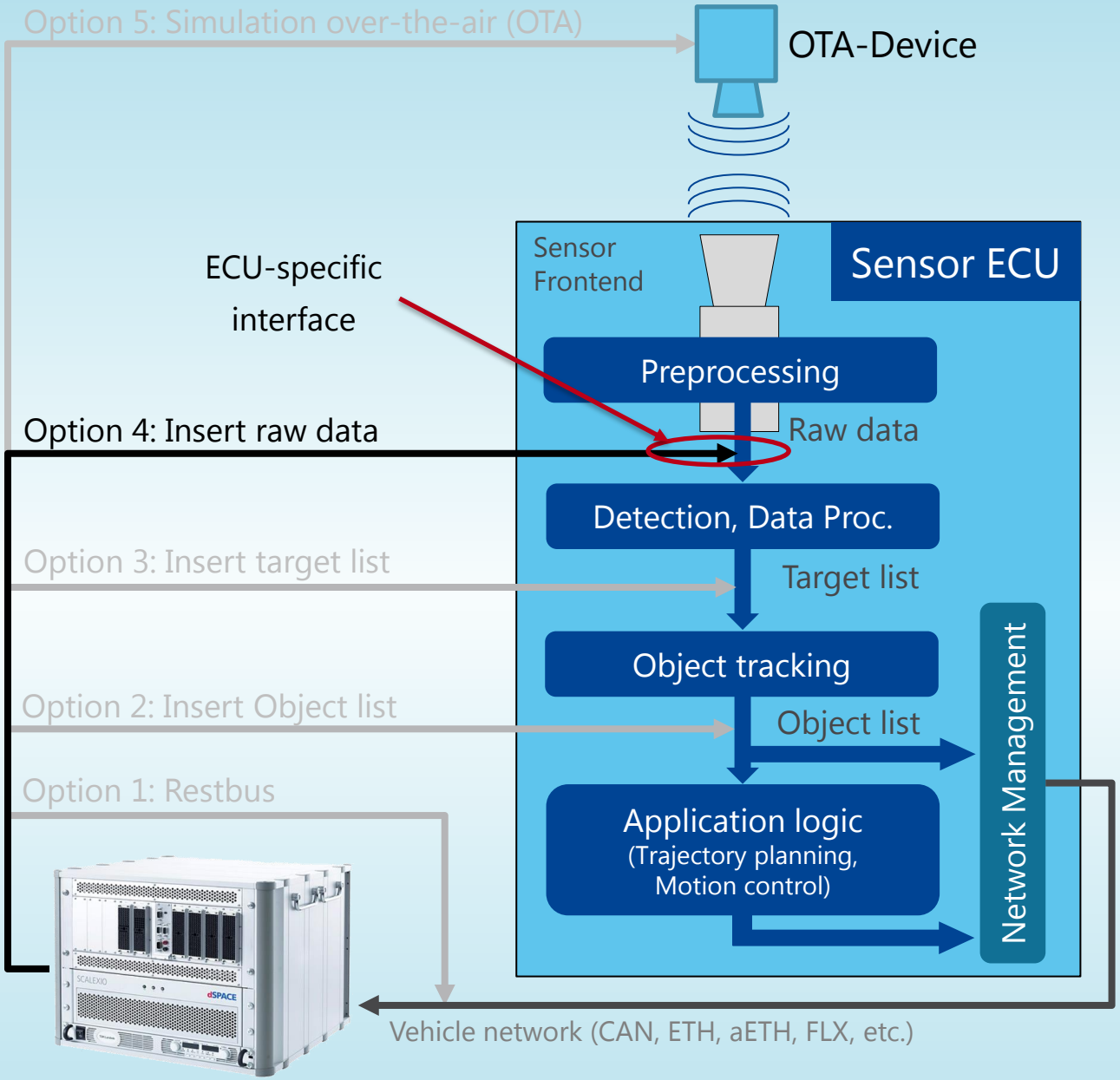
Sensor integration options

- **Technology independent options (1 & 2)**
  - Ideal ground truth and probabilistic based information
  - Part of ASM (calculated on CPU)
- **Physics-based options (3a & 3b)**
  - More related to the measurement principle of a sensor
  - „Raw data injection“
  - Part of MotionDesk SensorSim (calculated on GPU)
- **Simulation over-the-air (4)**
  - Test Bench with real Sensor ECU



Raw Data Generation for Cameras – HIL testing of Sensor ECU's

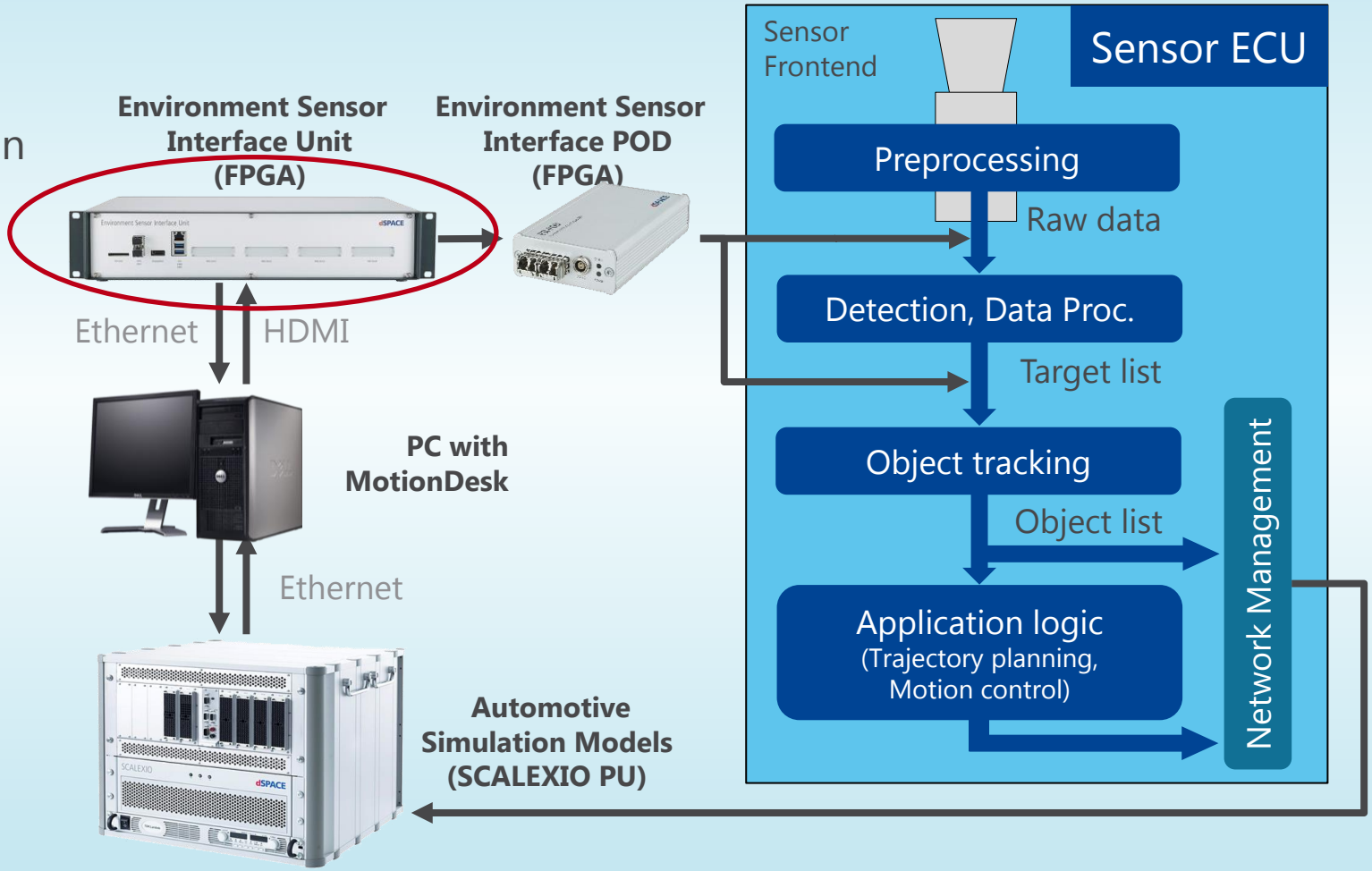
- Insert video frames between the imager and the microcontroller of the camera ECU
- A „stimulus" interface is required (similar to bypassing)



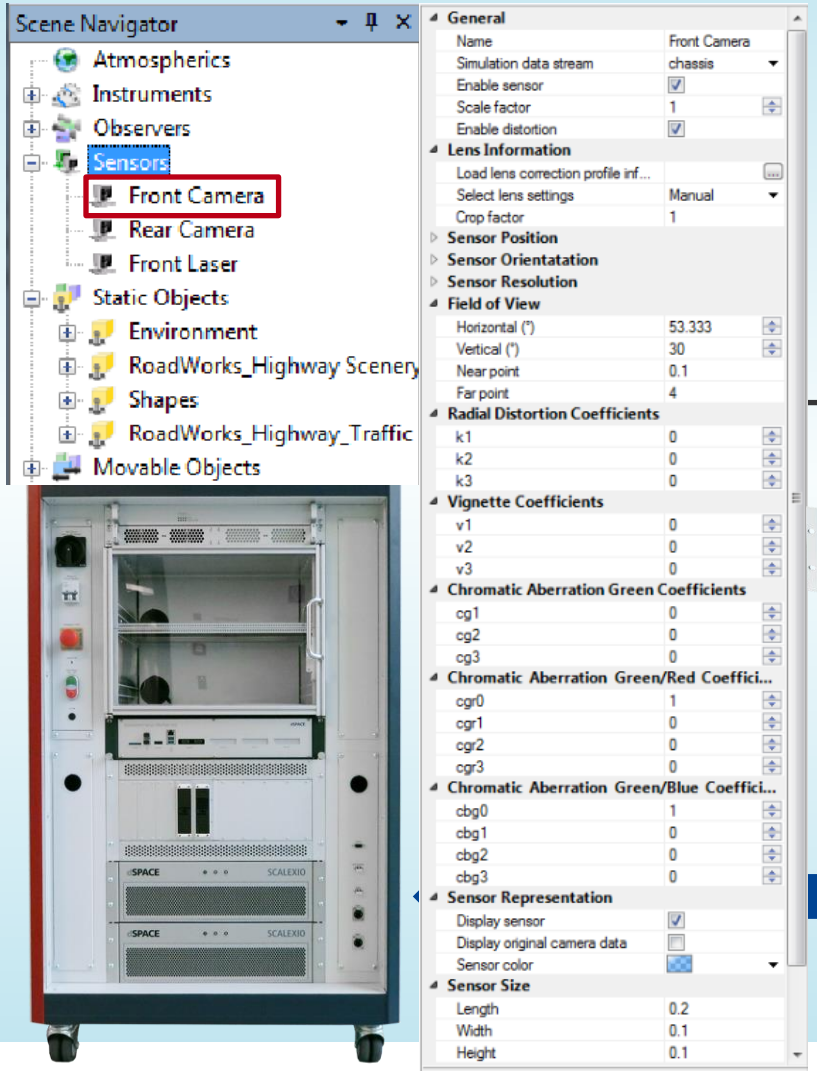
Raw Data Generation for Cameras – HIL testing of Sensor ECU's

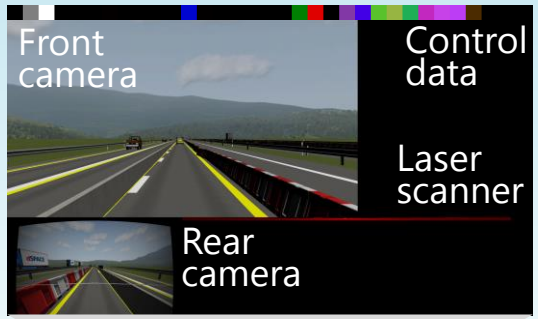
- Synchronously feed multiple sensors with low latency
  - Powerful Single source dSPACE tool chain
- GPU-based PC sensor simulation
  - dSPACE MotionDesk
- Raw data generation
  - High-performance FPGA
  - Sensor ECU adaptation
- Ability to adapt HDMI to camera ECU protocols – Pods, Open I/Fs

- **Modify Sensor Data On-the-Fly**



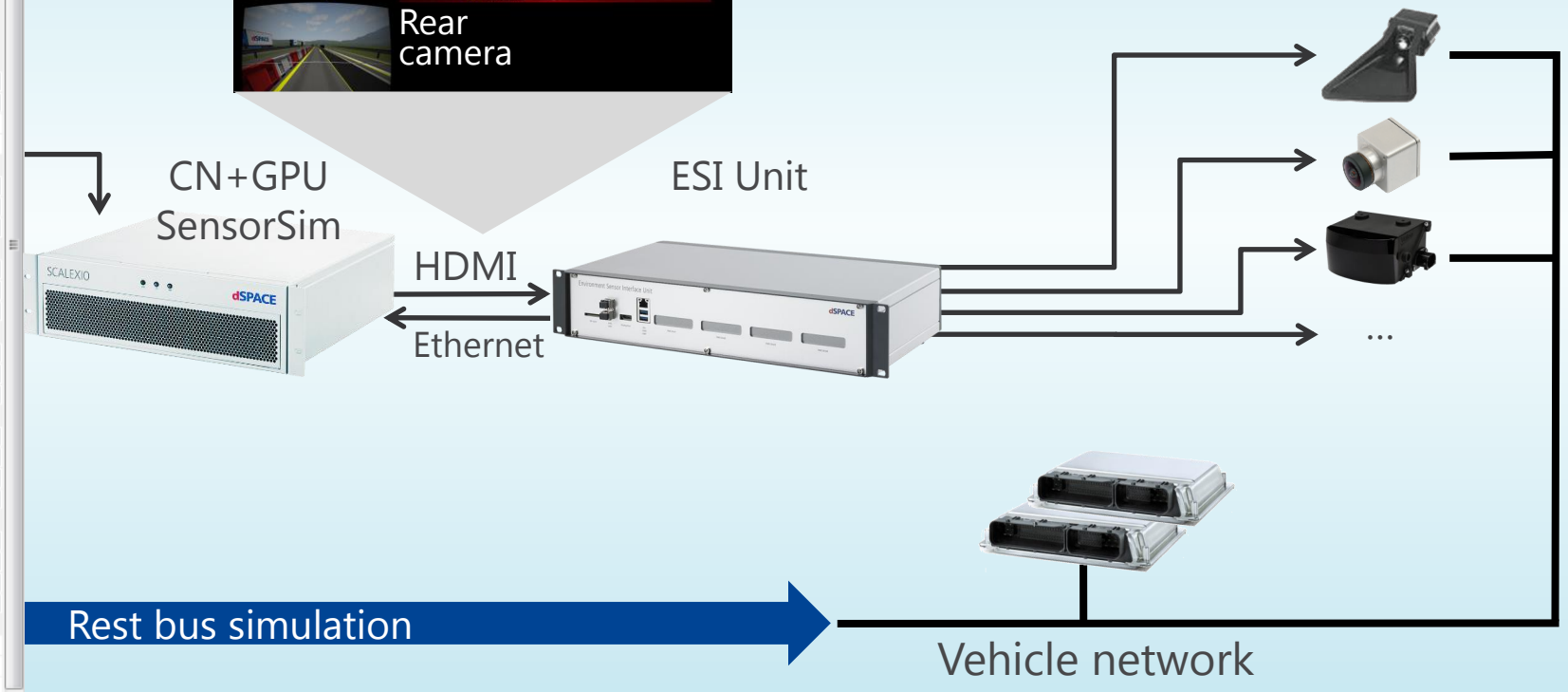
Raw Data Generation: Multiple sensor models (Camera, Radar, Lidar)





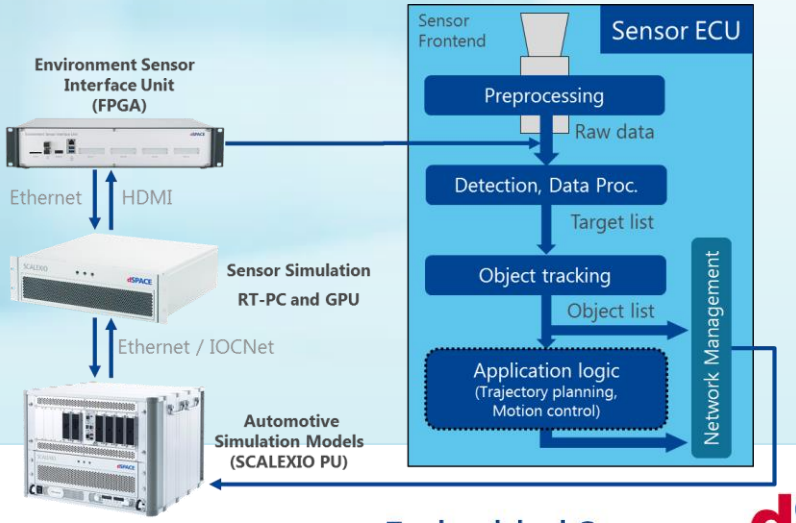
Sensor compositum

- combining multiple sensor outputs incl. meta-data



LIDAR Simulation – 3D Point Cloud

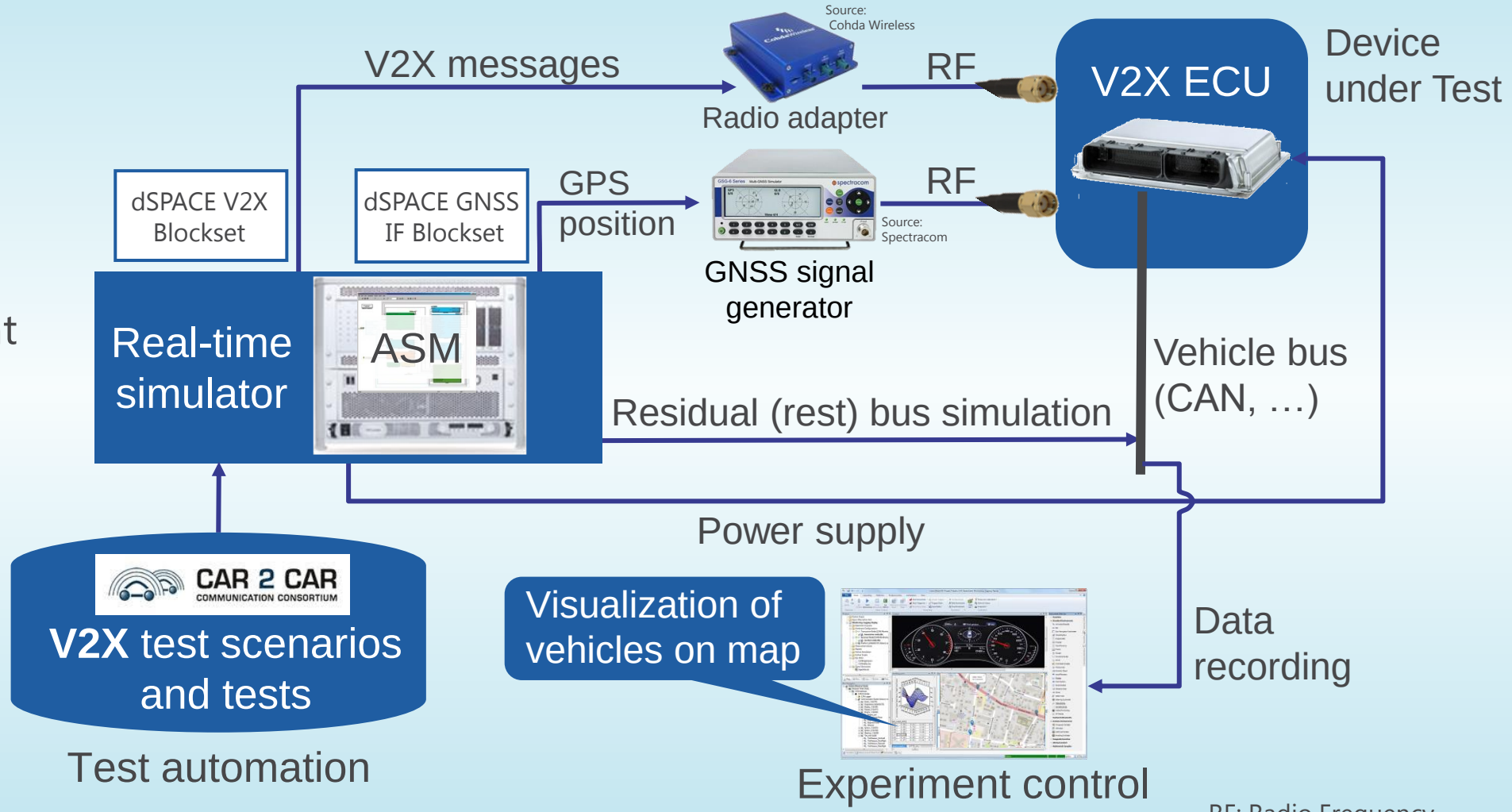
- Ideal simulation of laser sensors or **ray-based** systems
- Detection of all elements within the virtual sensor in MotionDesk, Logarithmic depth calculation
- Feedback of the information of all detected points into ESI, RTMaps or VEOS VPU, e.g. the distance to the objects and relative velocity
- **Freely configurable** field of view up to 180° and resolution, e.g. 100 000 points with 60 fps
- Closed-loop tests of ADAS applications incl. the image processing unit on a standard PC



HIL testing of V2X applications based on DSRC[1)]

Typical applications:

- Platooning (cooperative ACC)
- Electronic brake light
- Collision avoidance

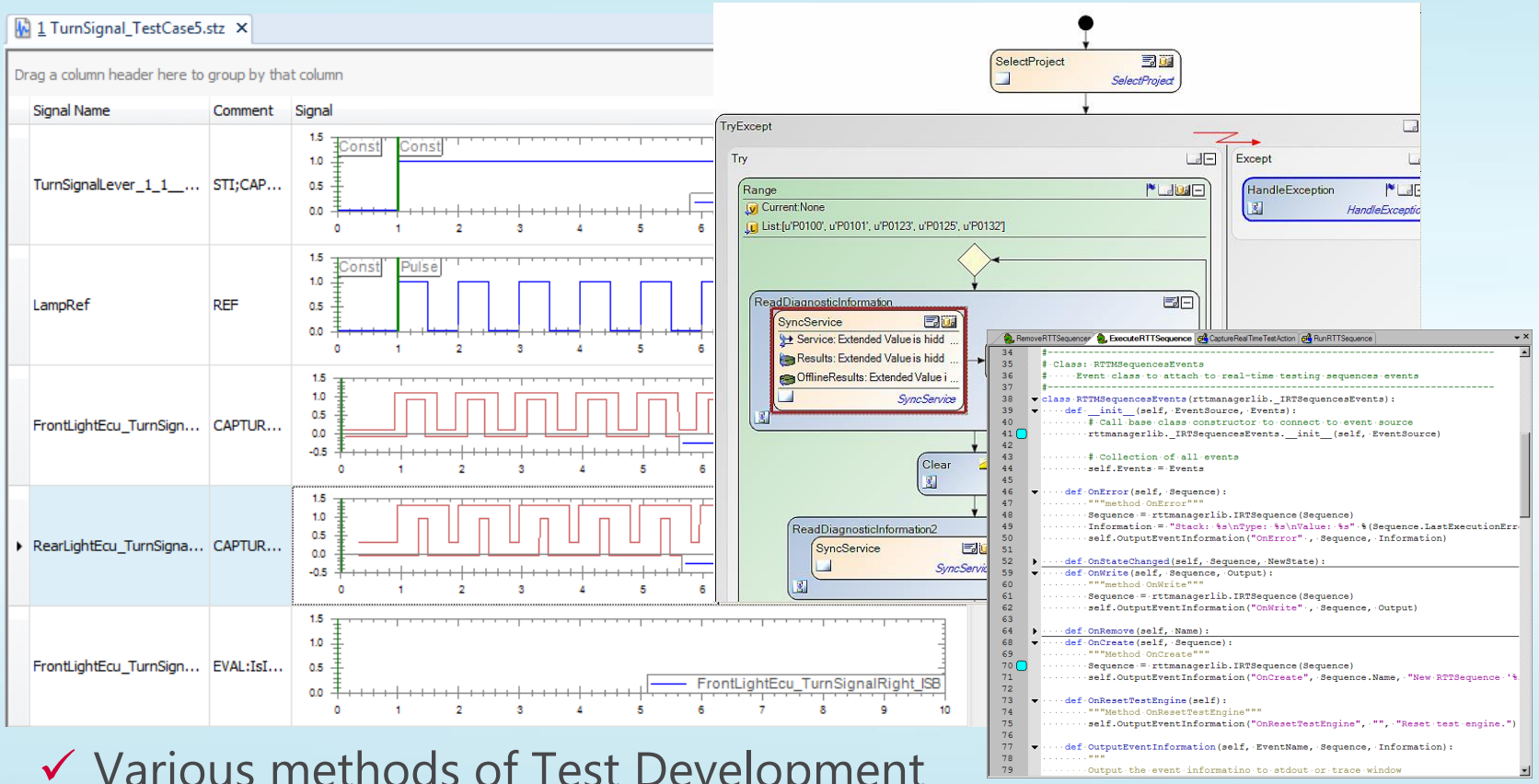


1) Dedicated Short Range Communication (IEEE 802.11p WLAN adhoc network)

RF: Radio Frequency

TESTING PROCESS AND AUTOMATION

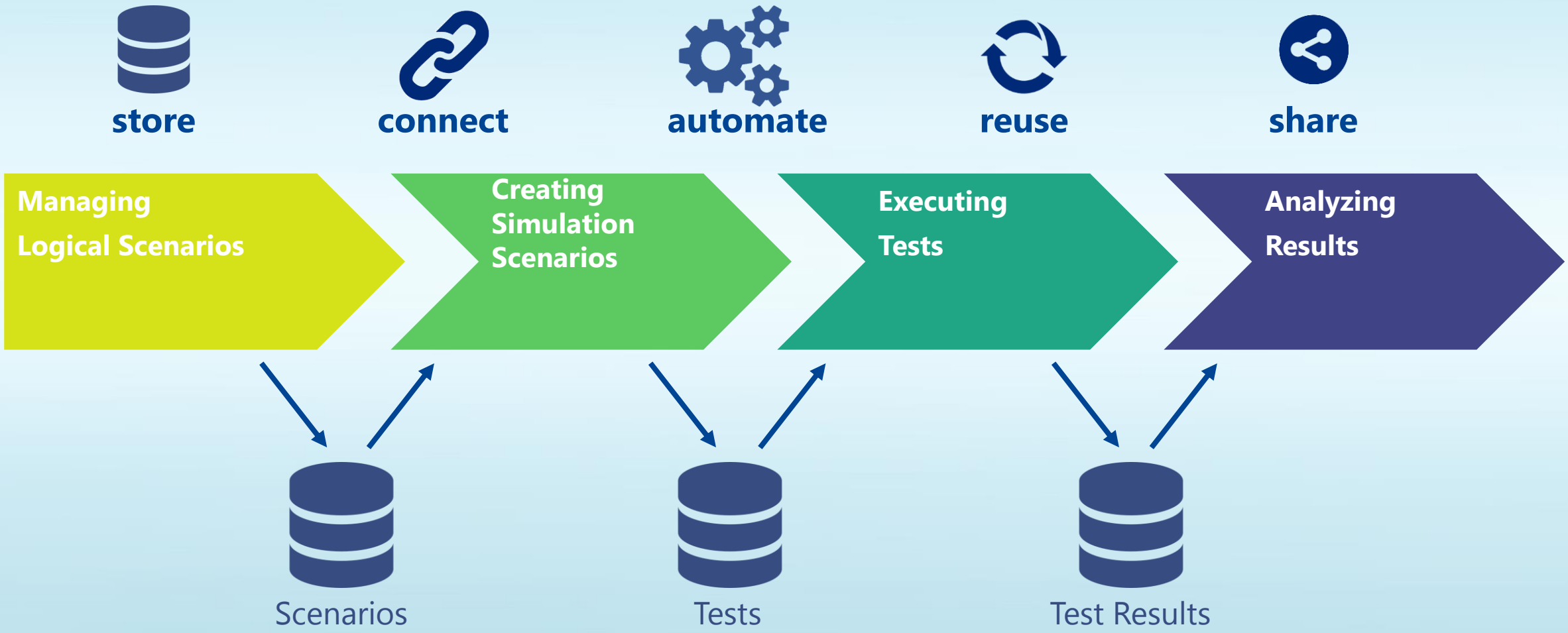
AutomationDesk Testing and Test Tools



- ✓ Various methods of Test Development
- ✓ Signal-based testing, XML and xIL-API Open Standards
- ✓ Real-time Testing for Scenarios and Observers

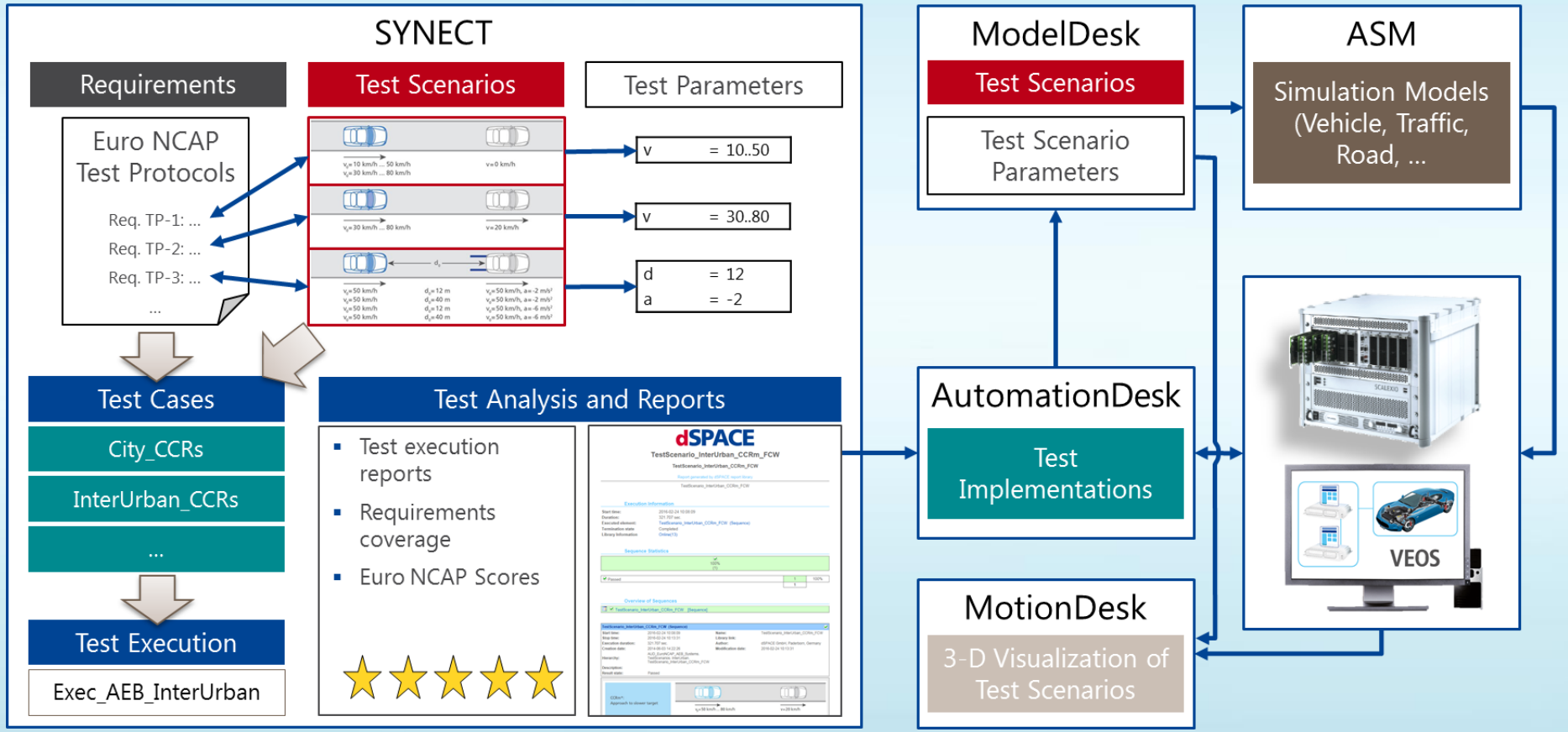
- **fit for purpose** for developing safety related software according to IEC 61508 and ISO 26262.
- **pre-qualified** for all ASILs according to ISO 26262

Scenario-based Testing Workflow – Data Management Tasks

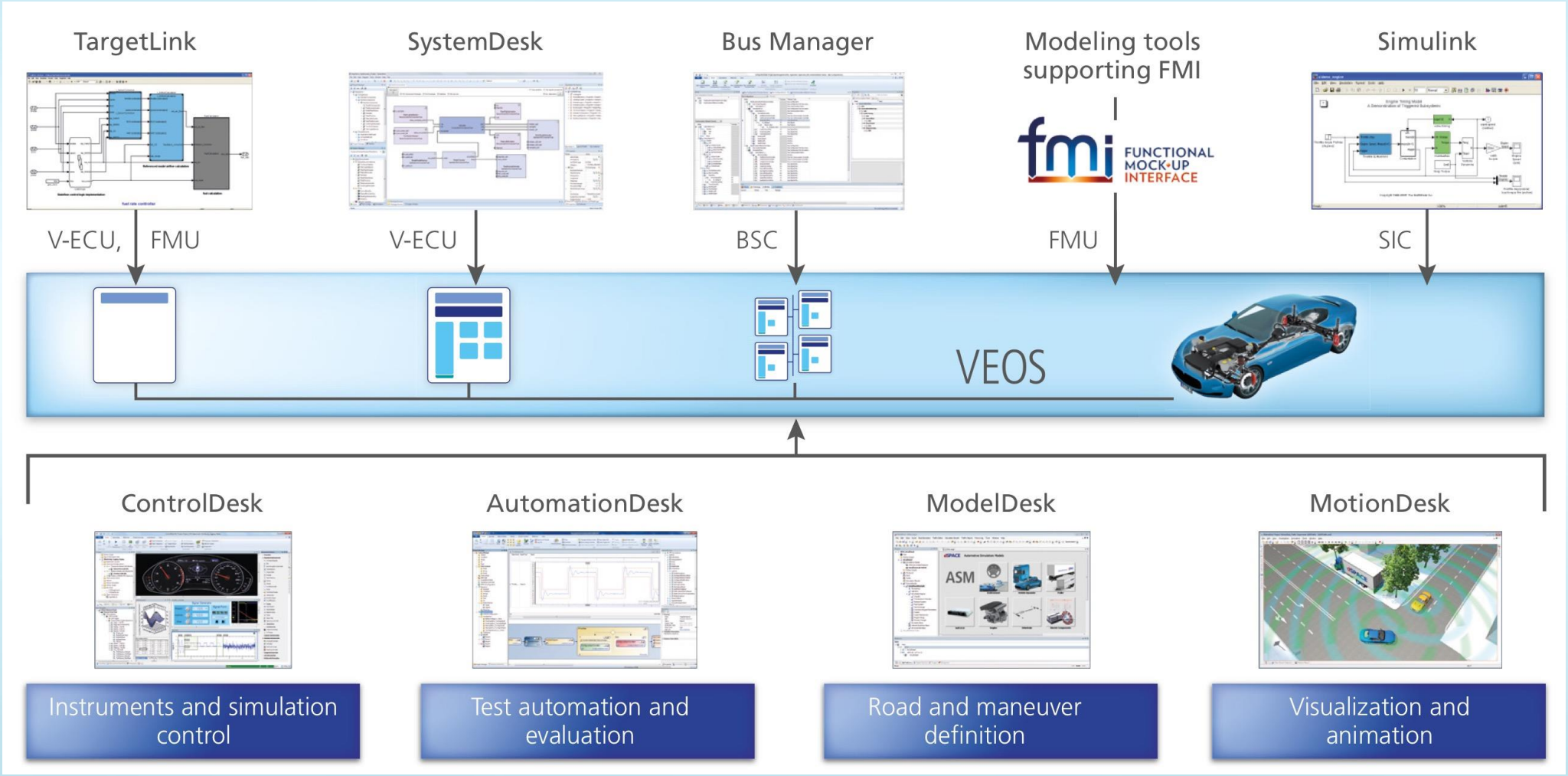


Integrated Tool Chain for Testing by Means of Simulation
Euro NCAP AEB Use Case

- Automatically execute Euro NCAP tests and generate score results
- Automated parameterization, execution and evaluation of Euro NCAP tests
- Example AutomationDesk NCAP AEB Test Demo available online
- Solutions for all NCAP tests available as an engineering service



VEOS – Realistic simulations of driving functions on standard PCs



PC SIL cluster simulation with Virtual ECUs

Driving millions of miles on your PC

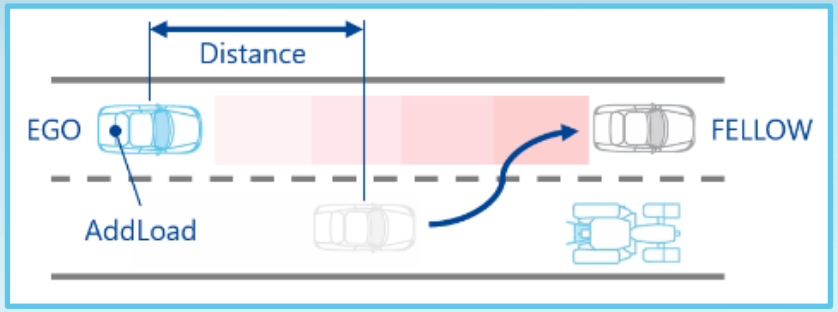
- Testing at an early development stage
- Highly scalable due to virtual ECUs
- Deterministic and reproducible test execution
- High test throughput through fast test execution

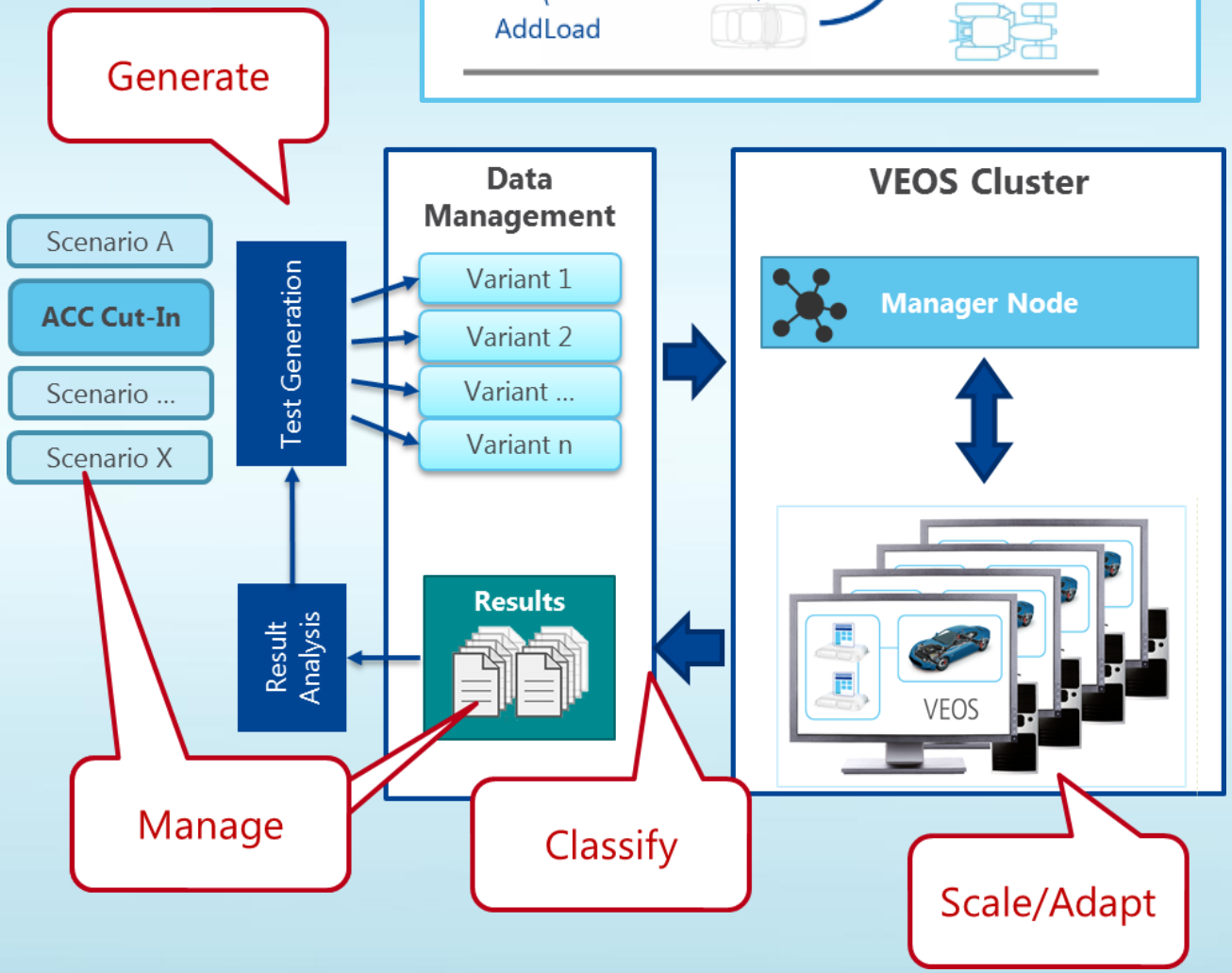
Simulation Cluster open to

1. Integrate with test generation methods
2. Cloud computing options

Simulation Cluster leverages

1. SIL tool chain in general (VEOS, xIL-API, ASM)
2. SYNECT Test Management
3. Real Time Testing

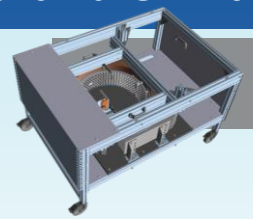




V-Cycle

PC-based Simulation

Hardware-in-the-Loop



Test Benches

Field Tests

Strategy | Concept Phase | Development and Validation | SOP

Requirements
Specification of fcns

System Concept

MIL

Prototyping

Target Implementation

Closed Loop SIL

Open Loop SIL

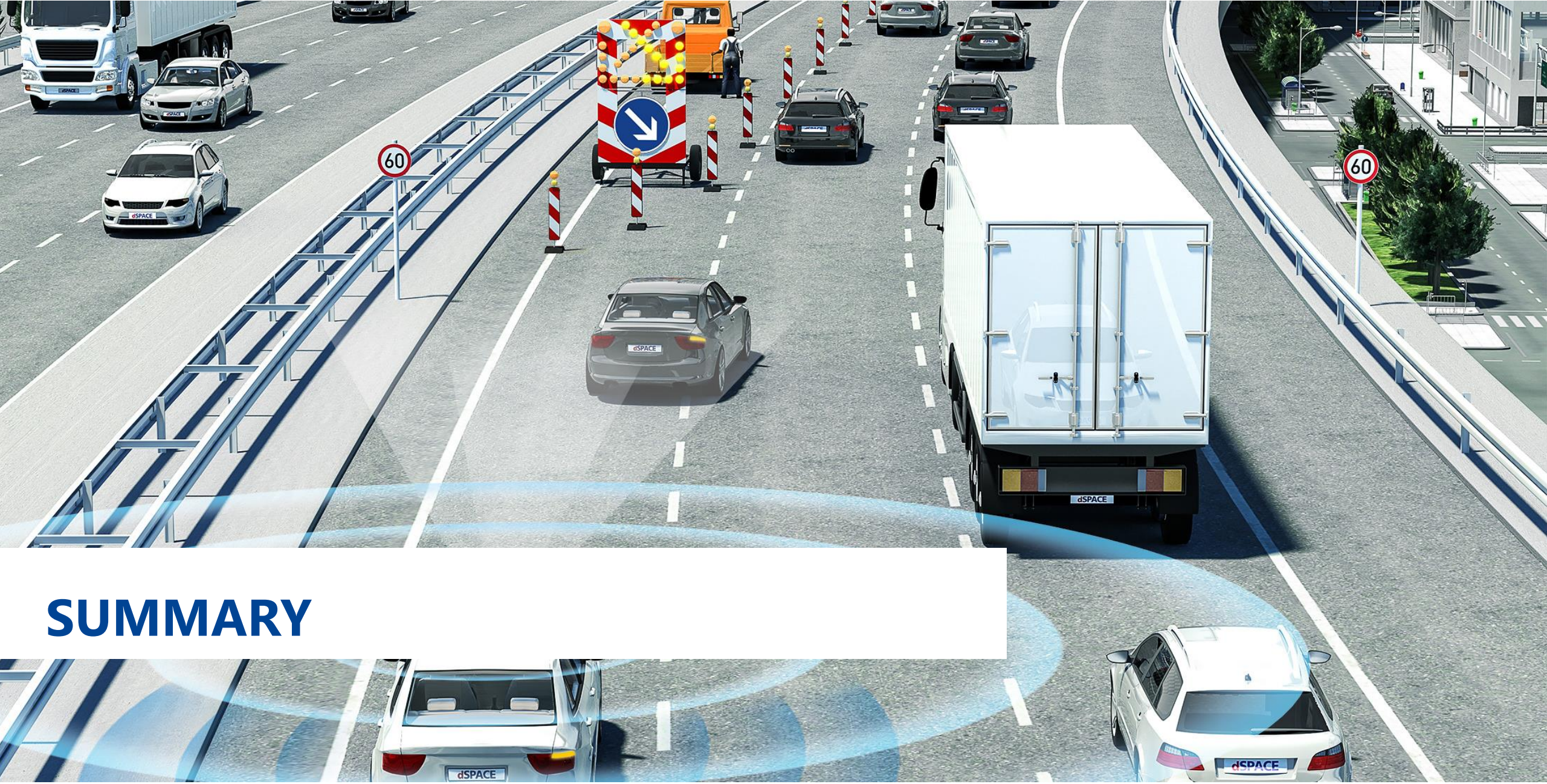
Closed Loop HIL

Open Loop HIL

ADAS Test Bench

Residual risk acceptable

ISO 26262



SUMMARY

One Tool Chain for ADAS/AV Testing

ISO 26262 ready.
Prequalified for
all ASILs

SYNECT
Data management

ASM
Open simulation models

MotionDesk
3-D visualization

ControlDesk
Experiment environment

AutomationDesk
Testing and evaluation

MIL/SIL

HIL

Early PC-based validation of
ECU software and functions

Seamless reuse of data

Real-time validation of
components and system

ASM: dSPACE Automotive Simulation Models

Thanks for listening!

Embedded Success