PROJECT of the PEGASUS FAMILY

VERIFICATION VALIDATION METHODS

Final Event 21 / 22 November 2023

PEGASUS VVM Context
From Foundations to Future Work

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Supported by:

Federal Ministry for Economic Affairs and Climate Action

on the basis of a decision by the German Bundestag

Why PEGASUS and the PEGASUS Family?

VERIFICATION VALIDATION METHODS

SAE Level 2 System

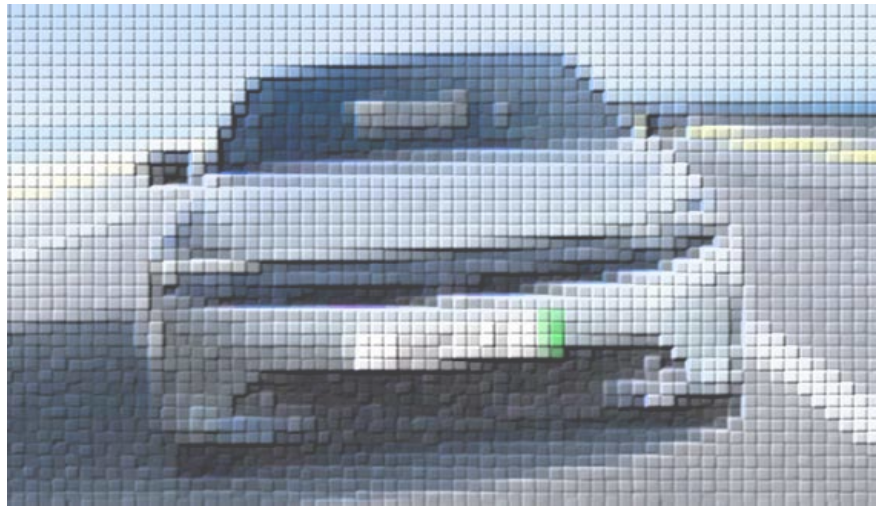
- Partial Driving Automation

ADS engaged

Object and Event Detection and Response **OEDR** transferred

SAE Level 3/4/5 Automated Driving System

- ADS-equipped vehicle



Need of validation and safety proof of the vehicle **+**
intended functionality of automated driving system within predefined operational design domain

N. Weber et al. “A simulation-based, statistical approach for the derivation of concrete scenarios for the release of highly automated driving functions”, in AmE 2020 - Automotive meets Electronics; 11th GMM-Symposium, Dortmund, Germany, 2020, pp. 1-6, DOI:10.13140/RG.2.2.15306.31683/1

Automated Driving is a Dream as old as the Automobile – Challenges Remain Even 100 Years Later

VERIFICATION VALIDATION METHODS

A) Traditional distance-based approach

- Random test case sampling
- Not to be accomplished for ADS by physical testing

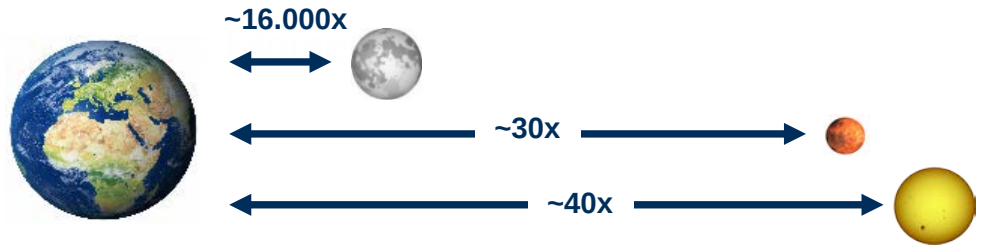
Statistical proof of safety for Autobahn-Chauffeur (SAE Level 3) would require around 6.1 billion test kilometers of brute-force driving

B) Scenario-based approach

- Reduction of test effort through testing of relevant scenarios
- Open-world problem

Virtual testing as additional crucial pillar

6.1 billion kilometers



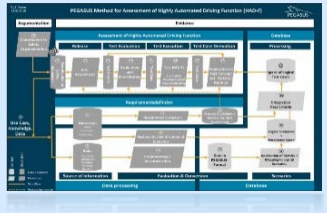
A distance-based test approach is **NOT FEASIBLE** for automated driving functions
Original PEGASUS proposed **SCENARIO-BASED TEST APPROACH**

PEGASUS Family and Scenario-Based Development &Testing

The **PEGASUS Family** focuses on development / testing methods and tools for AD systems on highways and in urban environments

PEGASUS

https://www.pegasusprojekt.de/en/home



- Scope: **Basic methodological framework**
- Use-Case: L3/4 on highways
- Partners: 17

PEGASUS FAMILY

VV-Methods

- Scope: **Methods, toolchains, specifications for technical assurance**
- Use-Case: L3/4/5 in urban environments
- Partners: 23 partners
- Timeline: 07/2019 – 12/2023

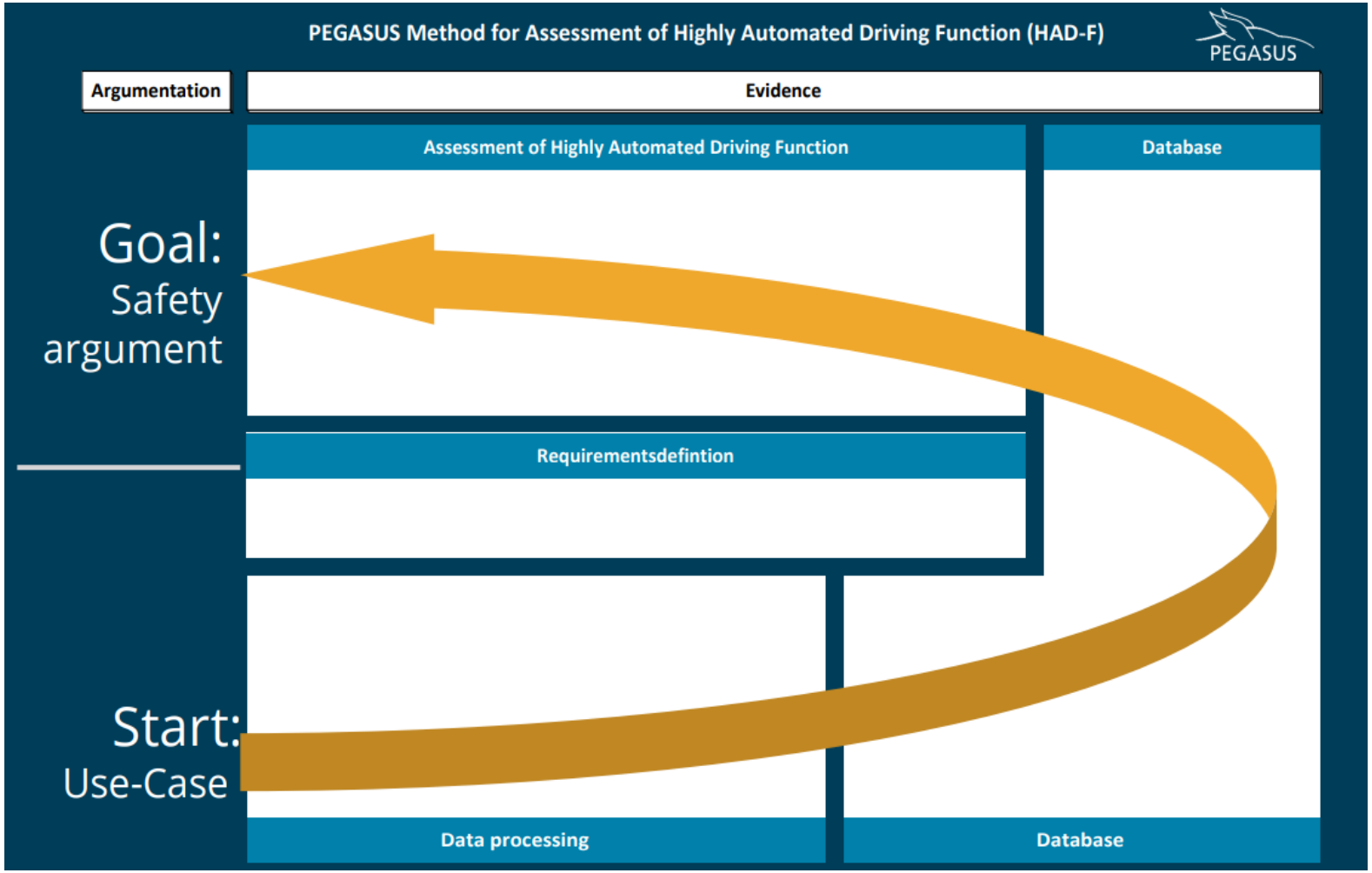
SETLevel4to5

- Scope: **Simulation platform, toolchains, definitions for simulation-based testing**
- Use-Case: L3/4/5 in urban environments
- Partners: 20 partners
- Timeline: 03/2019 – 10/2022

+ future potential projects of the PEGASUS Family

2016 **2019** *Time*

PEGASUS introduced Scenario-based Methods



More Refinement Needed

- Extension of OD to URBAN
- Knowledge and requirements analysis
- Regulatory and Legal Aspects
- Database architecture
- Test Distribution and Orchestration

- Coherent Overall Methodology
- Coherent Safety Argumentation

VVM: Further Steps on Methodology and Technology

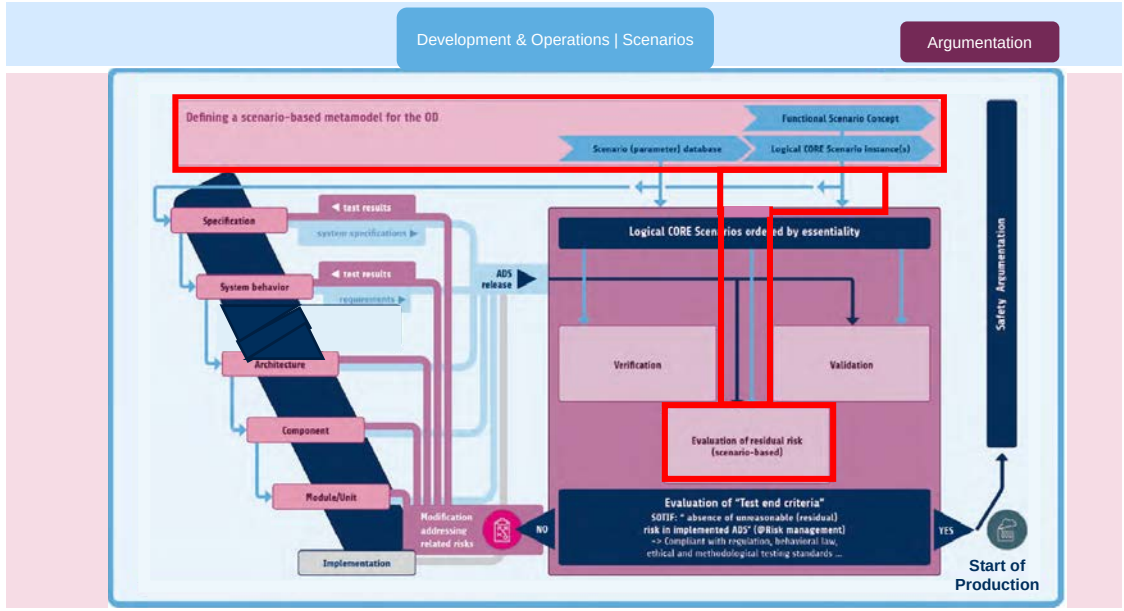
Exchange with Scenario Databases

ADScene Safety Pool

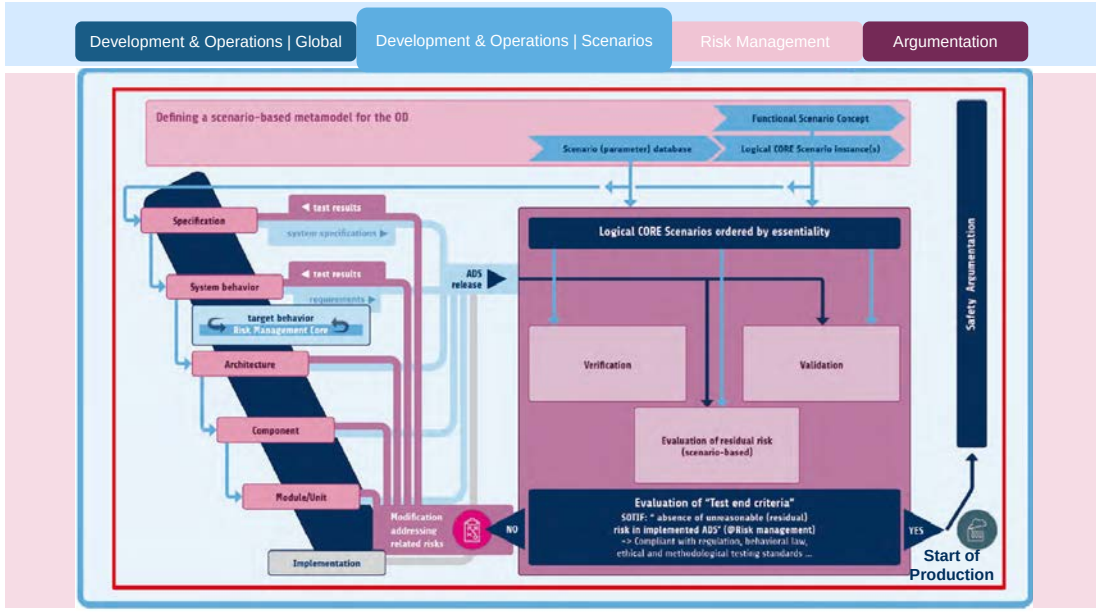
PEGASUS Approach – vs – VVMethods Approach

VERIFICATION VALIDATION METHODS

PEGASUS



VVMethods



PEGASUS	VVMethods
GSN-based argumentation	Framework-based Argumentation including risk management
6 Layer Scenario model, Set of Logical Scenarios	6 Layer Model & ODD Metamodel (set of CORE scenarios)
	Scenario-based behavior specification (ADF / ADS design)
	Scenario-based verification & validation
Scenario-based testing with risk evaluation in V&V	Scenario-based risk evaluation in V&V
Use of test instances: Simulation first, PG confirms simulation, endurance run assures stochastic aspects & complex situation	Simulation first, PG confirms simulation, endurance run assures stochastic aspects & complex situation & validates Metamodel

Major PEGASUS VVM Project Goals

- ASKING THE RIGHT QUESTIONS ON CRITICALITY, BENCHMARKS & TARGETS
- MASTERING COMPLEXITY AND PARAMETER EXPLOSION
- DRIVING IN AN URBAN ENVIRONMENT
- SAFETY THROUGH DECOMPOSITION, TRACEABILITY AND REASONING
- TEST DISTRIBUTION, ORCHESTRATION AND ANALYSIS

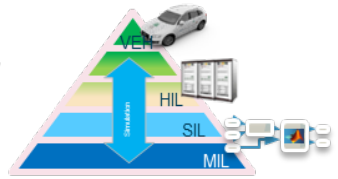
How can we cope with the OPEN-WORLD?

Major PEGASUS VVM Project Goals

VERIFICATION VALIDATION METHODS

Feasibility

Efficiency



Goal I **Systematic control of test space**

- Systematic decomposition of OD, Involve traffic-law perspective

Goal III **Shift to simulation**

- Seamless use of virtual and real artefacts

Goal II **Consistent interfaces**

- Systematic breakdown of technical contracts, requirements & tests

GOAL IV **Argumentation**

- Traceability, Consistency, Explainability

E.g. Cooperation on „Technical Language“

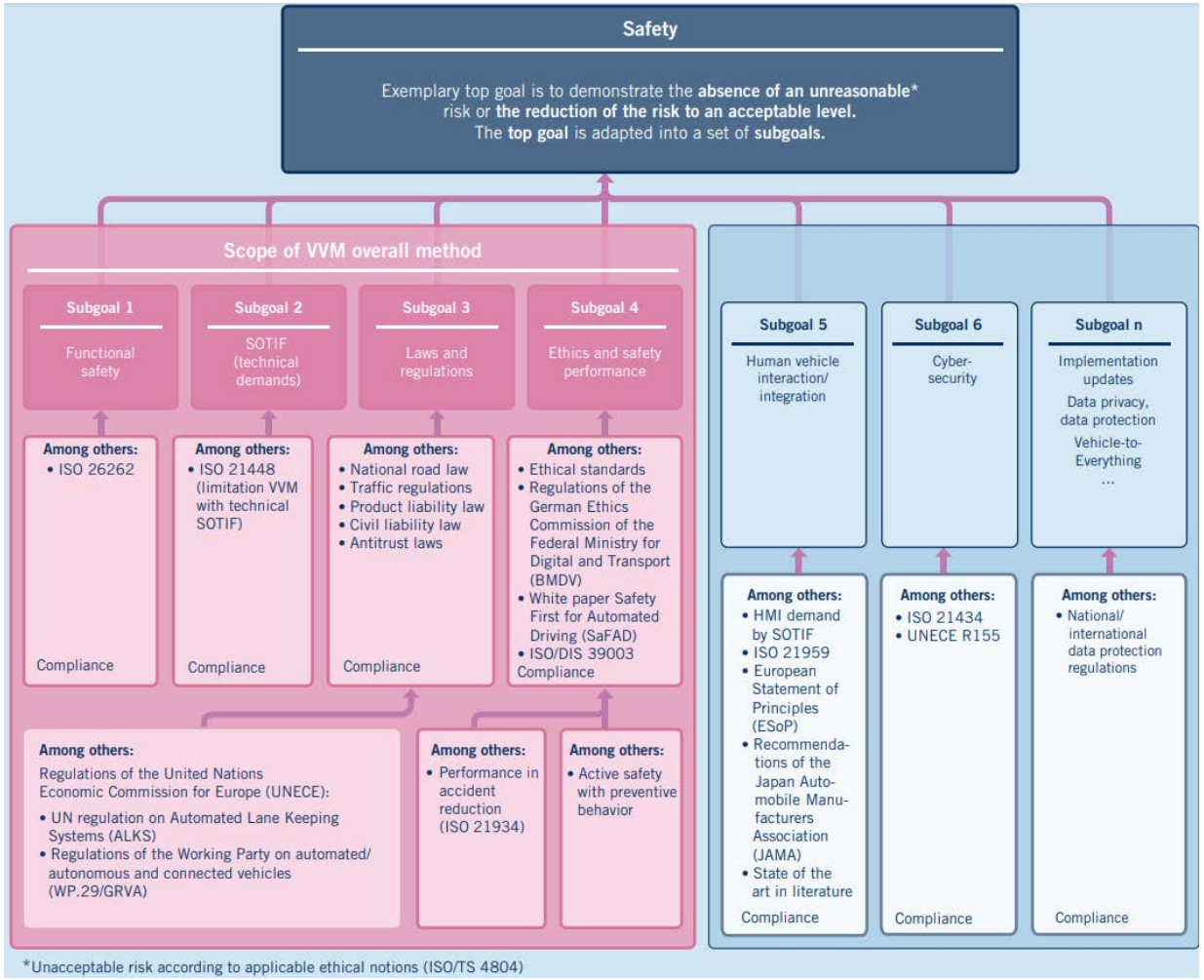
gaia-x

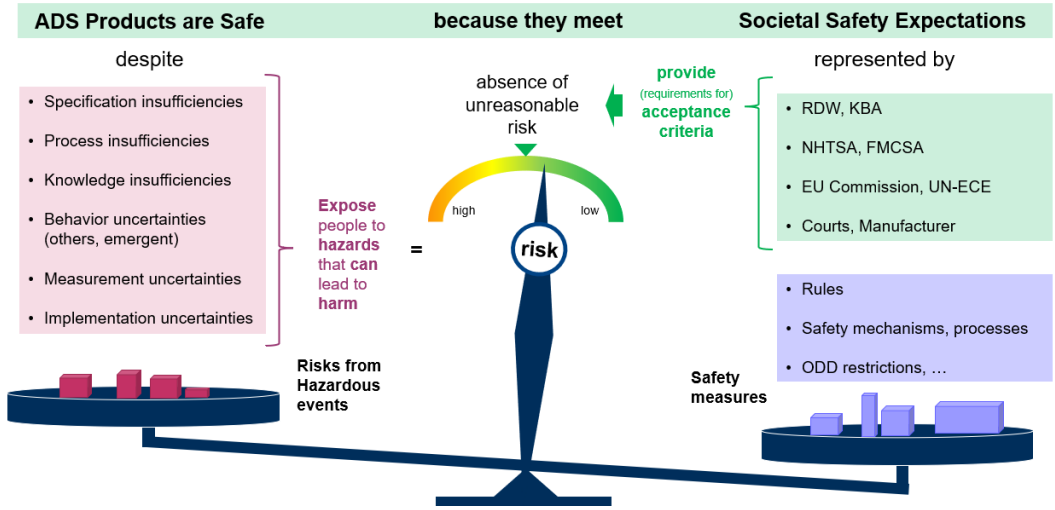
VIVID PARTNER PROJECT OF THE DIVP PROJECT

SET Level

Changeability

Safety: More than „JUST“ Technology

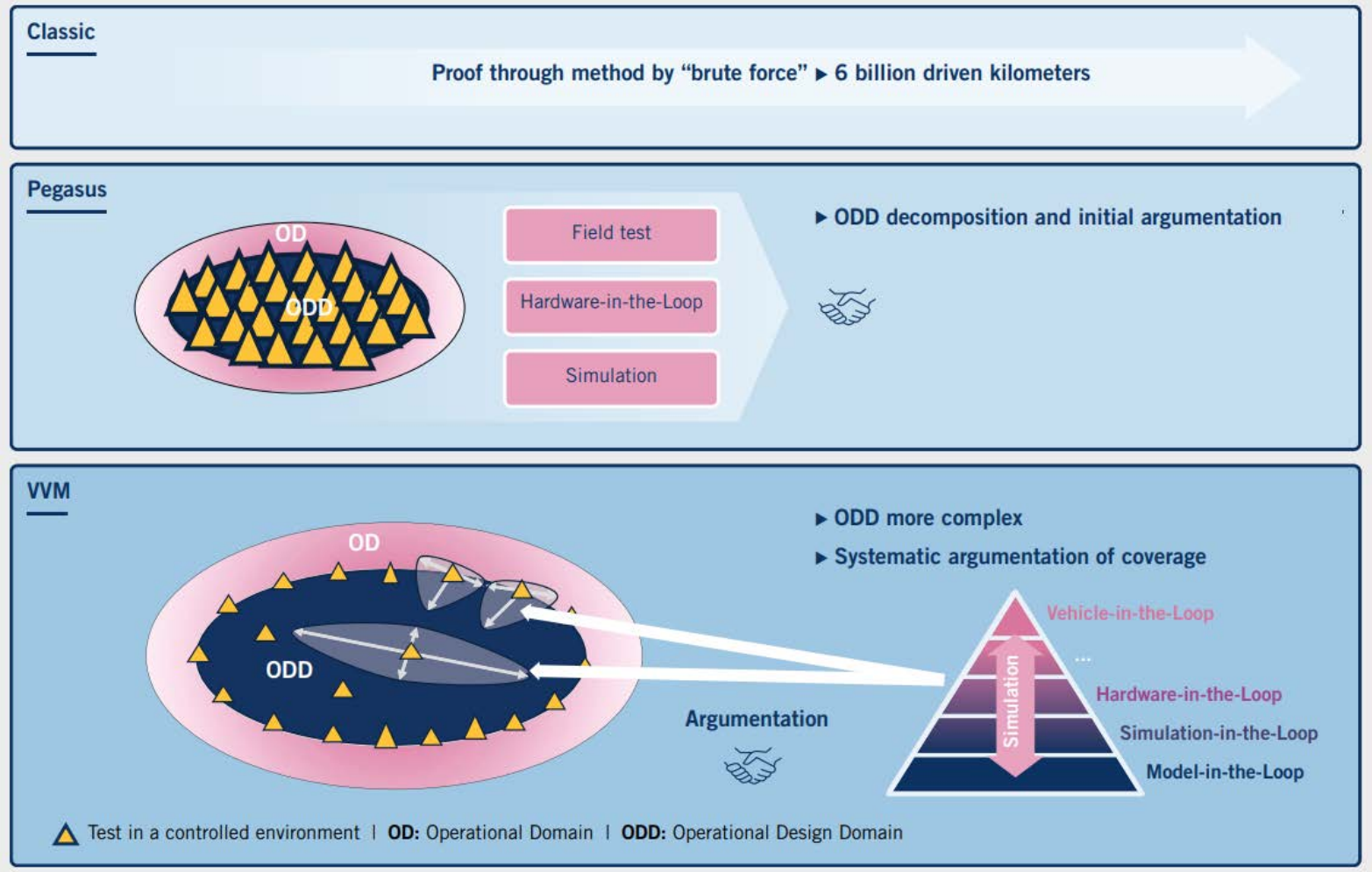




See presentation by
Thomas Kirschbaum, Stream #1

ATZ article by VVM consortium
https://www.vvm-projekt.de/fileadmin/user_upload/Newsmeldungen/ATZ_Artikel_en.pdf

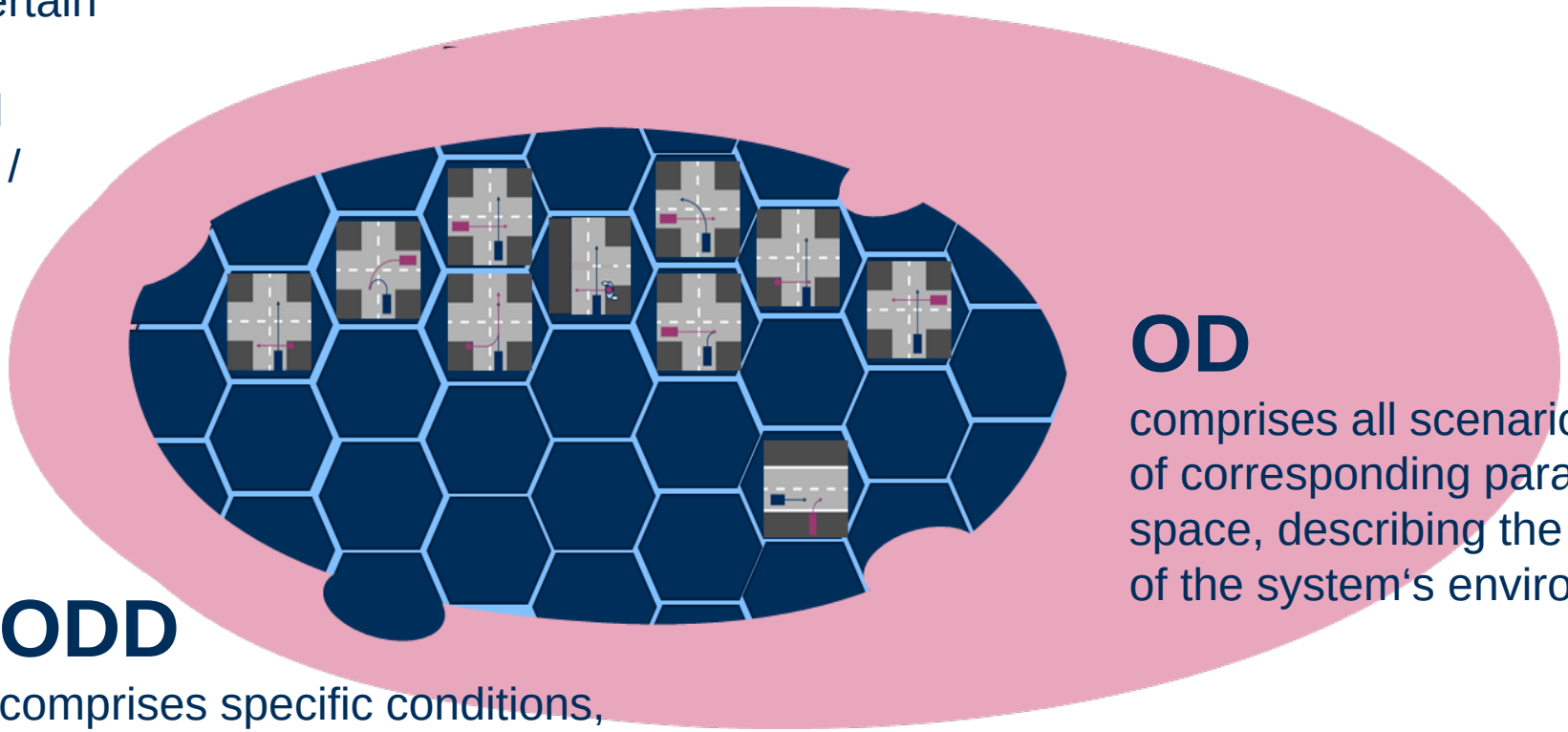
From Classic Approaches to PEGASUS and VVM …



A World Called Operational Domain

The **set of logical CORE scenarios** is defined as a set of logical scenarios that have certain properties:
minimum set of logical scenarios, that covers / represent the ODD, free of overlap with the underlying BASE scenarios, …

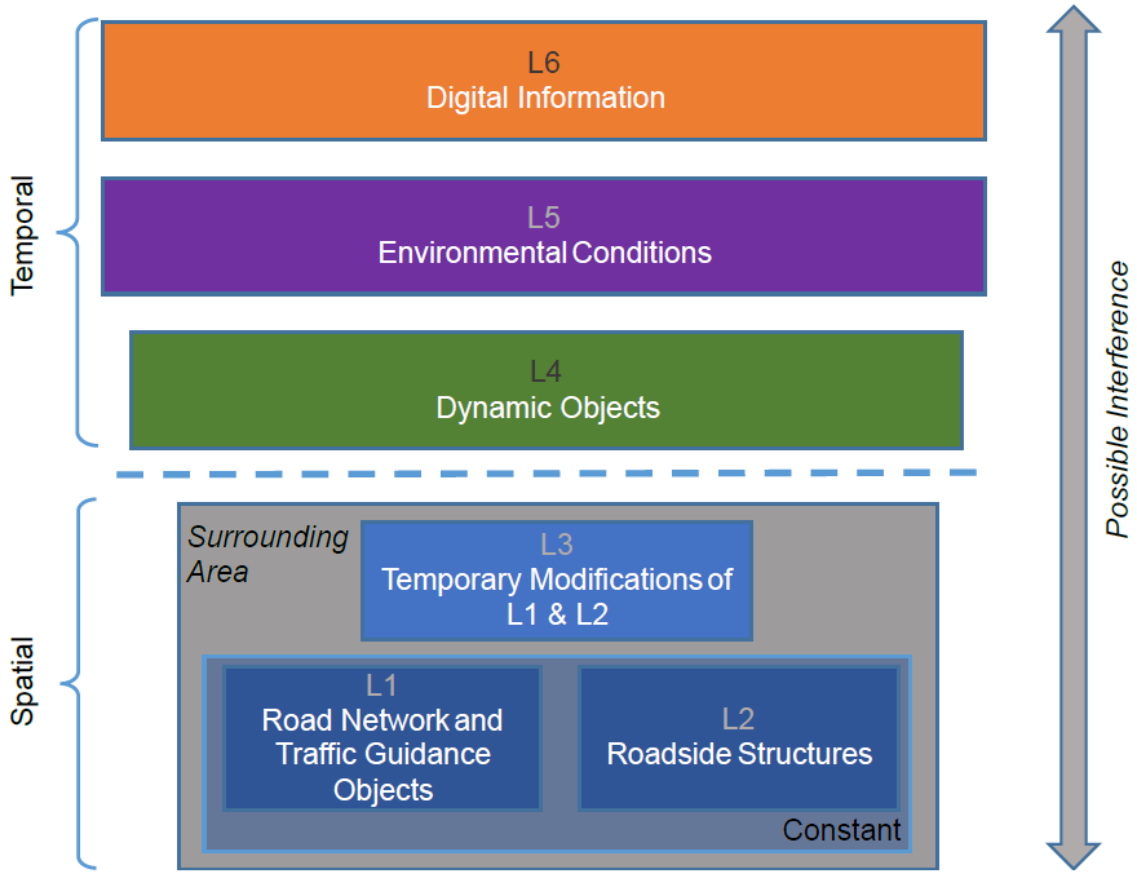
- **The Operational Domain OD can be the Full World or a Subset**

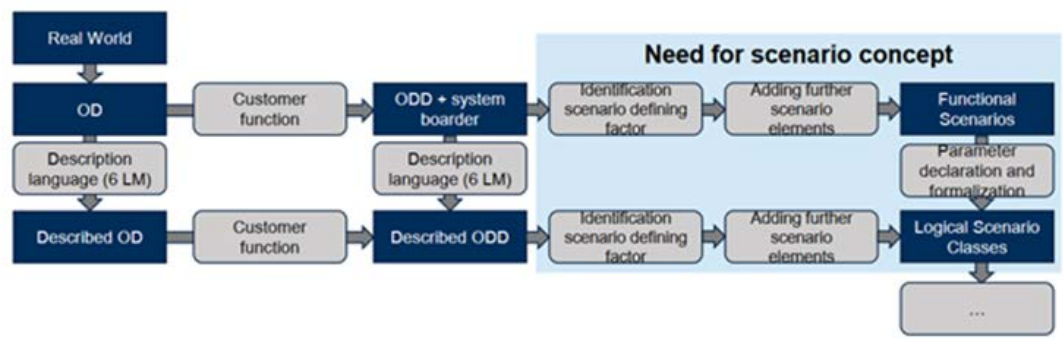


ODD
comprises specific conditions, ADS is designed to function

OD
comprises all scenarios of corresponding parameter space, describing the context of the system‘s environment …

Six Layers to Structure Them All





Structure is needed
to **understand the world**
and **decompose complex challenges**

E.g., using Ontology-based approaches, such as A.U.T.O. and/or OMEGA data format

https://github.com/lu-w/auto/

https://github.com/ika-rwth-aachen/omega_format

M. Scholtes et al., "6-Layer Model for a Structured Description and Categorization of Urban Traffic and Environment," in IEEE Access, doi: 10.1109/ACCESS.2021.3072739

L. Westhofen, C. Neurohr, M. Butz, M. Scholtes and M. Schuldes, "Using Ontologies for the Formalization and Recognition of Criticality for Automated Driving," in IEEE Open Journal of Intelligent Transportation Systems, vol. 3, pp. 519-538, 2022, doi: 10.1109/OJITS.2022.3187247

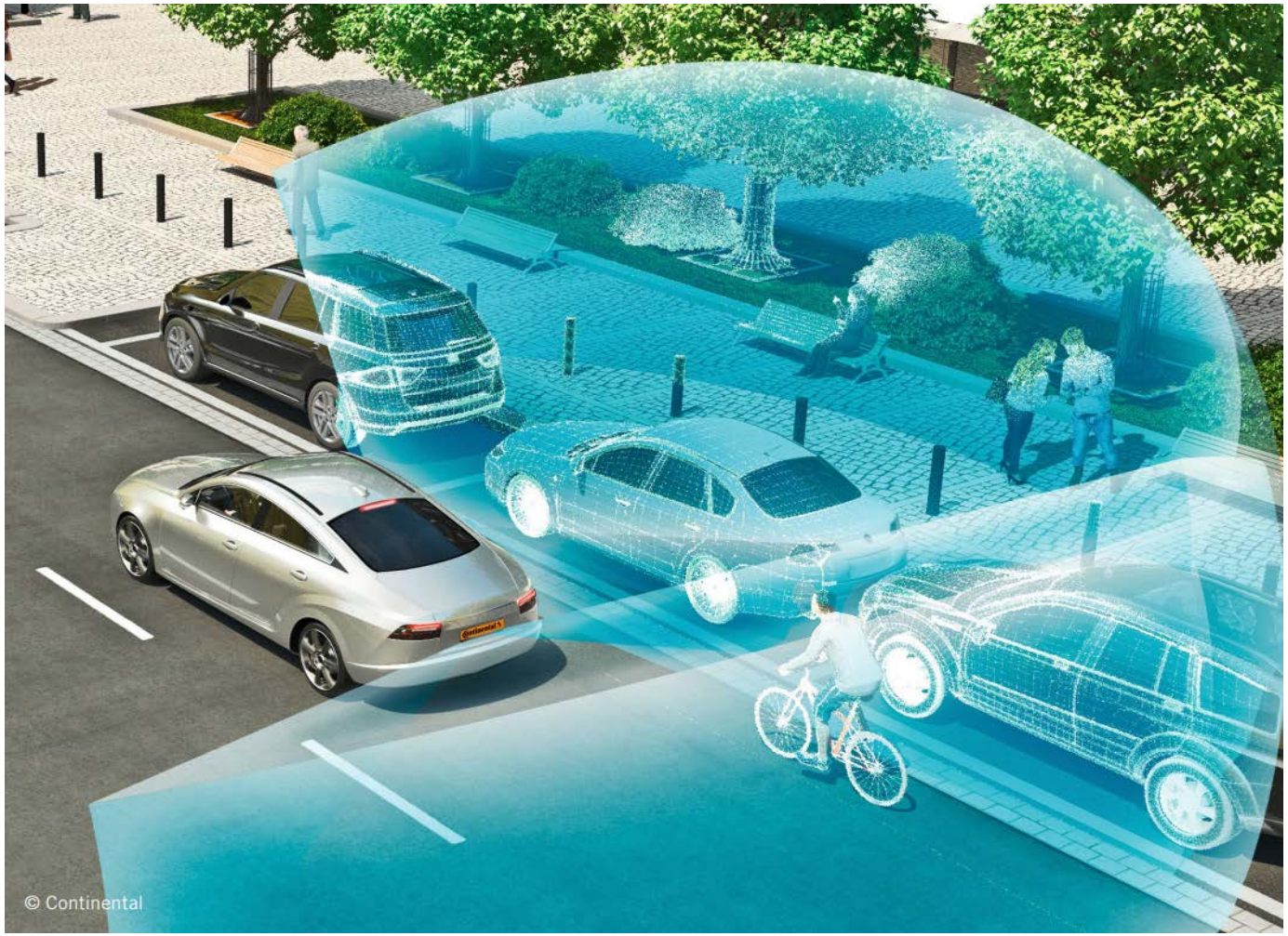
Refining Our Worlds

From
PEGASUS
Highway Chauffeur
functional description

to

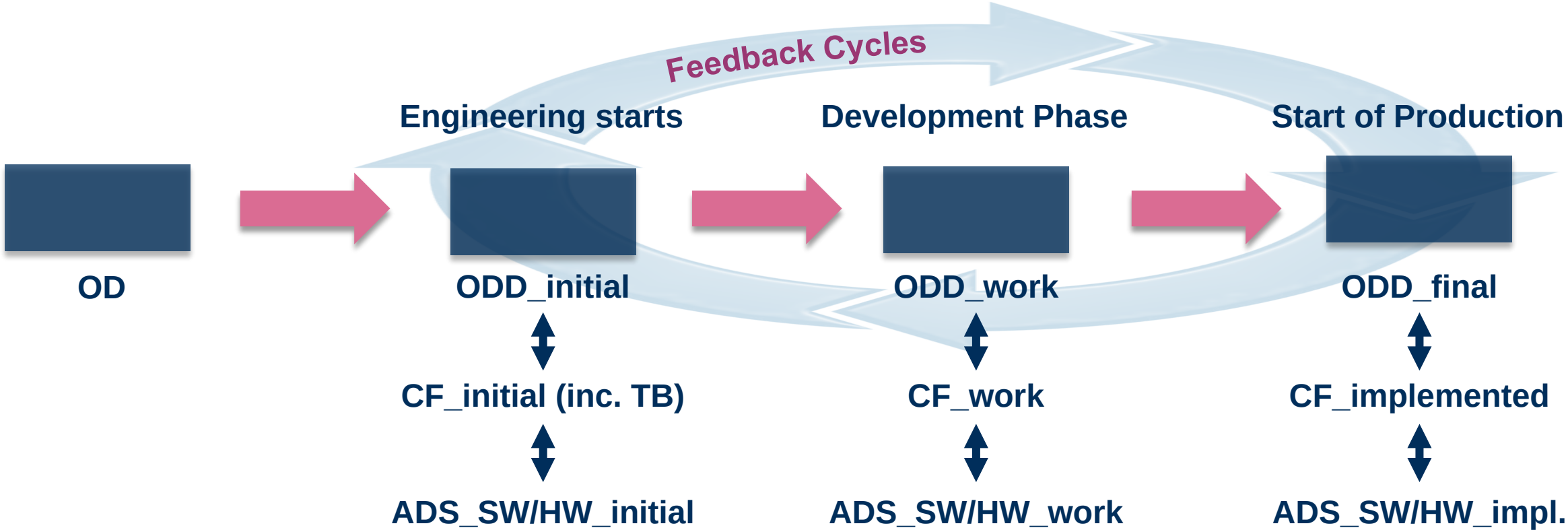
Exemplary PEGASUS VVM
„**Customer Function**“

Customer Function is
the Actor coping with the World‘s Challenges

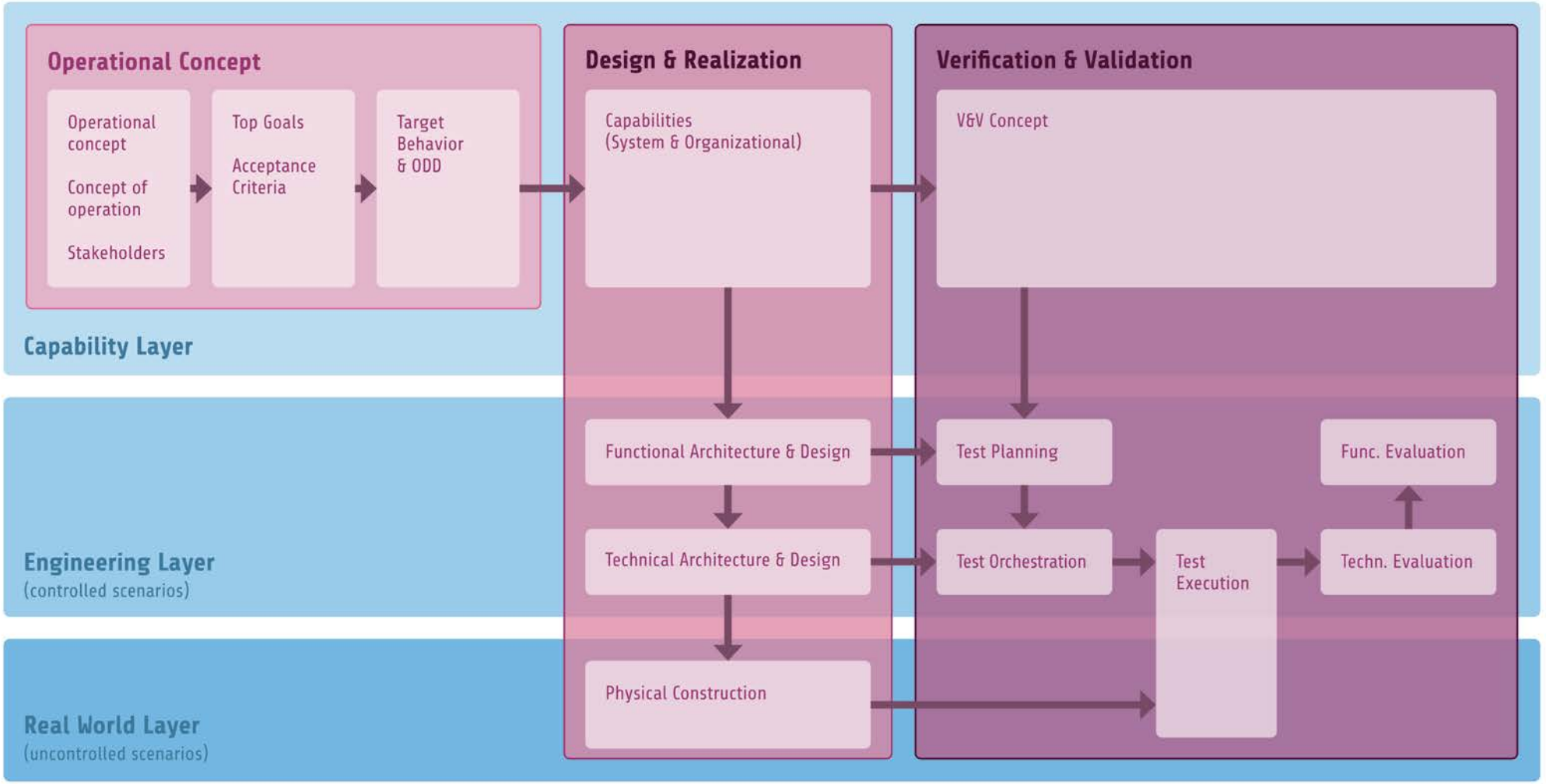


Refining Our Worlds

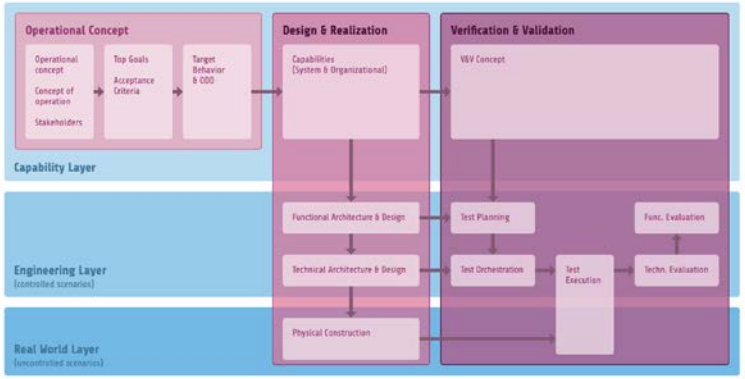
A “Target Behavior” TB of the ADS needs to be defined from prior knowledge (to be refined)
Development-related Requirements on safety and comfort are defined by OEM
“Customer Function” CF includes a Target Behaviour



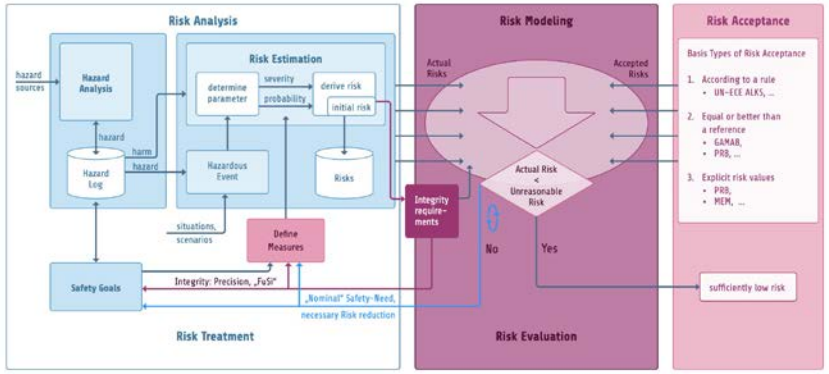
Deriving the Building Blocks out of the VVM Framework



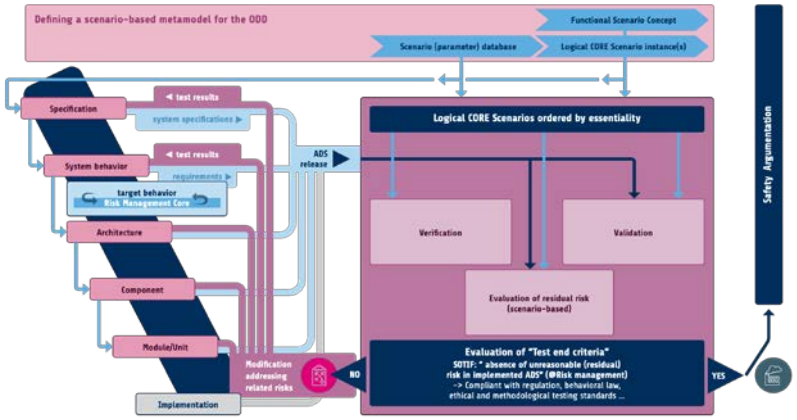
The Structure of the Exhibition – Four Perspectives



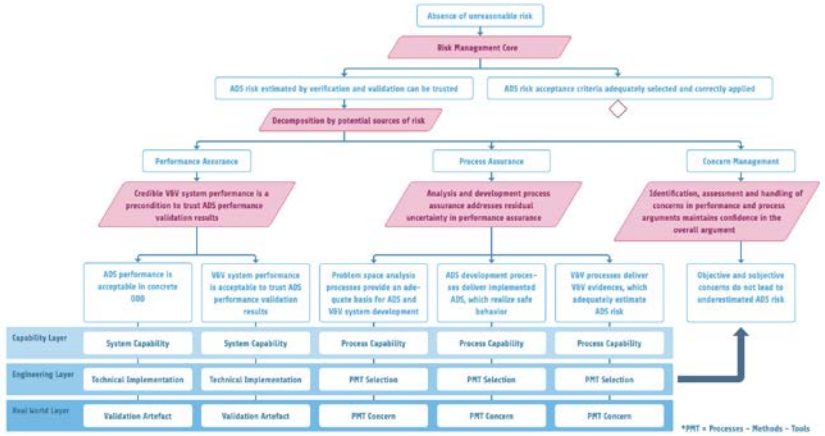
Development & Operation | Global



Risk Management



Development & Operation | Scenarios



Argumentation

VERIFICATION
VALIDATION
METHODS

Thank you!

Dr. Ulrich Eberle, Opel Automobile / Stellantis
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PROJECT of the PEGASUS FAMILY

VDA LEITINITIATIVE

A project developed by the VDA Leitinitiative
autonomous and connected driving

Supported by:

Federal Ministry
for Economic Affairs
and Climate Action

on the basis of a decision
by the German Bundestag

REFERENCES

[1] N. Weber et al. “A simulation-based, statistical approach for the derivation of concrete scenarios for the release of highly automated driving functions”, in AmE 2020 - Automotive meets Electronics; 11th GMM-Symposium, Dortmund, Germany, 2020, pp. 1-6, doi:10.13140/RG.2.2.15306.31683/1

[2] Mazzega, J., Lipinski, D., Eberle, U., Schittenhelm, H., & Wachenfeld, W. (2019), PEGASUS METHOD, Zenodo. https://doi.org/10.5281/zenodo.6595201

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[7] Road vehicles — Safety of the intended functionality, ISO/PAS 21448, 2019.

[8] M. Scholtes et al., "6-Layer Model for a Structured Description and Categorization of Urban Traffic and Environment," in IEEE Access, doi: 10.1109/ACCESS.2021.3072739

[9] L. Westhofen, C. Neurohr, M. Butz, M. Scholtes and M. Schuldes, "Using Ontologies for the Formalization and Recognition of Criticality for Automated Driving," in IEEE Open Journal of Intelligent Transportation Systems, vol. 3, pp. 519-538, 2022, doi: 10.1109/OJITS.2022.3187247