Euro SPI Conference 2022, August 29th – September 2nd 2022, Salzburg Austria

Data-Driven Engineering (DDE) Process –

An ASPICE Compatible Process for Machine Learning in Automated Driving

Thomas Geipel **)

An extension of:

DDE Process: A requirements engineering approach for machine learning in automated driving

By Ran Zhang **), Andreas Albrecht **), Jonathan Kausch **), Henrik J. Putzer *), Thomas Geipel **) and Prashanth Halady **)

Published at 29th IEEE Int. Requirements Eng. Conference, Notre Dame, South Bend, USA, Sept. 20-24, 2021

Presented also at VDA SYS Conference, Potsdam, Germany, June 28-30, 2022

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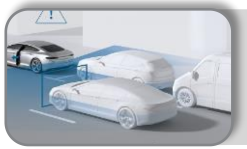
Agenda

Challenges in Automated Driving

Data in Machine Learning

DDE Process as Solution

Industrial Benefits from Our Approach



Summary and Future Work

AD: Automated Driving DDE: Data-Driven Engineering DNN: Deep Neural Network FoV: Field of View GT: Ground Truth ML: Machine Learning (connectionistic ML – esp. DNNs) ODD: Operational Design Domain TL: Traffic Light

Data-Driven Engineering (DDE) Process for Machine Learning in Automated Driving

Challenges in ML-Based Automated Driving (AD) System Development

Current process landscape in automotive domain is not able to deal with developing Machine Learning (ML) based functions and systems.

Requirements are no longer simple and crisp, but implicitly manifested in the data, or in requirements on data, respectively.

No established development process yet for integrating data requirements for ML based functions (like e. g. perception) in the overall development systematics.

Capability to handle increasing complexity

SAE Level 5
Full Automated Driving

SAE Level 4
Highly Automated Driving

SAE Level 3
Conditionally Automated Driving

SAE Level 2
Partially Automated Driving

SAE Level 1
Driver Assistance

ML offers generic solutions for complex automation tasks, but this requires new Data-Driven Engineering processes ...

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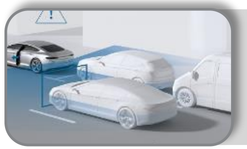

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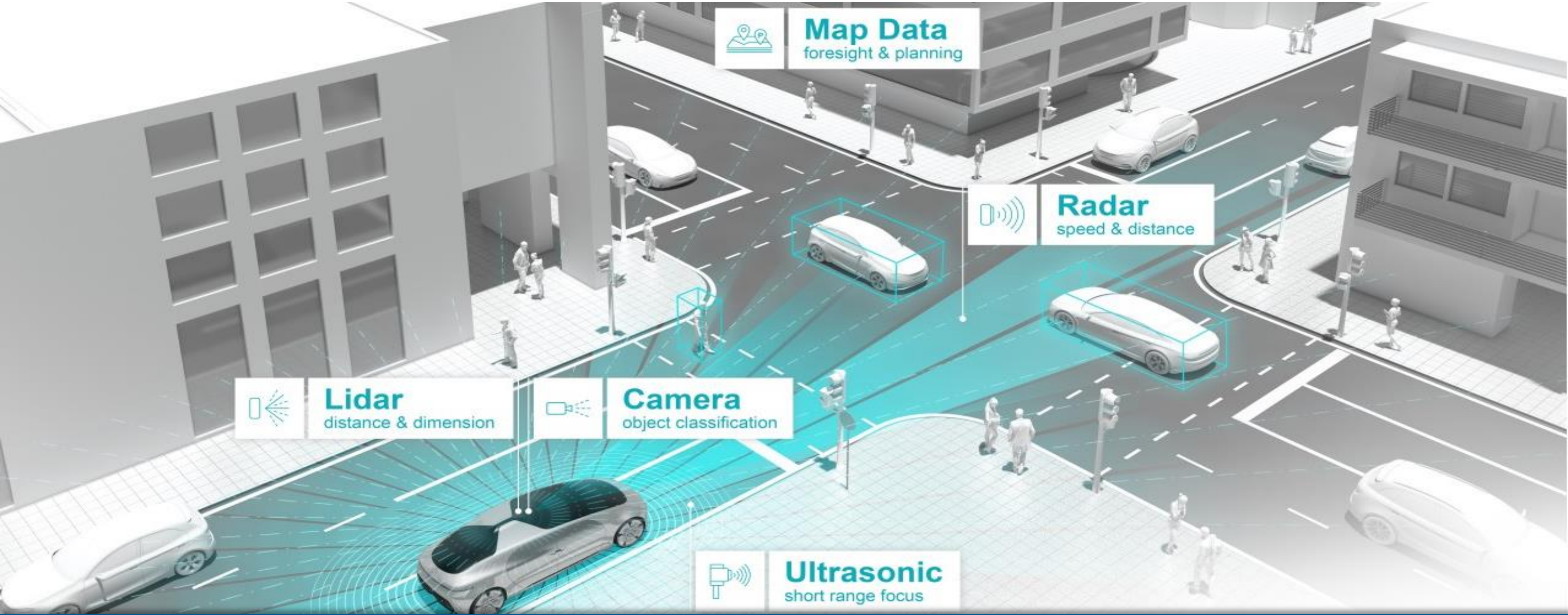
Sensor Data Used For Automated Driving



The sensor data for perception functions are the foundation for automated driving systems.

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Data-Driven Engineering (DDE) Process for Machine Learning in Automated Driving

Machine Learning Opens a Field of New Data-Driven Engineering Solutions

Detecting traffic lights in images is a vision-based perception task that Machine Learning solves better than classical methods.

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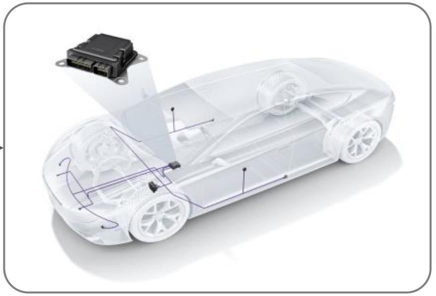
Classic SW Development versus Machine Learning

Requirements given explicitely in textual form, e.g.:

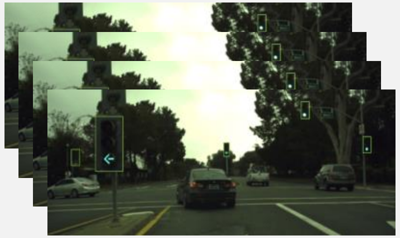
„If the steering angle does not match the driving direction, then start active compensation …

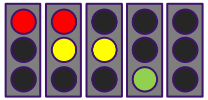
Requirements Specification

SW Coding → SW Units →



e.g. ESP

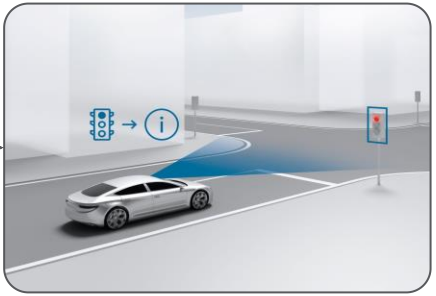




Requirements given implicitely by the data contents …

Data Sets

ML Model Training → SW Units →



e.g. video-based traffic light detection

In Data-Driven Engineering tasks requirements are no longer explicitely given by text, but implicitely given by data.

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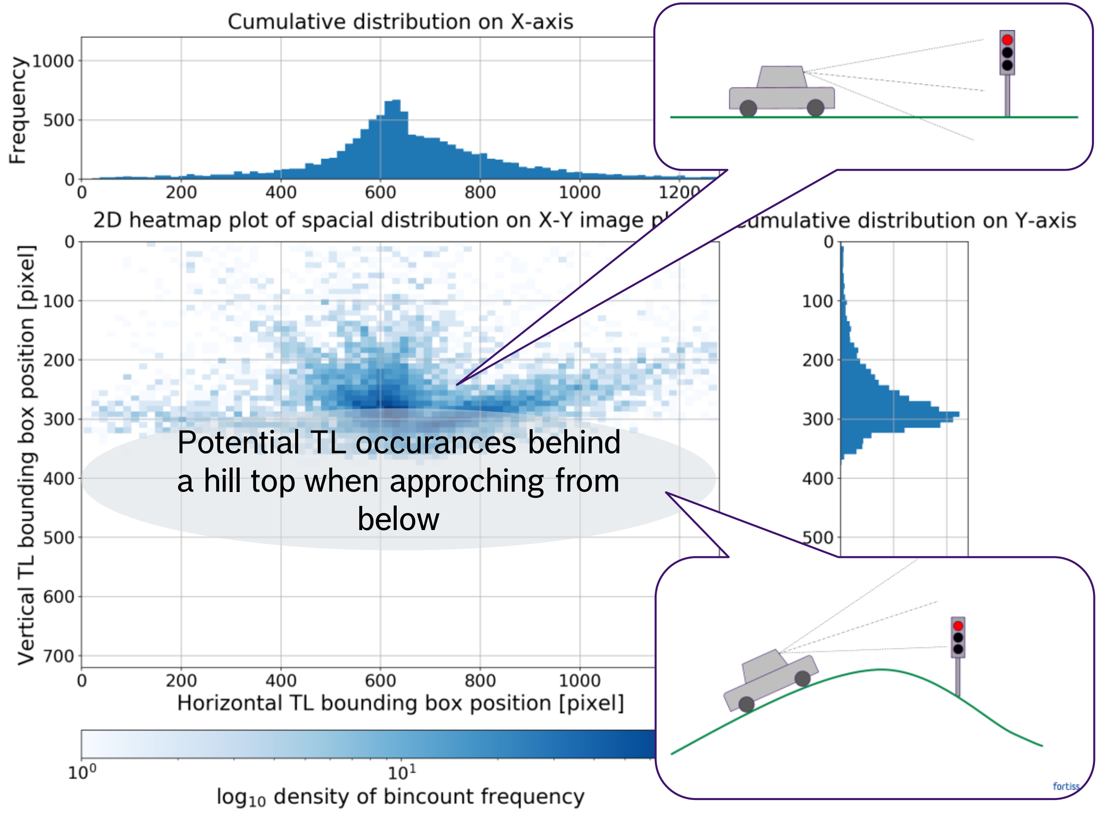
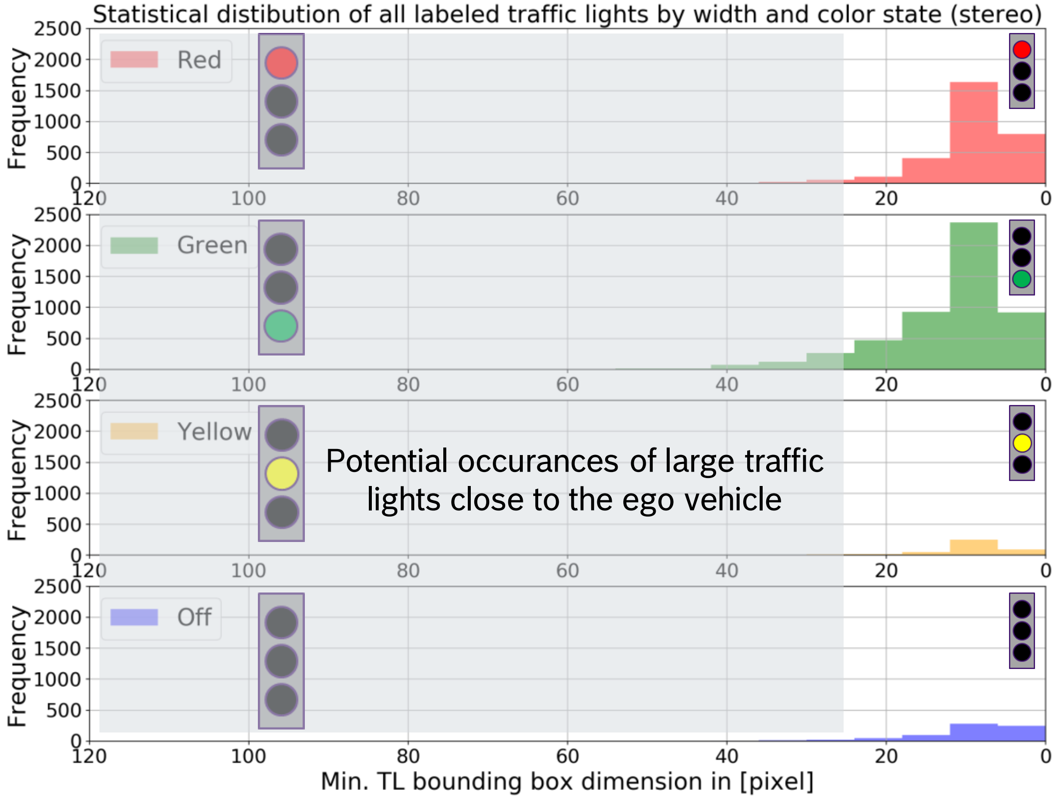
Data-Driven Engineering (DDE) Process for Machine Learning in Automated Driving

Data Content Analysis Results for a Public Traffic Light Data Set Example

Distribution of bounding box location on image plane



Distribution of bounding box dimensions as a distance-equivalent



New requirements may arise from gaps in data coverage of the ODD: Data gaps need to be identified and closed.

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Dataset: https://hci.iwr.uni-heidelberg.de/content/bosch-small-traffic-lights-dataset

GT: Ground Truth ML: Machine Learning (connectionistic ML – esp. DNNs) ODD: Operational Design Domain TL: Traffic Light

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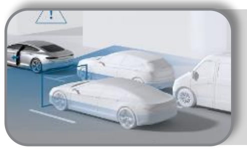
DDE Process as Solution


Industrial Benefits from Our Approach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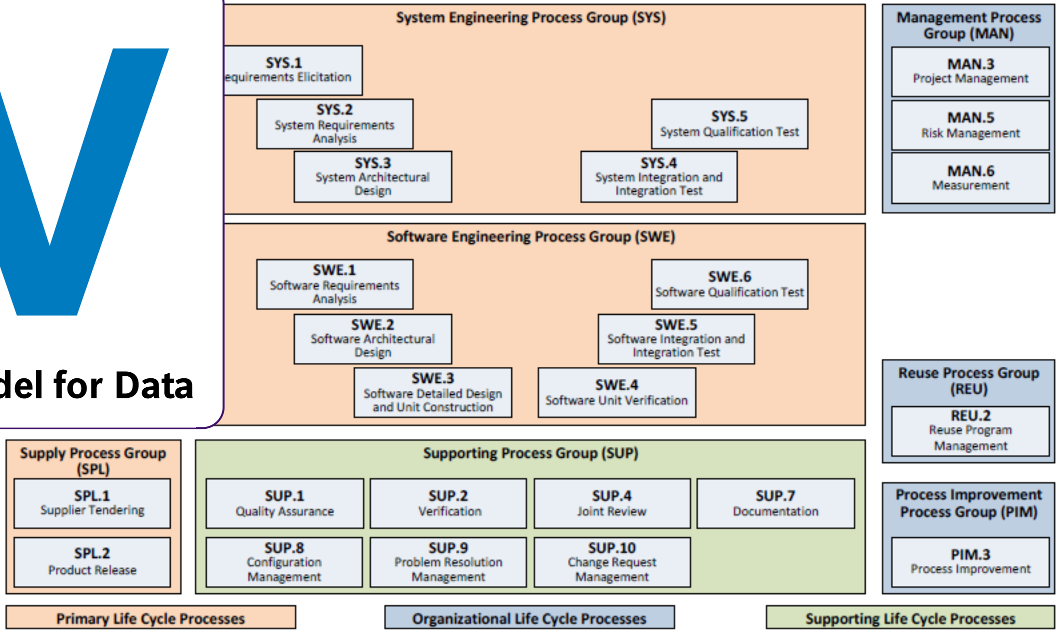
Data-Driven Engineering (DDE) Process for Machine Learning in Automated Driving

Our Solution: Extend ASPICE PRM by Data V-Model and SWE steps by ML

We want a process, which shall ...

- ... cover the data-driven characteristics of machine learning (ML) and include well-established ML workflows seamlessly
- ... be compatible to the existing ASPICE process reference model and collaborate with the SYS/SWE process also incl. ML
- ... be iterative using a systematic data-driven approach to incrementally address data coverage of the Operational Design Domain (ODD)
- ... introduce traceable coverage of data & ML requirements besides the coverage of classical non-/functional SYS/SW require-ments into the V&V argumentation

V-Model for Data



Automotive SPICE process reference model

(https://www.automotivespice.com/fileadmin/software-download/AutomotiveSPICE_PAM_31.pdf)

We propose a novel, ASPICE-compatible Data-Driven Engineering Process for Machine Learning in Automated Driving ...

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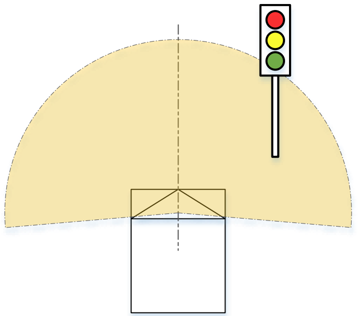
Data-Driven Engineering (DDE) Process for Machine Learning in Automated Driving

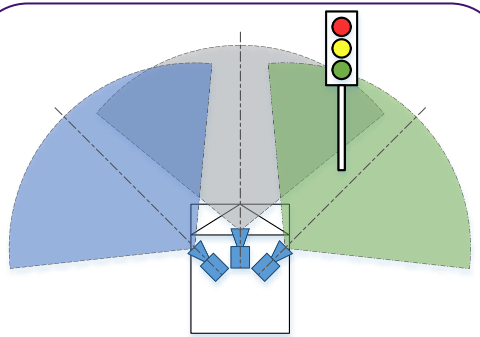
DDE Design Levels for Data



DDE0: Vehicle Level

Focus:

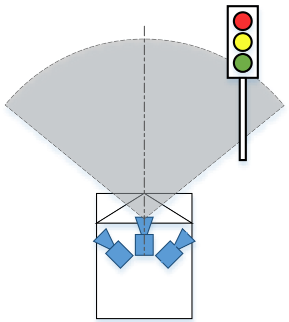
- Overall field of view from vehicle perspective



DDE1: Sub-/System Level

Focus:

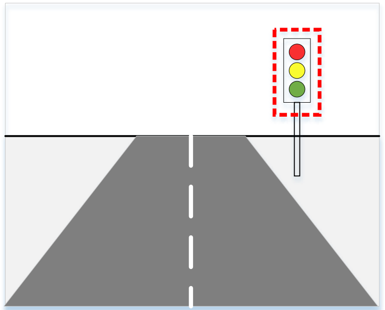
- Multi-sensor data sequences from system or functional chain perspective



DDE2: Fct. Domain Level

Focus:

- Single-sensor data frames or sequences from SW function perspective



DDE3: Implementation Level

Focus:

- ML model perspective (s. DDE2)
- All-DDE-Level-perspective for data pool implementation

Use Cases => Scenario collections → System data requirements (test) → Domain data requirements (test) → ML model & data pool implementation

The goal of the DDE process is to tailor data sets requirement-based to the individual needs of each design level.

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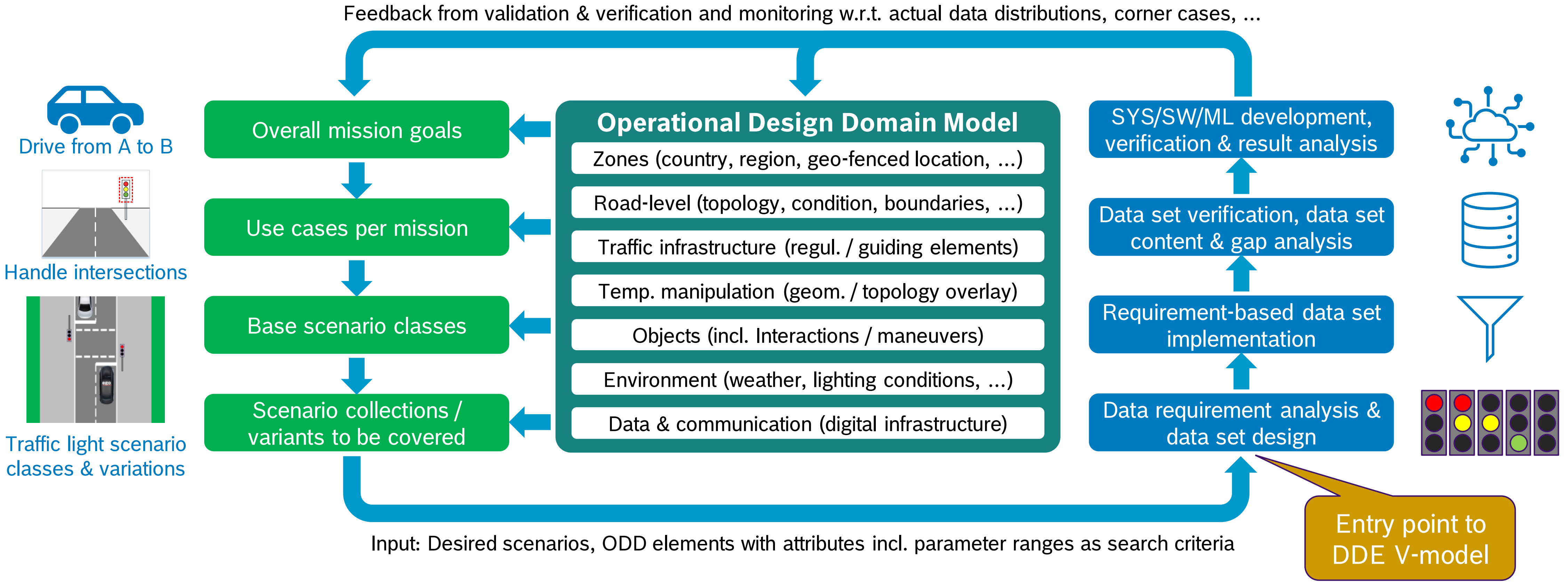
Data-Driven Engineering (DDE) Process for Machine Learning in Automated Driving

Operational Design Domain (ODD) as Entry Point to DDE on Vehicle Level



An aligned ODD model & ontology is the basis for deriving data requirements & criteria for data coverage on all design levels.

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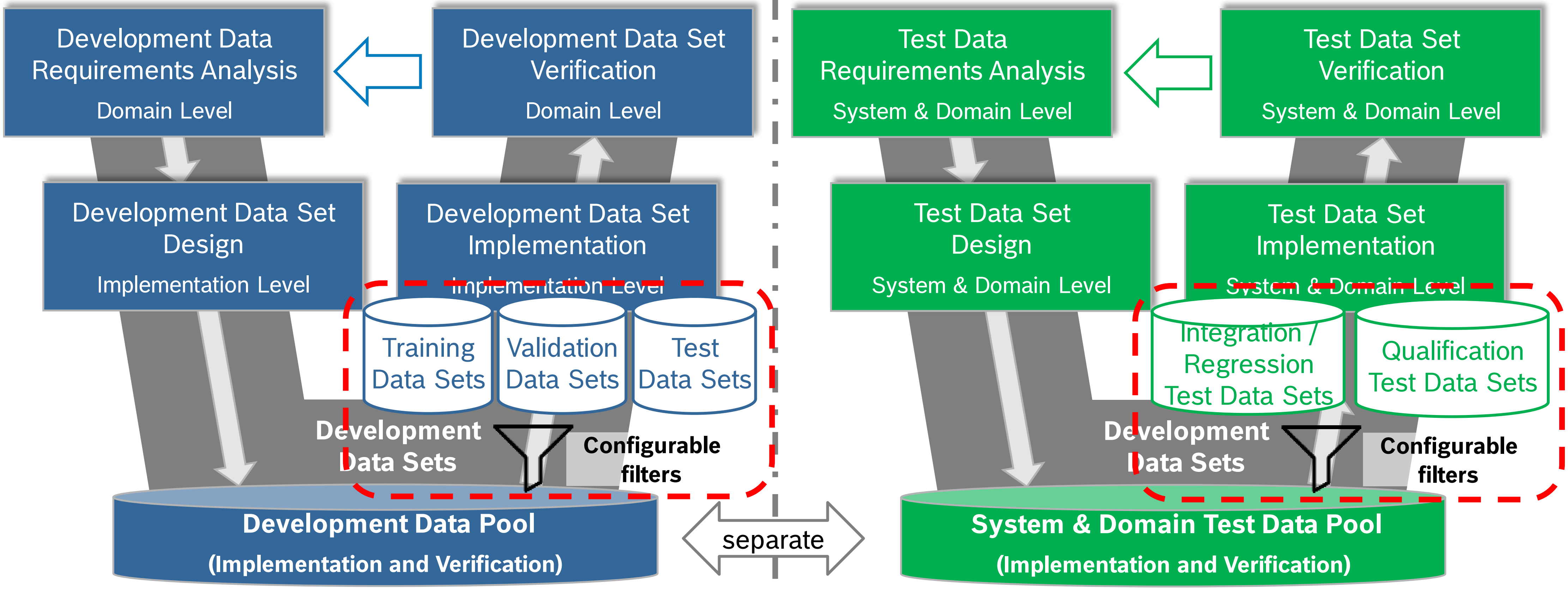
Data-Driven Engineering (DDE) Process for Machine Learning in Automated Driving

Implementation & Verification of Independent Development & Test Datasets

e.g. What TL color variations need to be covered by how many samples?



On all levels we need data set implementation & verification workflows that can be automated using configurable data filters.

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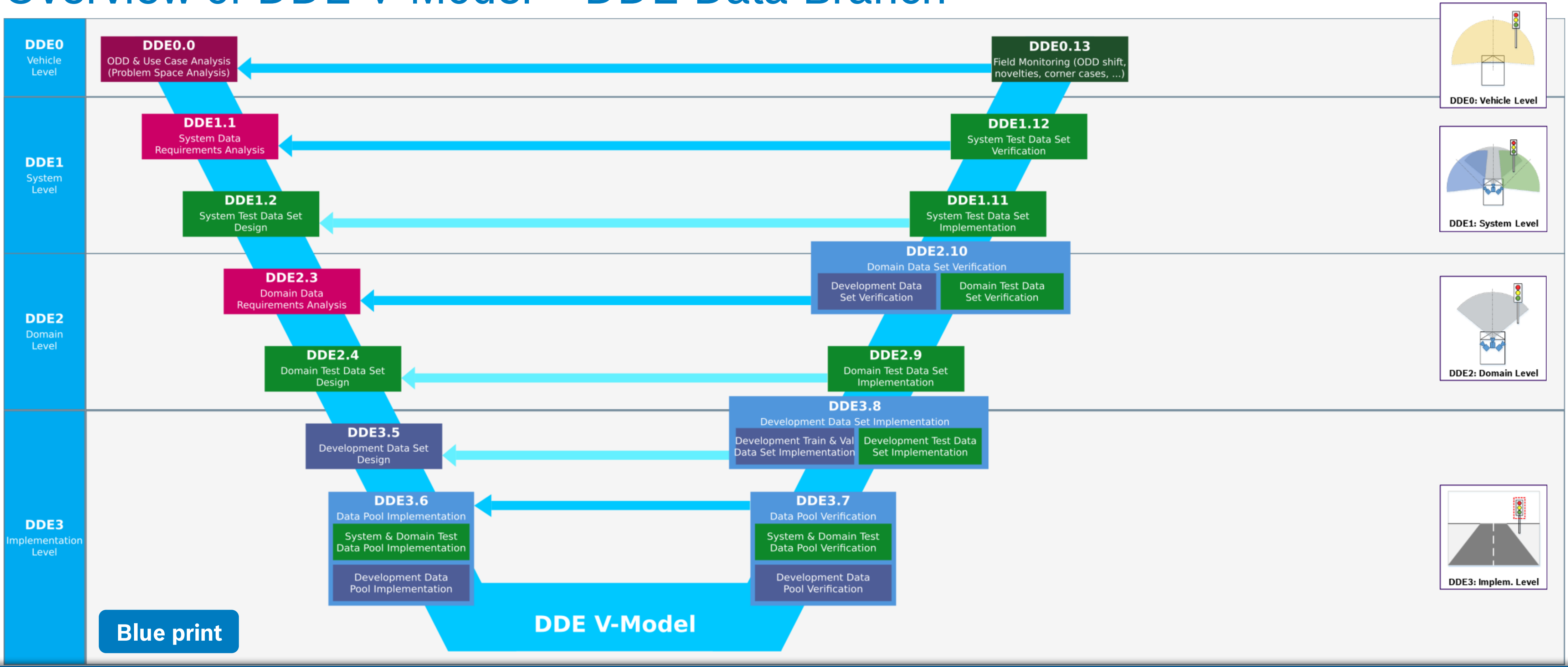
Data-Driven Engineering (DDE) Process for Machine Learning in Automated Driving

Overview of DDE V-Model – DDE Data Branch



The new DDE process components provide the SW/ML development process (ref. ASPICE) with verified data sets on all levels.

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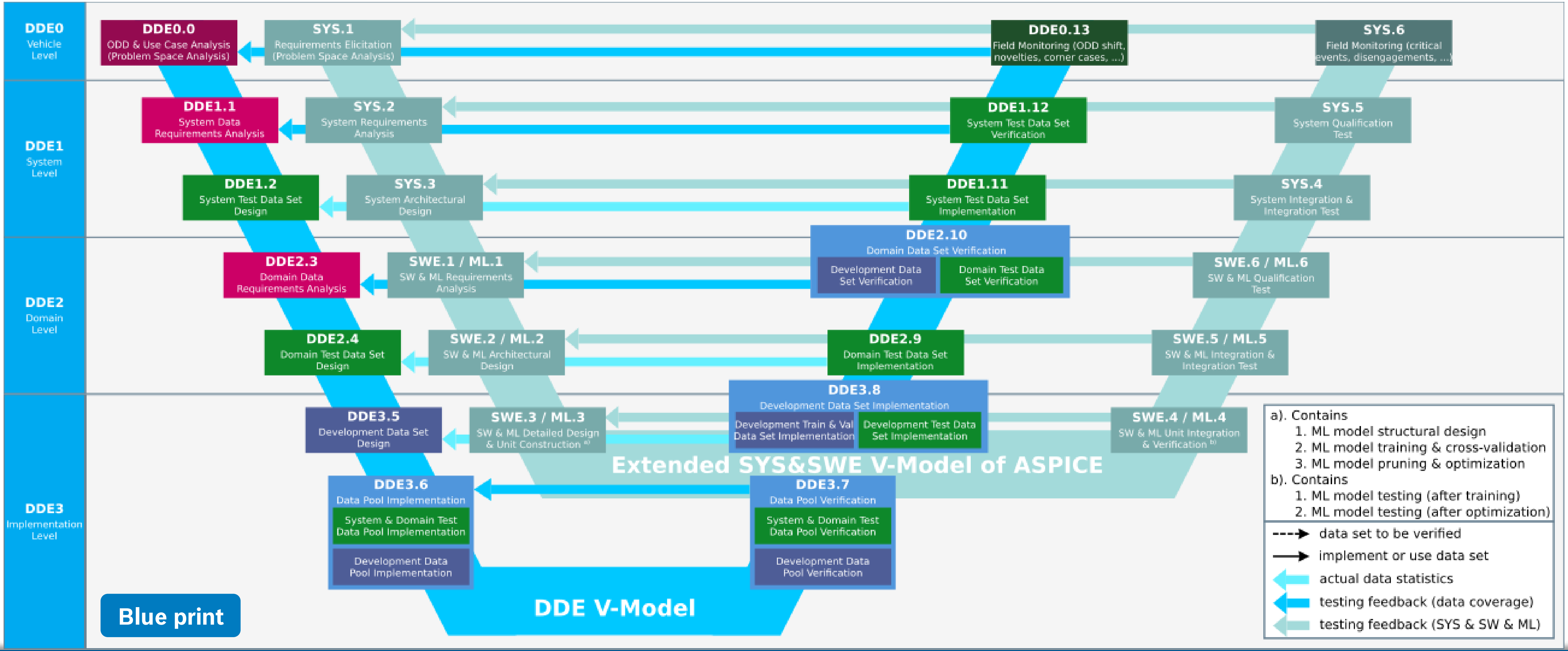
Data-Driven Engineering (DDE) Process for Machine Learning in Automated Driving

Overview of DDE V-Model – DDE Data Branch and SYS/SW/ML Branch



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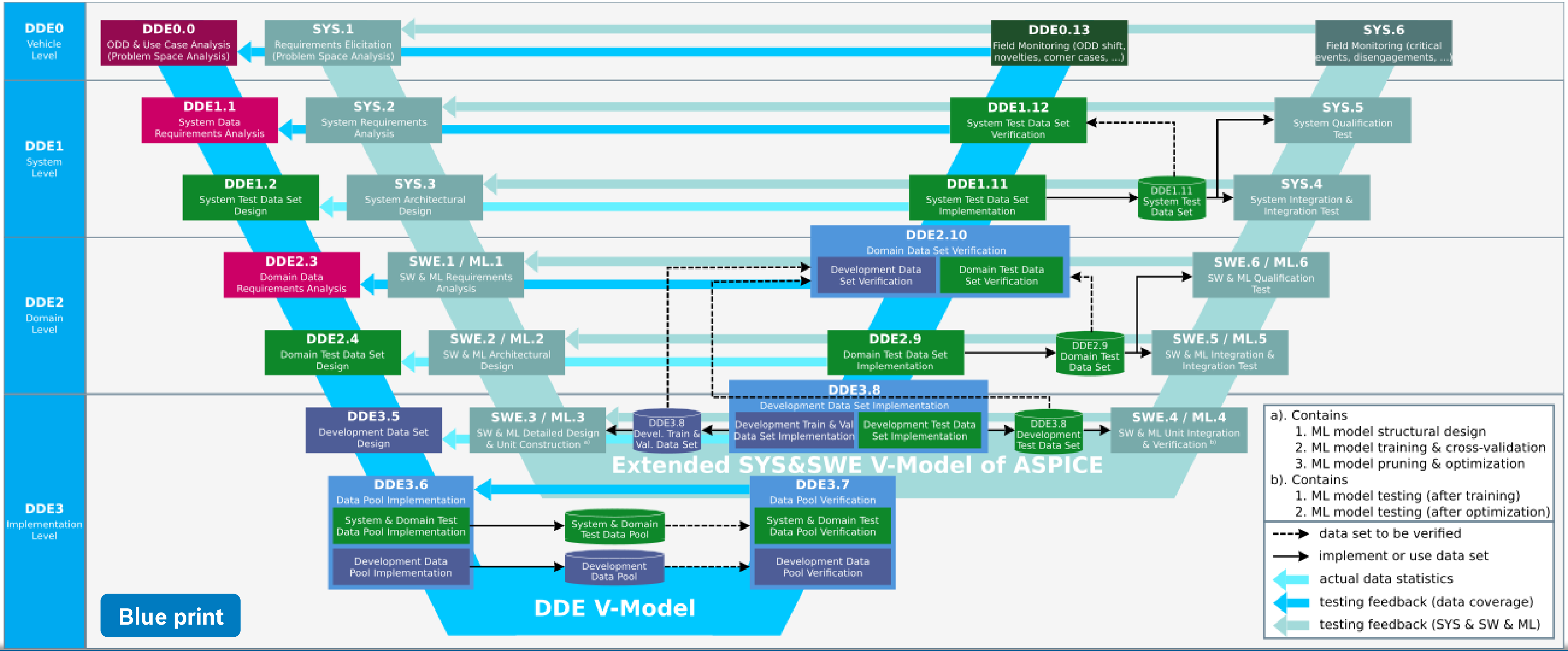
Overview of DDE V-Model – DDE & SYS/SW/ML Branch linked via Data Sets



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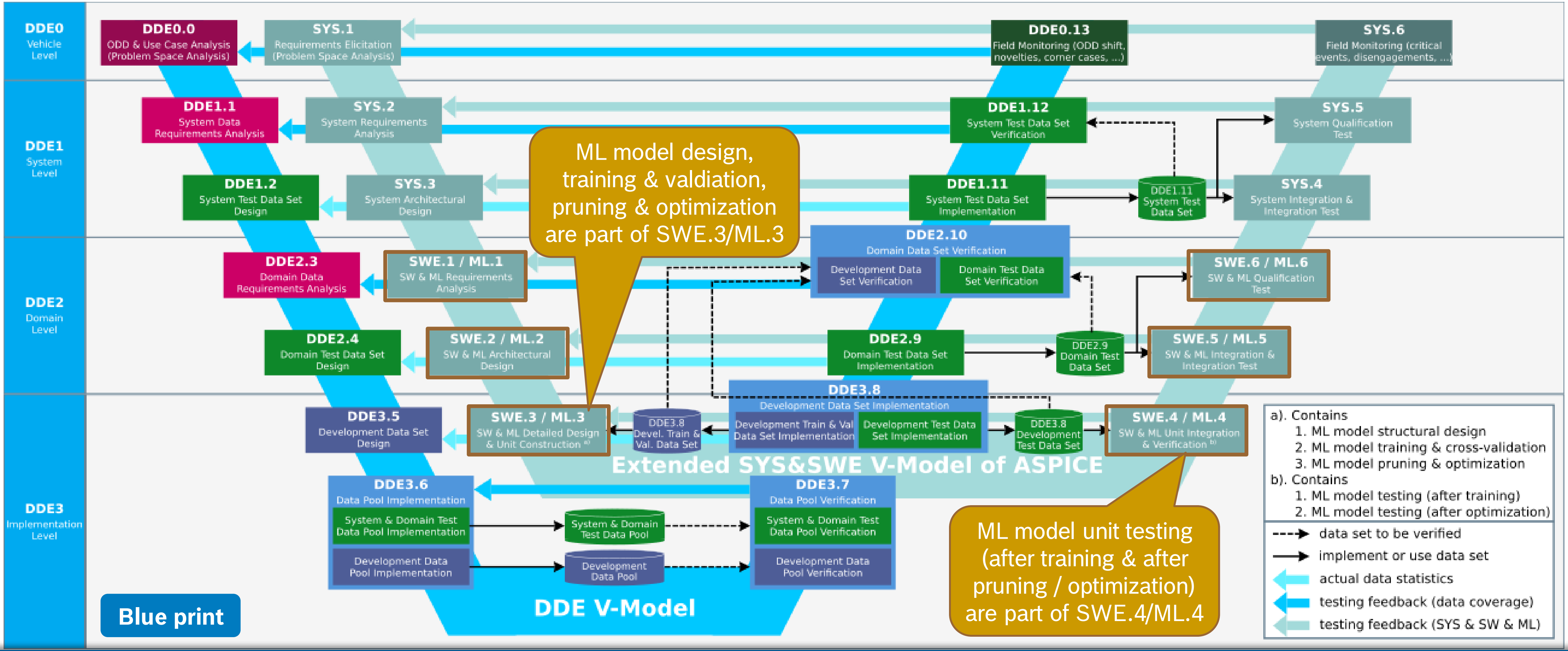
Overview of DDE V-Model – SYS/SW/ML Branch includes Machine Learning



ML architectural design, ML model training, validation & unit testing, pruning & optimization are part of the SYS/SW/ML branch.

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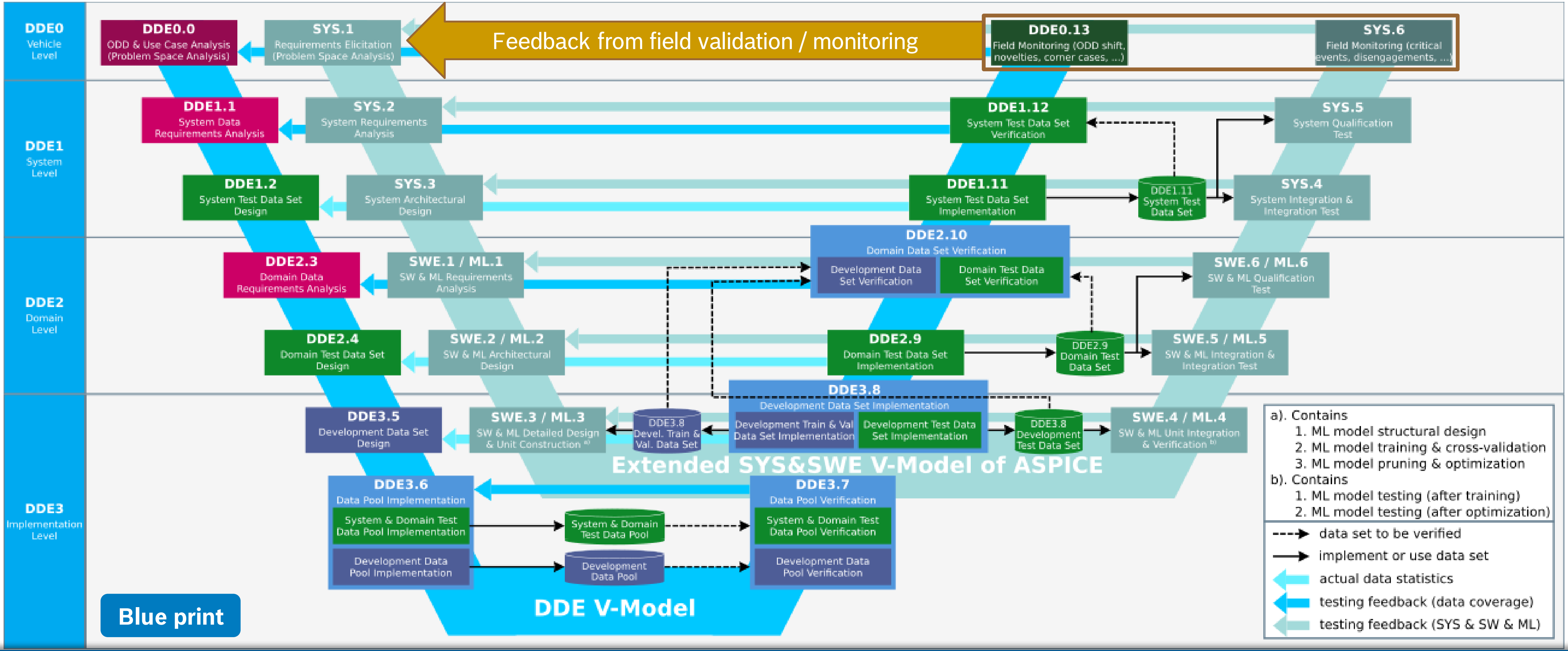
Overview of DDE V-Model – Validation & Testing Feedback on all Levels



Both DDE and SYS/SW/ML branch include cyclic validation & verification steps and experience-driven feedback on all levels.

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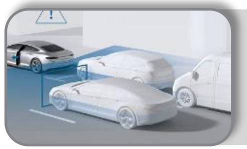
Industrial Benefits from Our Approach



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Industrial Benefits of Our Approach

The DDE V-model facilitates consistent derivation of data requirements and offers cross-project-wide reusability of development artifacts, data sets & tools.

Requirement-based data engineering fosters goal-oriented, systematic data collection and labeling, which helps to massively reduce labeling cost.

Consequent data set verification against clearly defined data requirements shows gaps in data sets & facilitates analysis of failures e.g. caused by data.

Our DDE V-model includes ML workflows and maps to existing SYS/SW engineering standards without changing them.

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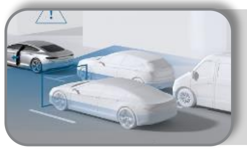

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Summary and Future Work

Summary

- We propose a new DDE process to overcome challenges in ML-based AD system development.
- Our process model consists of a novel DDE V-model for data engineering linked via the data sets to a V-model for SYS & SW engineering, which includes ML workflows.
- We have shown the consistency of our approach using the example of Traffic Light Detection.
- We find it essential to strengthen SYS.1 activities in combination with DDE.0 (ODD analysis, ...).

Next steps / Future Work

- We propose to extend the ASPICE model by a DDE branch, to integrate ML workflows, and to add appropriate validation processes during test phase followed by continuous field monitoring (DDE0.13/SYS.6) to cover future requirements for (highly) automated and autonomous driving.

Our DDE process is a generic approach that can be applied to other use cases.

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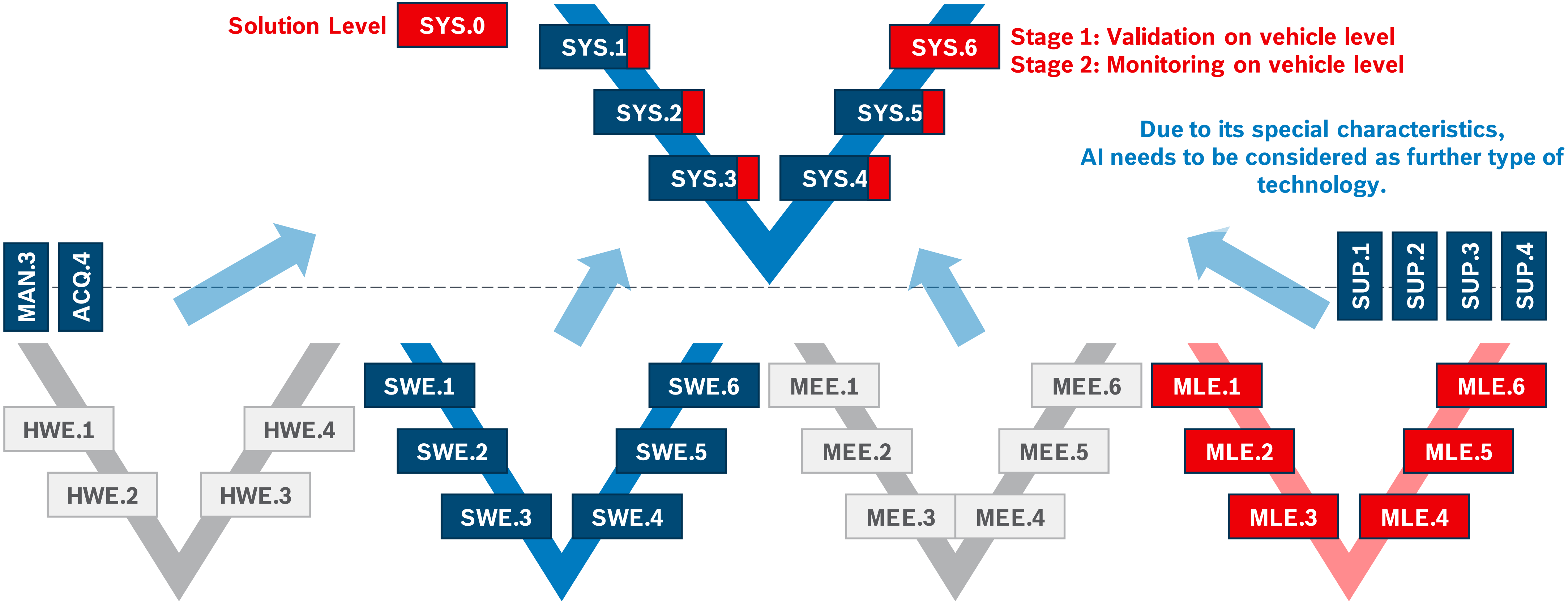
Proposal for a ML motivated Extension of ASPICE



DNNs (AI, ML) needs to be considered as 3rd kind / further type of technology (AI≠SW, AI≠HW).

Reference: VDE-AR-E 2842-61 Development and Trustworthiness of autonomous/cognitive Systems