



DENSO

Crafting the Core

CONFIDENTIAL

Transmission Control Unit Use Case for Virtual ECUs and SSP-based Collaborative Development

08.09.2025

16th International Modelica & FMI Conference
Lucerne, Switzerland

Hasan Esen⁽¹⁾, Nicolas Ochoa⁽¹⁾, Pierre Mai⁽²⁾

(1) DENSO AUTOMOTIVE Deutschland GmbH

(2) PMSF IT Consulting

CONTENTS

1. V-ECU Overview
2. Use Case Introduction: Transmission Control Unit Design
3. V-ECU for TCU Design
4. V-ECUs in prostep ivip SmartSE project
5. Conclusion & Outlook

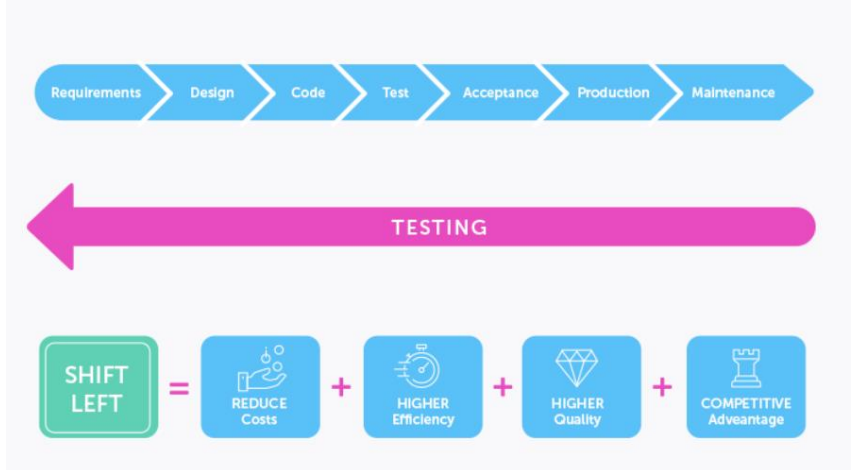
1

Virtual ECU Introduction

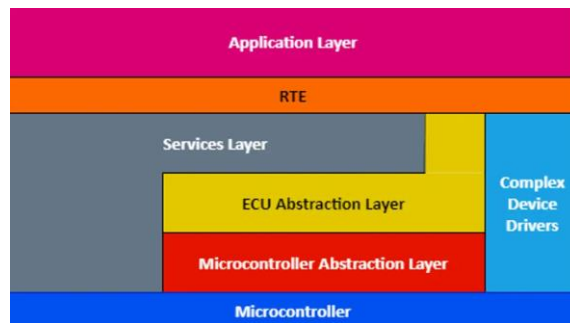
Shift-Left with Virtual ECUs

CONFIDENTIAL

ECU virtualization is a key to **shift-left** in automotive industry.



Physical (real) ECU has several layers, to integrate application SW into the product HW



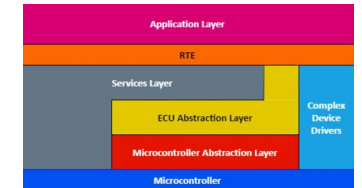
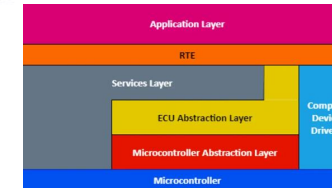
A Virtual ECU (vECU) is an **abstraction** that contains all the SW parts needed to simulate specific aspects of a real ECU.



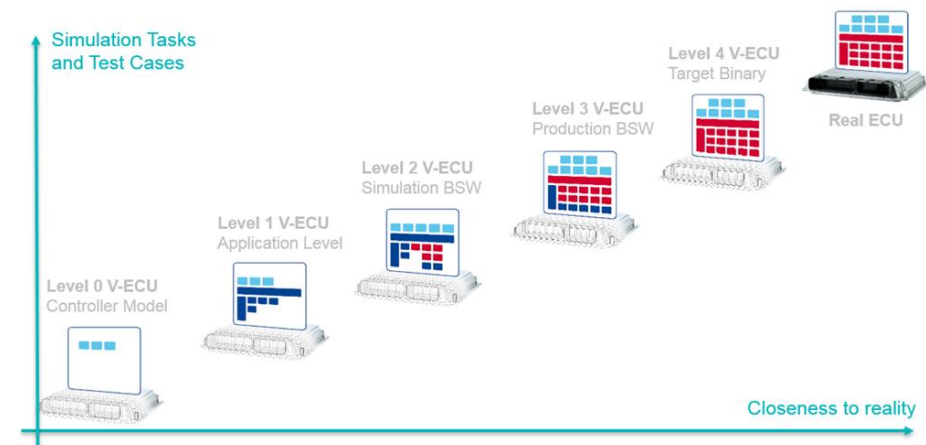
Physical ECU
-real-



Virtual ECU (Lvl4)
-simulated-



This **abstraction** can be at different **levels**.

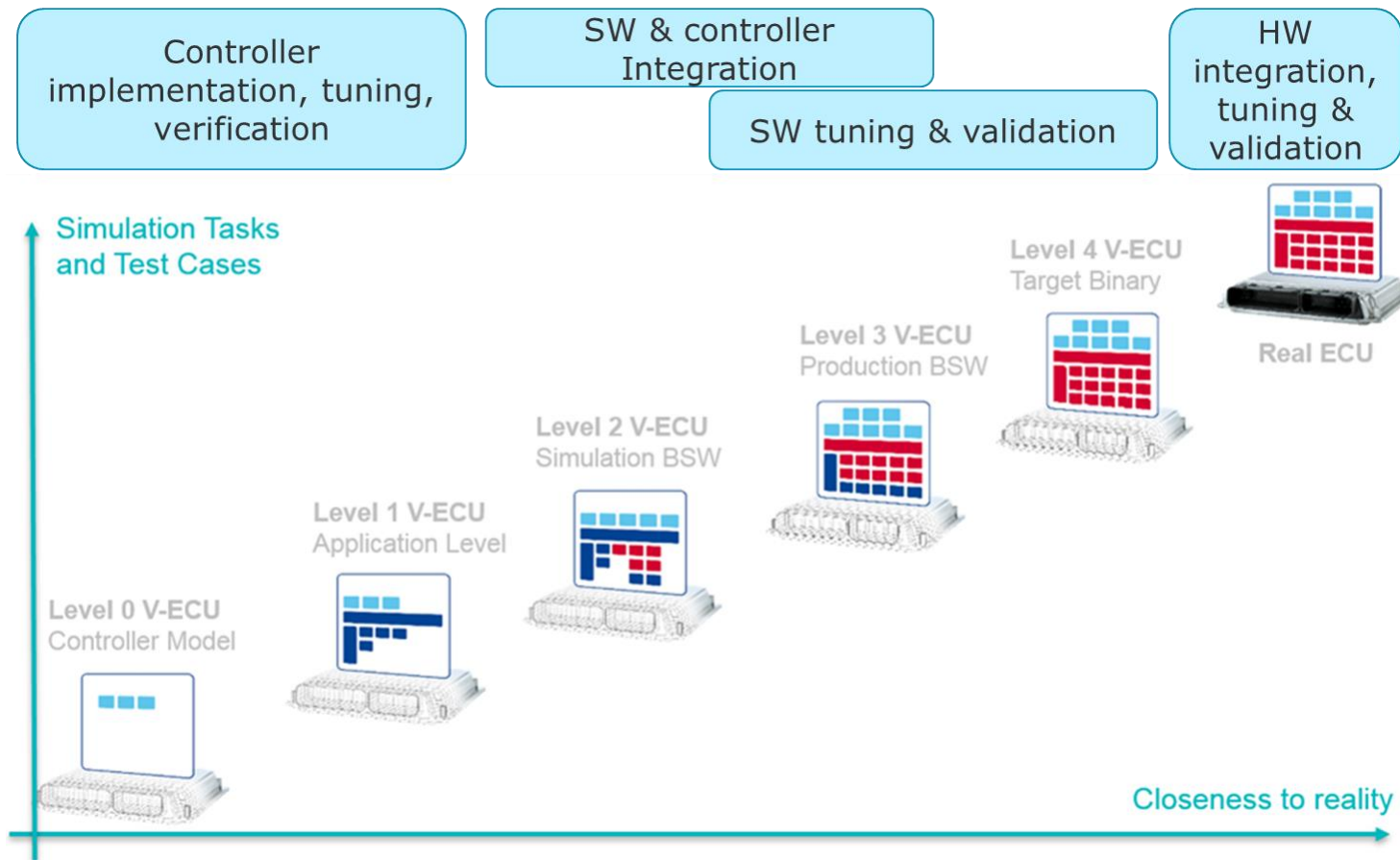


Abstraction Levels vs Applications

CONFIDENTIAL

The required level of abstraction depends on the testing target

Higher the level, closer to the real behaviour, but more complex simulations



Level 0
Controller model, no production code

Level 1
Application code as production, no basic software

Level 2
Application + Simulation Basic SW

Level 3
Application + Production Basic SW

Level 4
Application + BSW as target binary code

2

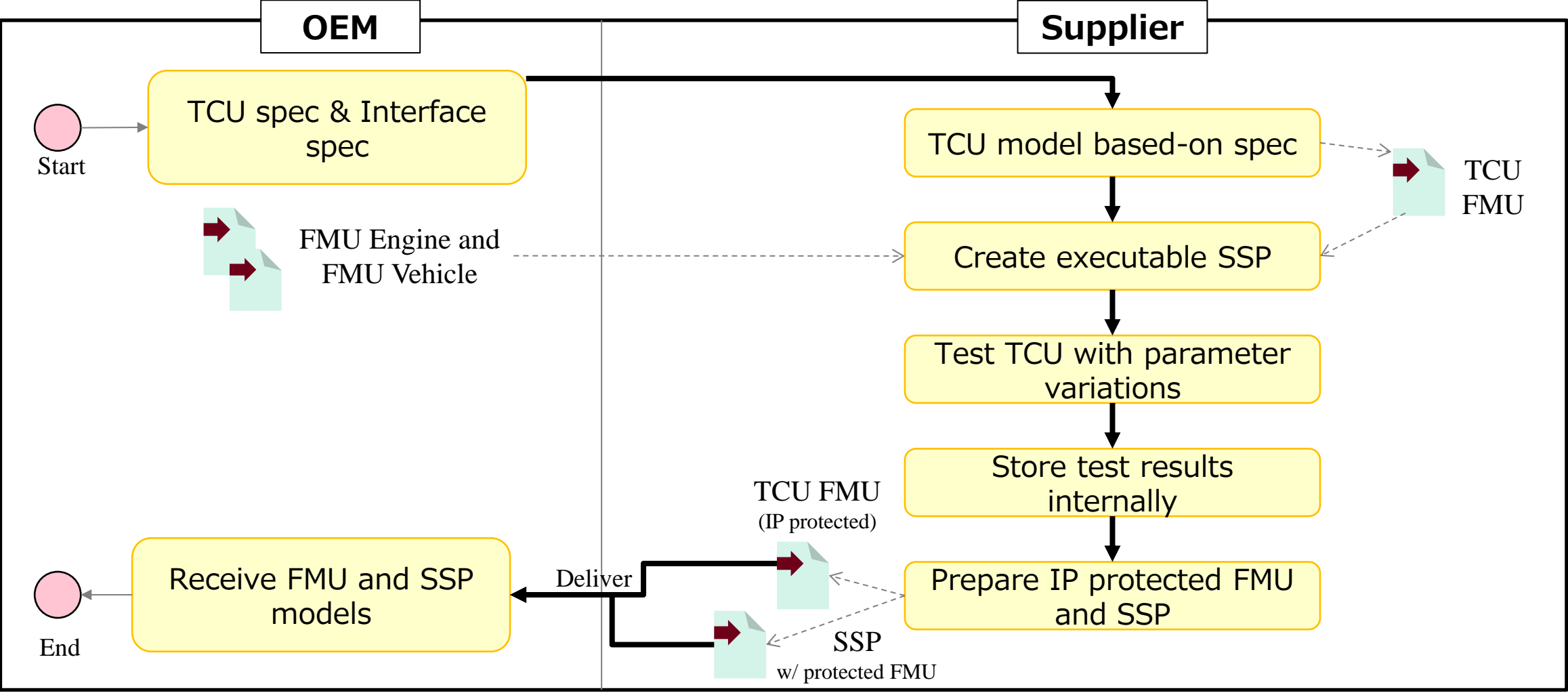
Use Case: Transmission Control Unit Design

Proof of Concept (PoC) Development for TCU Design

CONFIDENTIAL

Use Case*: Supplier to design, test and calibrate Transmission Control Unit (TCU) based on OEM specifications and requests.

**This is an example use case. It does not represent any real business case.*



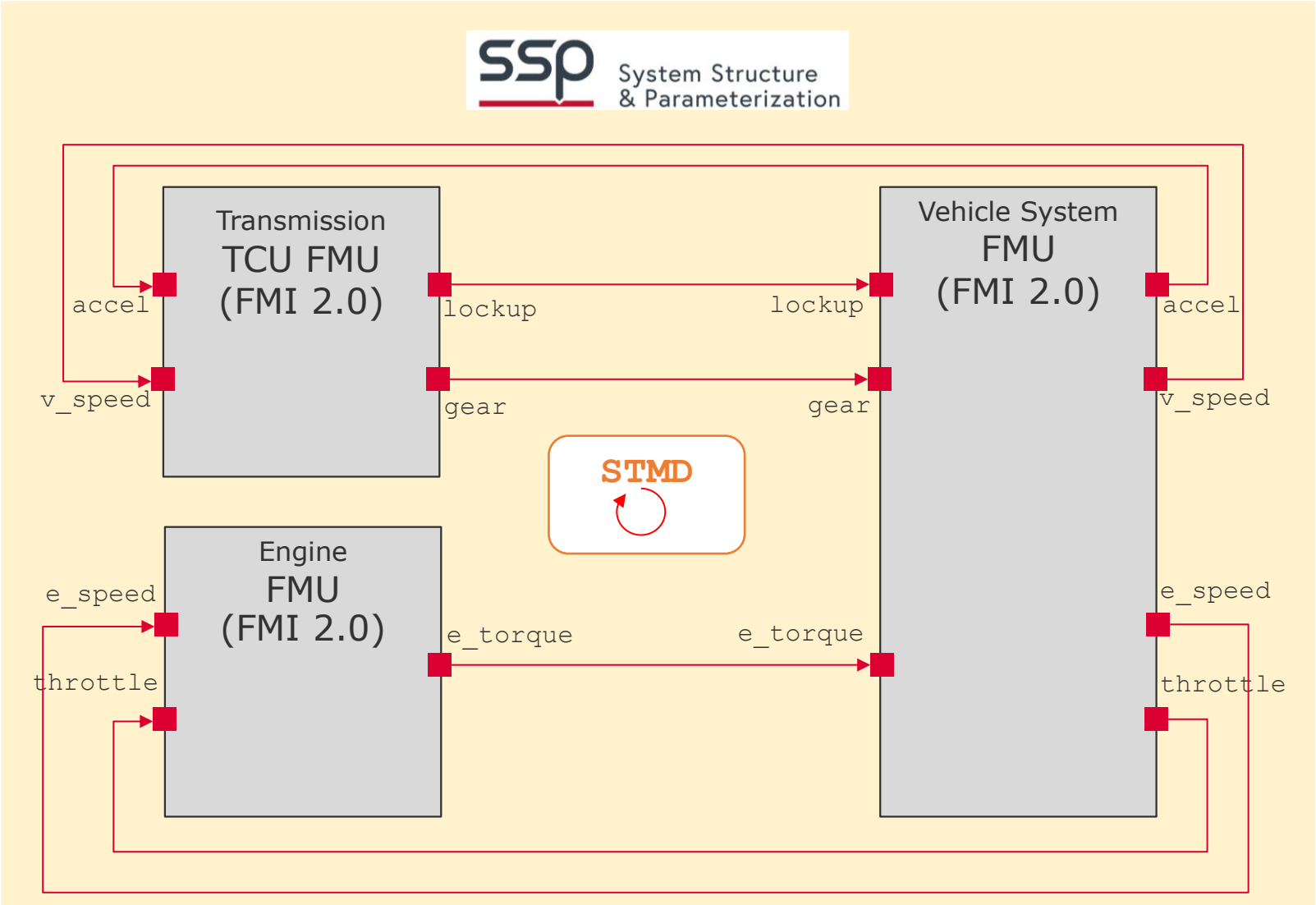
System Model

CONFIDENTIAL

Overall system architecture is defined in SSP format.
Component FMUs are integrated into the architecture:

- Engine FMU (Amesim)
- Vehicle FMU (Matlab)
- TCU model (FMU, Matlab)

STMD is implemented for traceability of system requirements, design goals, implementation details,...etc.



3

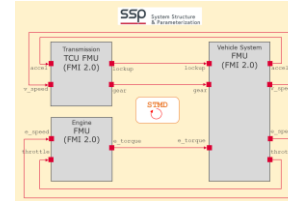
Virtual ECU for TCU Design

..

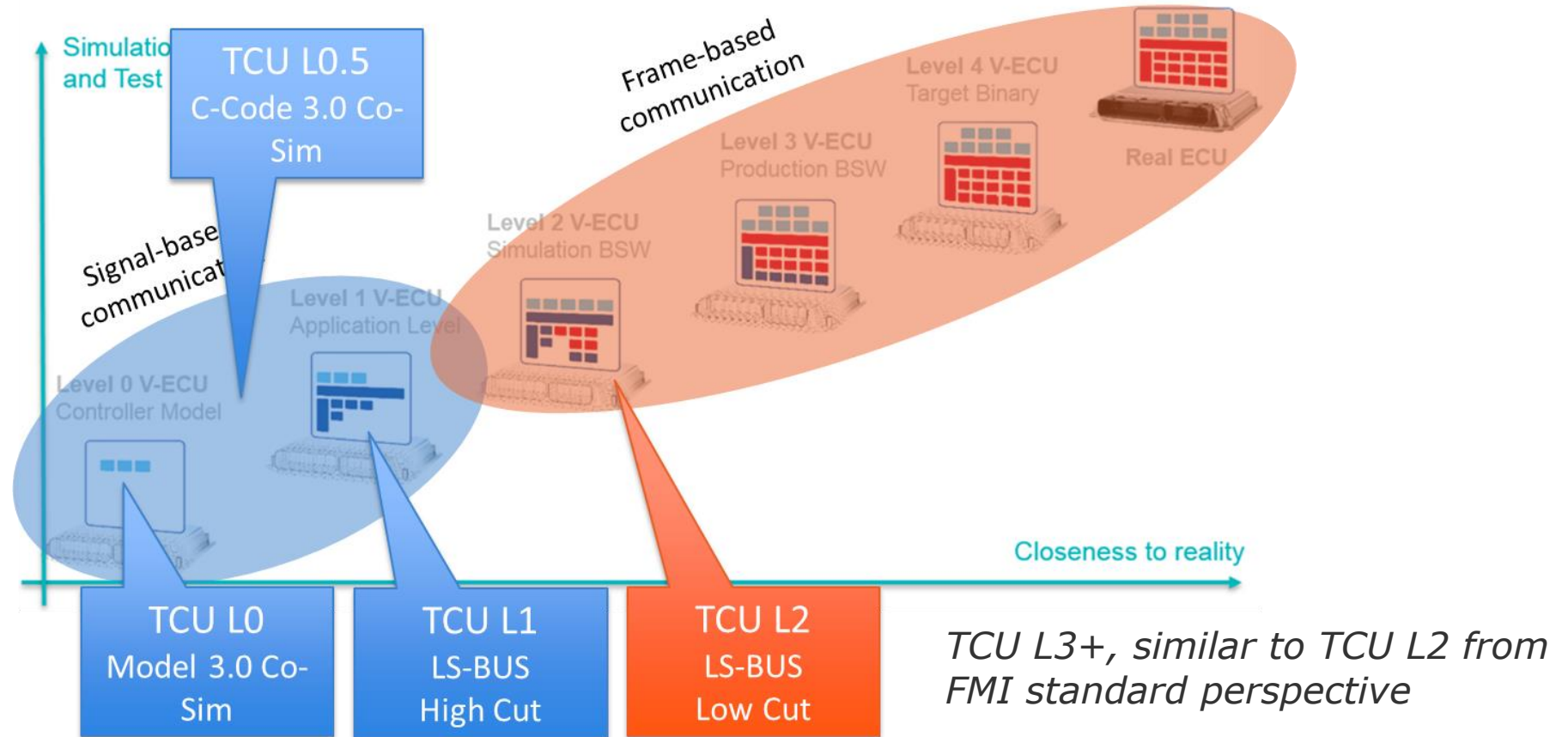
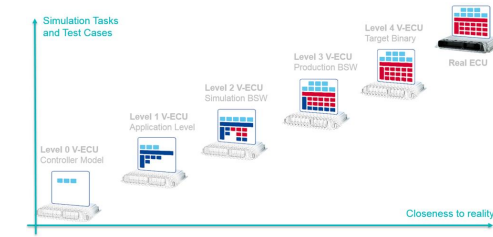
Virtual ECU for TCU Design

Based on TCU SSP Design and prostep ivip vECU levels, different vECU uses cases are defined and implemented definitions

CONFIDENTIAL

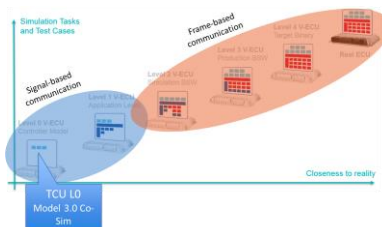


+



TCU L0 – vECU

CONFIDENTIAL



Starting Model:
SmartSE TCU SSP

Use Cases

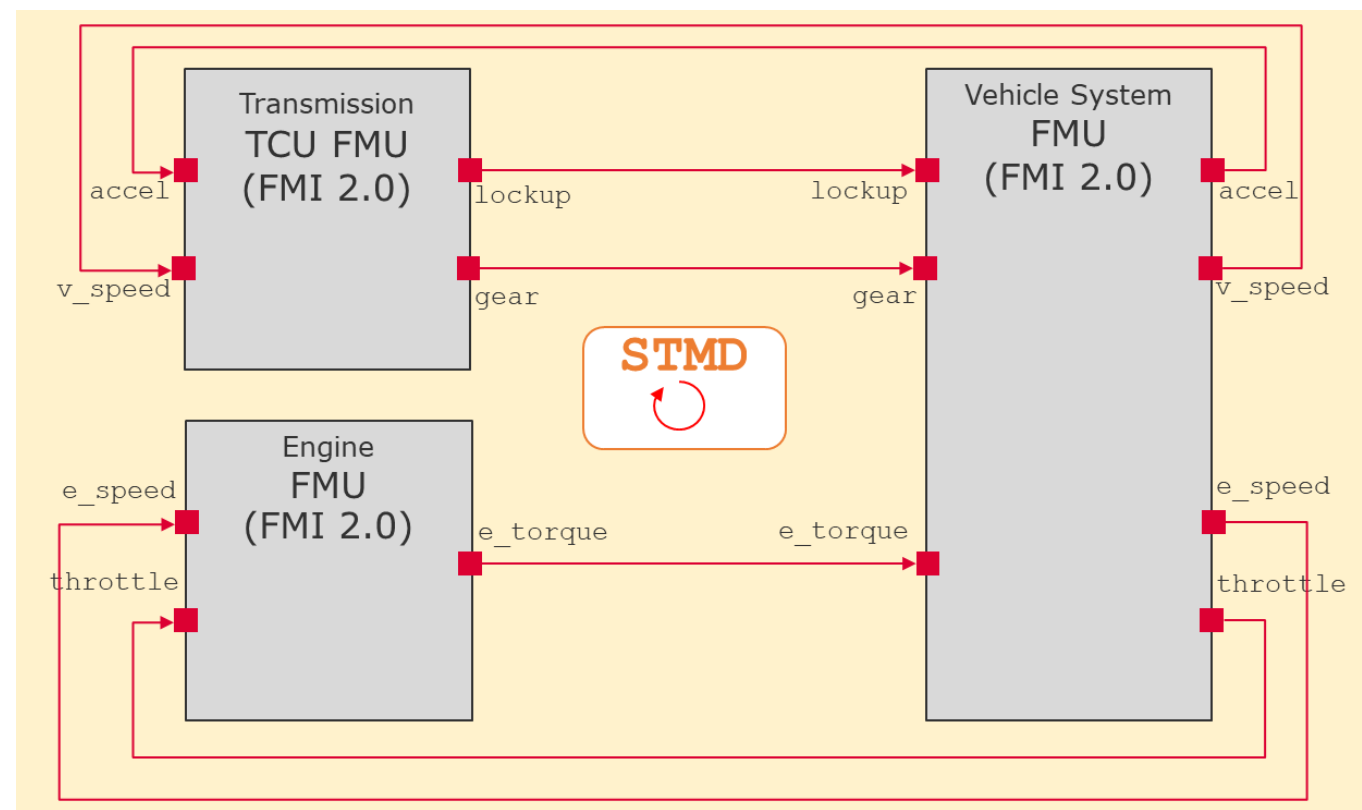
- Controller design and initial tuning
- Validation of control algorithm
- Robustness testing of control strategy

Restrictions

- No runtime performance or timing artefacts
- No implementation code, basic SW
- No bus communication

Added vECU feature:

-



CONFIDENTIAL



The diagram illustrates a vehicle system architecture with three Functional Mockup Units (FMUs) and a central STMD block:

- Transmission TCU FMU (FMI 3.0) hand-coded**: This block receives `accel` and `v_speed` inputs. It outputs `lockup` and `gear` signals.
- Engine FMU (FMI 3.0) converted**: This block receives `e_speed` and `throttle` inputs. It outputs `e_torque`.
- Vehicle System FMU (FMI 3.0) converted**: This block receives `lockup`, `gear`, `e_torque`, `accel`, and `v_speed` inputs. It outputs `v_speed`, `e_speed`, and `throttle`.

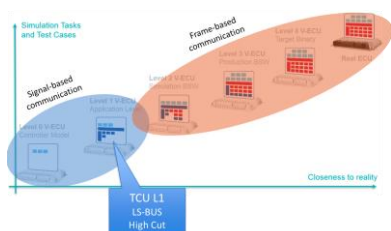
The **STMD** (State Transition Machine Definition) block is shown in the center, indicating the control logic governing the system. Red lines represent the data flow between the components and the STMD.

- Controller implementation design and initial tuning
- Validation of control algorithm implementation
- Robustness testing of numeric code

- No runtime performance or timing artefacts
- No scheduling, basic SW
- No bus communication

TCU L1.0 – vECU

CONFIDENTIAL



Starting Model:
TCU-L0.5 vECU

Use Cases

- Controller implementation design and initial tuning
- Validation of control algorithm and schedule implementation
- Robustness testing of numeric code and basic scheduling

Restrictions

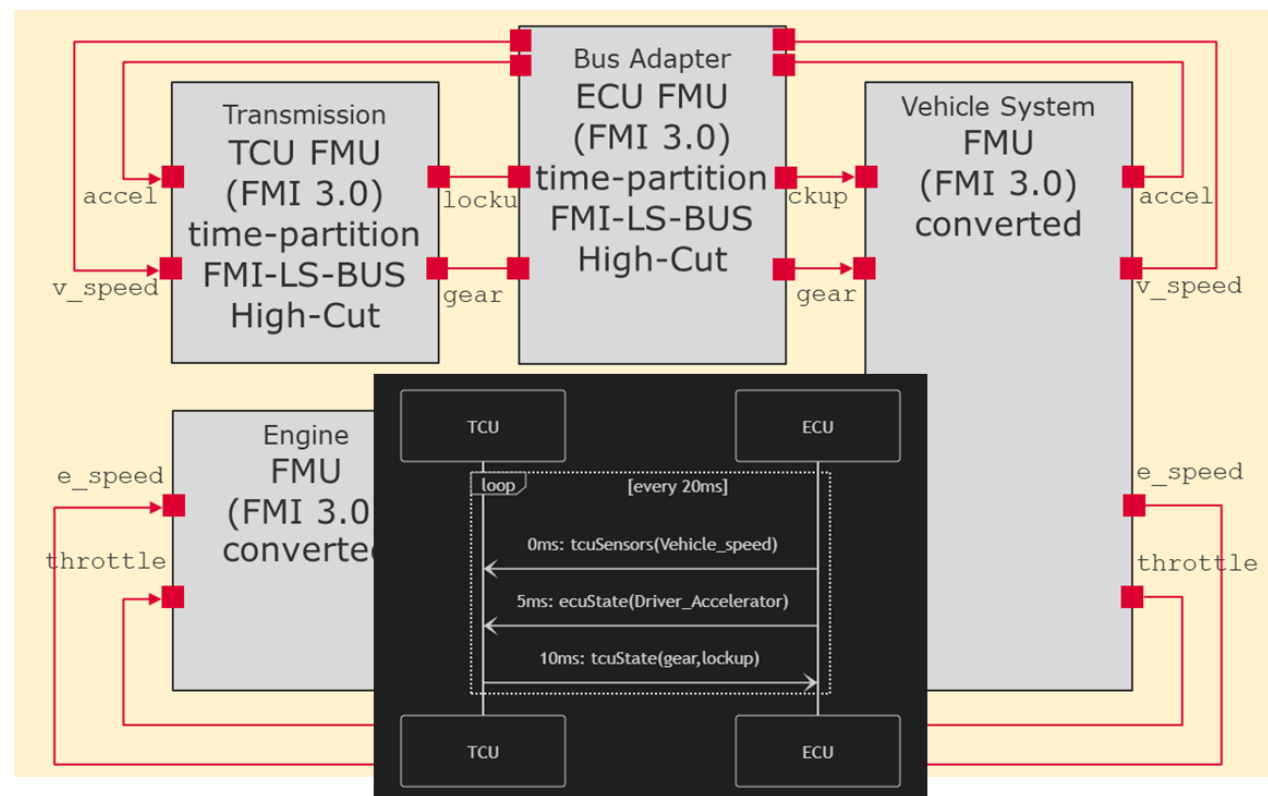
- No runtime performance, limited timing artefacts
- Only basic scheduling, no full basic SW stack
- Idealized bus communication, no error situations, net startup

Added vECU feature:

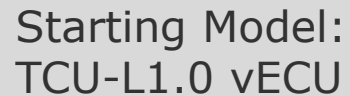
vECU Level 1

Time Partitioned, Clocked Co-Sim

LS BUS High-Cut



CONFIDENTIAL



- Full controller, basic SW implementation design and tuning
- Validation of controller and basic SW configuration
- Robustness testing of network communication and non-runtime related scheduling

- No runtime performance, only non-related timing artefacts
- Only partial basic SW stack, no drivers/HW, production compilers

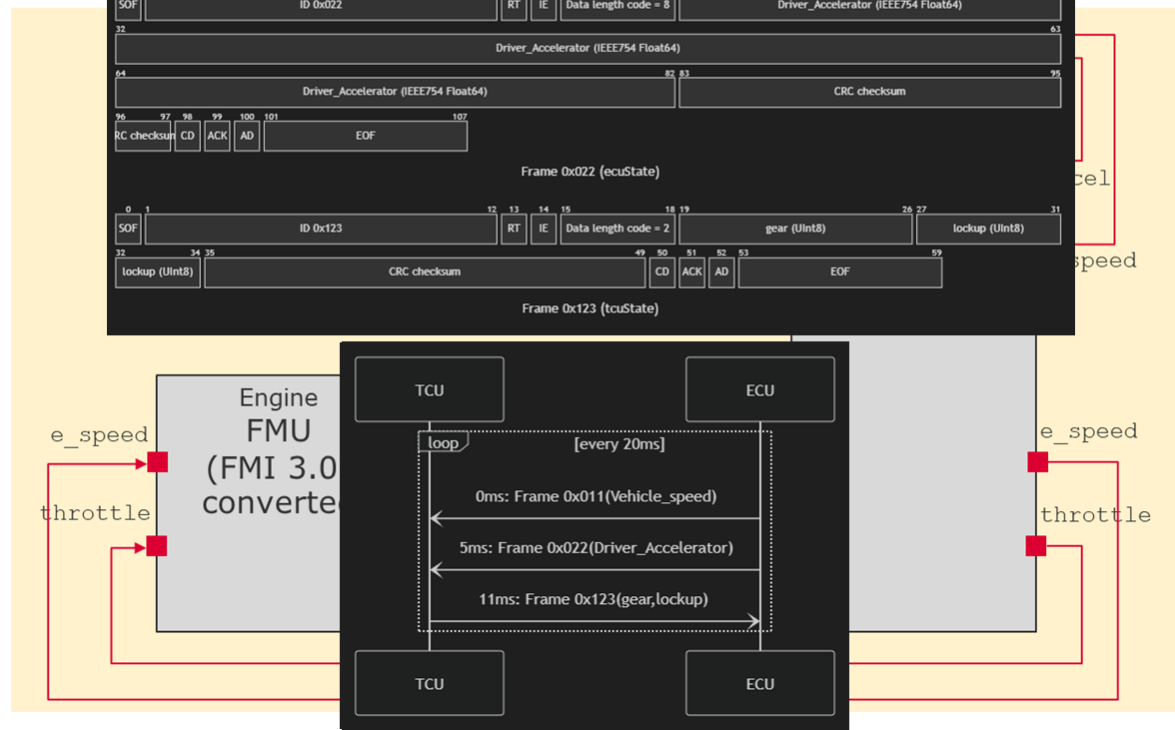
The diagram illustrates two CAN bus frames and their corresponding data structures.

Frame 0x011 (tcuSensors):

- Header:** SOF (0), ID 0x011 (12-13), RT (14), IE (15), Data length code = 8 (18-19).
- Data:** Vehicle_speed (IEEE754 Float64) (26-31).
- Checksum:** CRC checksum (32-37).
- Footer:** EOF (38-39).

Frame 0x022 (ecuState):

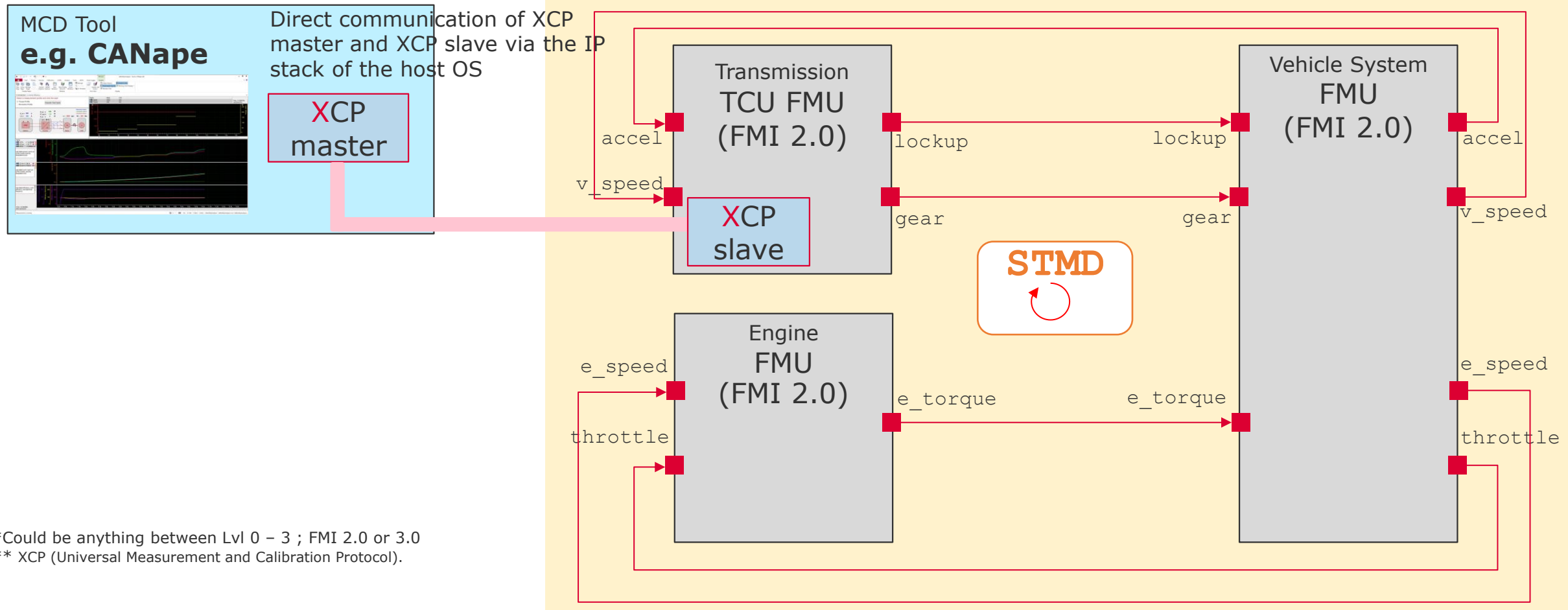
- Header:** SOF (0), ID 0x022 (12-13), RT (14), IE (15), Data length code = 8 (18-19).
- Data:** Driver_Accelerator (IEEE754 Float64) (26-31).
- Checksum:** CRC checksum (32-37).
- Footer:** EOF (38-39).



Calibration Virtual ECUs using XCP

CONFIDENTIAL

TCU vECU* parameters can be calibrated via FMI-LS-XCP, implementing XCP**. This would allow access to controller internal calibration and measurement via the usual ECU calibration tools like Canape/INCA/...demonstrating that the overall approach can be used at SIL, vECU and ECU levels



*Could be anything between Lvl 0 – 3 ; FMI 2.0 or 3.0

** XCP (Universal Measurement and Calibration Protocol).

4

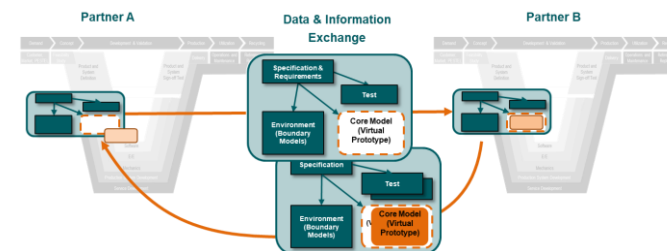
vECU in Prostep SmartSE

Prostep Smart Systems Engineering

CONFIDENTIAL

SmartSE Mission & History (2012-2024)

Focuses on **industrialization of MBSE standards** and **collaborative development between EU OEMs and suppliers**



2012 **Phase-I, II**

2016 **Phase-III**

2019 **Phase-IV**

2022

Phase-V

2024

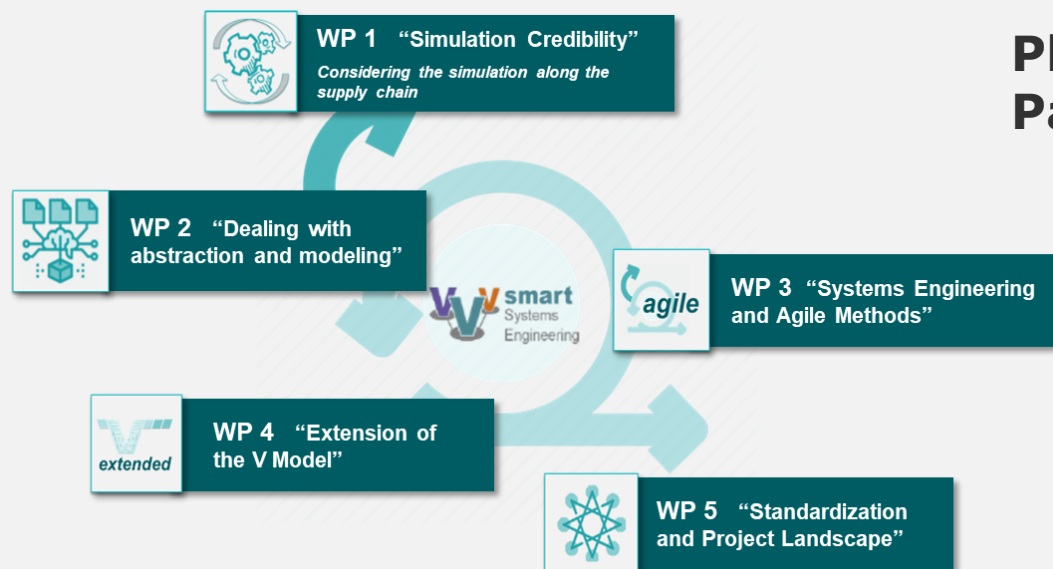
FMI Industrialization; industry best practices to ease the exchange of models and smooth process integration between the engineering disciplines and partners

Recommendations for industry for **model exchange**. Intensify the cooperation activities with other projects

Extensions towards **autonomous systems, VECUs**, and Modelica **SSP**

Enabling **collaborative development** and validation of complex products by simulation along a multi tier supply chain.

Phase V Scope:



Phase V Partners:




Prostep Smart Systems Engineering

CONFIDENTIAL


SmartSE Future – Phase VI (2025-2027)




DENSO

**Mission SmartSE
Phase 6** (2025 - 2027)

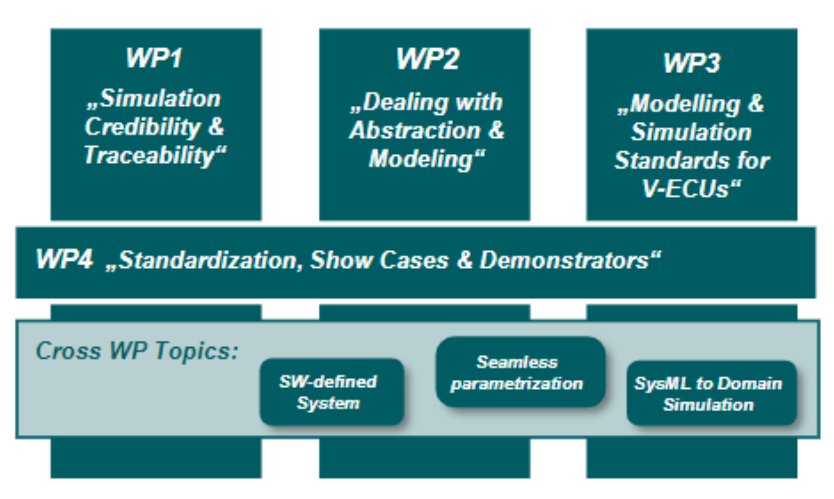
Enabling collaborative development and validation of complex products by simulation in networks and along multi-tier supply chains.


**WP1 „Simulation Credibility & Traceability“**

Benefit: Support decisions based on simulations in cooperation with partners.


**WP2 „Dealing with Abstraction & Modeling“**

Benefit: Enable adequate creation, selection and exchange of simulation models by a systematic, structured approach for their classification. This helps to improve understanding and communication of simulation tasks and needs-based model usage.



**WP3 „Modelling & Simulation Standards for V-ECUs“**

Benefit: For different use cases special V-ECUs are needed. Standardized V-ECUs based on the main use cases reduce the effort by exchanging processes.

**WP4 „Standardization, Show Cases & Demonstrators“**

Benefit: Evaluate existing and emerging Systems Engineering standards from applicability perspective. Provide feedback to standards, and support their improvement.



5

Conclusion & Outlook

Conclusion

CONFIDENTIAL

- ECU virtualization is a key to **shift-left** in automotive industry.
- The **required level of abstraction depends on the testing target** → Higher the level, closer to the real behavior, but more complex simulations
- **FMI 3.0 and layered standard FMI-LS-BUS** enables realization of **vECUs up to Lvl 2**
- **FMI-LS-XCP enables the calibration of vECUs** in a same as calibrating real ECUs
- SSP 2.0 will enable packing **multiple virtual ECU together** under a system architecture

- In prostep SmartSE we started now discussion on next application examples
 - Which **level of vECU** and modeling abstractions for which **applications**?
- Higher level virtualizations:
 - Integrate **production base SW to test L3 vECUs**. Potential use cases :
 - Integrate **production Base SW + Target Drivers, Emulator to test L4 vECUs**.

DENSO

Crafting the Core