AI4SE & SE4AI 2023 Agenda
VIRTUAL WORKSHOP

An MBSE Led ML Based Approach to Electric Vehicle Design, Development & Virtual Validation

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Concurrent Transformation Imperatives in Automotive Industry

Automotive industry

- Multiple transformative efforts

CONNECTED

SHARED

AUTONOMY (ADAS)

ELECTRIC

HEV PHEV BEV

Software integration

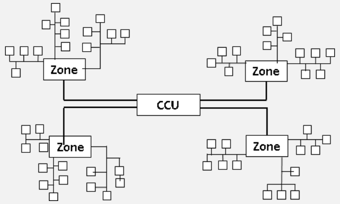
- New feature & functional needs vs. interoperability & safety across suppliers' stacks
  - Constraining data and software veracity
- AUTOSAR, Safety, and Security
  - Exponential development effort with discrete ECUs

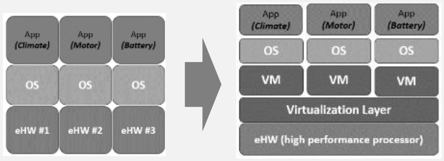
ISO 21434

ISO 26262

Response to Complexity Challenge

- Frequent B2C New features & functions delivery through ecosystem
- Scalability freedom to develop, test, implement & operate
- E/E Re-architecture, SW Federation, & ECU HW Virtualization





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Decoding Software Defined Vehicles

Why
*Address complexity in **CASE***

ECUs: 100+ ↑

Functions/ECU: ↑

Software (#LOC): 100M – 1B ↑

Wiring harness: 80 – 100 kg, 2 – 3 km ↑

Computing demand: ↑↑↑

How
*Unlock new **scaling** paradigm*

Consolidated Scalable Architecture

Common, interchangeable control hardware

SW modularity and reuse

Scalable Supply-Chain integration with IP controls

Shared technology across car models, generations, & apps

What
*Mitigate systemic **risks** in feature update management*

Integrated safety architecture (standards, compliance)

Data driven software updates (Dealers and OTA)

Agile hardware development, integration, & verification

Frequent integration and deployment (towards CI/CD)

Enable full traceability for diagnostics and troubleshooting

Overpowering Complexity Needs New Scaling Initiative

Enterprise Level Requirements

Stakeholders' Analysis

Core Concepts Architectures for HW, SW, & E/E

Arrive at the Top-Level Specification

Benefits to the Core Concepts

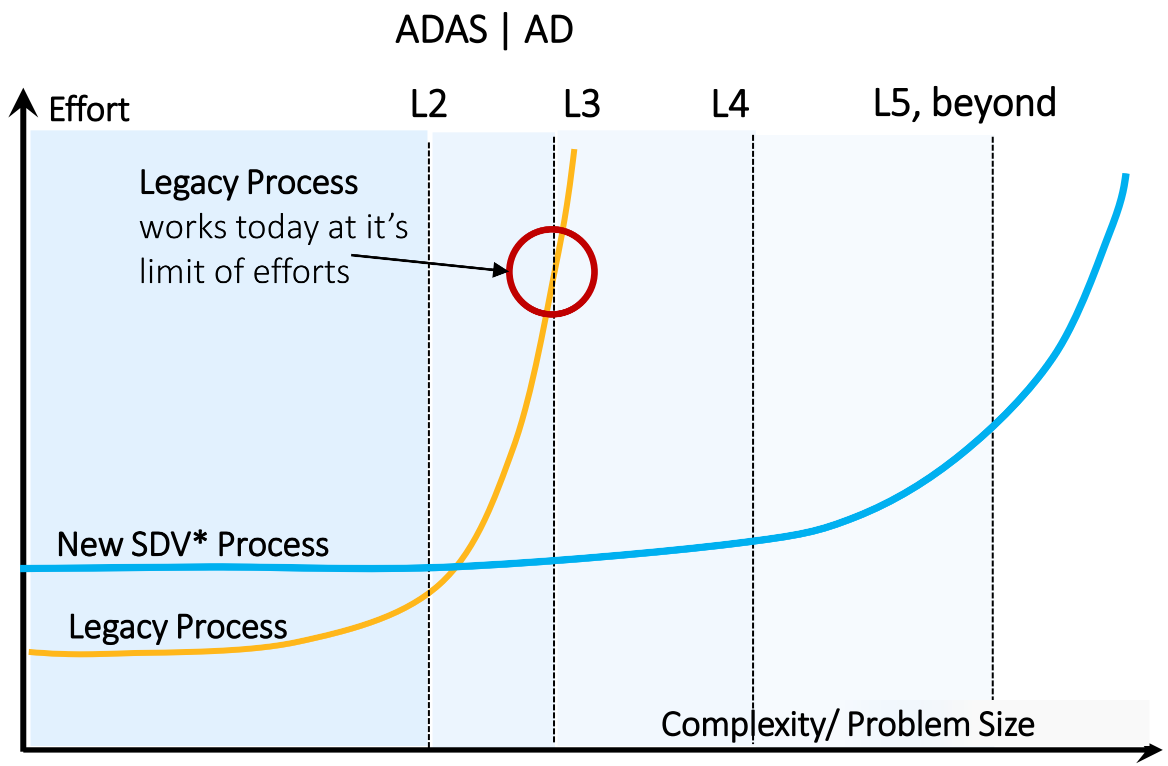
Prioritize Requirements

Perform MBSE, Trade Studies, Refine Specs

Identify Gaps

Separate SW, HW, & E/E development

Identify Dependencies & sync points among SW, HW, & E/E Development

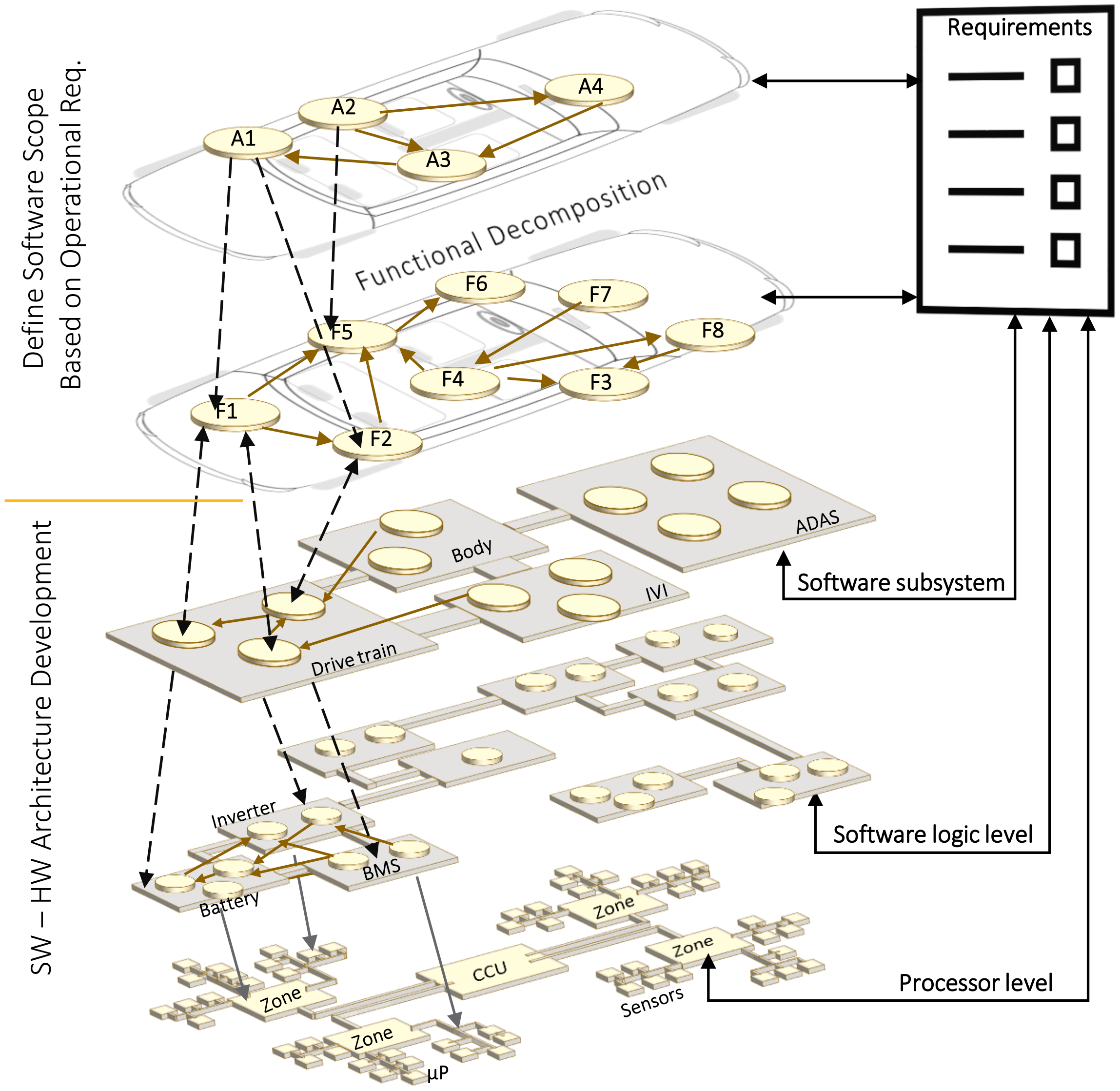


MBSE: Multi-domain complexity managed with Models in Systems Engineering

SDV* : commitment to investor, sustainability, business transformation, product line engineering

** SDV: Software Defined Vehicle*

Manage Software Complexity with System's Decomposition



Operational Perspective

Activity planning
Refine & verify operational map

Functional, display, & extrinsic elements
Perform trade analysis on baseline functional blocks to meet functional needs and user expectations

Logical Layer
Software performance modalities and organization

Physical Layer
Define, develop the eHW and deploy SW to verify integration and performance

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E/E Architecture Evolution for SDV

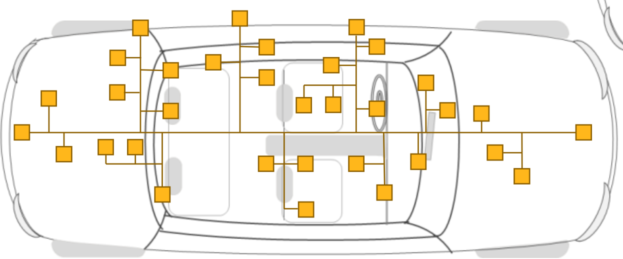
Requires roadmap driven maturity model including supply-chain re-imagining

Simplified vehicle network

Decoupling eHW & SW

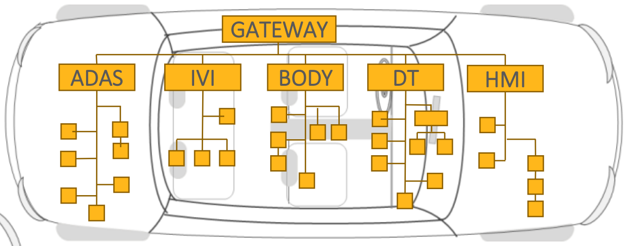
ECU consolidation & integration

Distributed



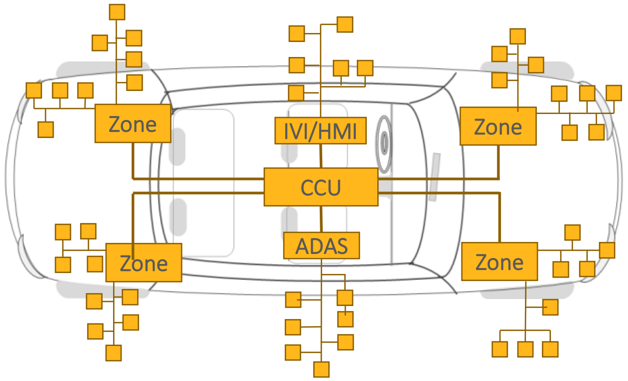
- *Function specific ECU*

Domain



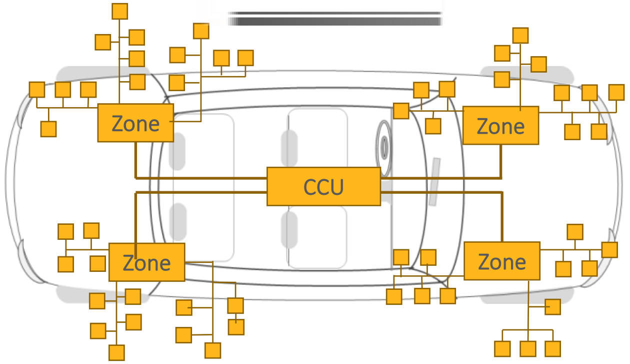
- *Domain - consolidation & optimization*
- *Ethernet: ADAS & IVI*
- *CAN: Body, Drivetrain & HMI*

Hybrid Zonal



- *ADAS & connectivity remains domain controlled*
- *Multi domain Centralized Compute Unit (CCU)*
- *Automotive ethernet between CCU and each Zone*

Zonal



- *ADAS & Connectivity blended into Zones*
- *Zonal ECUs with ethernet and CAN/LIN based communication*
- *Zonal ECU varies from just I/O aggregators to power control and computing units*

Layered Architecture(SW + HW) for SDV

Off Board | Business Services | Digital Twin (Cloud Based)

On Board

- Facilitate OTA Updates
- Enable SOA via Middleware
- Decouple SW & HW
- Enhance Safety & Security
- Provide Life Cycle Management

In-Car Apps

APIs — Vehicle Abstraction layers

Automotive OS

APIs — HW Abstraction layers

Hardware

Cloud services
- OTA services
- personal services
- Digital Twin
- Connected services

Shared services
- Edge data
- 5G & V2X
- OTA updates

Vehicle Applications
- Drivetrain
- ADAS / AD
- Infotainment
- Connect
- Battery
- Comfort

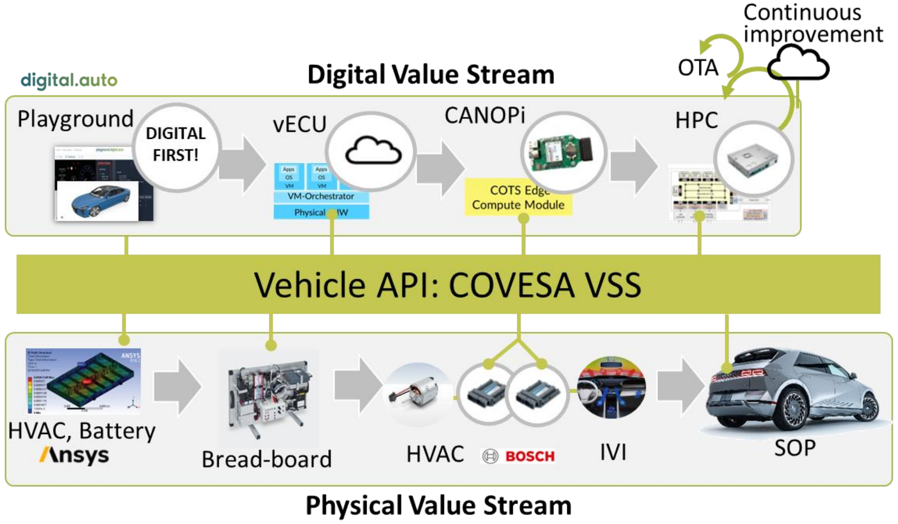
Middleware & Automotive OS
- Middleware / OS
- App Store (Vehicle Func.)
- OEM Cloud

E/E Architecture (eHW)

Mechanical Layer(mHW)
(Sensors/Actuator/Body/Chassis)

Use Case: COVESA EV Power Optimization

- Cloud services
- Vehicle abstraction APIs — COVESA
- Shared Services
- Vehicle Apps
- MW & Auto-OS
- HW abstraction APIs — COVESA
- E/E Architecture (eHW)
- Mechanical Layer(mHW)



HYUNDAI MOBIS | BOSCH | digital.auto | Ferdinand-Steinbeis-Institut | COVESA

digital.auto AIOT Platform Integration for SDV
Virtual Front end

COVESA VSS -APIs

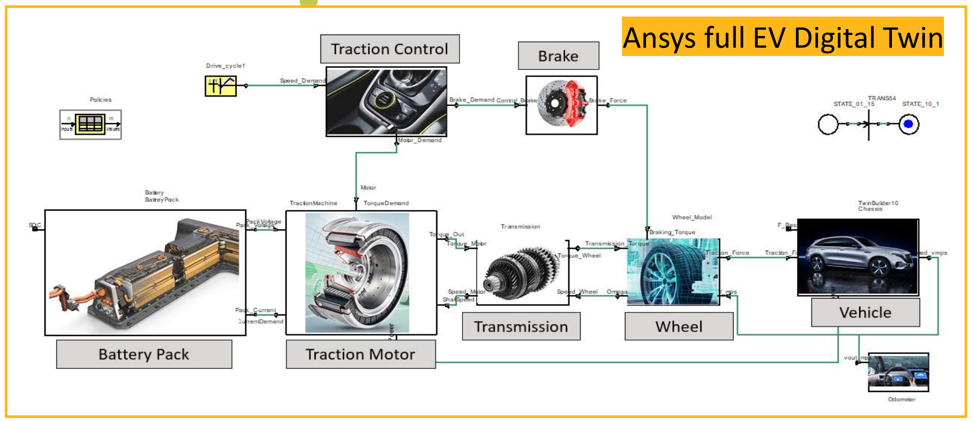
EV Power consumption systems

- ❑ Power train
- ❑ Chassis
- ❑ Electronic Systems
- ❑ Networking
- ❑ Safety & Control
- ❑ Infotainment
- ❑ Comfort & Control

Power Distribution	Power train (~ 60 to 80%)	HVAC (~10 to 15%)	Steering, Window & sunroof (~ 3 to 8%)	Lighting (~ 2 to 5%)	IVI (~ 1 to 2%)	Others (ADAS sensors, Cameras etc.) (~ 1 to 2%)
Policy (HYUNDAI MOBIS)	Speed Limit Eco Drive ON	Fan Control Ambient Temp. Control	Speed Control On/off Control	Light Intensity Control	Brightness Control Audio Control	On/off or Partial Control

Digitally validate EV power optimization policies / algorithms

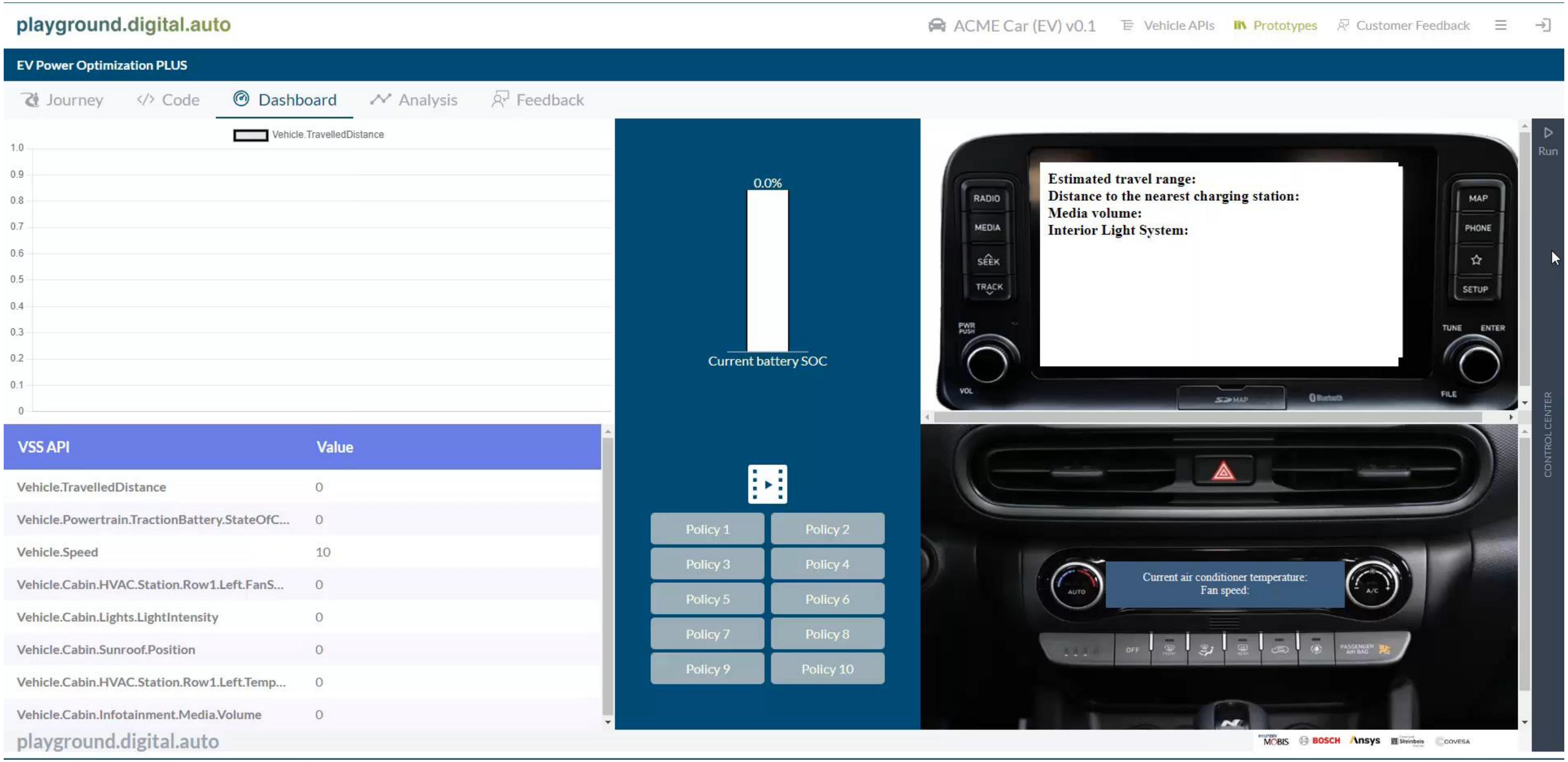
- Increasing Range
- Avoiding Last Mile Anxiety
- Policy for crisis: Running out of battery



Use Hi-fidelity ROMs for system optimization study at speed & scale
Digital.auto platform | COVESA APIs | BOSCH models | Ansys ROMs & SW

Ansys

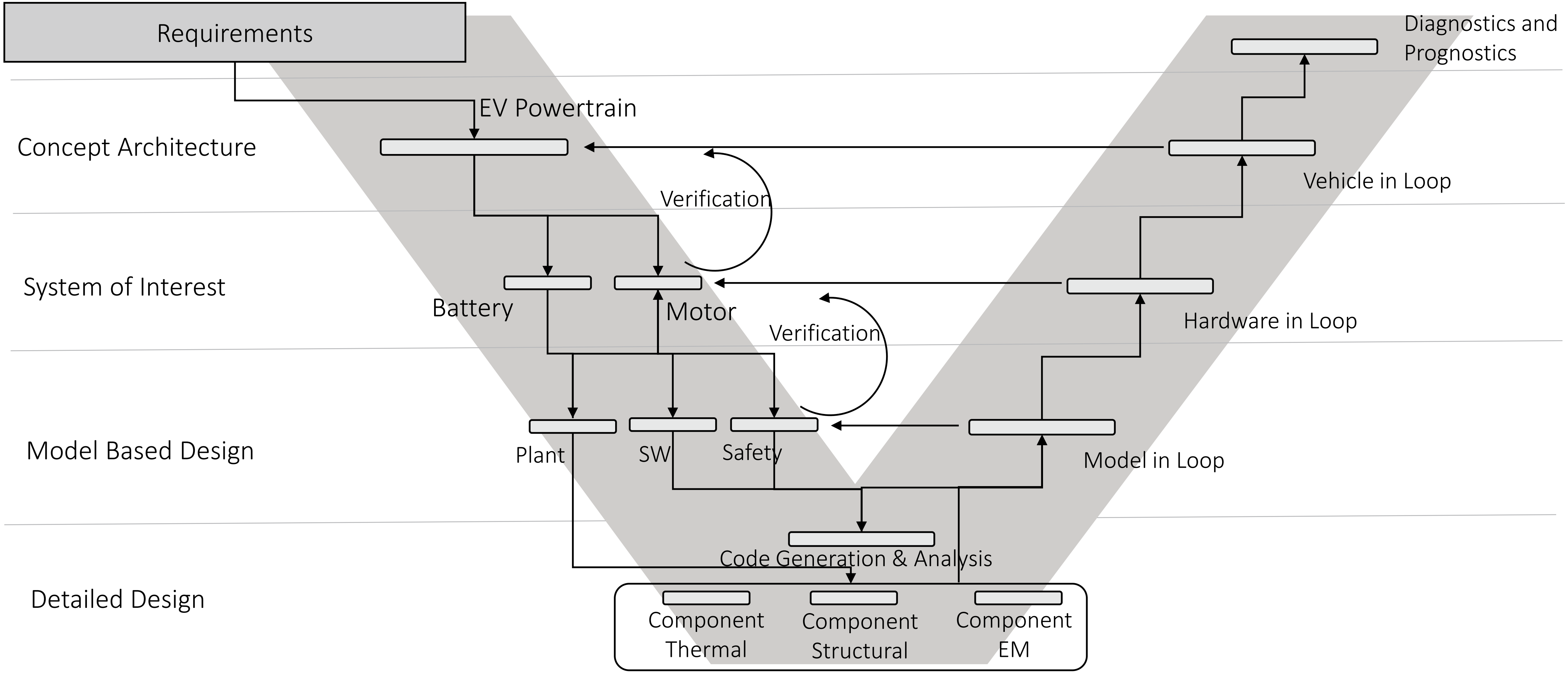
Digital.auto Demo at COVESA AMM



https://COVESA.global

Check out this online configurable Demo at playground.digital.auto

EV MBSE Workflow



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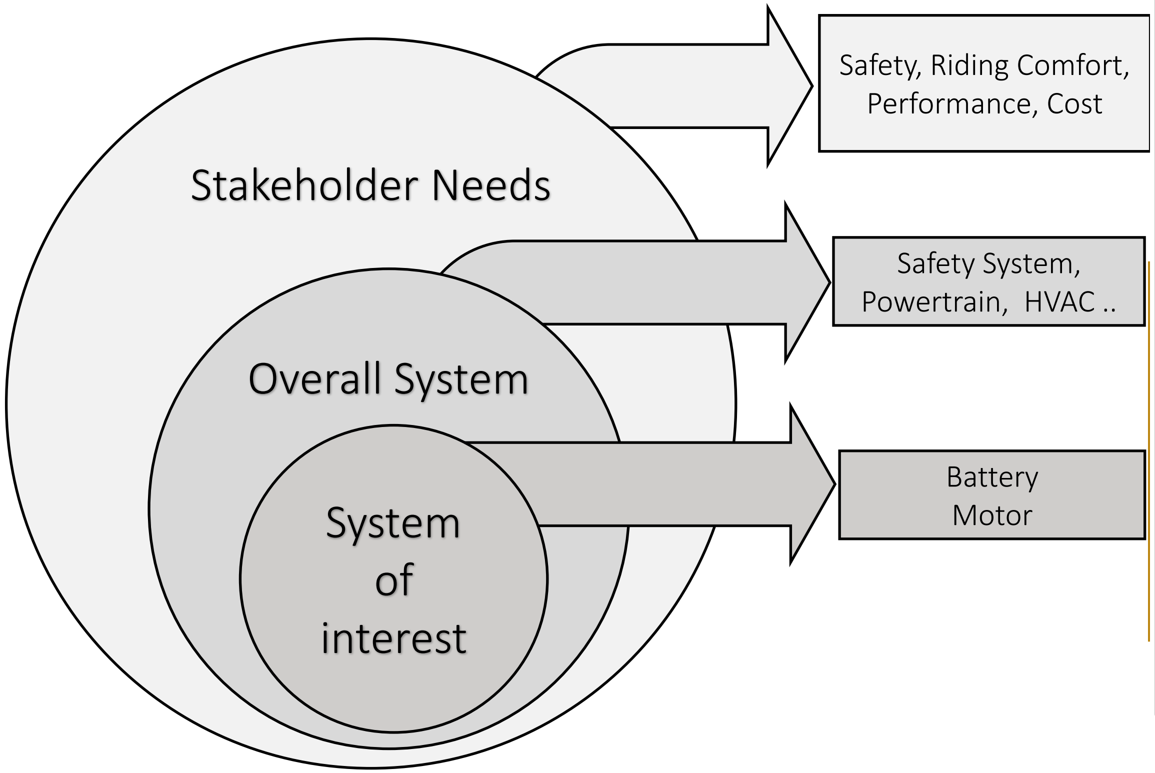
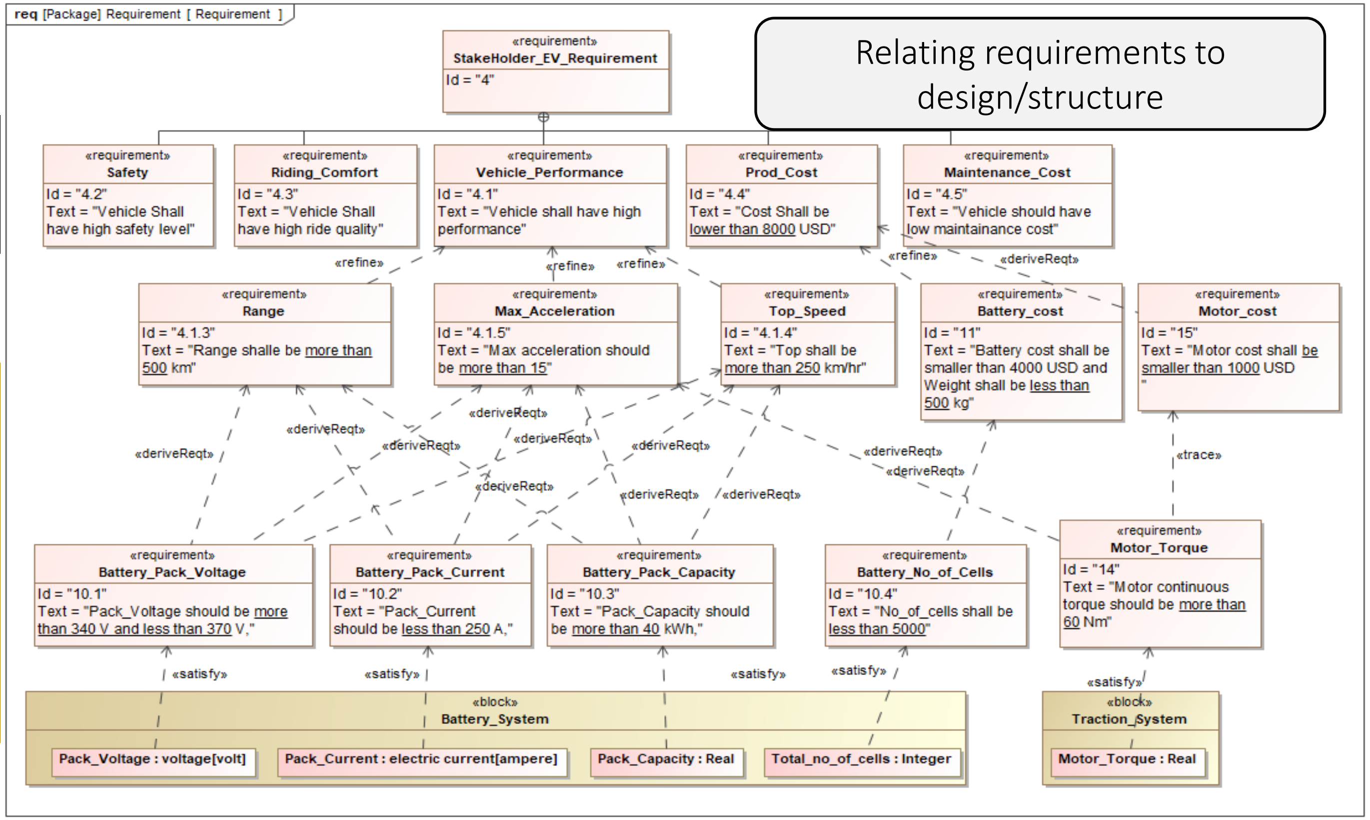
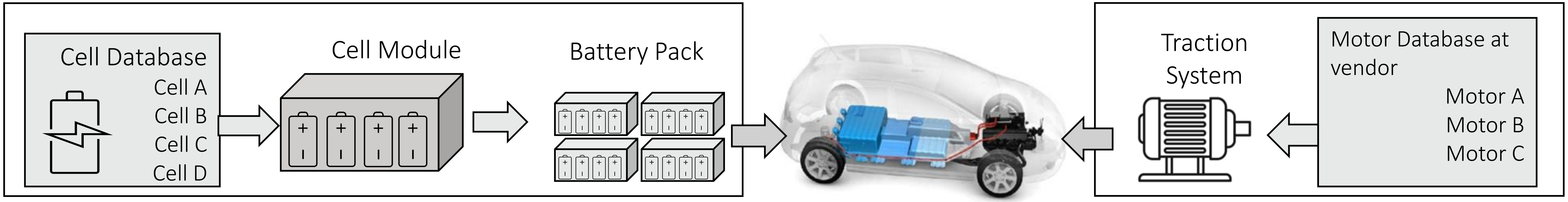
System of Interest





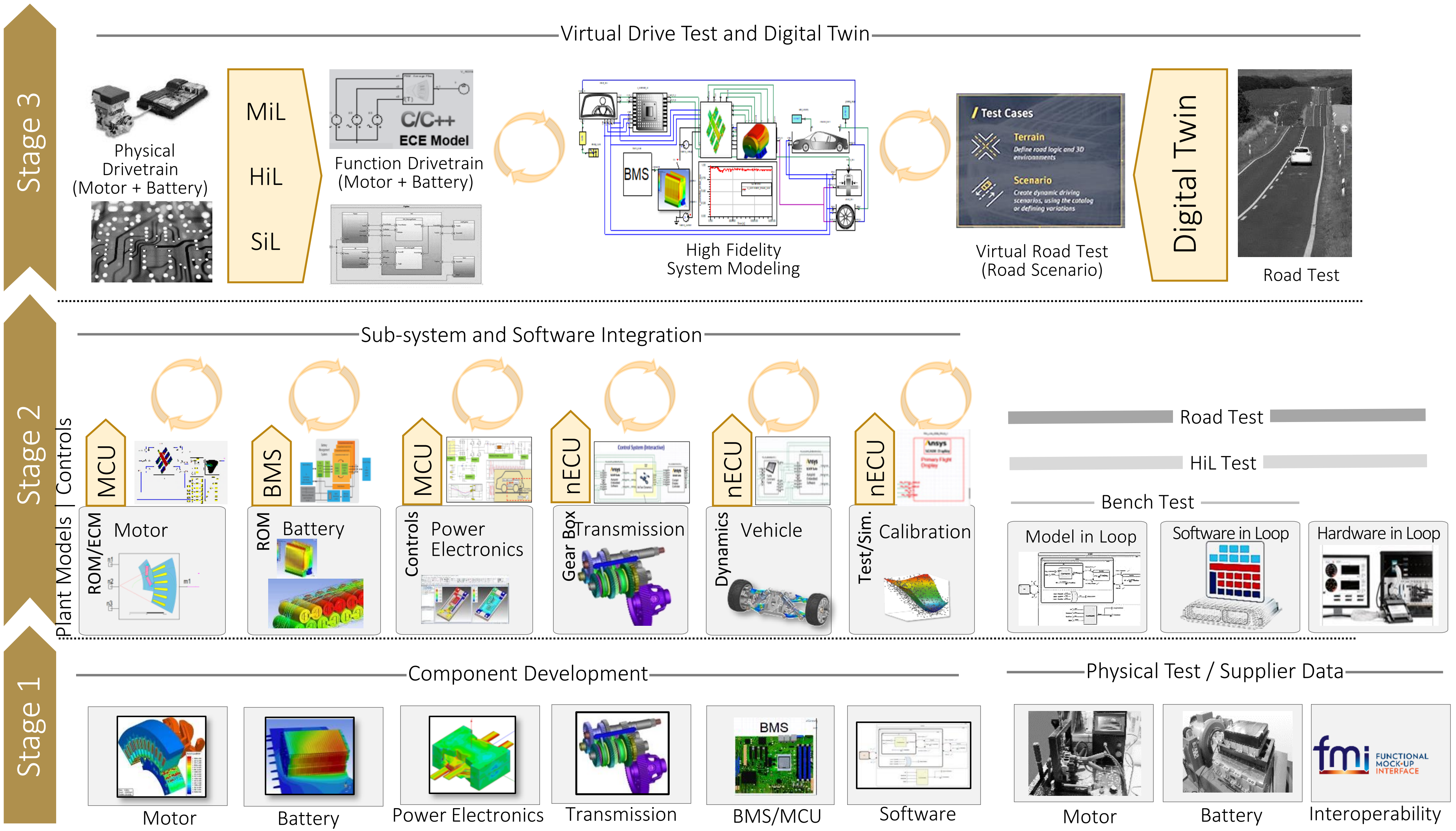


Stages of Virtual Validation

1. Acceleration
2. Range
3. Gradeability
4. Validation
5. …

1. Plant model calibration
2. MCU Calibration
3. Software, Safety validation
4. Charge – discharge validation
5. ….

1. Unit Tests
2. Subsystem performance tests
3. Performance characterization
4. Software unit testing
5. …



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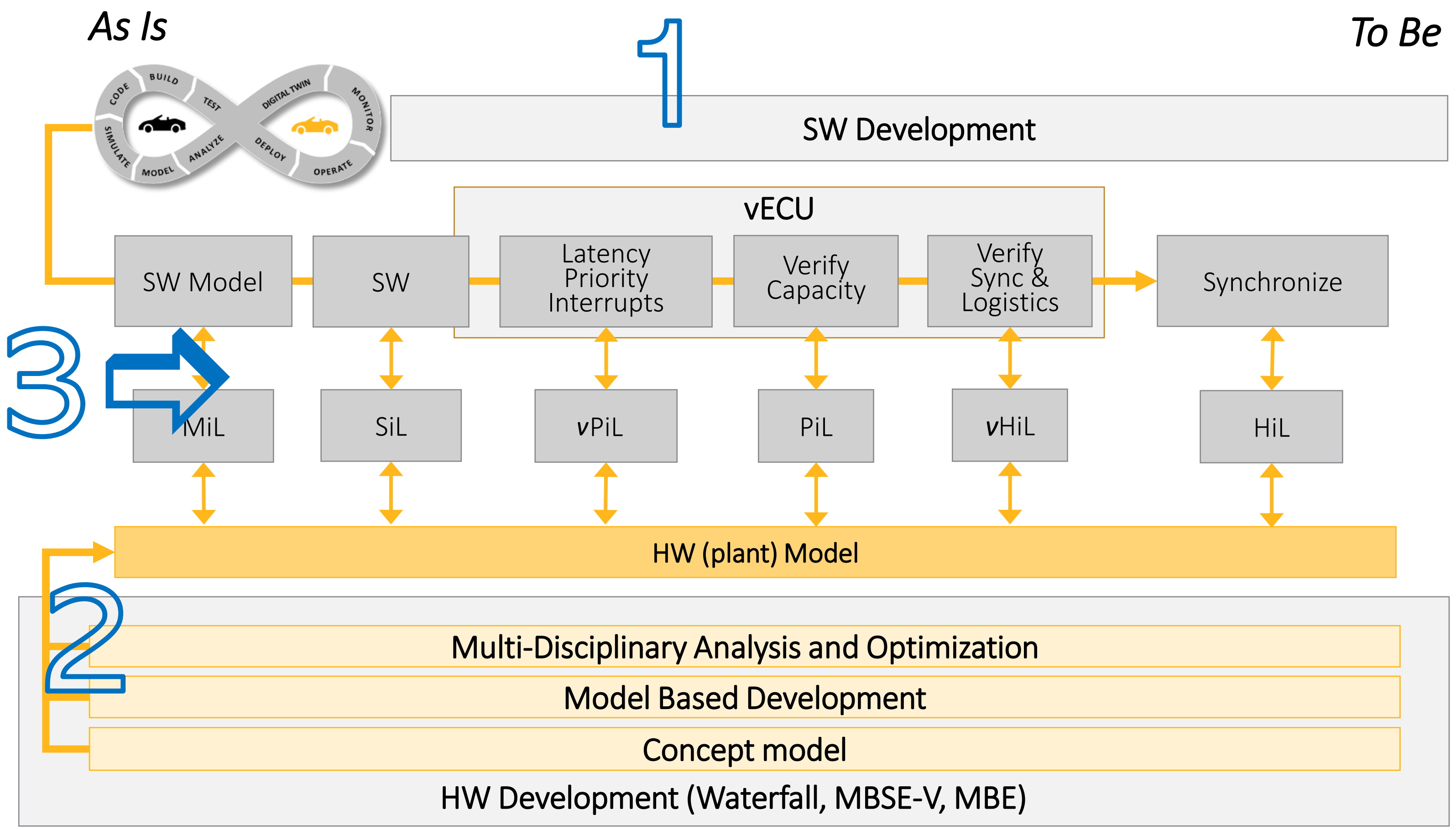
Addressing Complexity in Continuous V & V



- ECU virtualization for next gen **supply chain integration**

MiL

- Logic verification
- Incremental synchronization with the evolving plant models

SiL

- Latency, interrupt and prioritization
- Consistent plant model

PiL

- Compilation on target processor (eHW)

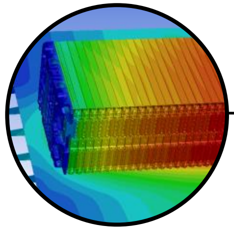
HiL

- Clock speed, bandwidth, latency synchronization
- Real time
- Consistent plant models

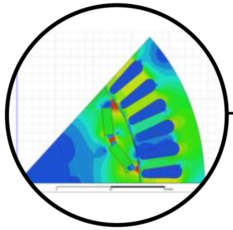
PiL → vPiL & HiL → vHiL

- Parallelization (**emulated targe ECU, co-sim, distributed sim with Plant model**)
- Scenario analyses at scale

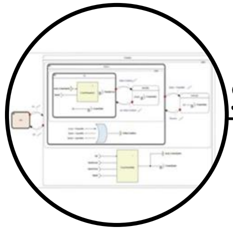
Example: Hi-Fi Electric Powertrain Plant Model



Battery Electrothermal ROM

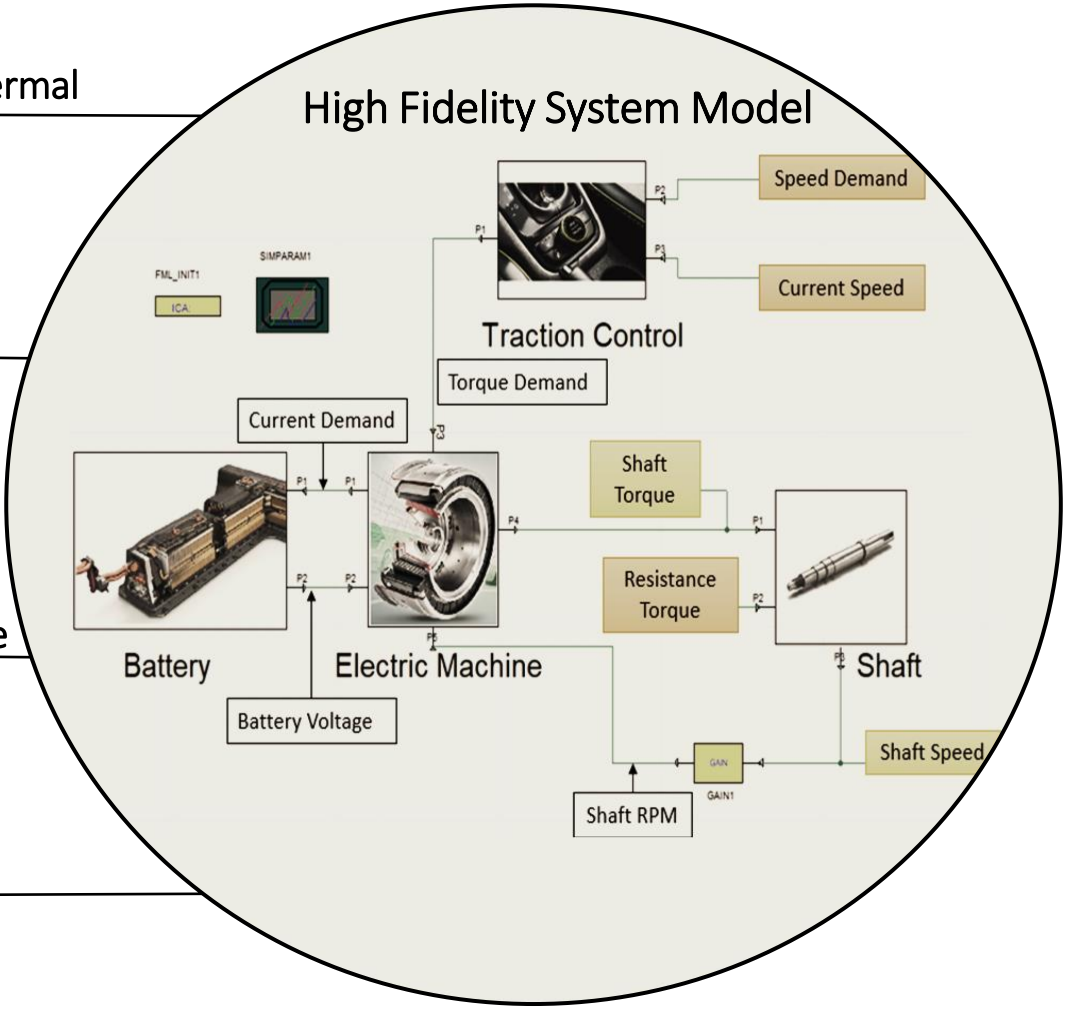


Motor ECM

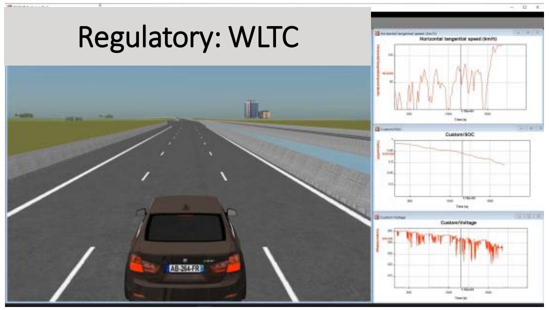


Software FMU

Calibrated Test Data



ESTIMATED RANGE



180 KM

123 KM

75 KM

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Virtual Test Driving with Ansys and IPG /Car Maker

Battery
Thermal, Abuse,
Life Electrochemistry

Electric Machine
Magnetics, Cooling
Durability, NVH

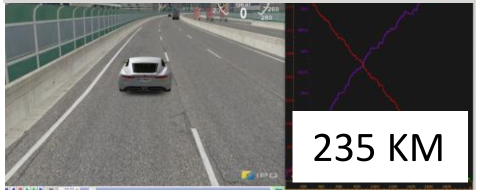
Controls
BMS, PT Control
ISO26262, AUTOSAR

Power Electronics
IGBT, Waveforms,
EMI-EMC, Inductors

Regulatory: WLTC

Performance: Nürburgring

Urban : Traffic and Signal



Vehicle System
Vehicle Dynamics,
Control Systems

Driver
Driving styles, cycle
driver

Traffic & Environment
Signs, Signals and Junctions
Terrain, Altitude, Weather

Traffic
Phenomenological,
Dynamic Objects

Vehicle Performance

Range	Acceleration	Drivability	Gradeability	Regeneration	Max Speed

Motor Testing

Test Type	No	Test Name	Virtualization Possibility
Motor Component test	1	Performance testing over operating Envelop	Yes
	2	Fault Testing: Short Circuit, Demag	Yes - Partially
	3	Thermal testing: Continuous Load	Yes
	4	Thermal testing: peak and cyclic Load	Yes
	5	Impulse and insulation test	No
	6	Temperature and Humidity Test	No
	7	Magnetic Characterization	Yes
	8	Noise and NVH testing	Yes
	9	Imbalance testing	No
	10	Ingress testing	Yes-Partially
	11	Durability test	Yes-Partially
MIL Testing	1	Unit and Functional testing	Yes
	2	Integration Testing	Yes
	3	Controller Tuning	Yes
	4	Acceleration testing	Yes
	5	Regeneration testing	Yes
	6	Overload protection test	Yes-Partially
HiL testing	1	Controller calibration	Yes-Partially
	2	Fault Injection Testing	Yes-Partially
	3	PWM period and Gate driver signal test	No
	4	Communication test	No
	5	Encoder Decoder response test	No
	6	Regeneration testing	Yes-Partially
Vehicle Validation	1	Acceleration test	Yes
	2	Gradeability test	Yes
	3	Cabling and connection test	No
	4	Drive test: Rural	Yes
	5	Drive Test: Urban	Yes
	6	Durability Test	Yes - Partially
	7	Crash test	Yes
	8	Torture track test	No
	9	Vehicle Vibration and Pass By noise test	No

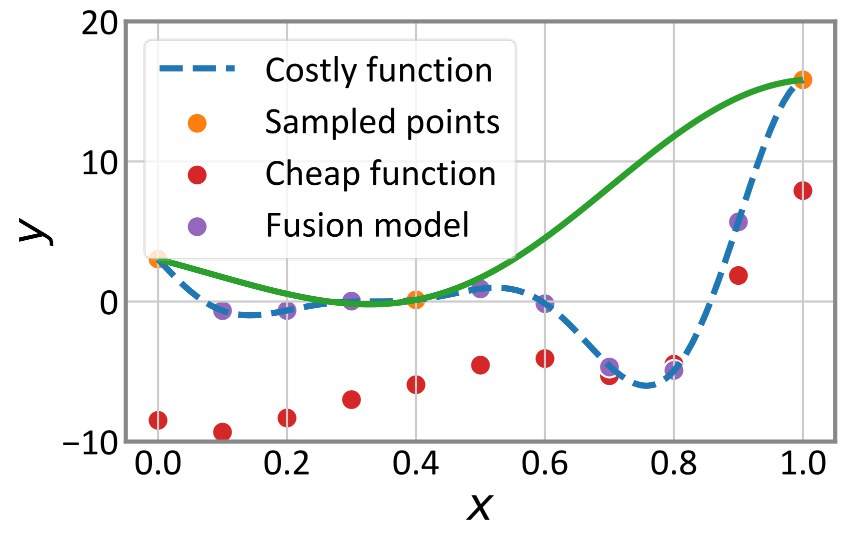
Battery Testing

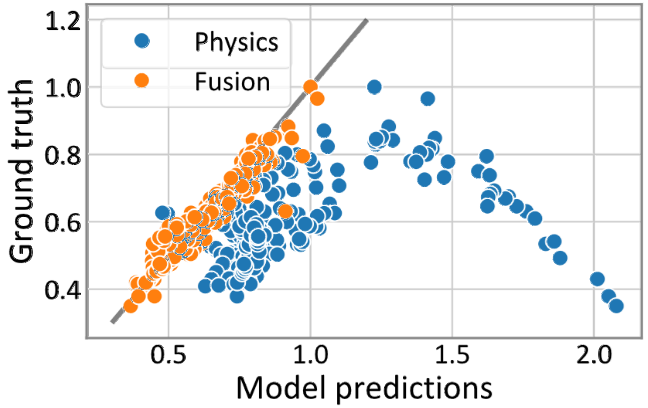
Test Type	No	Test Name	Virtualization Possibility
Battery Component test	1	Cell Characterization: HPPC Test	No
	2	Thermal Testing: High temperature	Yes
	3	Thermal testing: Low Temperature	Yes
	4	Mechanical Testing: Nail Penetration	Yes
	5	Mechanical testing: Crash and Crush	Yes
	6	Environmental testing: Humidity and altitude	No
	7	Enviornmental testing: Ambient temperature	Yes
	8	Charge and Discharge testing	Yes
	9	Vibration and shock testing	Yes
	10	Lifecycle testing	No
	11	Thermal runaway and fire	Yes-Partially
MIL Testing	1	Unit and Functional testing	Yes
	2	Integration Testing	Yes
	3	Algorithm testing: SOC	Yes
	4	Protection Testing: Overvoltage and Overcurrent	Yes
	5	Protection Testing: Overtemperature and under temperature	Yes
	6	Overload protection test	Yes-Partially
HiL testing	1	SoC Algorithm testing	Yes-Partially
	2	Fault Injection Testing	Yes-Partially
	3	Fault testing: HV termination	No
	4	BMS IO Communication test	No
	5	Voltage and current sensor testing	No
	6	Regeneration testing	Yes-Partially
Vehicle Validation	1	Acceleration test	Yes
	2	Gradeability test	Yes
	3	Cabling and connection test	No
	4	Drive test: Rural	Yes
	5	Drive Test: Urban	Yes
	6	Durability Test	Yes - Partially
	7	Crash test	Yes
	8	Torture track test	No
	9	Vehicle Vibration and Pass By noise test	No

45 Out of 64 physical tests can be done in virtual environment

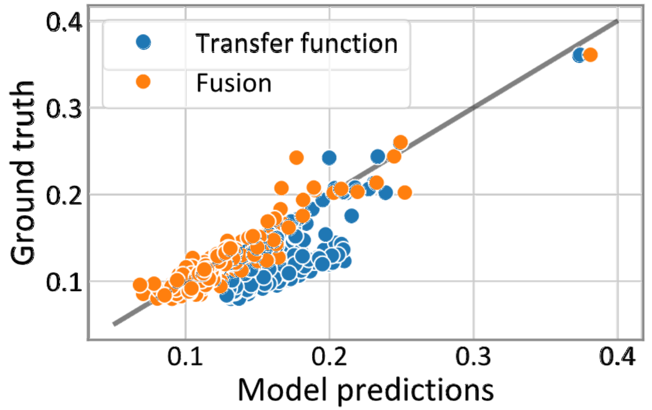
The Fusion Model

Long Range View of Digital Validation Roadmap





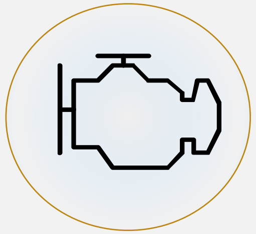
Physics# (●): R^2 = -13.14
Fusion Model (●): R^2 = 0.87
 # NOX, SOX



Transfer Function* (●): R^2 = -0.97
Fusion Model (●): R^2 = 0.88
** Without good physics model (HC, PM)*

Breakthrough Speed & Accuracy	• Reverse Engineering • Multi-Fidelity, data-driven Fusion Model • Generative Design
Virtual Validation	• Model Calibration • Bi-directional CI-CD • Validated Plant & Control Models
ML-Driven CBM	• Fatigue & Lifing model (Physics +ML) • Hierarchical Fusion Model • PLM, MBSE integrated Digital Twins

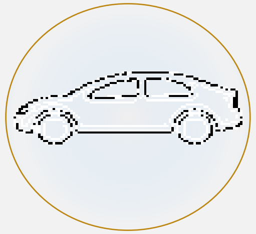
ML-Based Calibration, Virtual Validation & Uncertainty Quantification



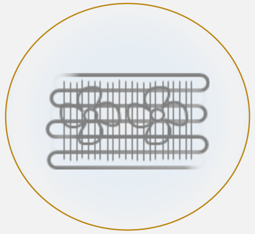
Engine OEM
North America
Model calibration

Car OEM
EMEA
Virtual Testing for real drive emissions(RDE)

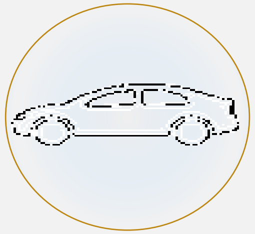
Truck OEM
APAC
Virtual engine calibration



Car OEM
APAC
Rapid exterior styling concepts evaluation

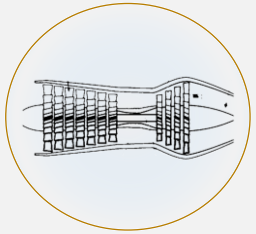


Industrial
APAC
Model based controller



Car OEM
North America
Model-Based Calibration

Industrial
EMEA
Blade Health Monitoring



Aviation
GLOBAL
Compressor Lifing Model

90% Physics Model + 10% Data ⇨ Low cost + high predictability + high speed

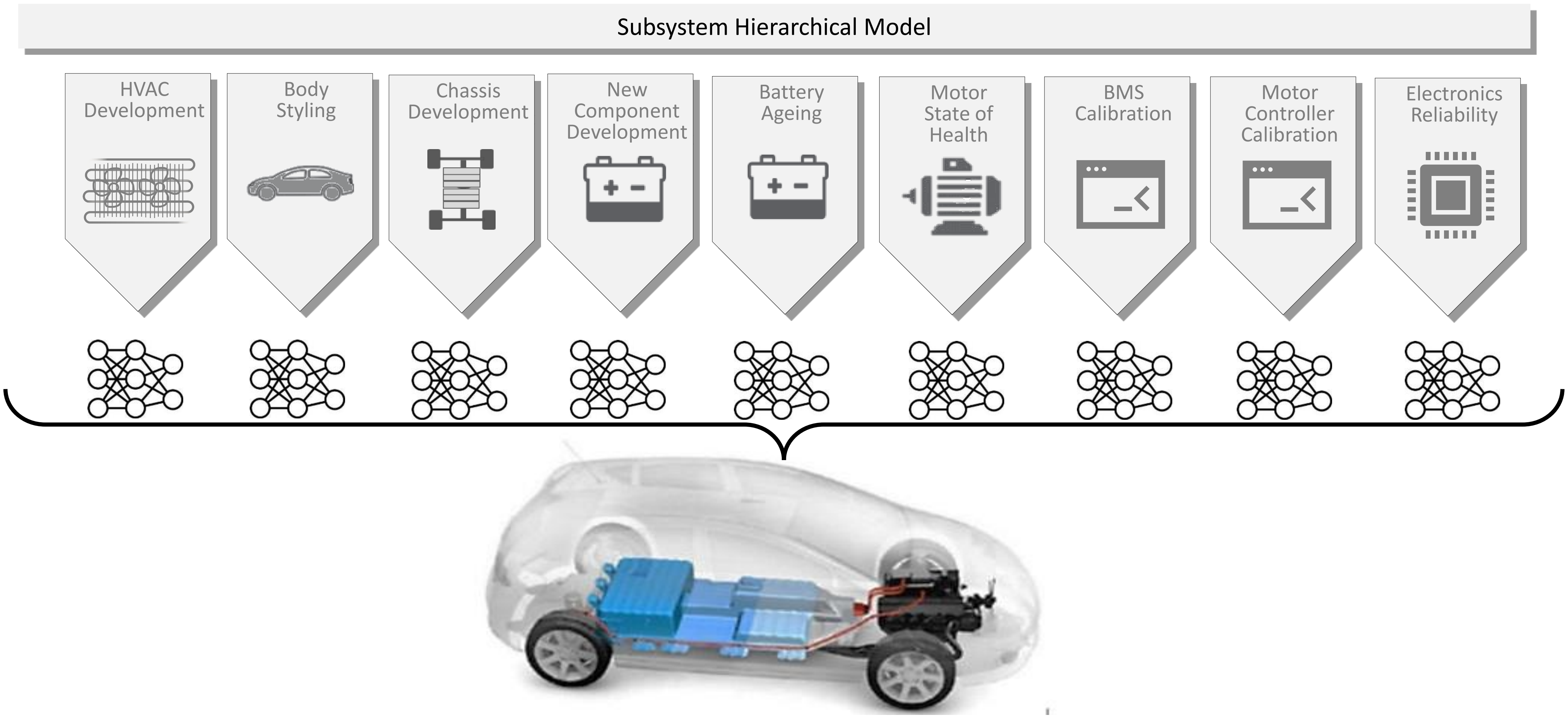
Value of Current VVUQ-ML Based Fusion Model

1. 3-9 months effort for every engine
2. GT, AVL, dSpace, ETAS: Solutions limited for accuracy & speed
3. ANSYS: 3X faster; 90+% accurate; 90+% confidence

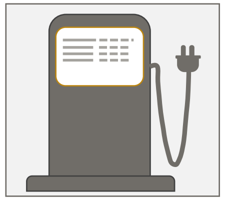
1. Model Based Calibration
2. Virtual Validation
3. Concept Design (Rapid prototyping)

...and there are other customers: FMCG, Consumer Electronics, Tier-1s, A&D

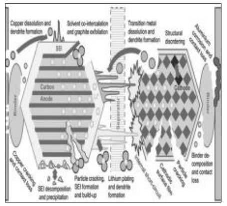
ML for EV Applications and Hierarchical System Models



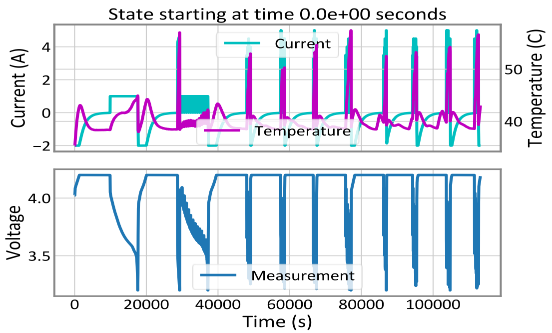
Battery Aging, Charging And Discharging

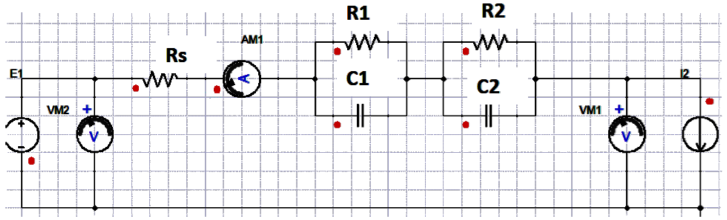


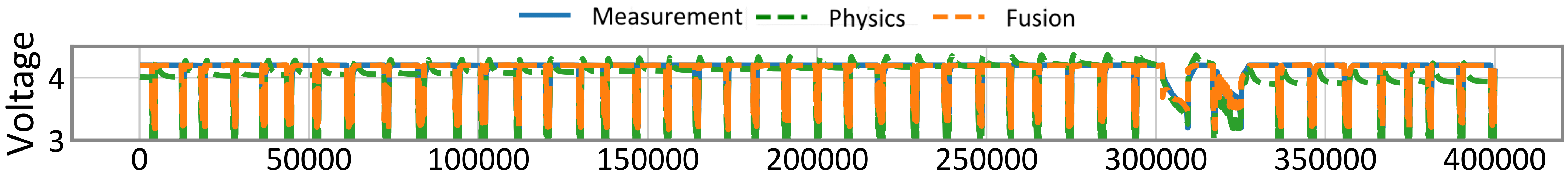
Need
- Predict life, performance & maintenance
- Conceptual design
- No physical prototype available



Challenges
- Long time scale, variabilities
- Differences in electro-chemistry
- Complicated degradation



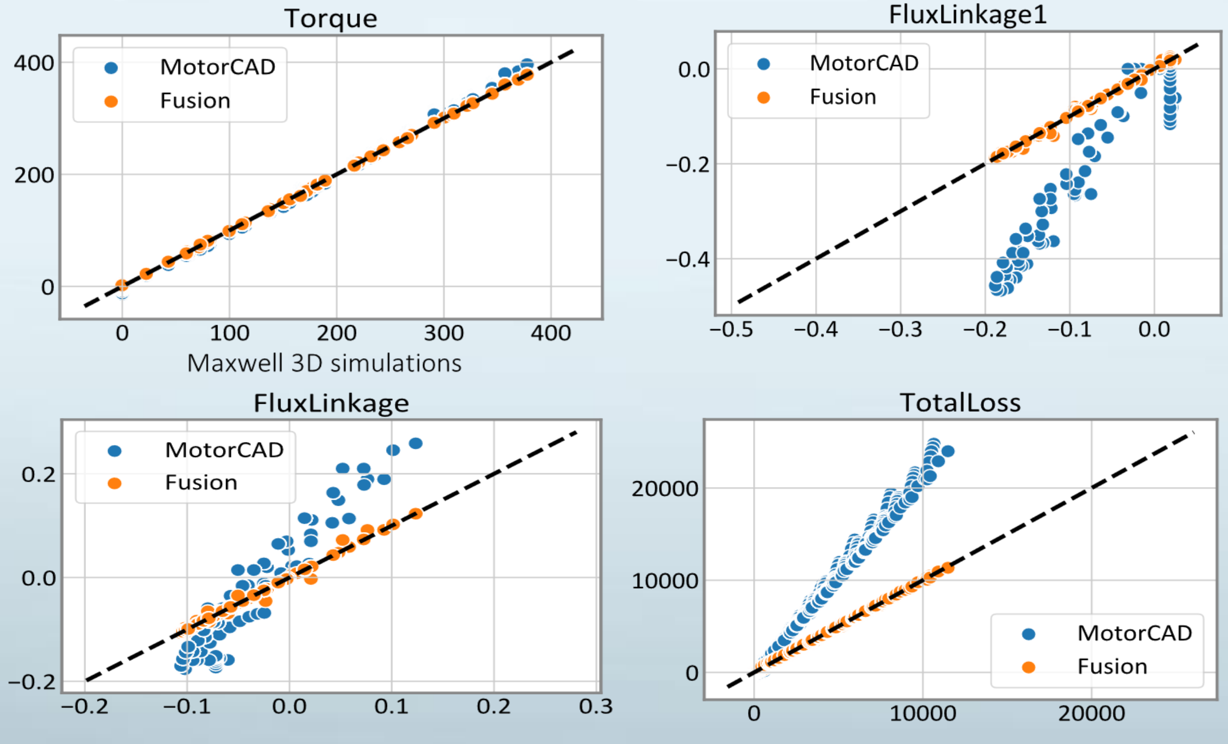




Ansys DynaROM: Train for first 600 sec; predictable for the rest of its life (6.10^6 sec)
Graphics shows up to 400K seconds

Accelerating Electric Motor Design

Methodology	Accuracy	Time for one design eval	Solution
Physical prototype	100%		
MotorCAD	50-90%	~ 3 hrs	MotorCAD (480 DPs)
Maxwell	95-100%	~ 4500 hrs	Maxwell (480 DPs)
Maxwell ROM	95-100%	~ 450 hrs	Maxwell + oSL
Fusion	95-100%	~50 hrs	Maxwell, MotorCAD + TwinDeployer



80x Speed up per design

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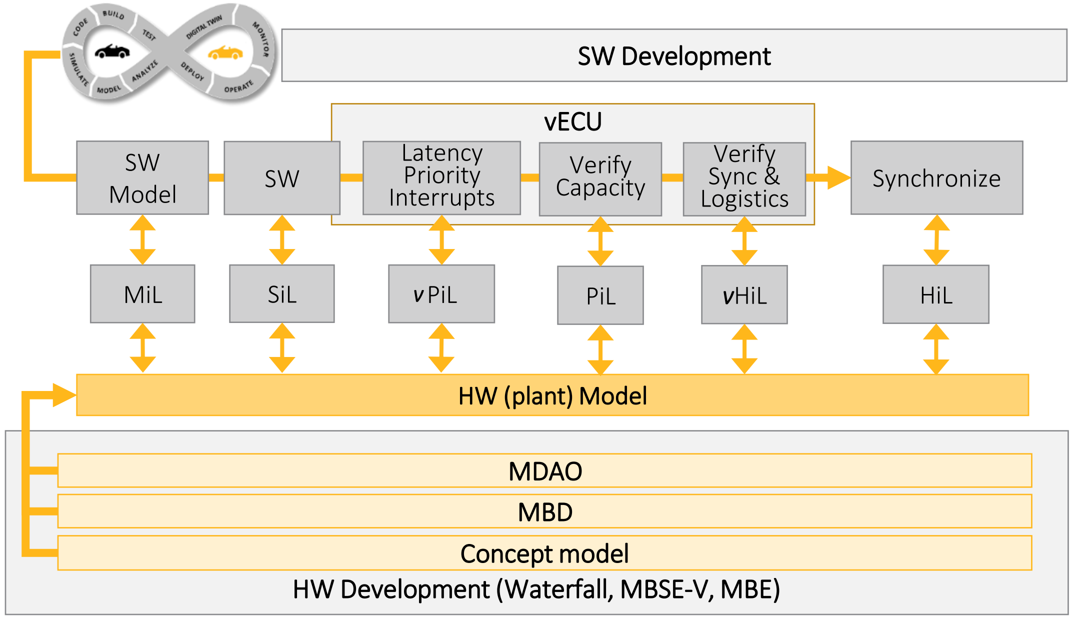
End Note

- Like MBSE, Software Defined Vehicle is evolving with collaborative efforts and a maturity model is envisioned
- AUTOSAR, functional safety and hierarchical software
- Virtualization is a critical enabler
  - For continuous V&V, integration
  - Supports design evolution and through lifecycle
  - Virtualization needs proper representation
    - Ansys ROMs from physics-based design models
    - Multi-domain, multi-physics, multi-scale
    - Steady, transient, frequency-domain



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Thank you!

Ansys

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