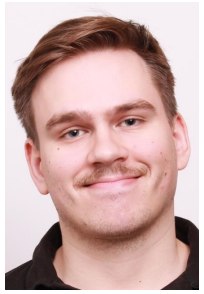
34th Annual INCOSE international symposium

hybrid event

Dublin, Ireland
July 2 - 6, 2024



Mälardalens universitet

AVL

Early Validation of SysML Architectures by Extending MBSE with Co-Simulation using FMI and SSP

Johan Cederbladh, Daniel Krems

Introduction

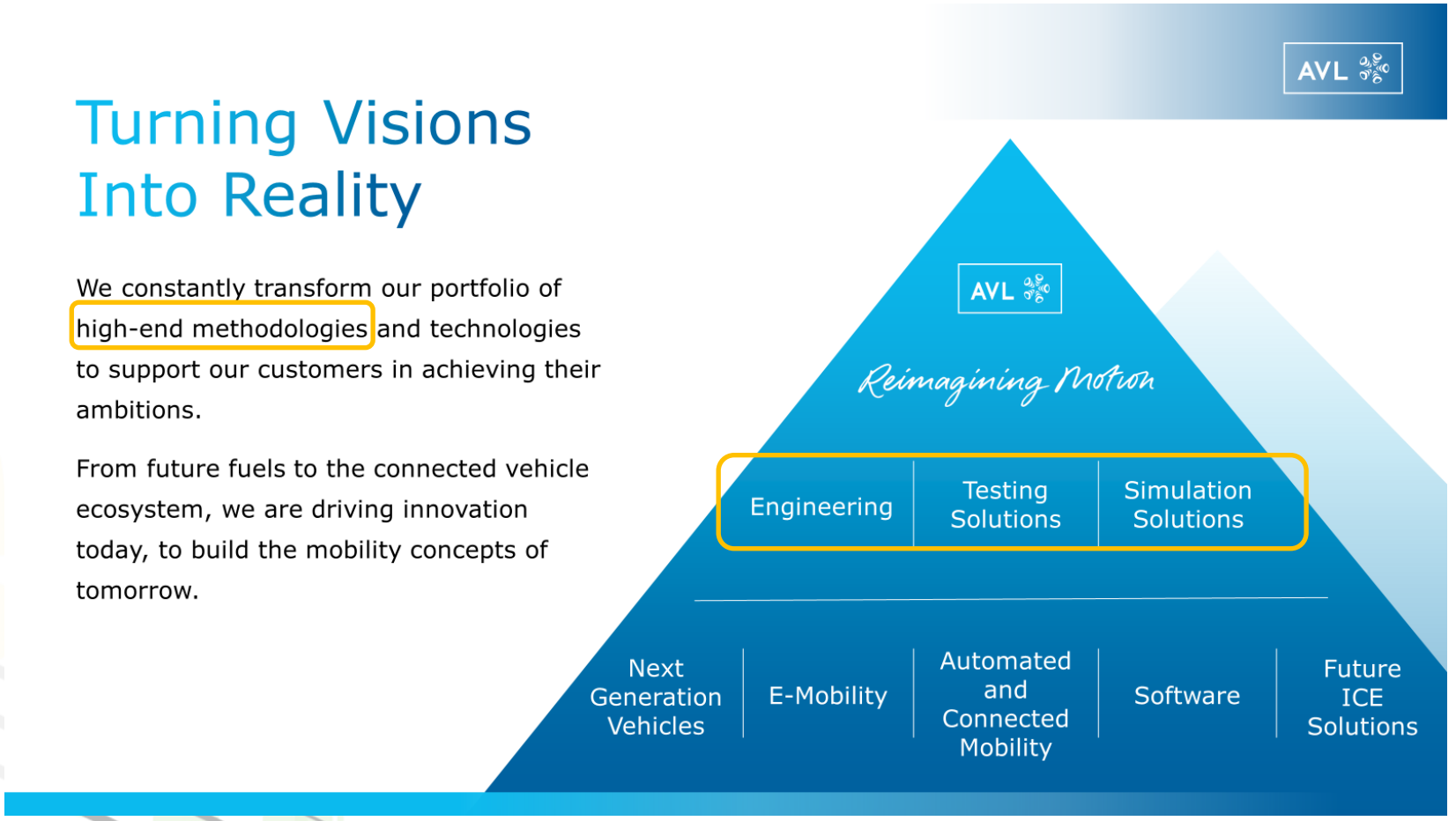
AVL List

- Founded in 1948
- Headquarters in Austria
- Represented in 26 countries around the world
- Technology-driven company (68% engineers & scientists)
- 12200 employees worldwide
- Over 2 billion Euro turnover in 2023
- 10% of turnover invested into inhouse R&D

Turning Visions Into Reality

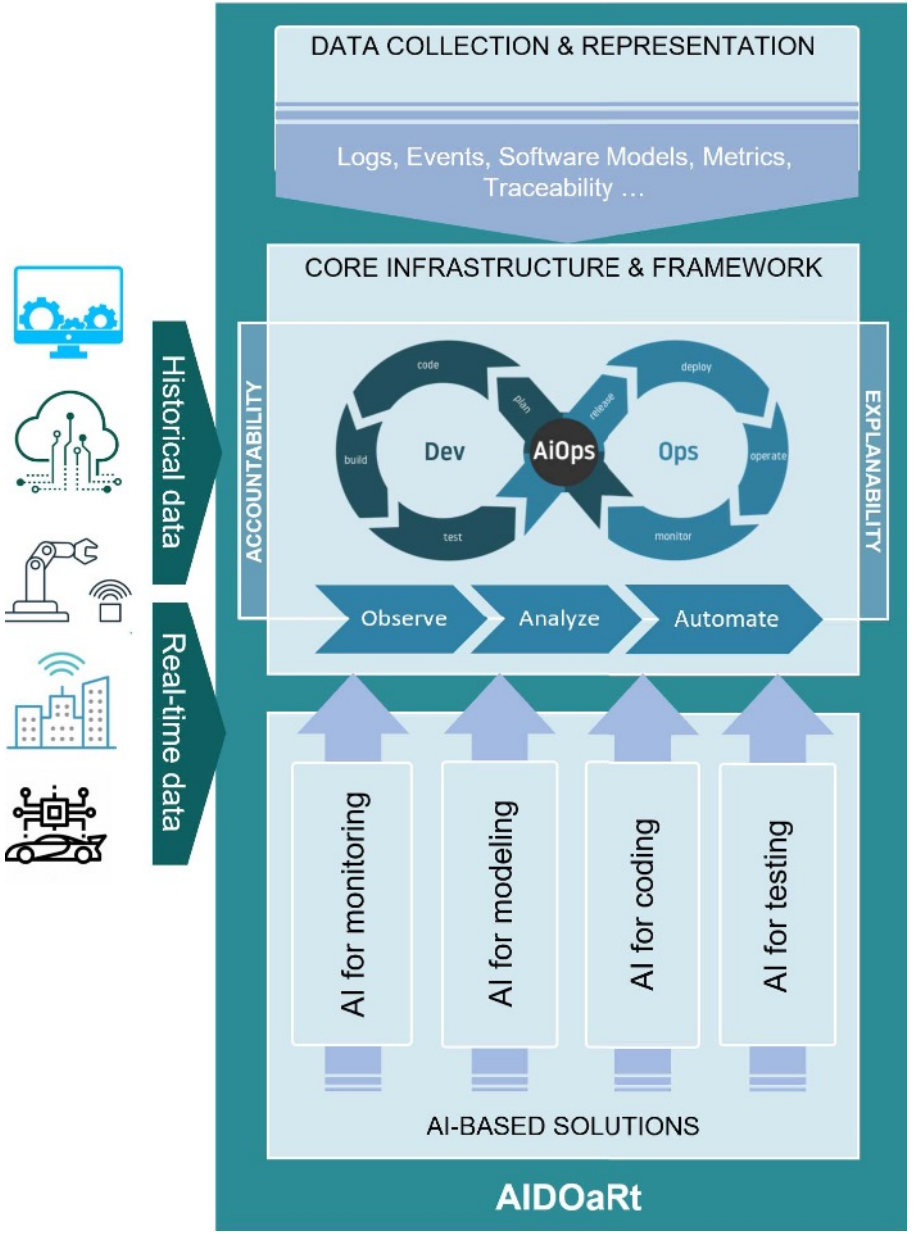
We constantly transform our portfolio of high-end methodologies and technologies to support our customers in achieving their ambitions.

From future fuels to the connected vehicle ecosystem, we are driving innovation today, to build the mobility concepts of tomorrow.



AIDOaRt

- This paper originates from activities in the AIDOaRt [1] research project
- The project transfers academic solutions to industry
  - Models
  - AI
  - DevOps
- AVL use case for process improvement and Volvo CE use case for Model-Based adoption



[1] https://www.aidoart.eu/ AI-augmented Automation for DevOps

The world we live in

- Complexity of systems are increasing in several domains
- Partially this is due to software concerns becoming more central
- Partially this is due to the digitalization paradigm shift
- Companies are put in a position to evolve large parts of the organization to encompass these changes

The world we are moving towards

Model-Based Systems Engineering (MBSE)

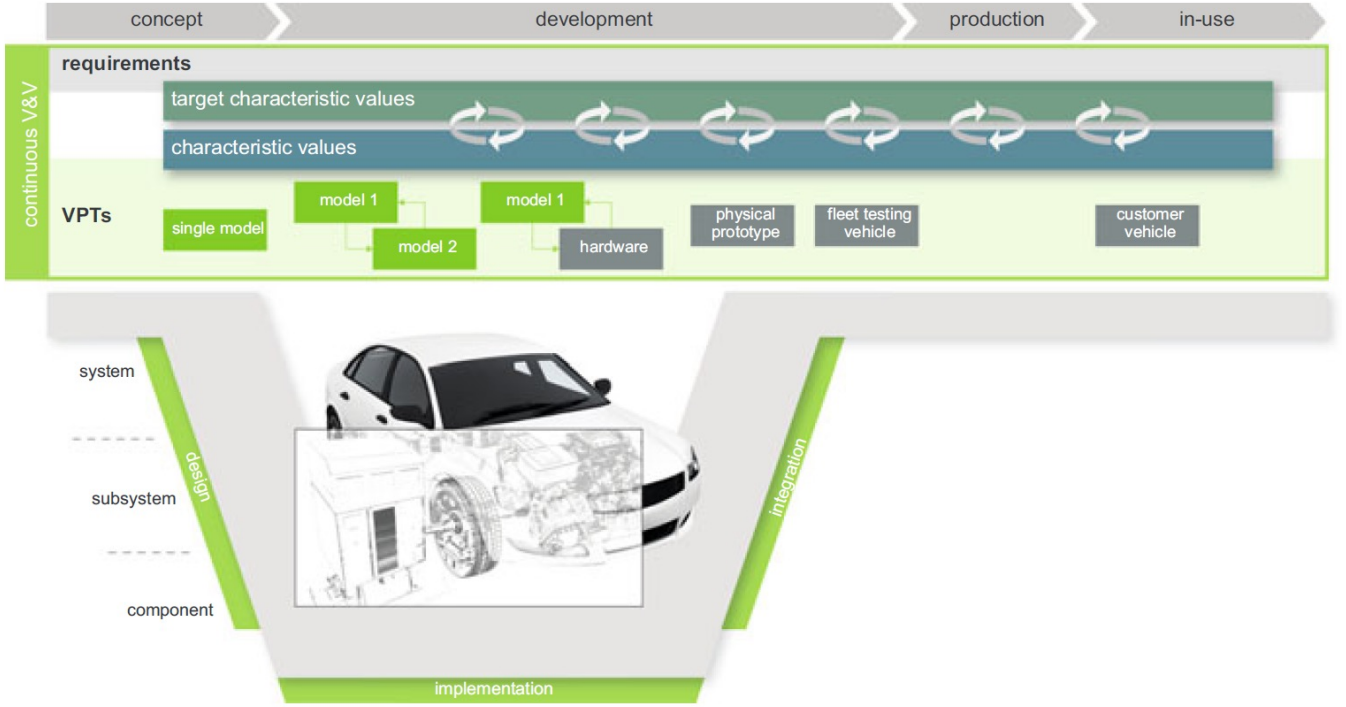
Formalization of knowledge in models, notably from very start of development

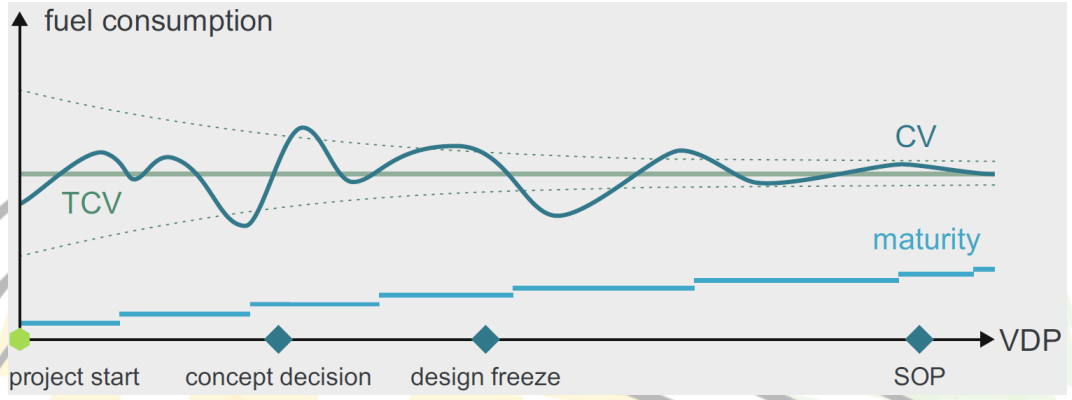
Current status
- Industrial hype but difficult adoption
- Mostly SysML-based
- Somewhat ad-hoc

Where the field is moving
- Digital Thread/Twin/Engineering
- Simulation as continuous capability

Vision: Continuous Verification & Validation

- Capability to assess product target fulfillment at any time in the development process
- Systematically use Virtual Prototypes (VPTs) throughout development
- Leverage MBSE system architecture models to drive V&V using VPTs





Puntigam, W., Zehetner, J., Lappano, E., Krems, D. (2020). Integrated and Open Development Platform for the Automotive Industry. In: Hick, H., Küpper, K., Sorger, H. (eds) Systems Engineering for Automotive Powertrain Development. Powertrain. Springer, Cham.

Motivation

Simulation

- Simulation is seen as a standard capability of MBSE [1]
- A well-known standard is the FMI standard for model exchange and co-simulation [2]
- Emerging SSP standard focused on model exchange for co-simulation [3]
- Key ingredient for virtual prototyping

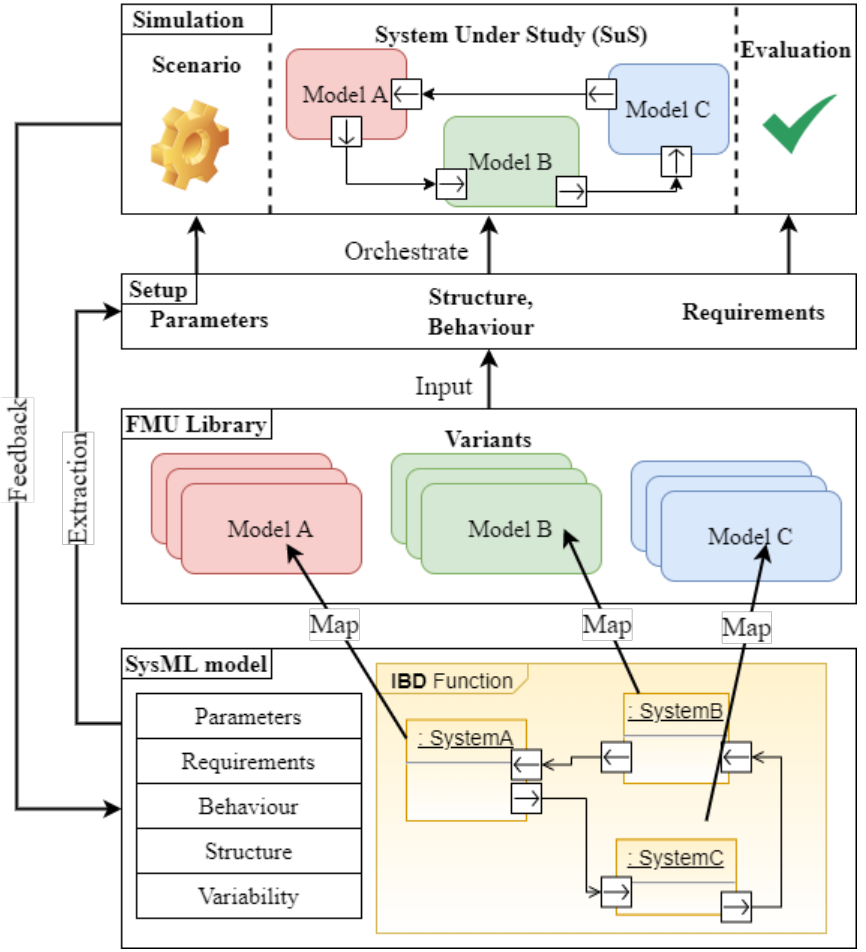
[1] Cederbladh, J., Cicchetti, A., & Suryadevara, J. (2024). Early validation and verification of system behaviour in model-based systems engineering: a systematic literature review. *ACM Transactions on Software Engineering and Methodology*, *33*(3), 1-67.

[2] https://fmi-standard.org/

[3] https://ssp-standard.org/

Co-Simulation as a tool in MBSE

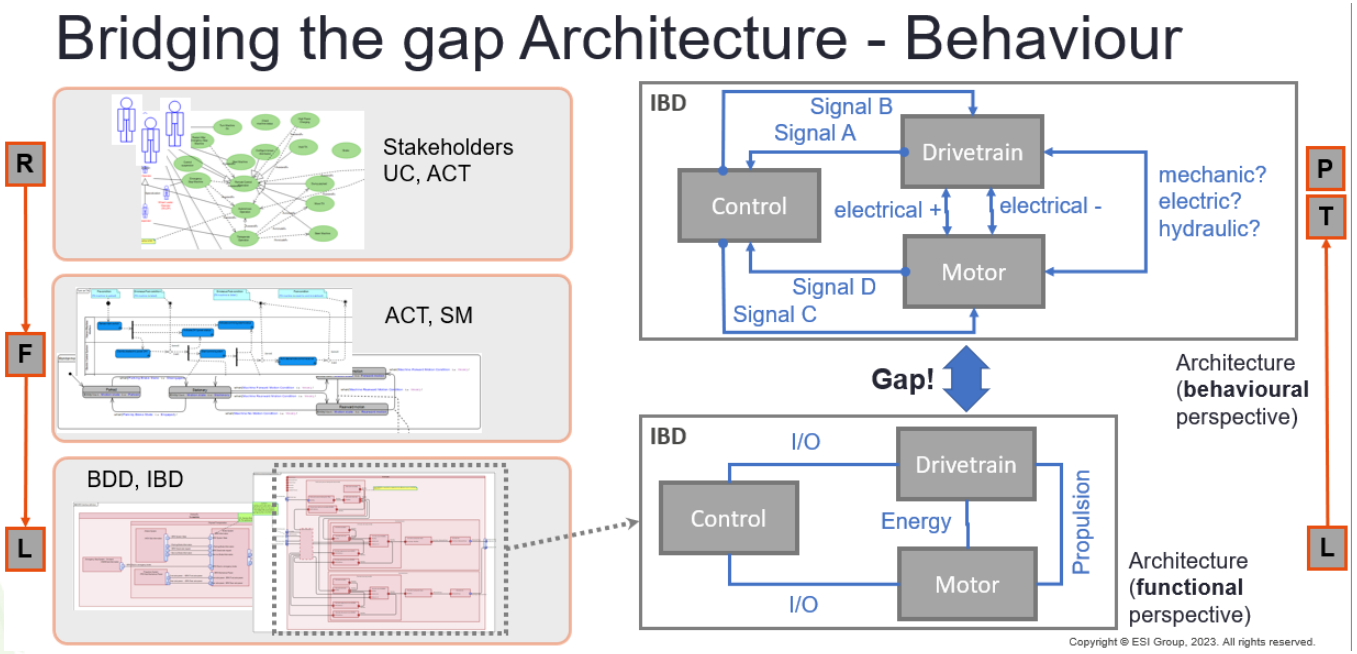
- One use of standards like FMI is SysML-based (Co-)simulation
- SysML acts as the information “backbone”
- With this kind of integration an early and continuous simulation capability can be established
- Overall method & technology framework required [1]



[1] Cederbladh, J., Reale, A., Bergsten, A., Mikelöv, R., & Cicchetti, A. (2023, October). Barriers for Adopting FMI-Based Co-Simulation in Industrial MBSE Processes. In *2023 ACM/IEEE International Conference on Model Driven Engineering Languages and Systems Companion (MODELS-C)* (pp. 510-519). IEEE

Co-Simulation limitations

- One of the more evident issues with this approach is the abstraction gap between SysML and simulation
- Consider a RFLP architecture: Not enough technical depth for simulation
- Overcoming this abstraction gap without overthrowing current roles and processes in an organization is challenging!

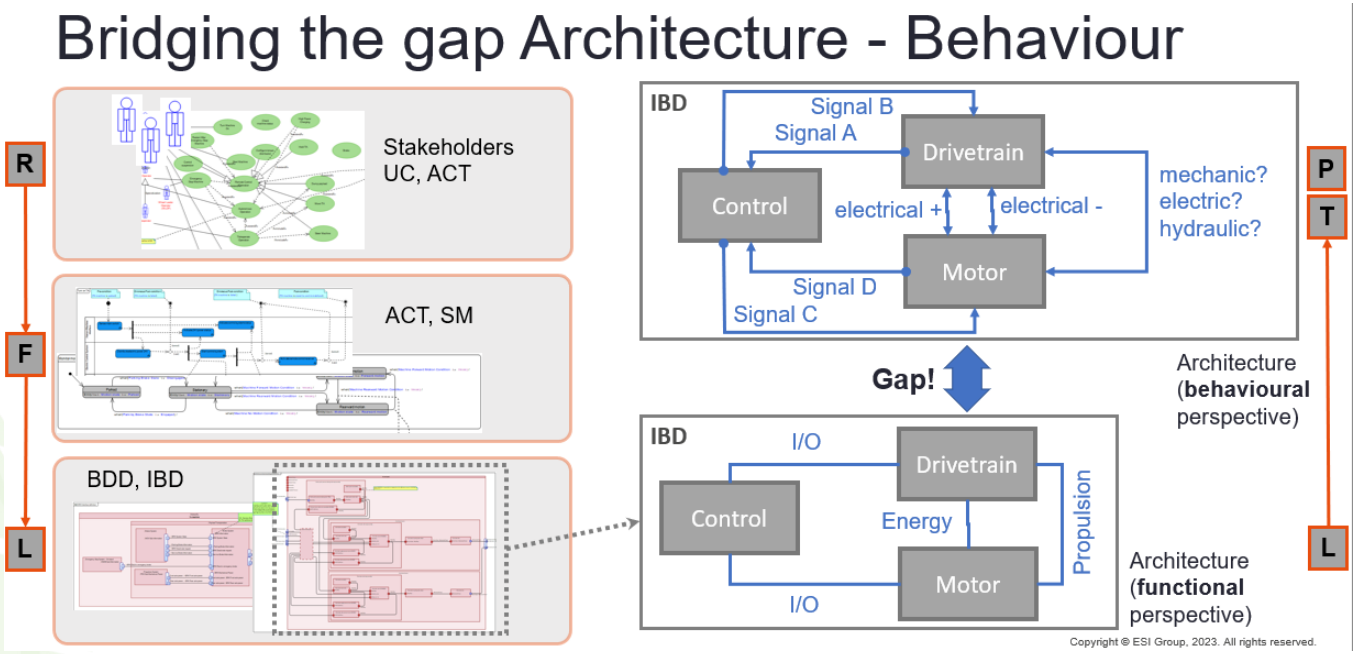


Cederbladh, J., Gottschall, M., Suryadevara, J., & Alekeish, K. (2024, April). Correlating Logical and Physical Models for Early Performance Validation-An Experience Report. In *2024 IEEE International Systems Conference (SysCon)* (pp. 1-8). IEEE

Challenges

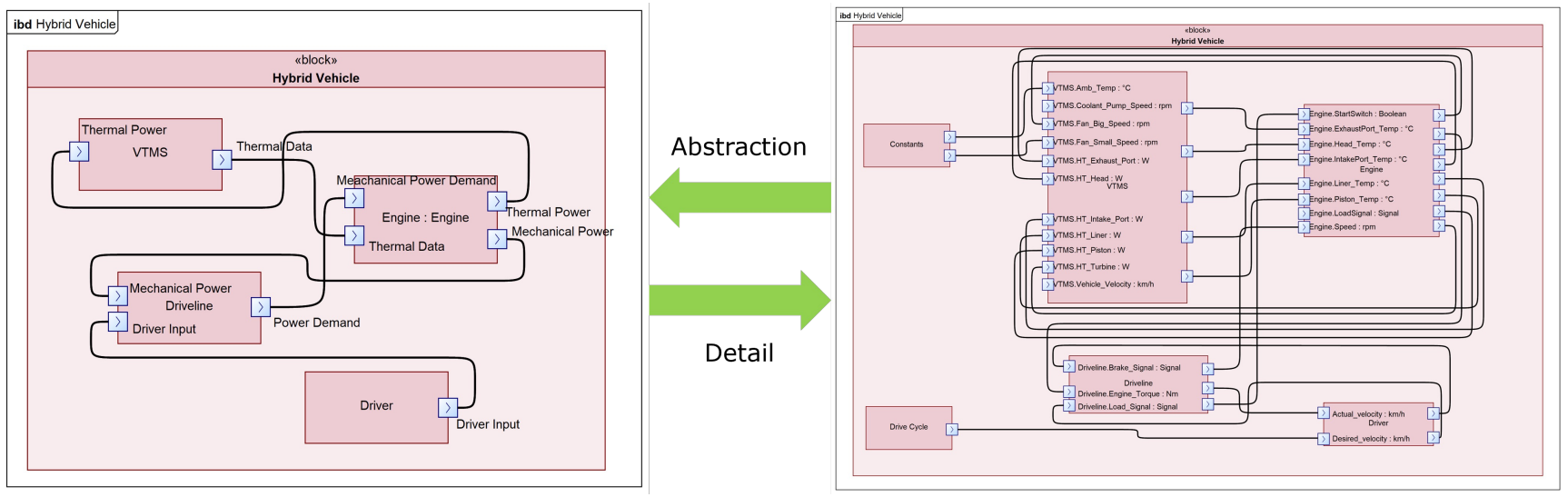
Challenge 1 - Lack of common interface across abstraction for communication/collaboration

- Abstraction gap naturally leads to friction in collaboration/communication
- Bridging domains across abstraction is easier said than done
- Often this results in quite naïve model mappings between system and simulation architecture



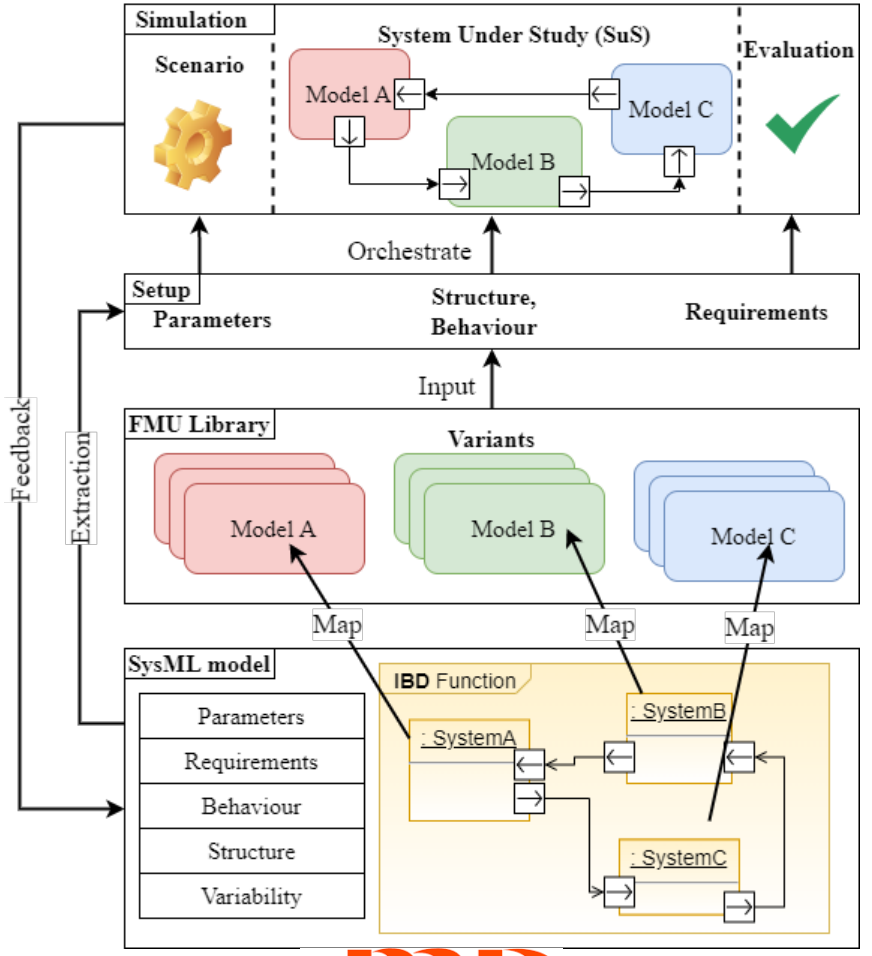
Challenge 2 - Lack of common interface in tool abstraction

- Coming back to the abstraction gap, how do facilitate tool support?
- Interfaces between abstraction layers are often not compatible.
- Often the range of abstraction in SysML is wide.



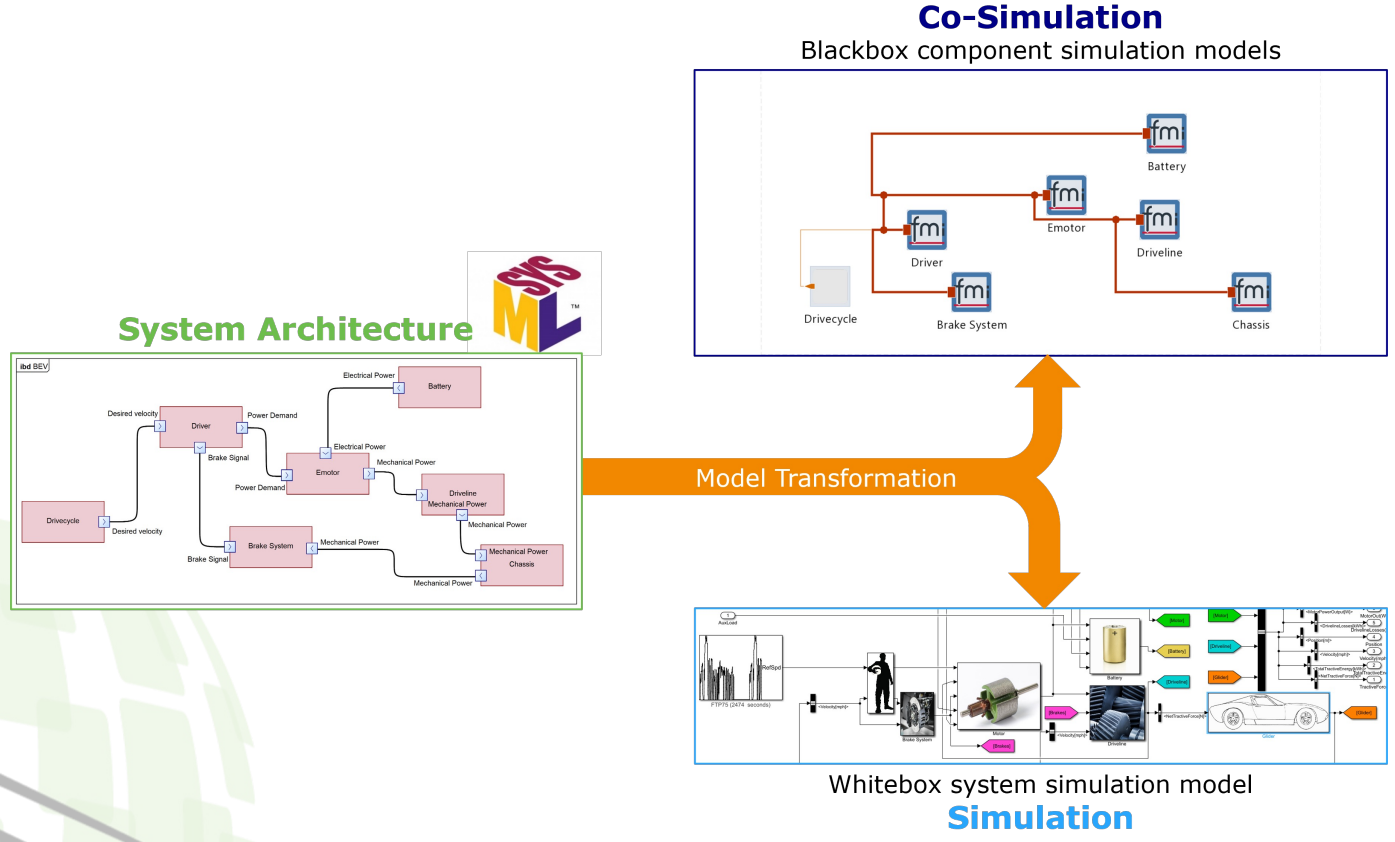
Challenge 3: Lack of mutual understanding of what belongs to SysML contra simulation models

- Who needs to model what?
- Finding the balance of abstraction between models at different stages
- How do we introduce mapping/transformations?



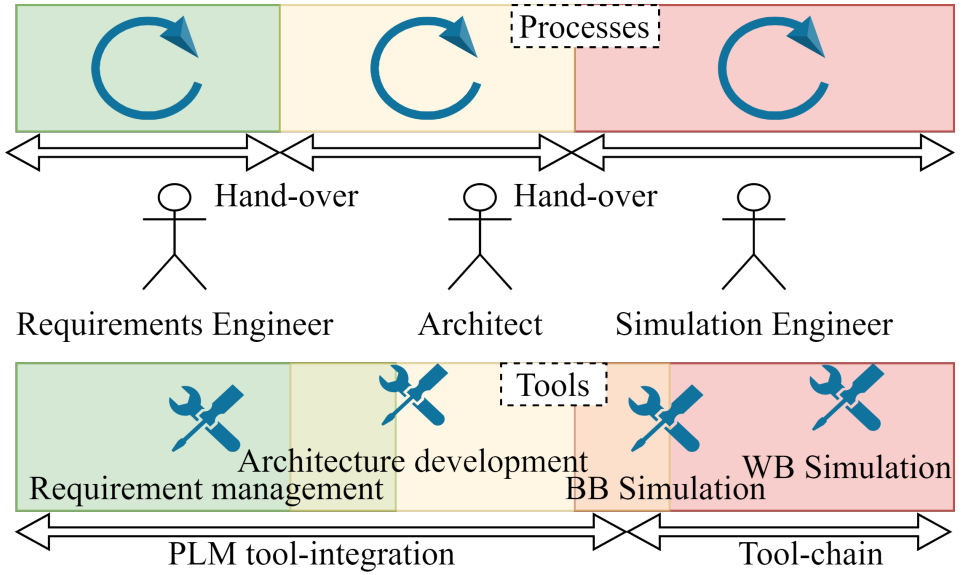
Challenge 4: Lack of a commonly shared Co-simulation use case

- Black box?
- White box?
- Gray box?



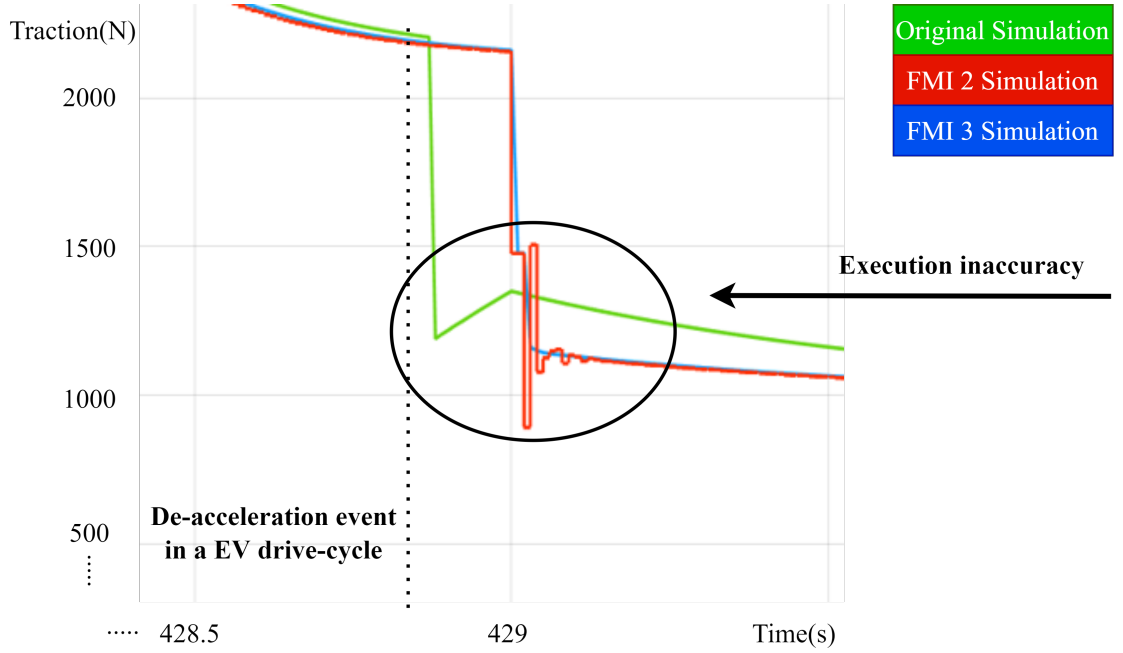
Challenge 5: Lack of process integration

- Bridging roles in organization, who has responsibility of what?
- Who is this solution for?
- What value does the approach have?
- How do we find suitable integration in the existing tooling landscape?



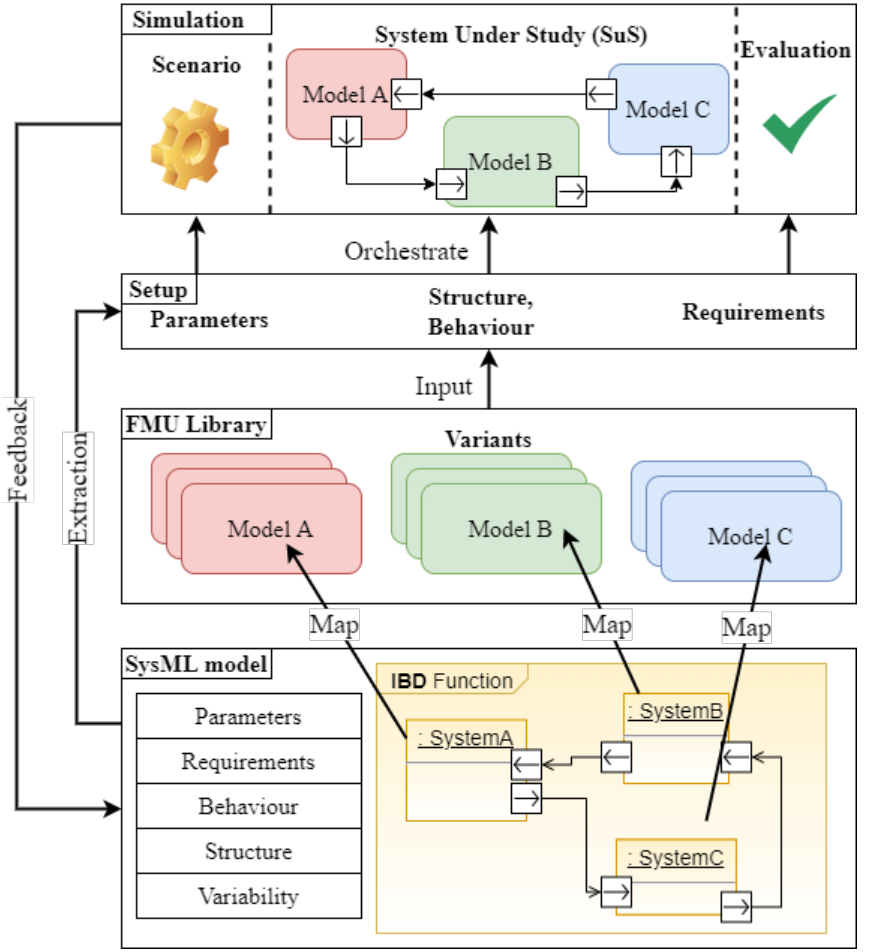
Challenge 6: Lack of uncertainty management in simulation results

- FMI standards hide details, which can be good
- It can also be problematic, as valid simulation is tied to assumptions and configuration
- General instability



Challenges summary

- Integration of simulation through FMI difficult to fully achieve
- Abstraction gap naturally introduces many challenges at different levels, from technical to organizational
- Usefulness of simulation not always easy to understand



Solution overview

Extension through standards

Architecture
SysML tool

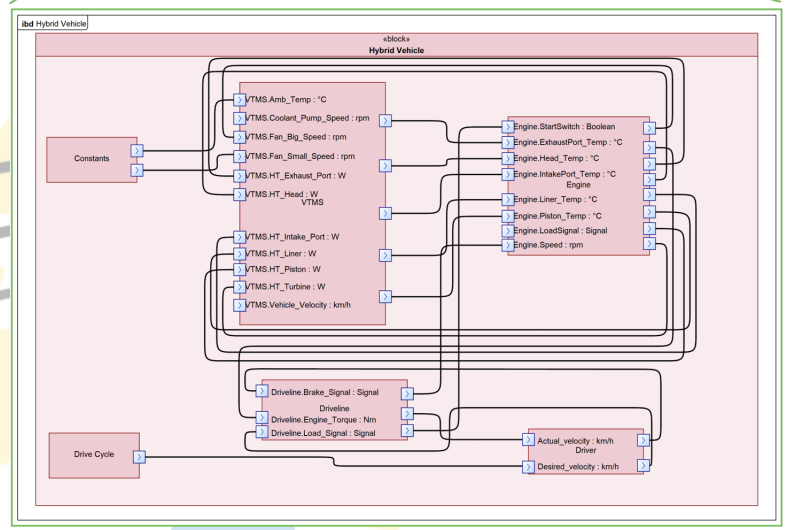
OMG Standards Development Organization
XMI

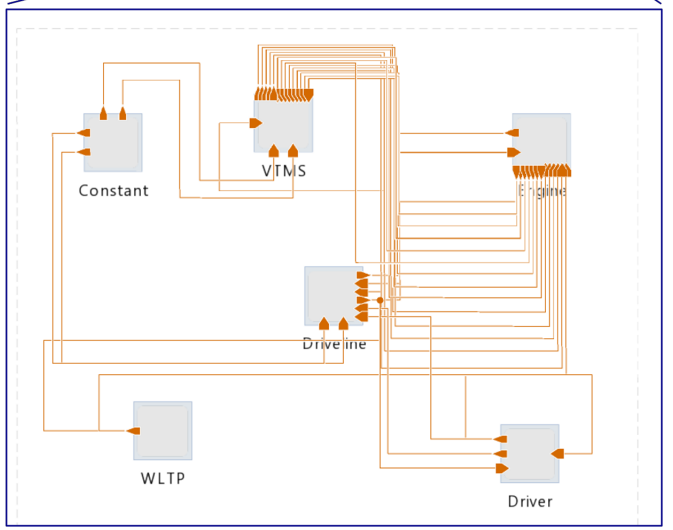
XML transformation & simulation model embedding

fmi Functional Mock-Up Interface

ssp System Structure & Parameterization

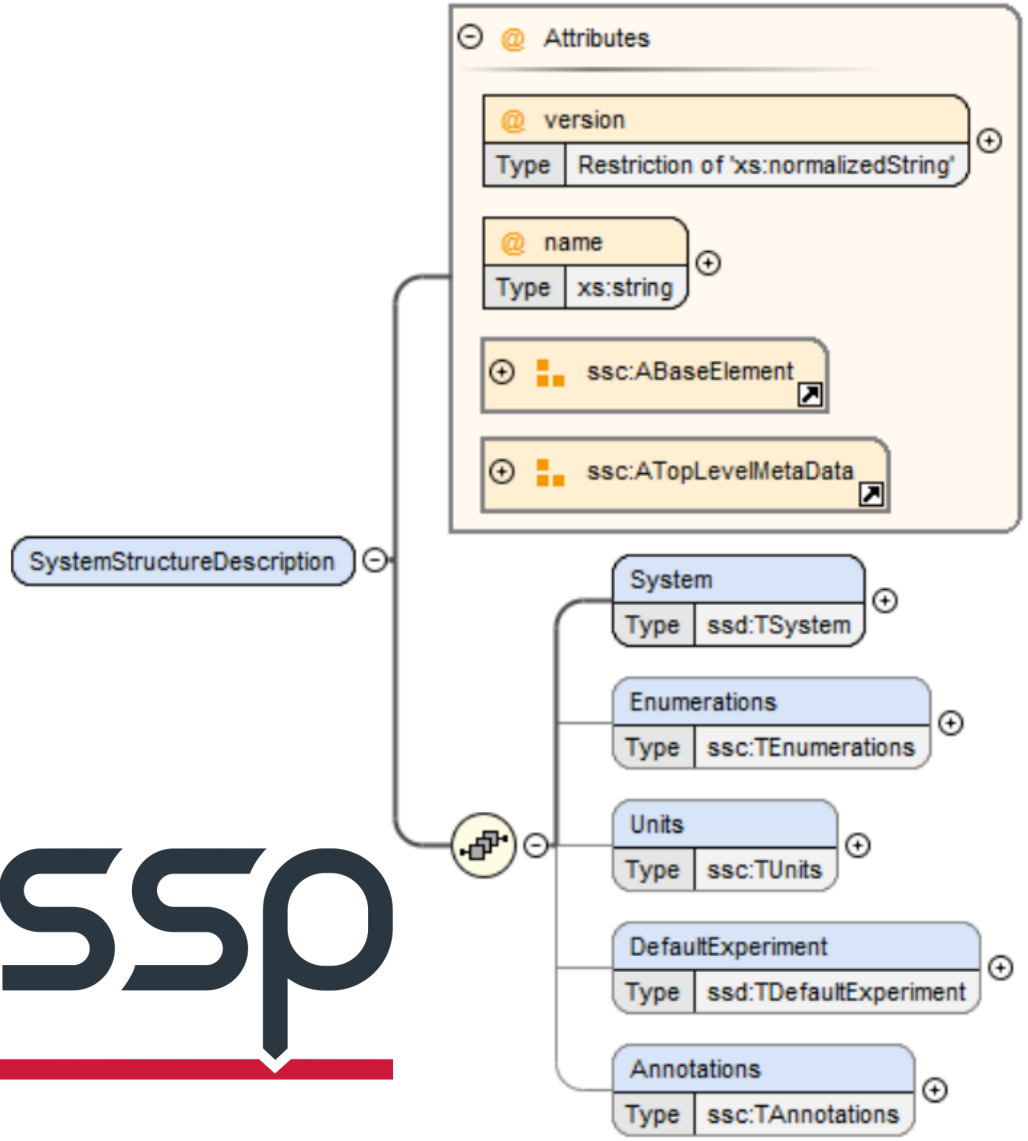
Co-Simulation
Model.CONNECT™





Inside view

- The SSP standard promotes more systematic model annotation compared to FMI
- There is a lot of optional parameters that can be used
- Let's user keep using FMI files



Inside view


ssp
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</ssd:Connectors>
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</ssd:Component>
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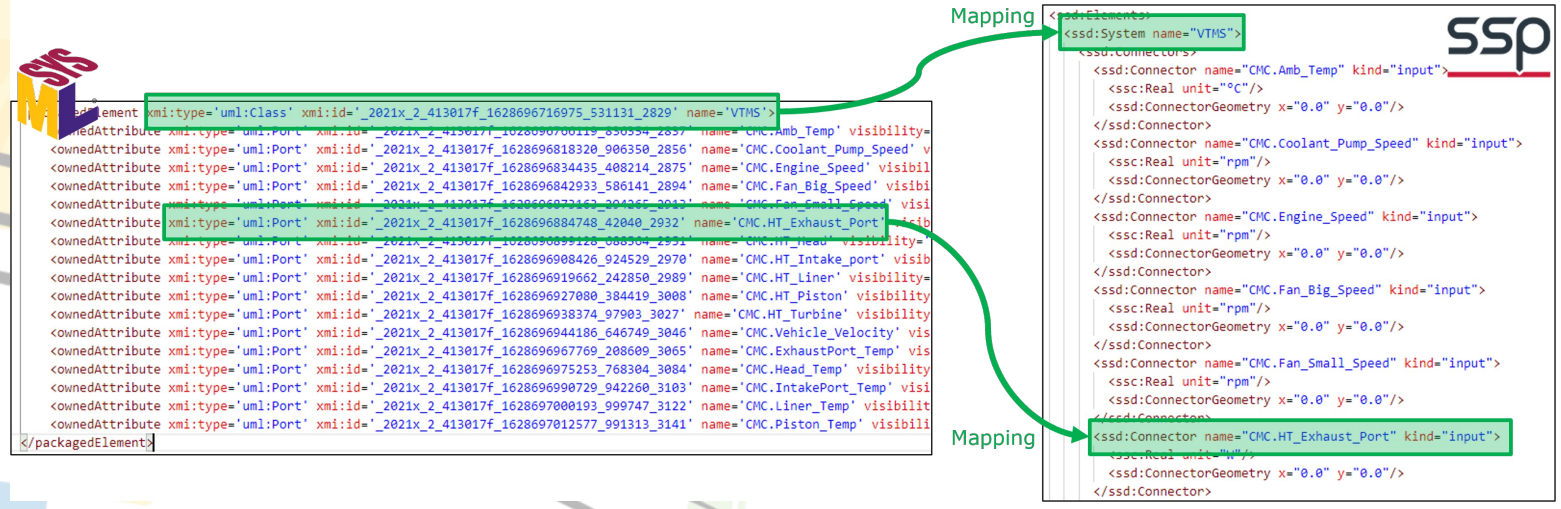
Embedding
fmi
VTMS
VTMS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Mapping
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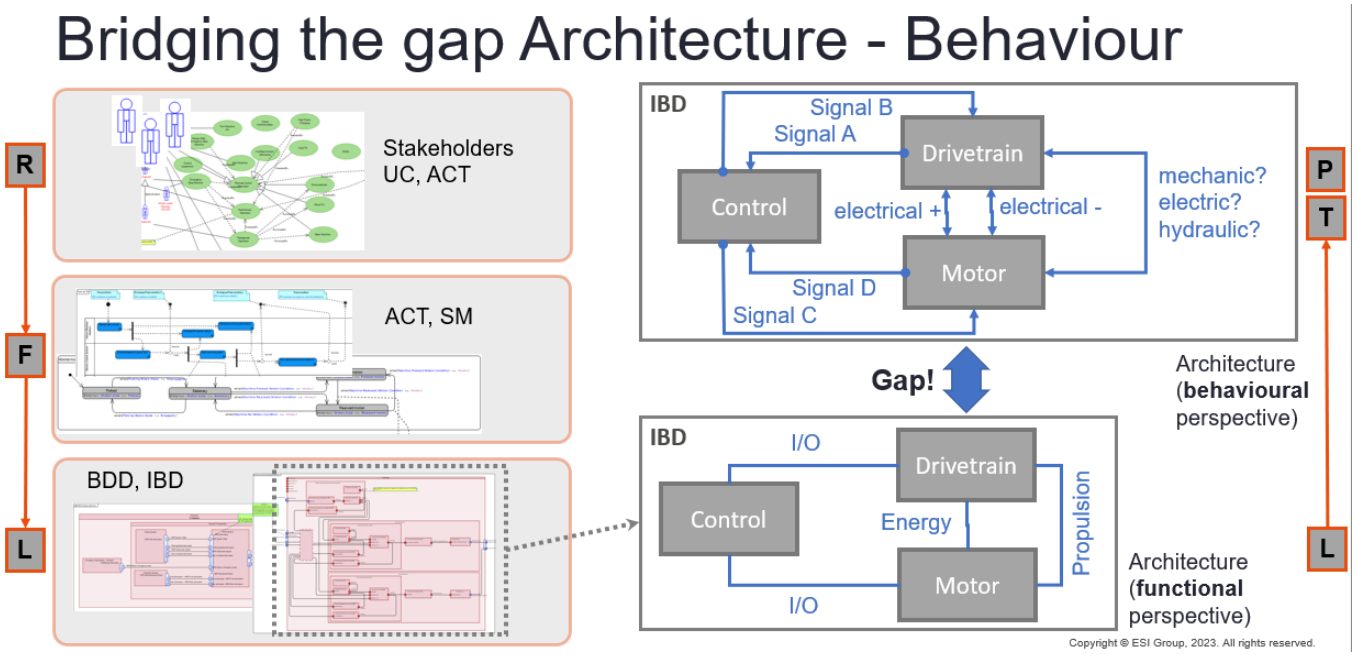
Challenges - revisited

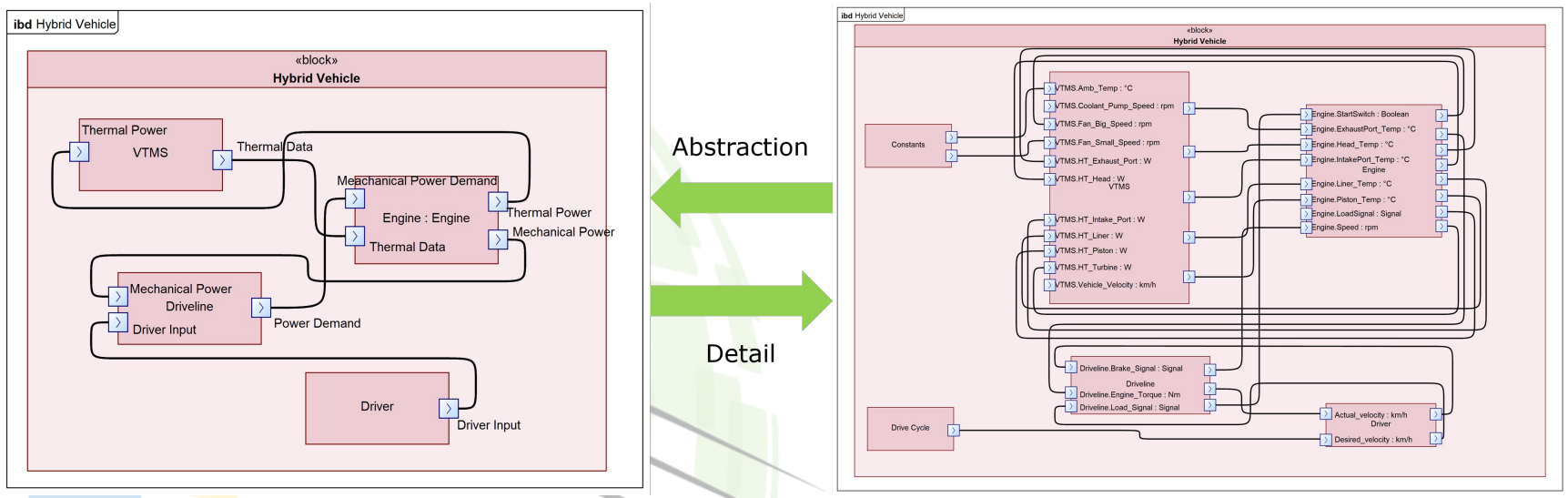
Challenge 1 - Lack of common interface across abstraction for communication/collaboration

- Encapsulate simulation models using FMI/SSP
- Map SysML elements to FMI/SSP abstraction
- Emphasize the interfaces and signals of the models



Challenge 2 - Lack of common interface in tool abstraction

- Rely *only* on standards for data
- Find common-ground in interface abstraction and representation



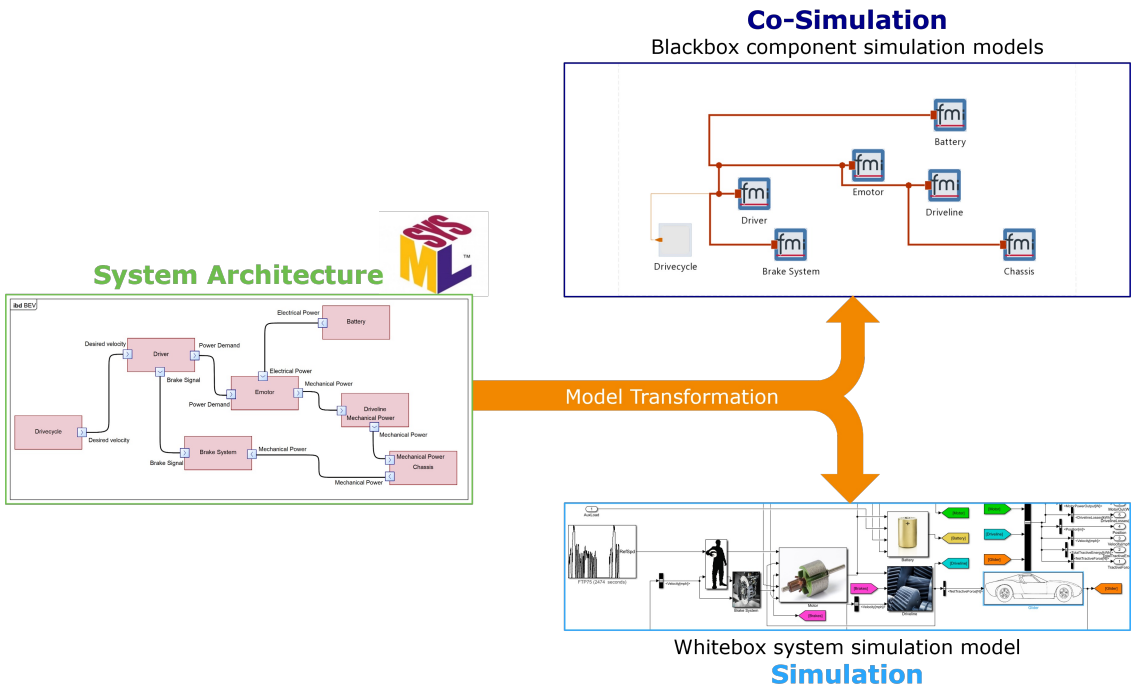
Challenge 3: Lack of mutual understanding of what belongs to SysML contra simulation models

- Minimum information in SysML to match SSP requirements (example on the right)
- Common base for black/white box simulation
- Use standards as the common point in alignment

- Any entities in the model related to the subsequent simulation domain should be marked (e.g., using tags) to ensure meaningful simulation model creation
- Each logical block with inner structure should have IBDs representing domain-specific views, and at least 1 IBD ("standard model") should contain all inherited elements describing the full structure for reuse in subsequent design steps (e.g., bill of materials)
- Each port needs to have a physical meaning and type (domain), SysML stereotypes are not sufficient
- Attributes have to be defined on blocks, they can be assigned in part properties by different values
- Attributes to be reused as simulation model parameters have to have a physical meaning, value, and ideally unit, otherwise the value has to be in SI system
- Changes to the SysML metamodel need to be explicit to ensure adaption and seamless transfer of information to physical domain
- Any changes in the data need to be similarly explicit, do not *hide* dependencies

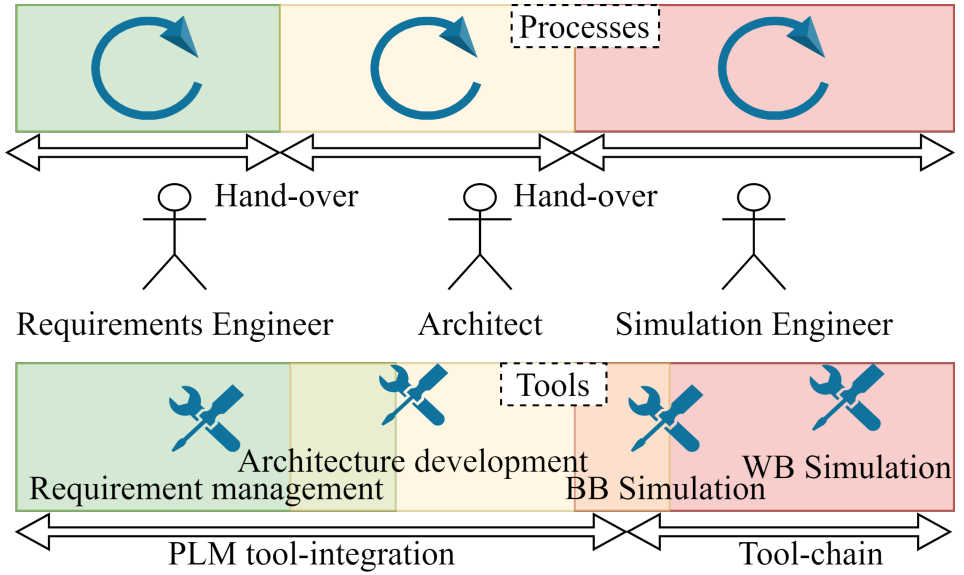
Challenge 4: Lack of a commonly shared Co-simulation use case

- Using typing/tags to separate co-simulation usage scenarios
- Identify SysML diagrams to be used for simulation (and what type)



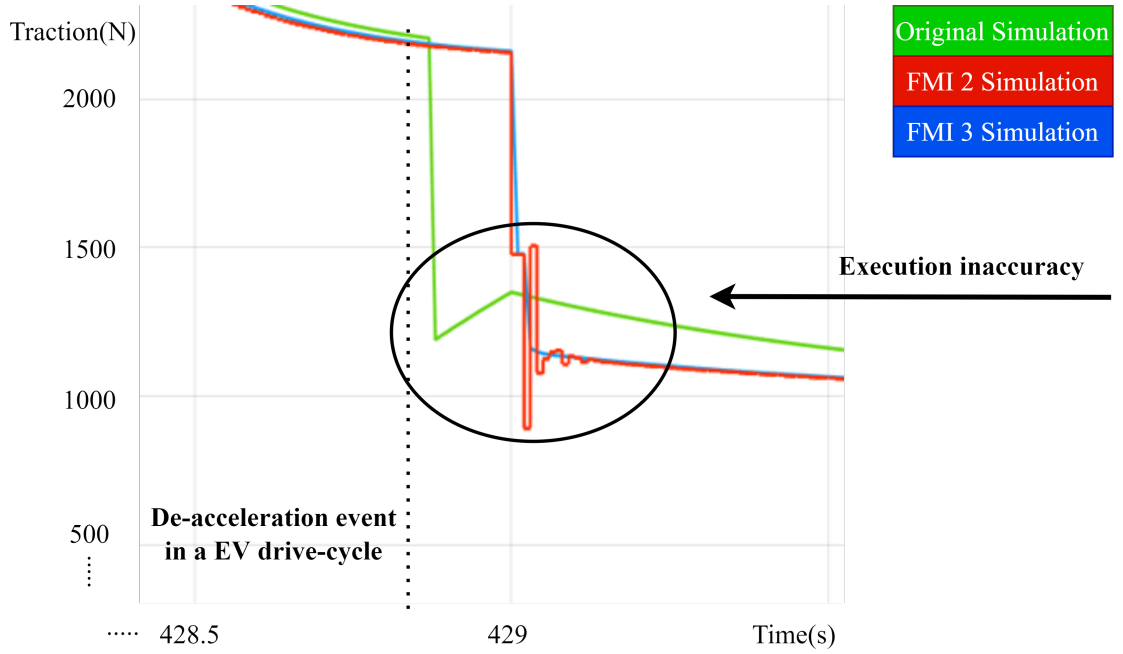
Challenge 5: Lack of process integration

- More organization specific
- Communication required in the company
- Finding a good match between organizational change and stability



Challenge 6: Lack of uncertainty management in simulation results

- Annotate simulation models
- Traceably requirement
- Validity ranges
- Match needs and simulation performance (e.g., “Do I need a very accurate result or not?”)



Discussion

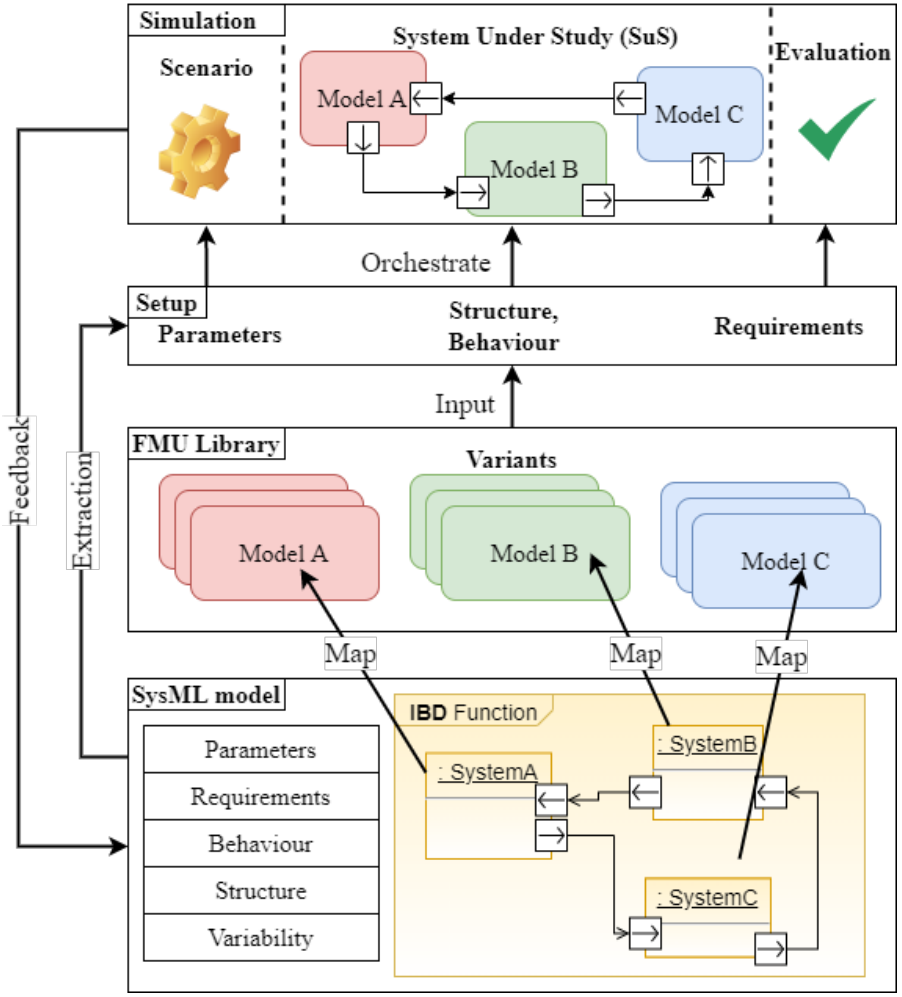
Holistic perspective

- Our work is part of a larger collaborative effort in early and continuous V&V
- Early V&V is a highly subjective notion, and might not always be feasible/useful
- At the core of challenges are the SE processes, and how we can best support them with useful decision-support
- While we emphasize SysML and FMI/SSP there are a plethora of standards for both system description and analysis

Conclusion & Future work

Looking back

- We make Co-Simulation more standard-oriented to support a more robust integration
- We discuss a set of challenges we have encountered in our works and their implications
- Our work should assist practitioners in applying the overall concept (seen on right)



Looking forward

- Parallel work on early V&V to identify challenges and future research directions
- Process agnostic methods for applying simulation
- Early V&V method selection guidelines

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Backup slides

Backup slides

- Put anything here not possible to fit before that could be useful! For example very technical stuff