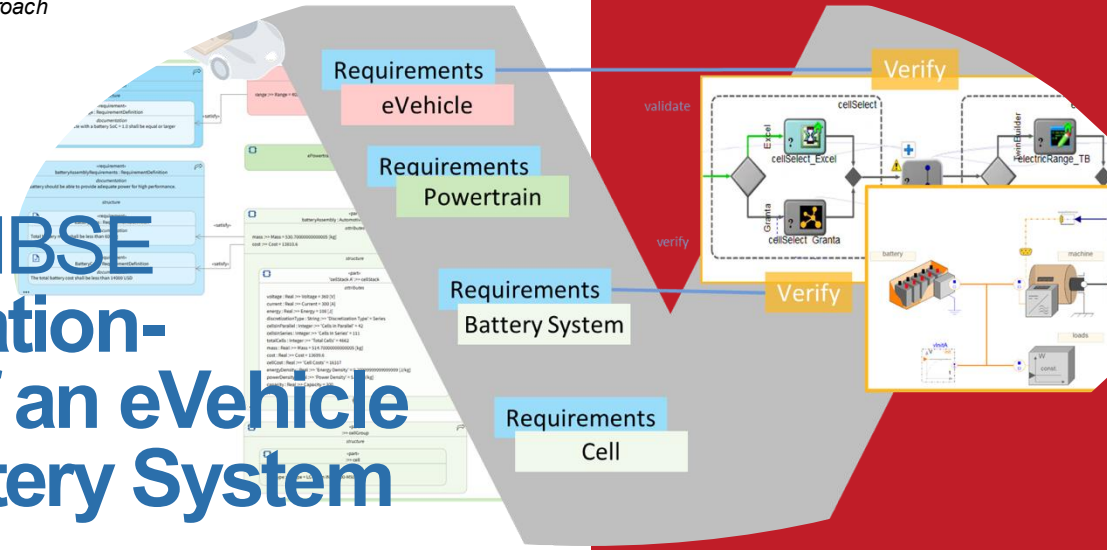
International Council on Systems Engineering
A better world through a systems approach



Driving the Future of MBSE
SysMLv2 and Simulation-Driven Verification of an eVehicle ePowertrain and Battery System

Alexander Busch, Ph.D., CSEP
Soeren Schreiner, M.Sc.
Christoph Edeler, Ph.D.
Hemesh Patil
Tushar Sambharam
Bernhard Kaiser, Ph.D.
Rajagopalan Badrinarayanan, Ph.D.

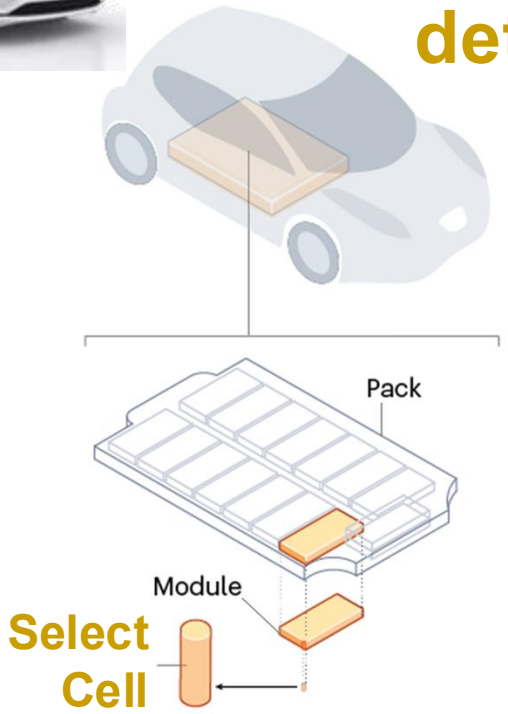
INCOSE International Symposium 2025 | Ottawa, Canada

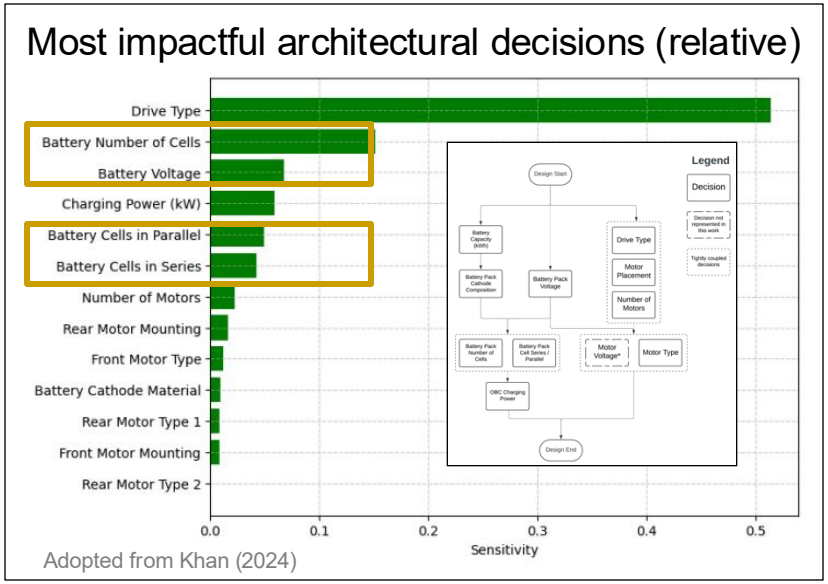
eVehicle Architectural Definition & Trade Study

Size battery pack & determine EV range

Requirements

- Range > 275 km
- Budget & derive
- Mass < xxx kg
- Cost < xxx $
- …





Adopted from Khan (2024)

Collaborative engineering approach

2 M&S Development

Subject Matter-Experts

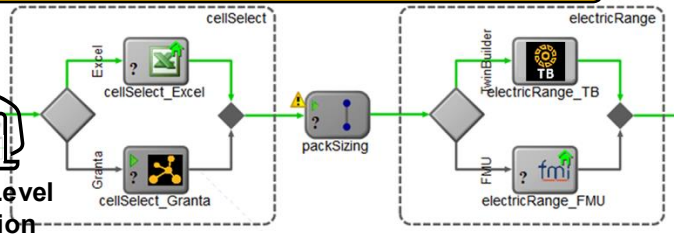
Release & Publish

SAM

OMG SYSTEMS MODELING LANGUAGE

2 Analysis Workflow Development

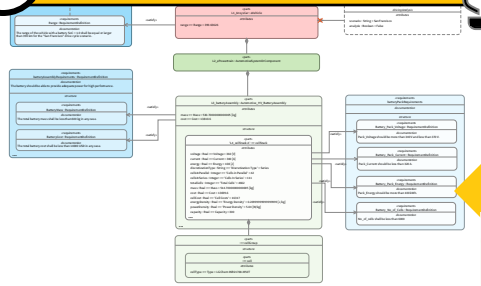
System-Level Simulation Specialist



Release & Publish

Systems Engineer

1 Architectural modeling

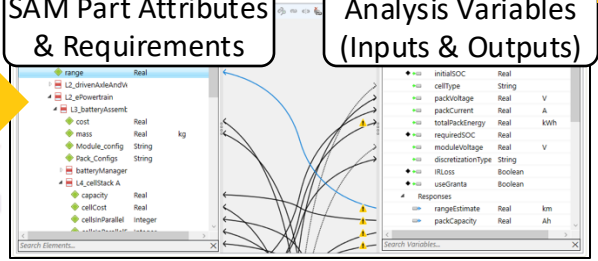


API

4 Analyses, V&V & Trade Studies

SAM Part Attributes & Requirements

Analysis Variables (Inputs & Outputs)

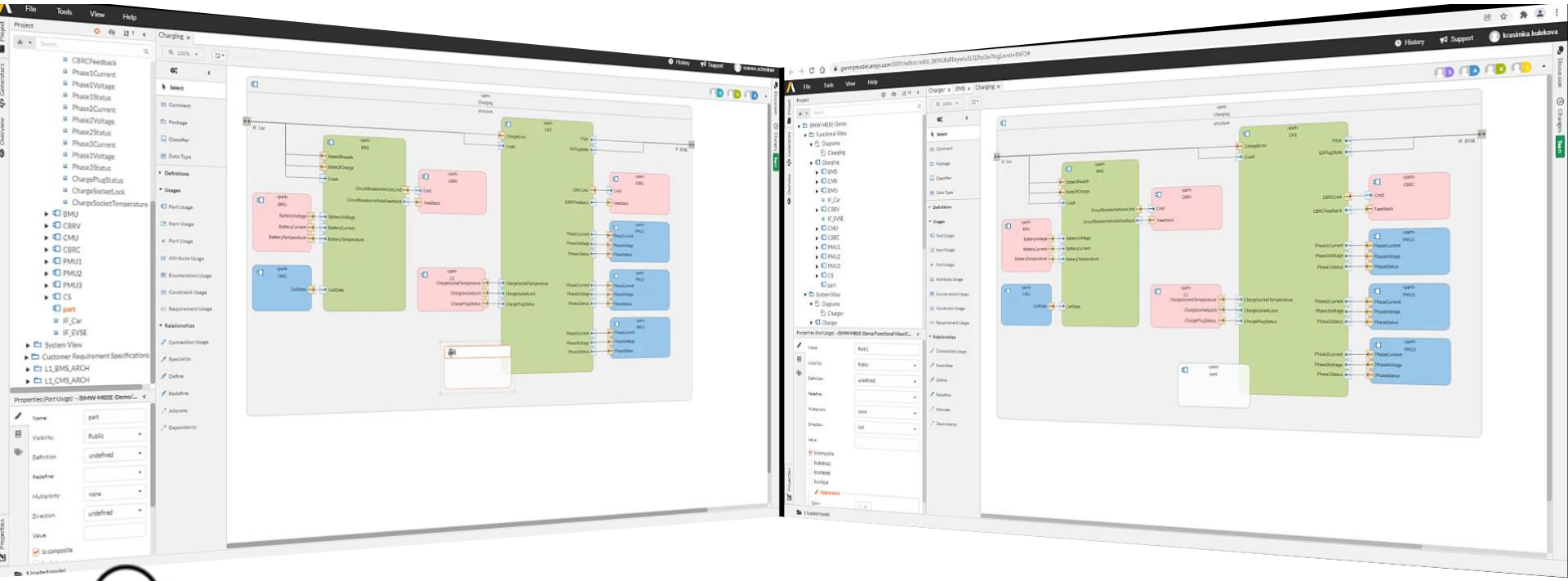


3 Workflow Deployment

Execution server

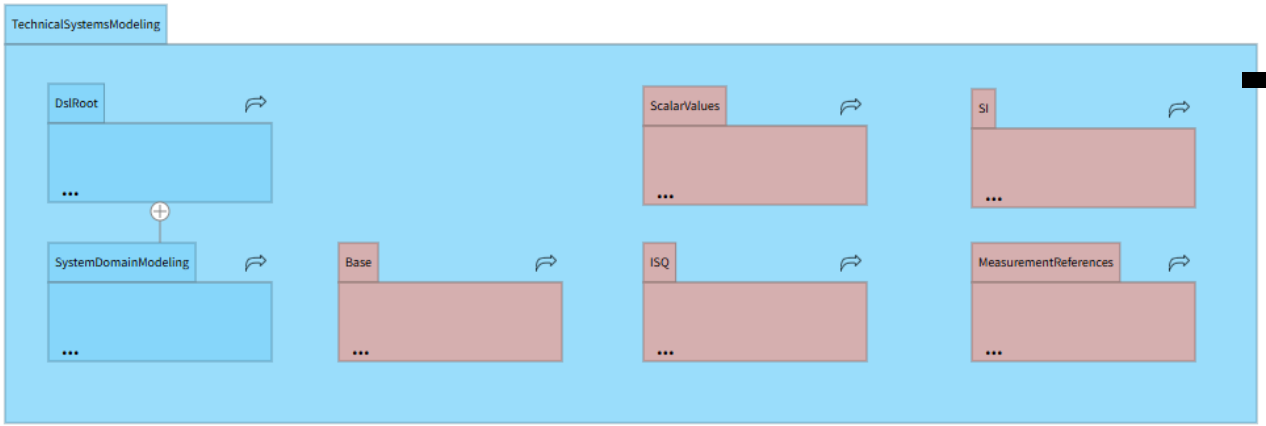
SPDM

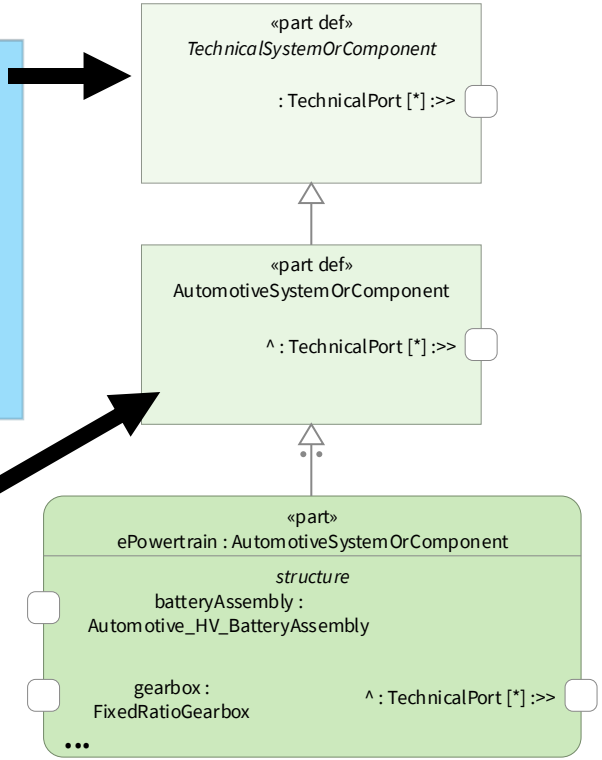
Architectural modeling



Cloud-based SysMLv2 modeling for real-time collaboration

Architectural modeling

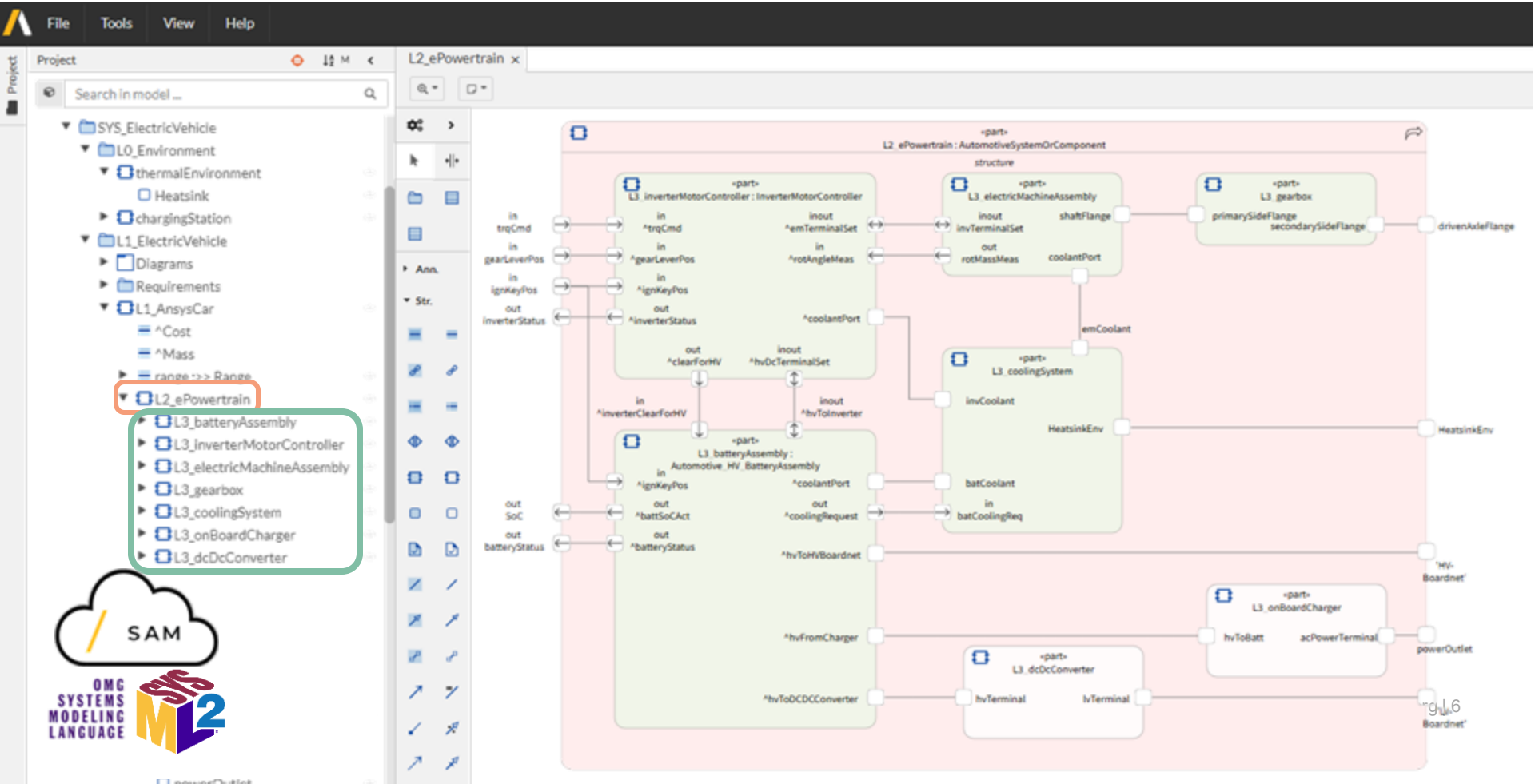




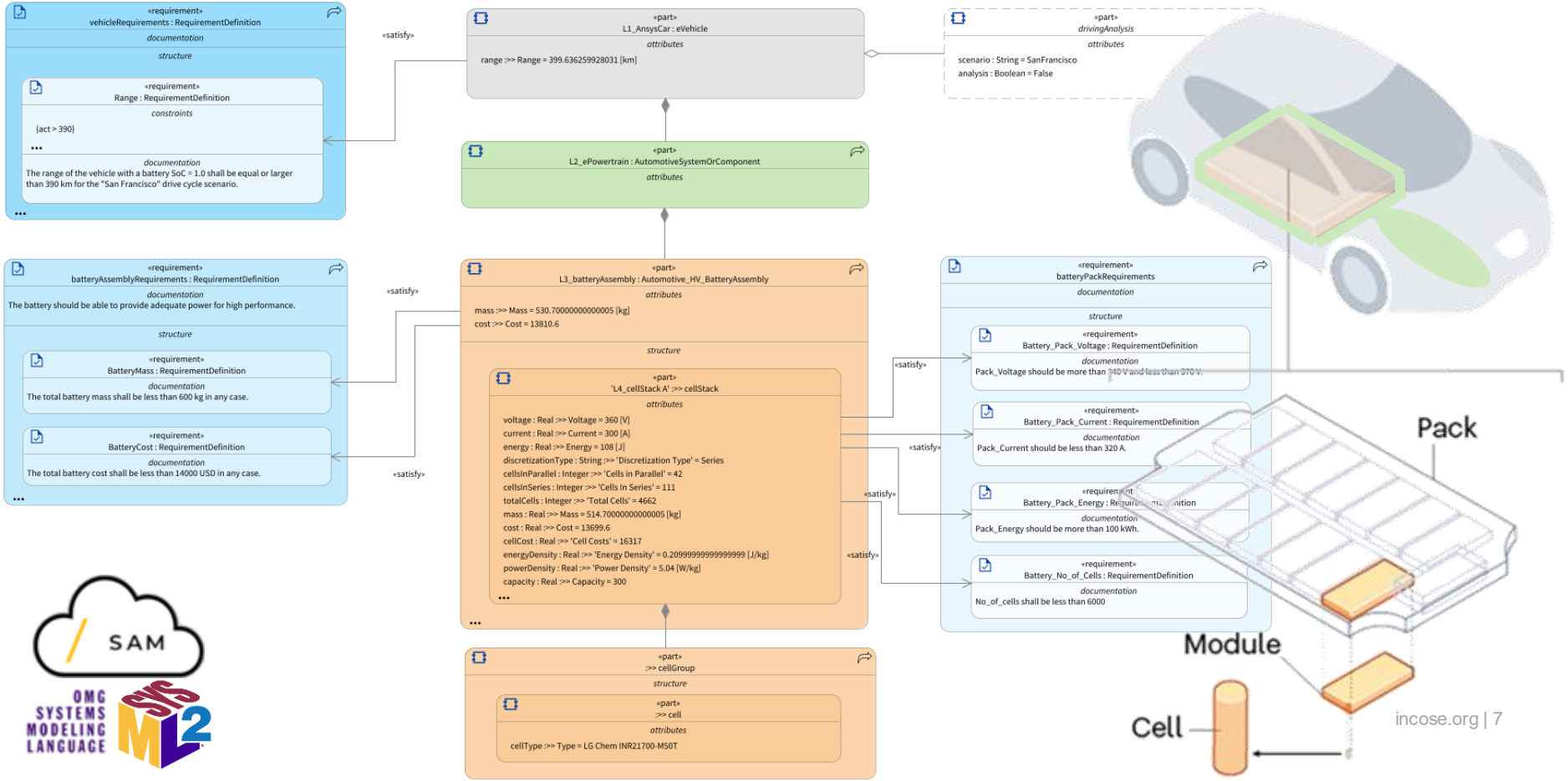
Blend of

- SysMLv2 standard libraries
- User-defined libraries to provide Automitve context

Modelling Overview



Battery sizing and range requirements



Collaborative engineering approach

2 M&S Development

Subject Matter-Experts

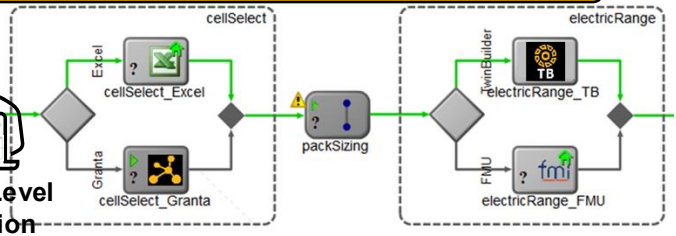
Release & Publish

SAM

OMG SYSTEMS MODELING LANGUAGE

2 Analysis Workflow Development

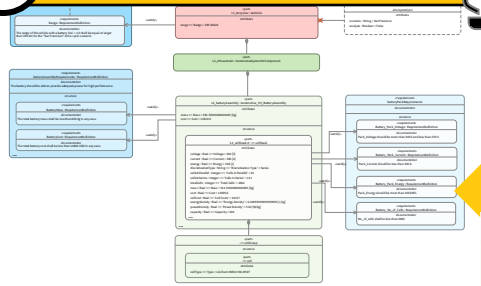
System-Level Simulation Specialist



Release & Publish

Systems Engineer

1 Architectural modeling

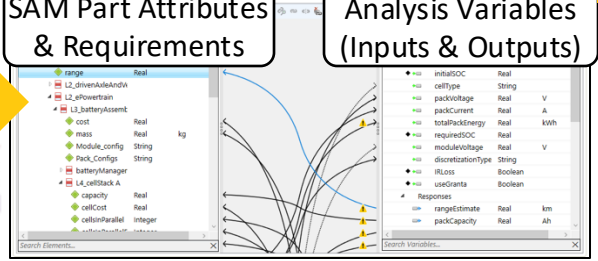


API

4 Analyses, V&V & Trade Studies

SAM Part Attributes & Requirements

Analysis Variables (Inputs & Outputs)



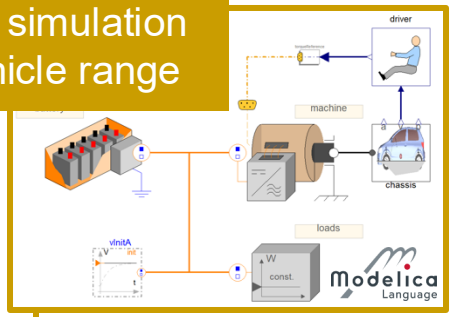
3 Workflow Deployment

Execution server

SPDM

Simulation workflow and connection to MBSE

Run a Modelica system simulation model to evaluate eVehicle range

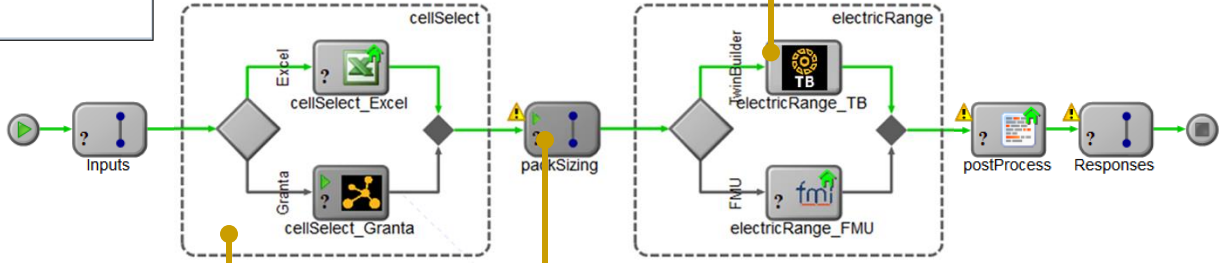


Inputs from SAM

Name	Value	Units
cellType	LG Chem IN...	
packVoltage	360	V
packCurrent	300	A
totalPackEnergy	108	kWh
requiredSOC	0.5	
moduleVoltage	0	V
discretizationType	Series	
IRLoss	true	
useGranta	false	

Cell characteristics

Name	Value	Units
type	LG Chem I...	
cost	3.5	$
mass	0.069	kg
maxCurrent	7.2	A
nomCapacity	5	Ah
nomResistance	0.025	Ohm
nomVoltage	3.6	V



Outputs to SAM

Name	Value	Units
rangeEstimate	399.636	km

Responses | Battery Pack (Cell Stack)

Name	Value	Units
batteryMass	530.7	kg
packMass	514.7	kg
batteryCost	13810.6	$
packCost	13699.6	$
packCellCost	16317	$
packEnergyDensity	0.21	kWh/kg
packPowerDensity	5.04	VA/kg
totalCellsInPack	4662	
totalCellsInPack...	0	
cellsInSeriesInPack	111	
cellsInSeriesInPa...	0	
cellsInParallelInP...	42	
cellsInParallelInP...	0	

Select battery cell information from look-up table or material database

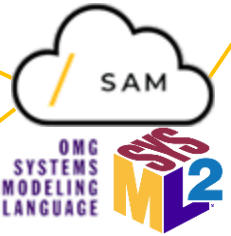
Size a battery using simple canonical equations in a script

Collaborative engineering approach

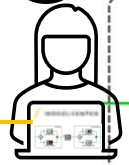
2 M&S Development

Subject Matter-Experts

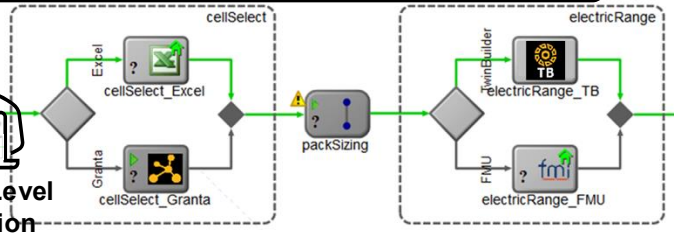
Release & Publish



2 Analysis Workflow Development



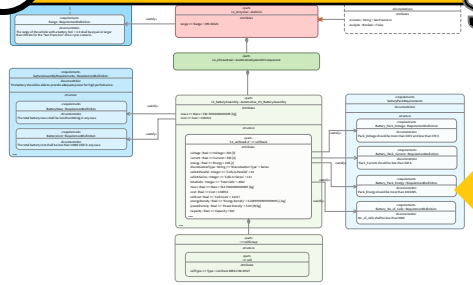
System-Level Simulation Specialist



Release & Publish

Systems Engineer

1 Architectural modeling

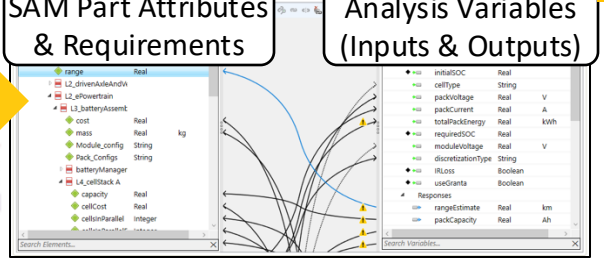


API

4 Analyses, V&V & Trade Studies

SAM Part Attributes & Requirements

Analysis Variables (Inputs & Outputs)



3 Workflow Deployment

Execution server

SPDM

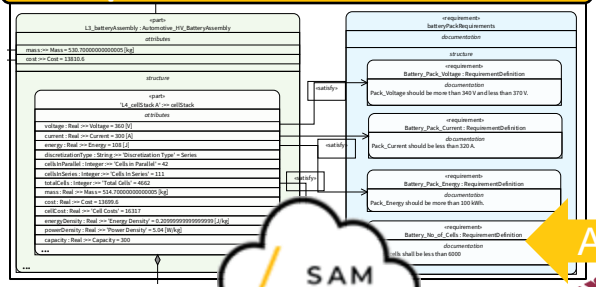
Linking MBSE with Engineering Simulation

Enabling System Analysis, V&V by Simulation and Trade Studies

Model-based Systems Engineering

Engineering Simulation

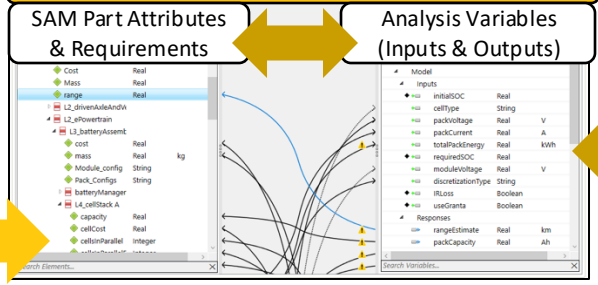
Requirements & Architecture



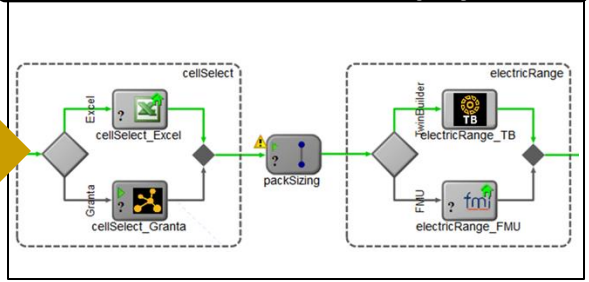
Analyses, V&V & Trade Studies

SAM Part Attributes & Requirements

Analysis Variables (Inputs & Outputs)



M&S of behavior and physics



API

SAM

OMG SYSTEMS MODELING LANGUAGE

SysML2

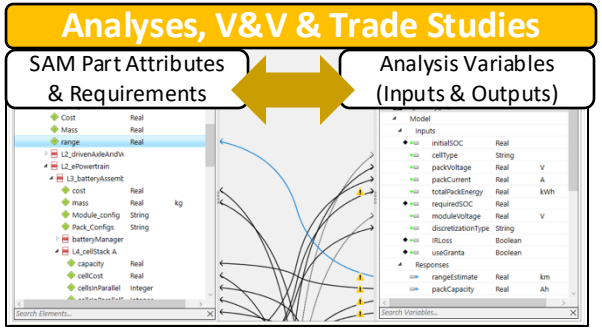
IBM Rational

CAMEO SYSTEMS MODELER

… with full digital continuity

…

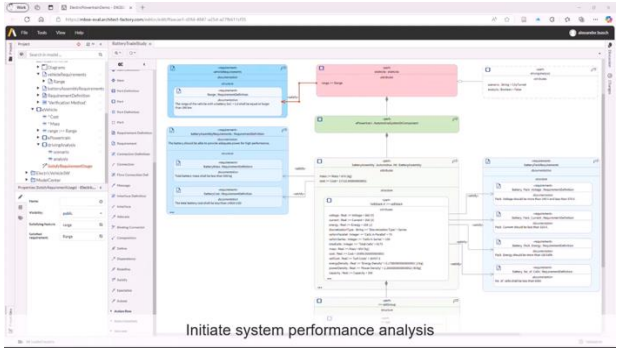
Example



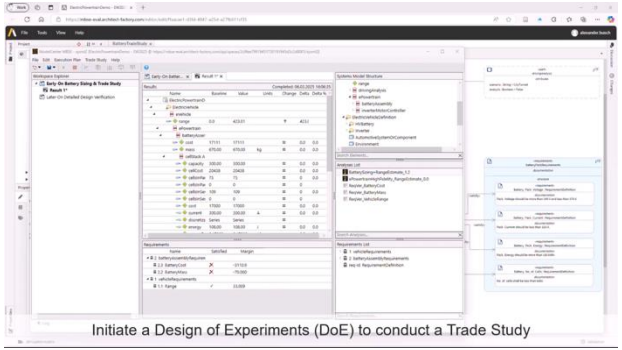
① Execute verification by system-level simulation

② Perform trade study to identify viable system

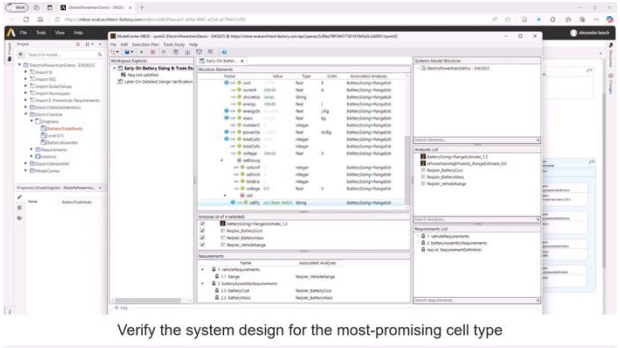
③ Verify the viable system design & save back to the SAM



Initiate system performance analysis



Initiate a Design of Experiments (DoE) to conduct a Trade Study



Verify the system design for the most-promising cell type

Collaborative engineering approach

2 M&S Development

Subject Matter-Experts

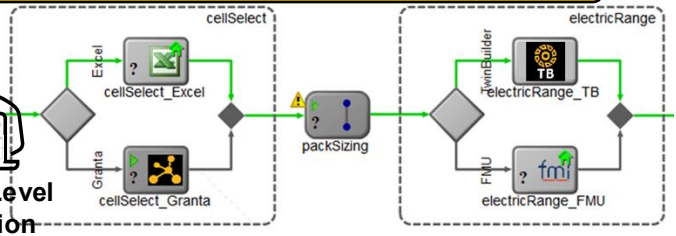
Release & Publish

SAM

OMG SYSTEMS MODELING LANGUAGE

2 Analysis Workflow Development

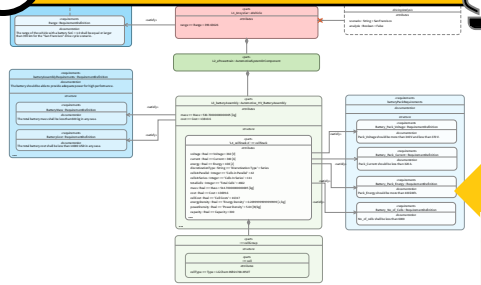
System-Level Simulation Specialist



Release & Publish

Systems Engineer

1 Architectural modeling



API

4 Analyses, V&V & Trade Studies

SAM Part Attributes & Requirements

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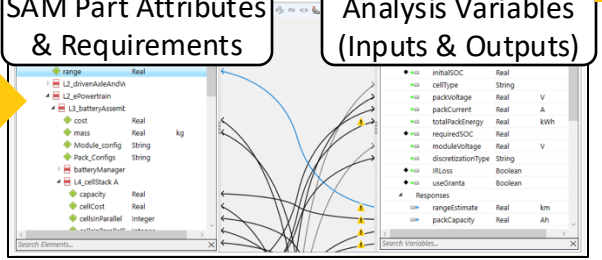


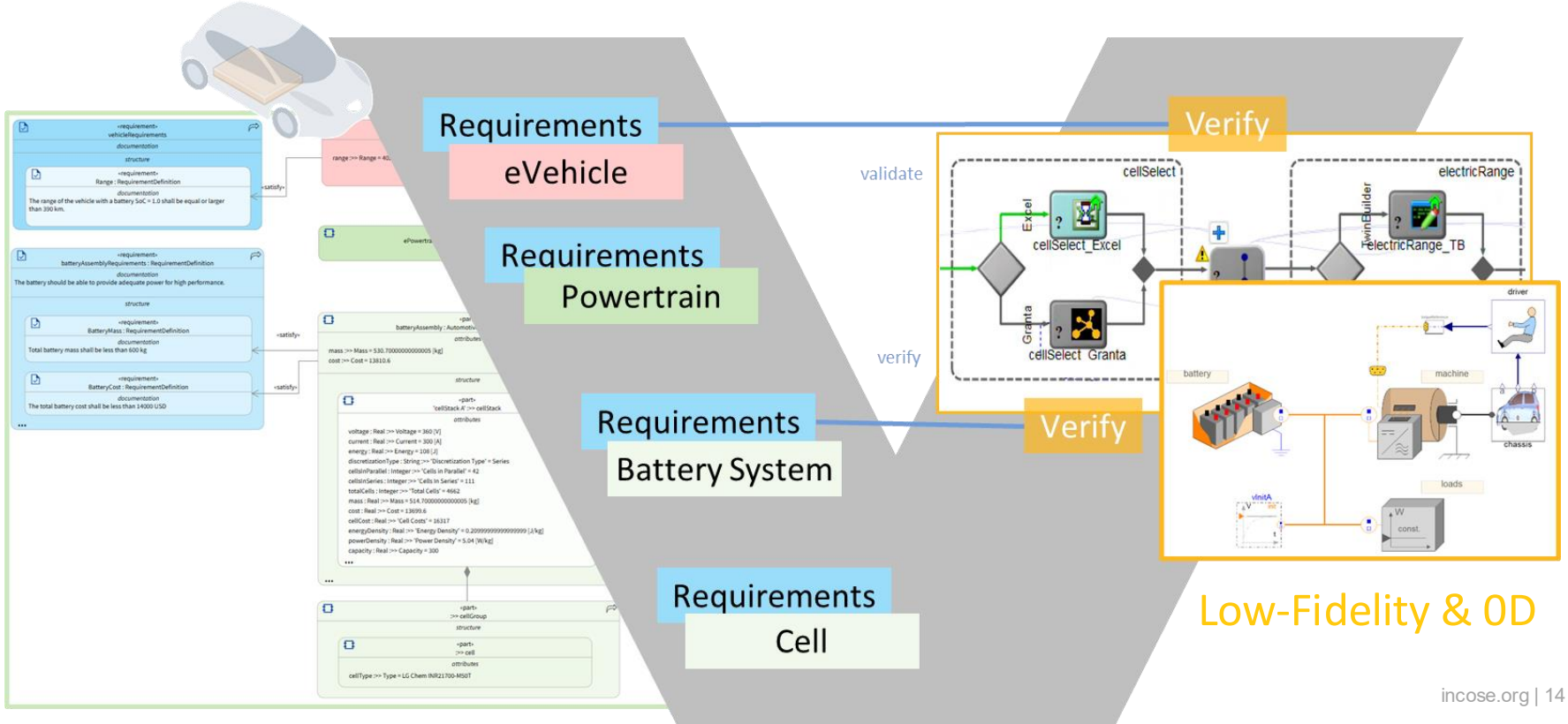
3 Workflow Deployment

Execution server

SPDM

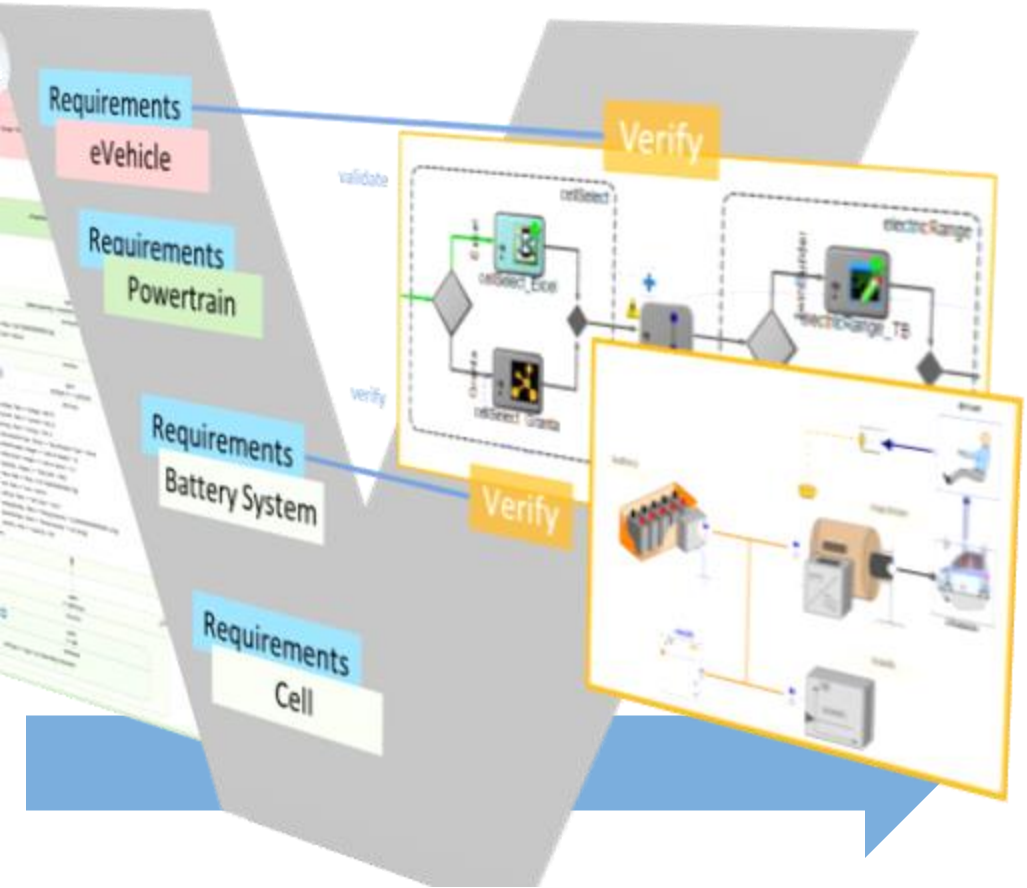
Early-on conceptual design

Verify by Simulation

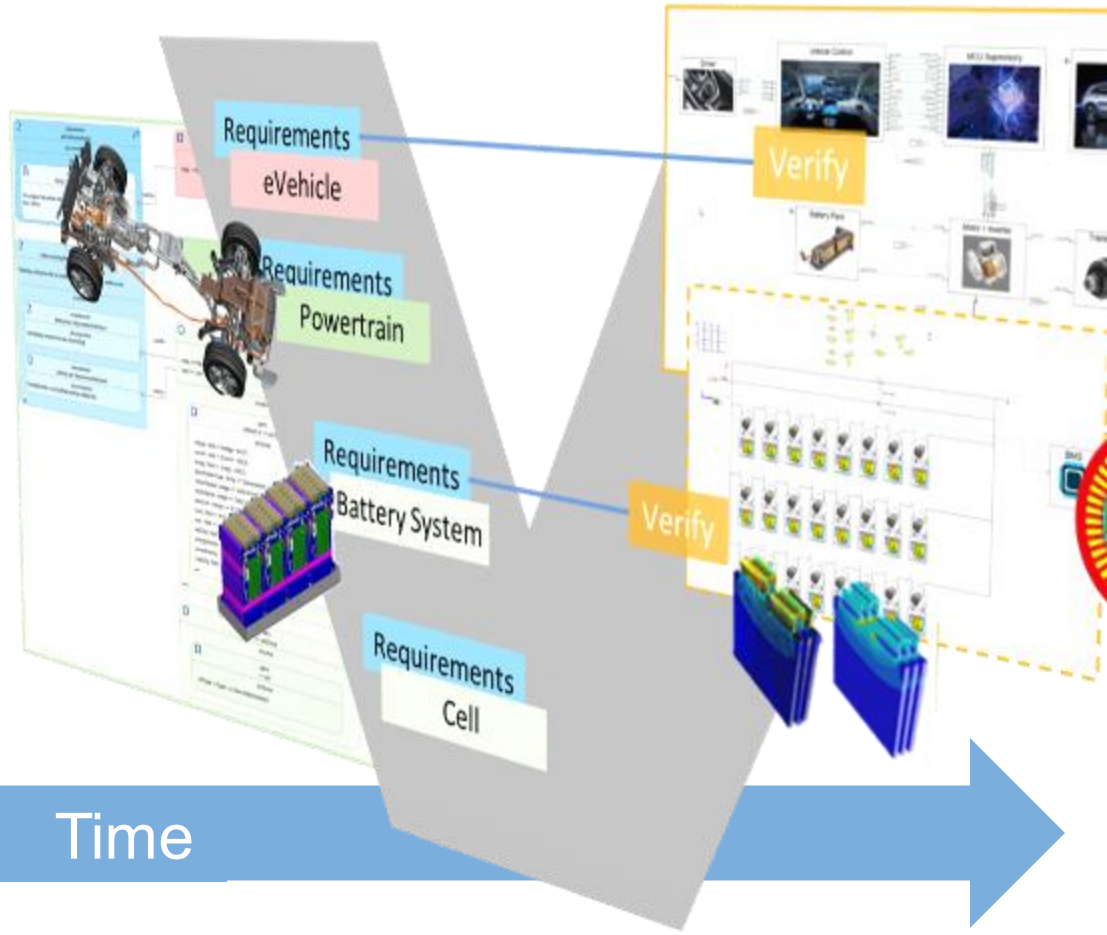


Low-Fidelity & 0D

Early-on conceptual design



Later-on detailed design



Later-on detailed design

Verify by Simulation

Requirements
eVehicle

Requirements
Powertrain

Requirements
Battery System

Requirements
Cell

Verify

High-Fidelity & 3D

High-fidelity System Simulation Model

2 **M&S Development**

Subject Matter-Experts

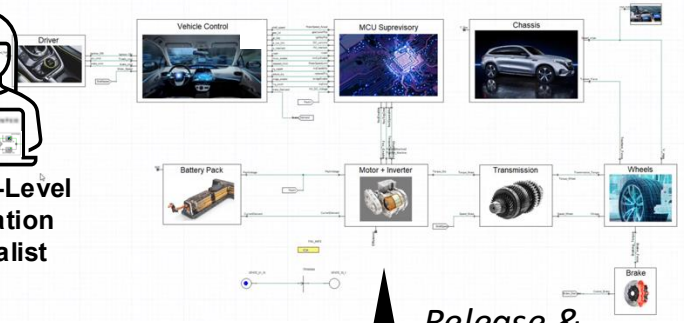
Release & Publish

SAM

OMG SYSTEMS MODELING LANGUAGE SysML2

2 **Analysis Workflow Development**

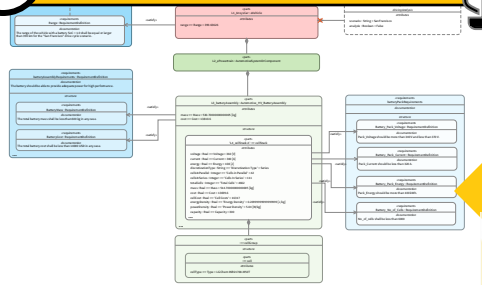
System-Level Simulation Specialist



Release & Publish

Systems Engineer

1 **Architectural modeling**



API

SysML v2

4 **Analyses, V&V & Trade Studies**

SAM Part Attributes & Requirements

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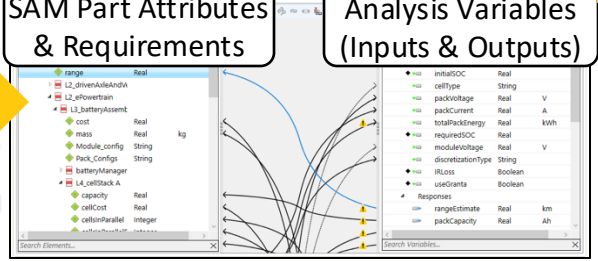
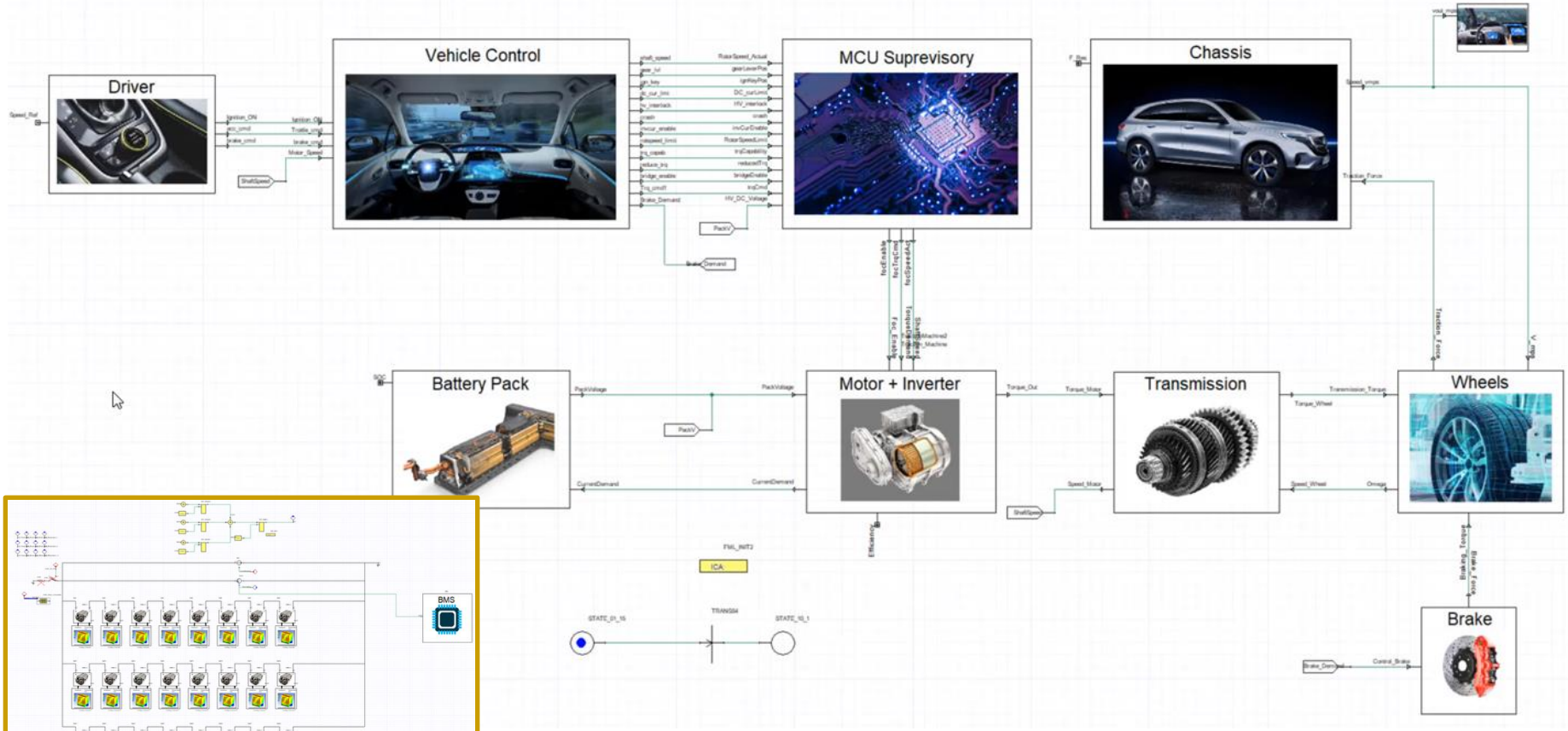


3 **Workflow Deployment**

Execution server

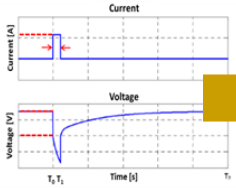
SPDM

High-fidelity System Simulation Model

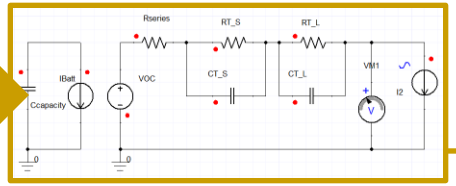


Battery Electro Thermal Submodel

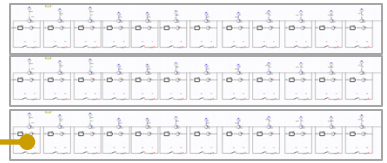
Electrical Equivalent Circuit Model



HPPC Data

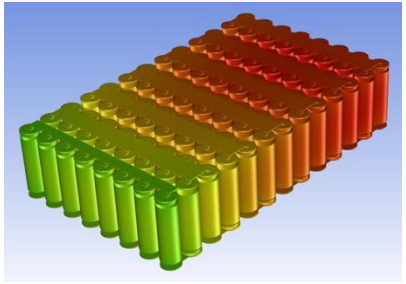


ECM Cell

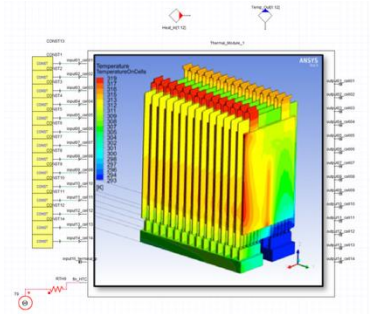


Battery Pack

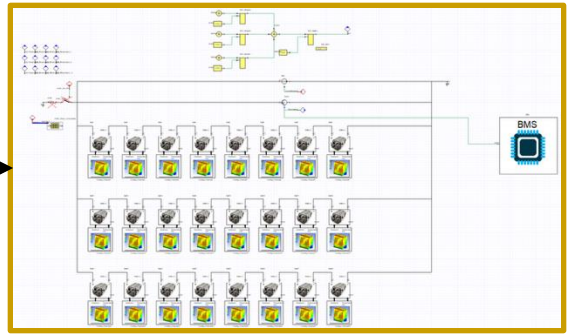
3D CFD-based Thermal Model



CFD Simulation

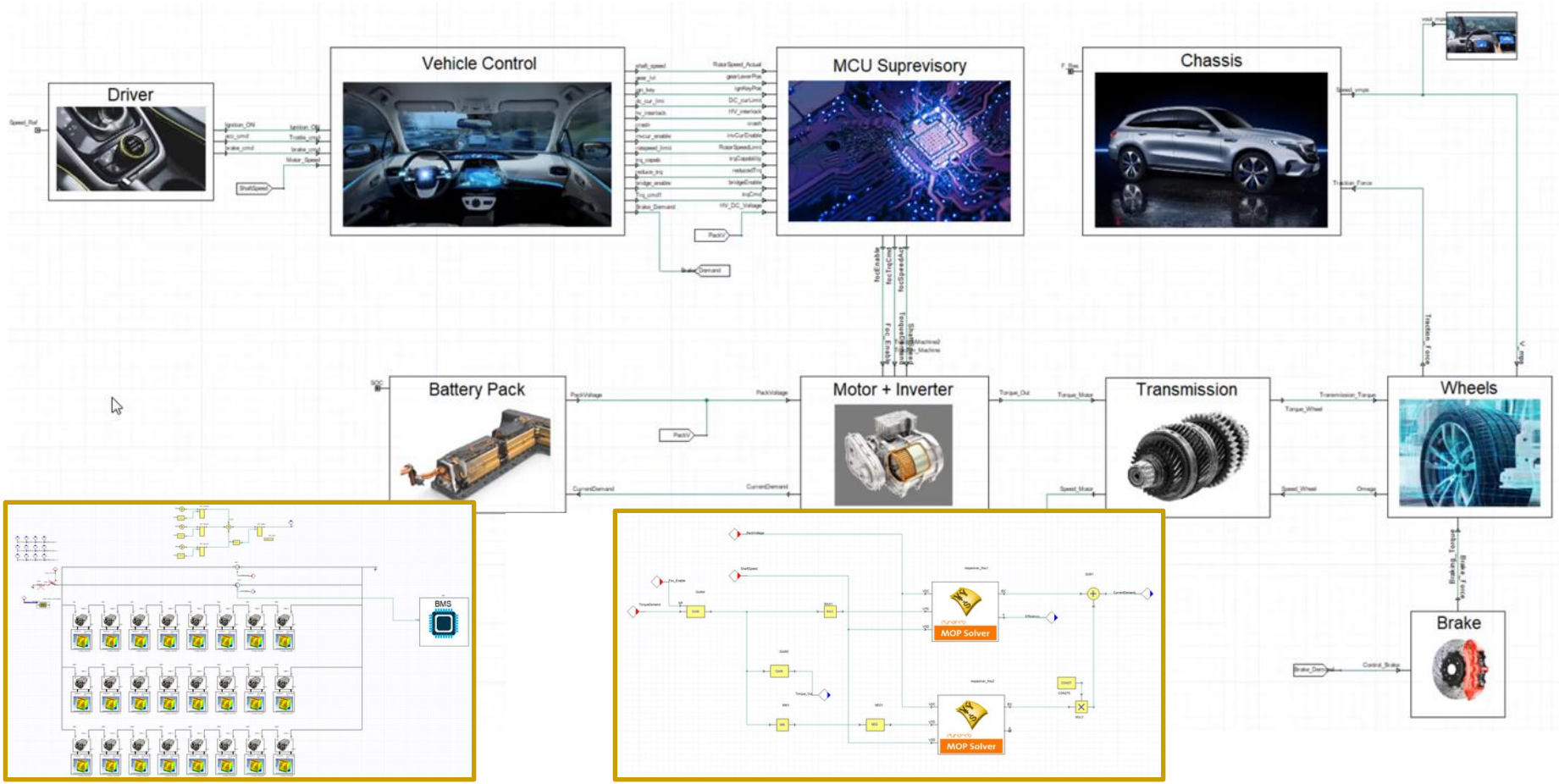


Thermal ROM



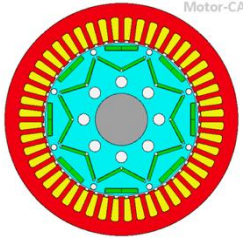
Battery Pack

High-fidelity System Simulation Model



Motor + Inverter Plant submodel

Motor-CAD



1

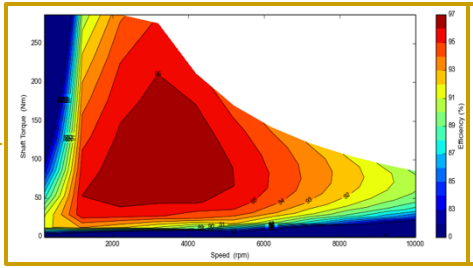
Saturation Model Buildup

Model Status:

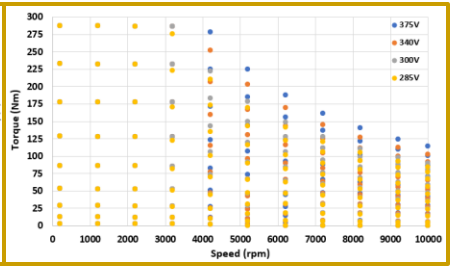
Model	Build Date	Method	Max Current
			A (peak)
Saturation	15-04-21 16:09	30 points full cycle	480.8
Iron Loss	15-04-21 16:09	FEA Map 30 points	480.8
AC Loss	15-04-21 16:09	FEA Map 30 points	480.8
Magnet Loss	15-04-21 16:09	FEA Map 30 points	480.8

2

Efficiency Map at 375V DC



Torque Grid as a function of DC Voltage



3

Ansys OPTISLANG

Generating the motor response surface

Input Output

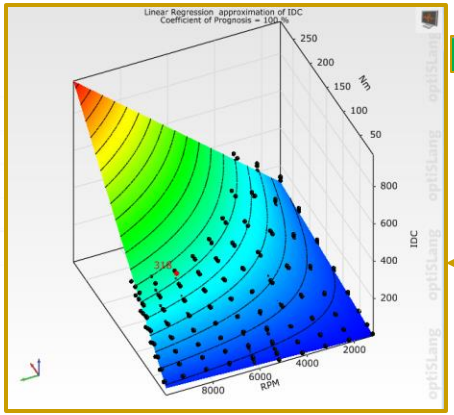
RPM	DCV	Nm	IDC

RPM	DCV	Nm	IDC
1200	375	12.37019	4.45323
2200	375	12.2165	8.146037
3200	375	12.06282	11.84119
4200	375	11.5237	15.0819
5200	375	10.21633	16.97984
6200	375	14.4315	27.62573
7200	375	18.10331	40.06474
8200	375	18.41855	47.30359
9200	375	17.77634	52.65166
10000	375	16.99017	56.15805
1200	375	28.76105	10.07146
2200	375	28.59893	18.37174
3200	375	28.43682	26.67932
4200	375	27.36635	33.91131
5200	375	24.49532	37.97839
6200	375	27.27296	50.13851
7200	375	31.30598	67.08542

Motor Data Preparation

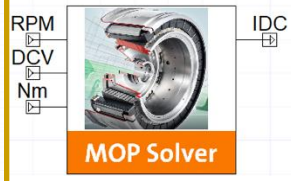
4

MOP



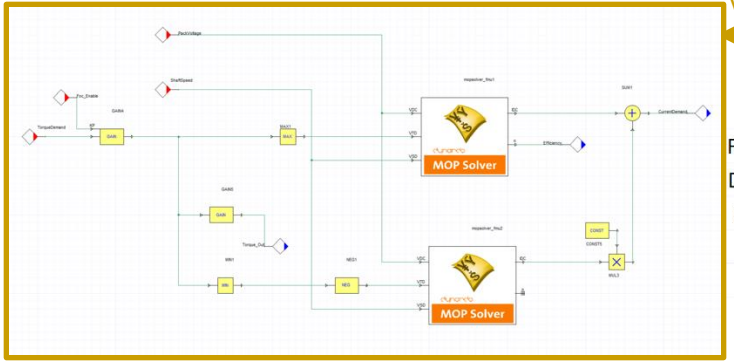
5

FMU Export (Plant Model)



6

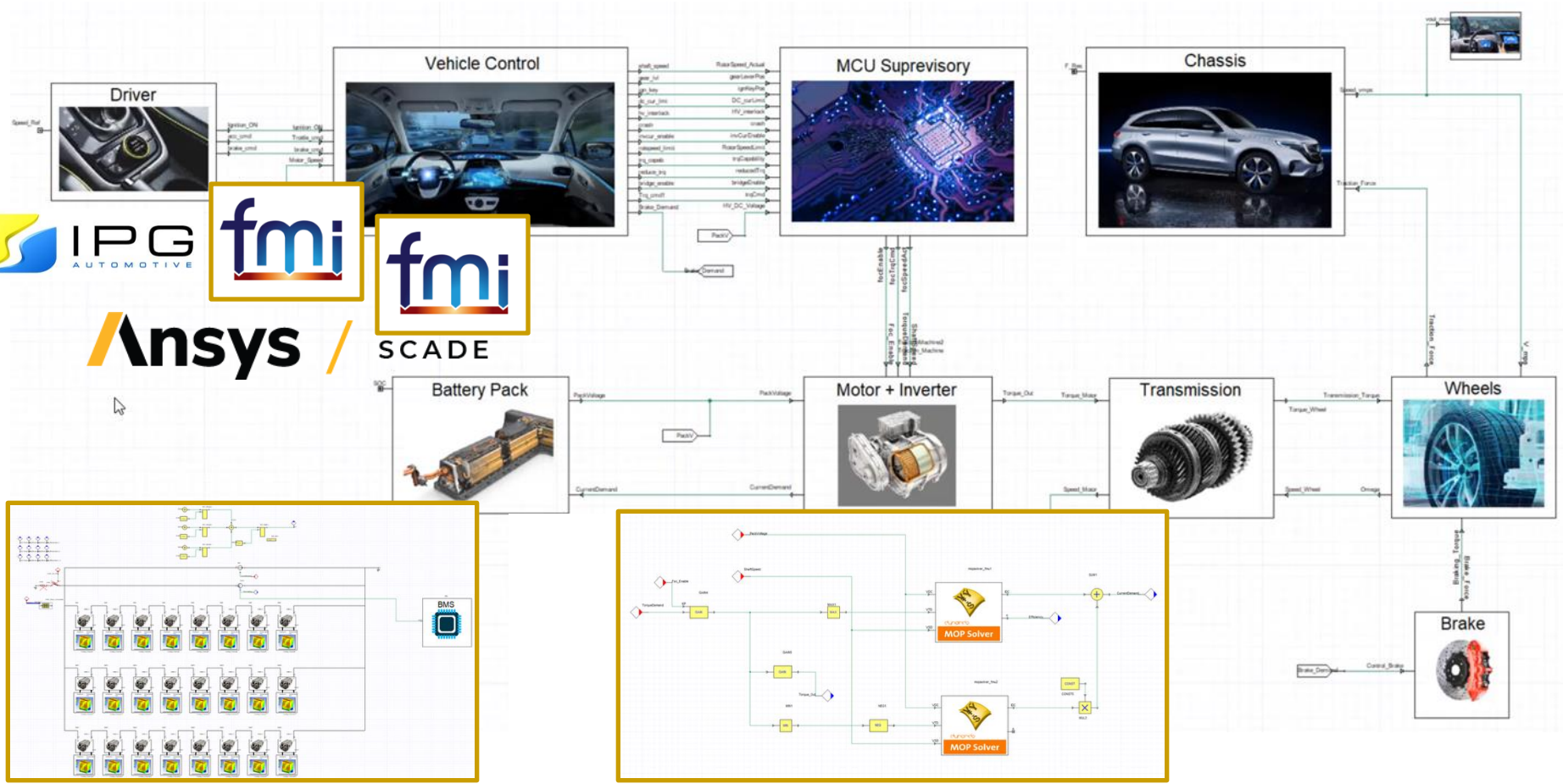
Plant model Verification



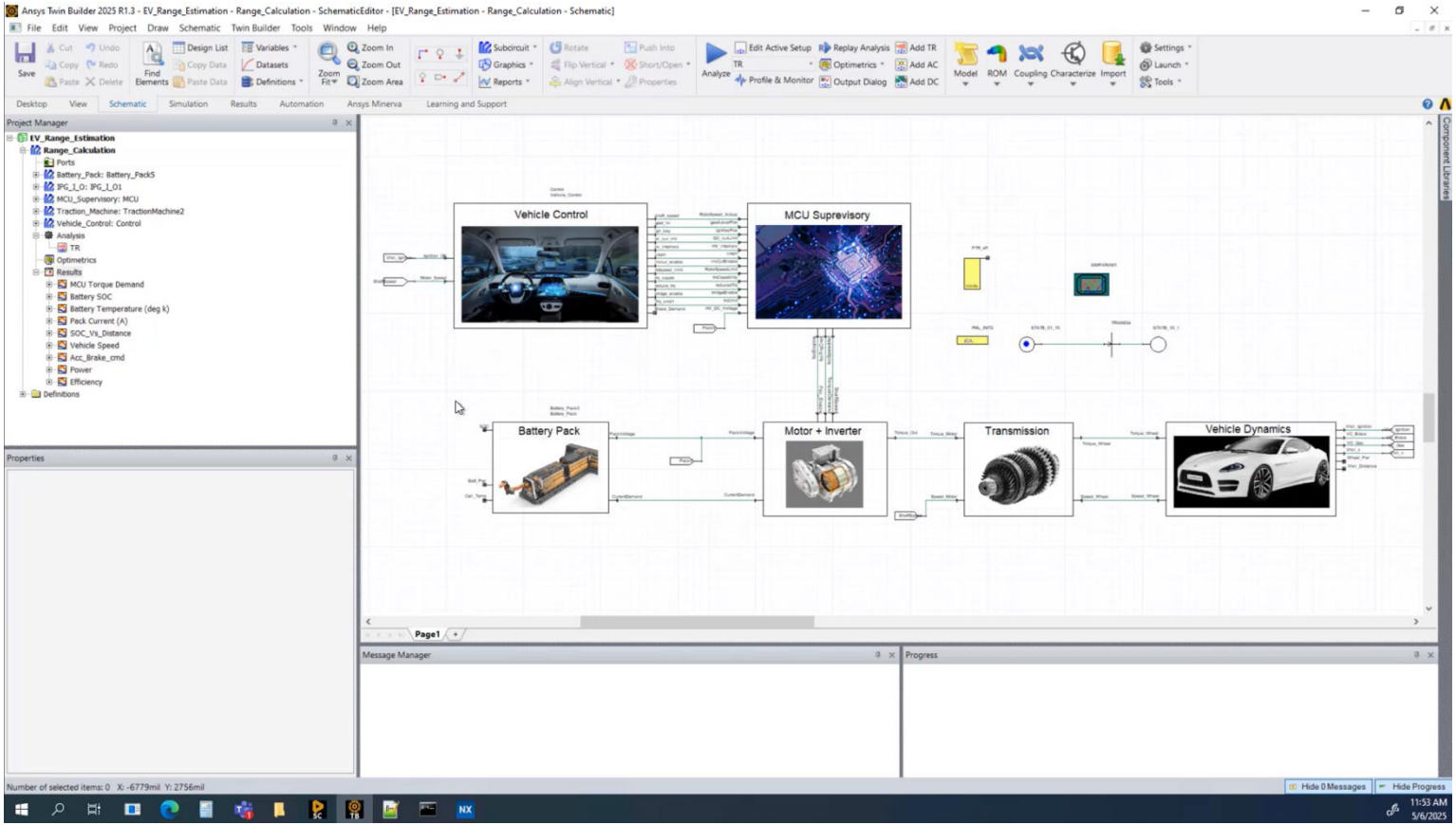
6

Motor CAD Output

High-fidelity System Simulation Model



Virtually verify and validate vehicle performance with simulation in system context



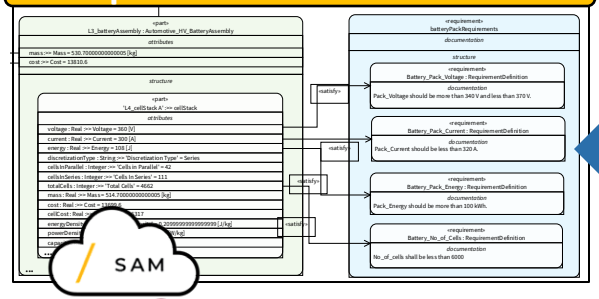
- Range
- Acceleration
- Drivability
- Gradeability
- Regeneration
- Max Speed

Takeaways

21st century product & system development faces increased complexity, tighter budget, faster time-to-market as well as distributed engineering teams.

MBSE

Requirements & Architecture

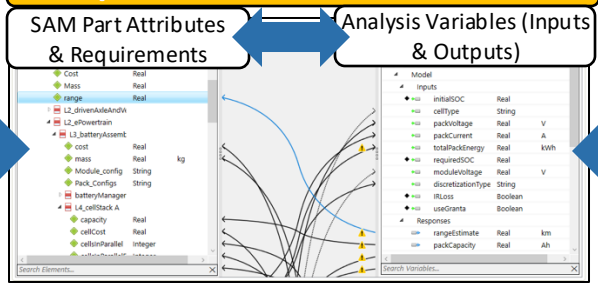


OMG SYSTEMS MODELING LANGUAGE SysML2 | Cameo Systems Modeler | IBM Rational

Connectivity

Req. Verification & Trade Studies

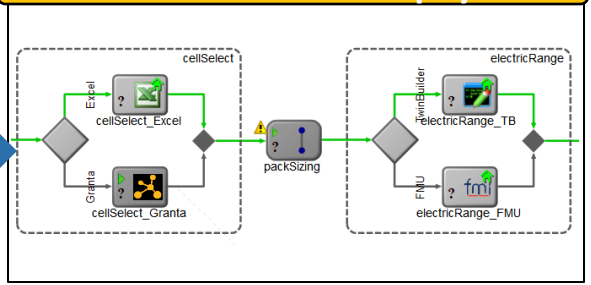
SAM Part Attributes & Requirements ⟷ Analysis Variables (Inputs & Outputs)



for Virtual Verification & Trade Studies

Engineering Simulation

M&S of behavior and physics



Ansys | Python | fmu Functional Mock-up Unit | Excel | MATLAB | …

An open tool ecosystem that leverages open standards to connect architecture & requirements with simulation for distributed teams across organizations.

OMG SYSTEMS MODELING LANGUAGE SysML2 | Modelica Language

MBSE with Ansys / SAM and / ModelCenter

Speakers:
Saeed Jahangirian
Subodh Chaudhari
Michael Walickii
Krishnakumar Patel

Key Discussions & Insights:

- LEARN THE BASICS OF MODELING IN ANSYS SAM
- LEARN MDAO IN ANSYS MODELCENTER
- LEARN HOW TO CONNECT ANSYS SAM AND MODELCENTER FOR REQUIREMENTS VERIFICATION

11 AM EST

SEPTEMBER 23, 2025

Register Here

Thank you.

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Rajagopalan Badrinarayanan, Ph.D.

35th Annual INCOSE international symposium

hybrid event

Ottawa, Canada
26 - 31 July 2025