Towards Integrated System Model

Nerijus Jankevičius, SIEMENS, 2016 Nov 9

Speaker

- **Nerijus Jankevičius**, nerijus@nomagic.com
- *Product Manager @ No Magic Europe*
- *Since 1997*

- Leads the development of MBSE tools and solutions

- Consulting companies such as NASA/JPL, ESO, BAE Systems, Kongsberg Defense and Aerospace, Nokia, Bernafon, GE Transportation, Bombardier Transportation, Pratt & Whitney, MITRE and others.

- OMG member since 2004
- INCOSE member since 2007
- Co-author of UML and SysML languages

Meet No Magic

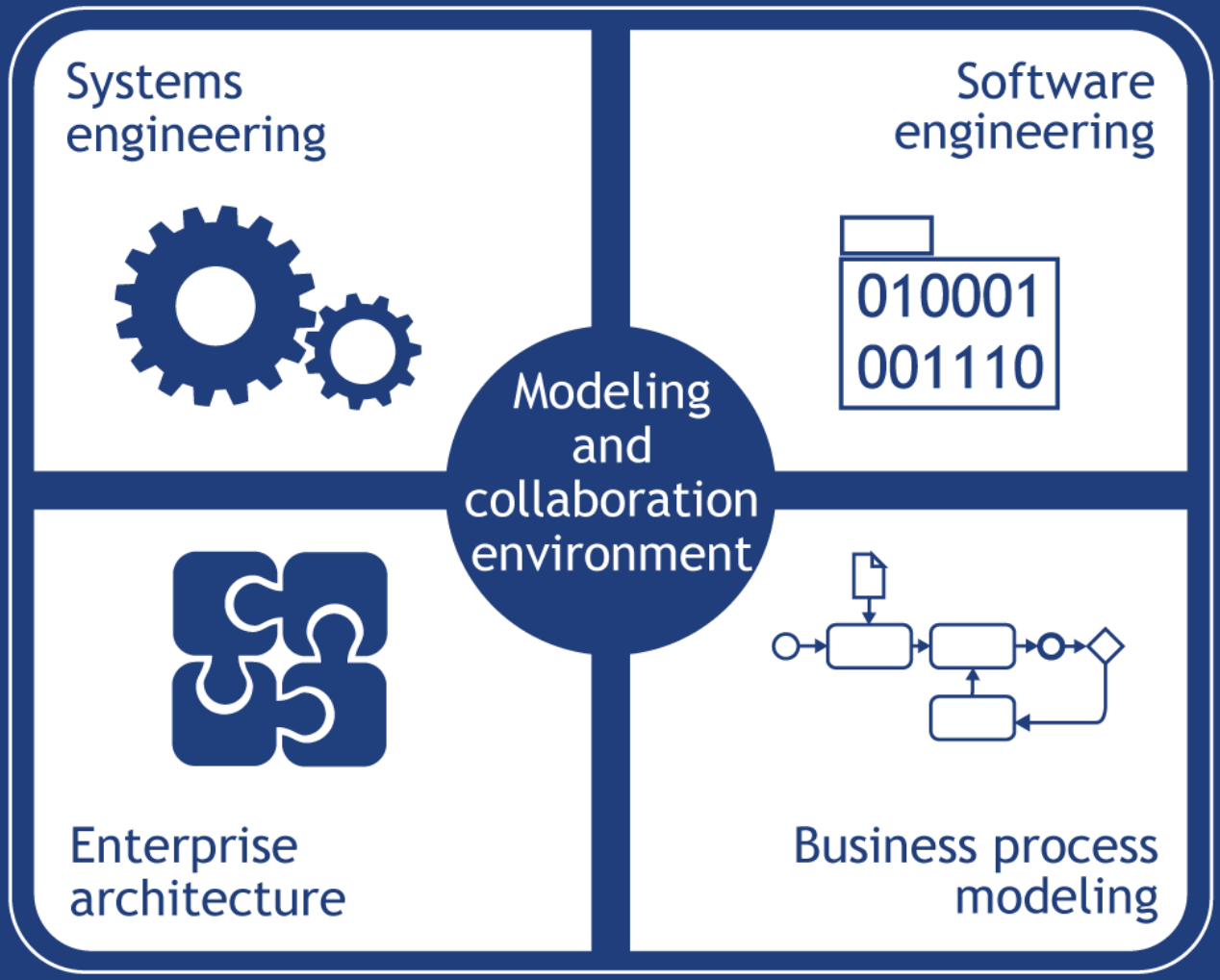
4000+ trainings

1000 000+ installations

10 000 companies

in **90** countries

Solutions for Enterprises from No Magic



They Trust Us

LOCKHEED MARTIN

NASA

JPL

NOKIA

Pfizer

Ford

U.S.ARMY

SIEMENS

Microsoft

NORTHROP GRUMMAN

Abbott

BMW

AIRBUS

Raytheon

GENERAL DYNAMICS

GE

GENERAL ATOMICS

BAE SYSTEMS

INSPIRED WORK

esa

Pratt & Whitney

A United Technologies Company

KONGSBERG

Sandia National Laboratories

BOMBARDIER

ThyssenKrupp

BOSCH

Outline

- Model Based Systems Engineering vision
- State of the art of the current solutions
- Future directions and trends
- Questions, discussion

Systems Engineering

Systems engineering is an interdisciplinary field of engineering that focuses on how to design and manage complex engineering systems over their life cycles.

Wikipedia

MBSE Definition

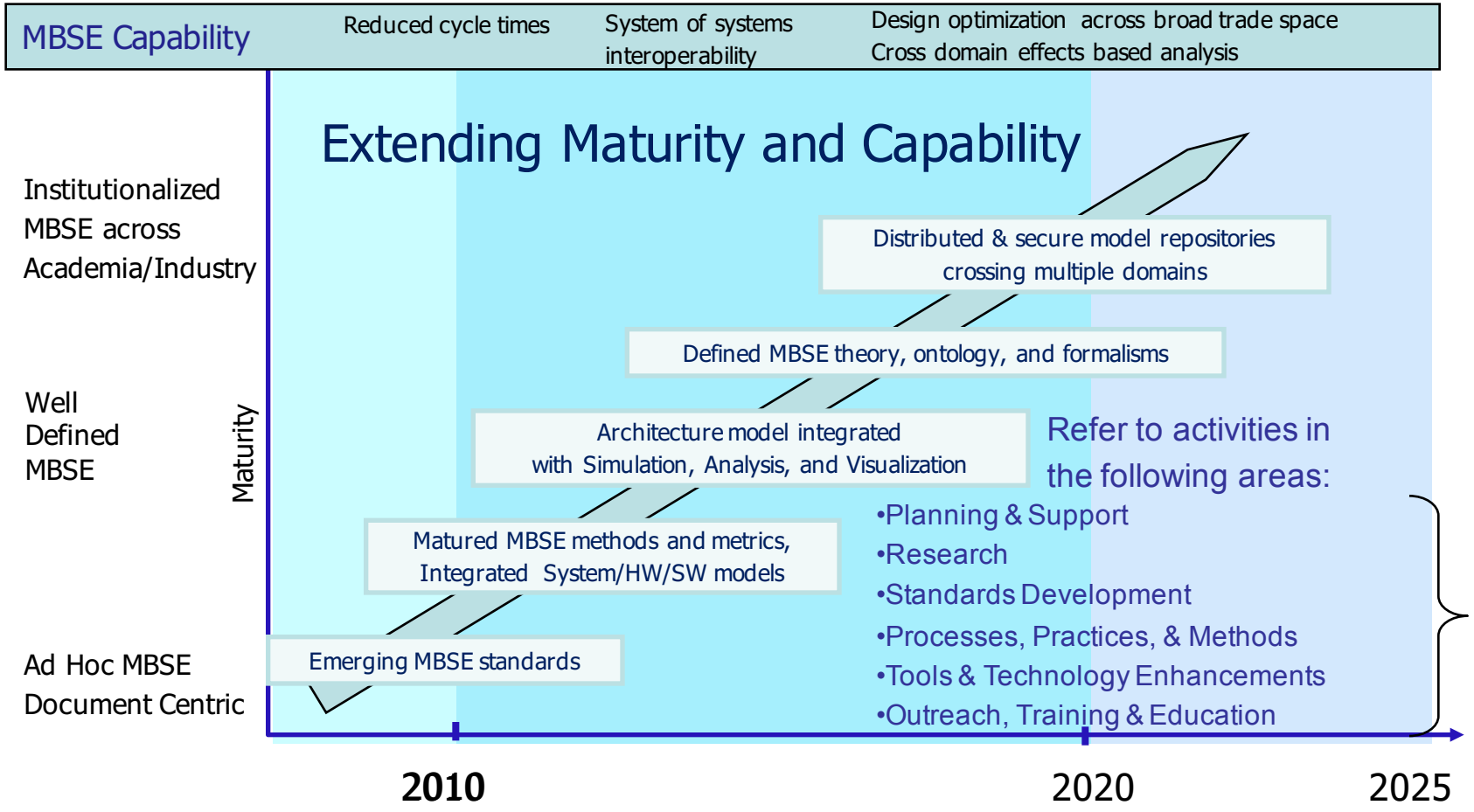
"Model-Based Engineering (MBE): An approach to engineering that *uses models as an integral part of the technical baseline* that includes the requirements, analysis, design, implementation, and verification of a capability, system, and/or product throughout the acquisition life cycle."

Final Report, Model-Based Engineering Subcommittee, NDIA, Feb. 2011

"Model-based systems engineering (MBSE) is the *formalized application of modeling* to support system requirements, design, analysis, verification and validation activities beginning in the conceptual design phase and continuing throughout development and later life cycle phases."

INCOSE SE Vision 2020 (INCOSE-TP-2004-004-02, Sep 2007)

INCOSE MBSE Roadmap

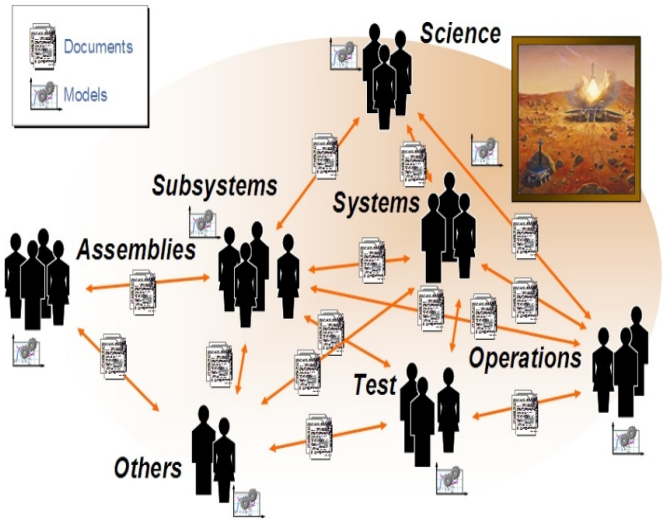


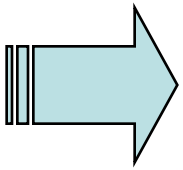
INCOSE Systems Engineering Vision 2025

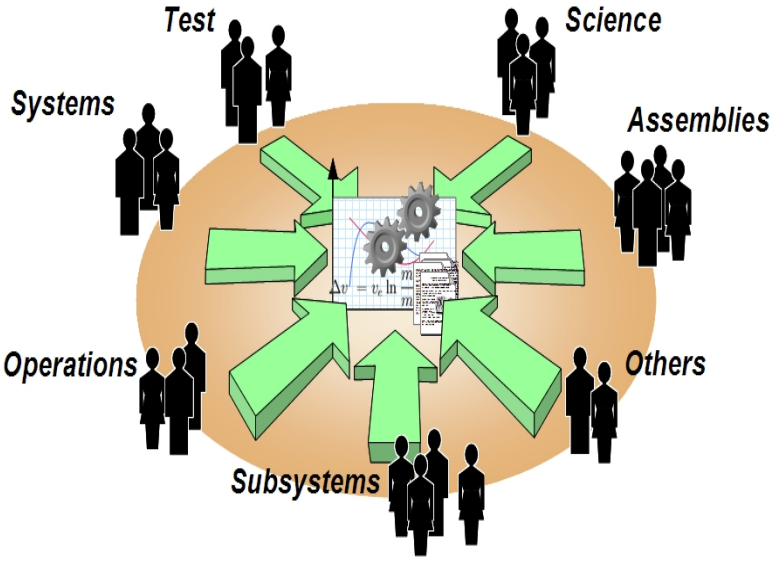
Describes the projected state for MBSE in 2025 as:

"Formal systems modeling is standard practice for specifying, analyzing, designing, and verifying systems, and ***is fully integrated with other engineering models****. System models are adapted to the application domain, and include a broad spectrum of* ***models for representing all aspects of systems****.* ***The use of internet-driven knowledge representation and immersive technologies enable highly efficient and shared human understanding of systems*** *in a virtual environment that span the full lifecycle from concept through development, manufacturing, operations, and support."*

Current Practice to Future Practice







Today: Standalone models related through documents

Future: Shared system model with multiple views, and connected to discipline models

Source : MBSE 101 by Elyse Fosse

System Modeling Assessment and Roadmap Working Group

- A collaborative effort that draws upon a diverse range of end users, tool vendors, academics, and others who can help provide a language that is broadly accepted by the engineering community, industry, and academia.

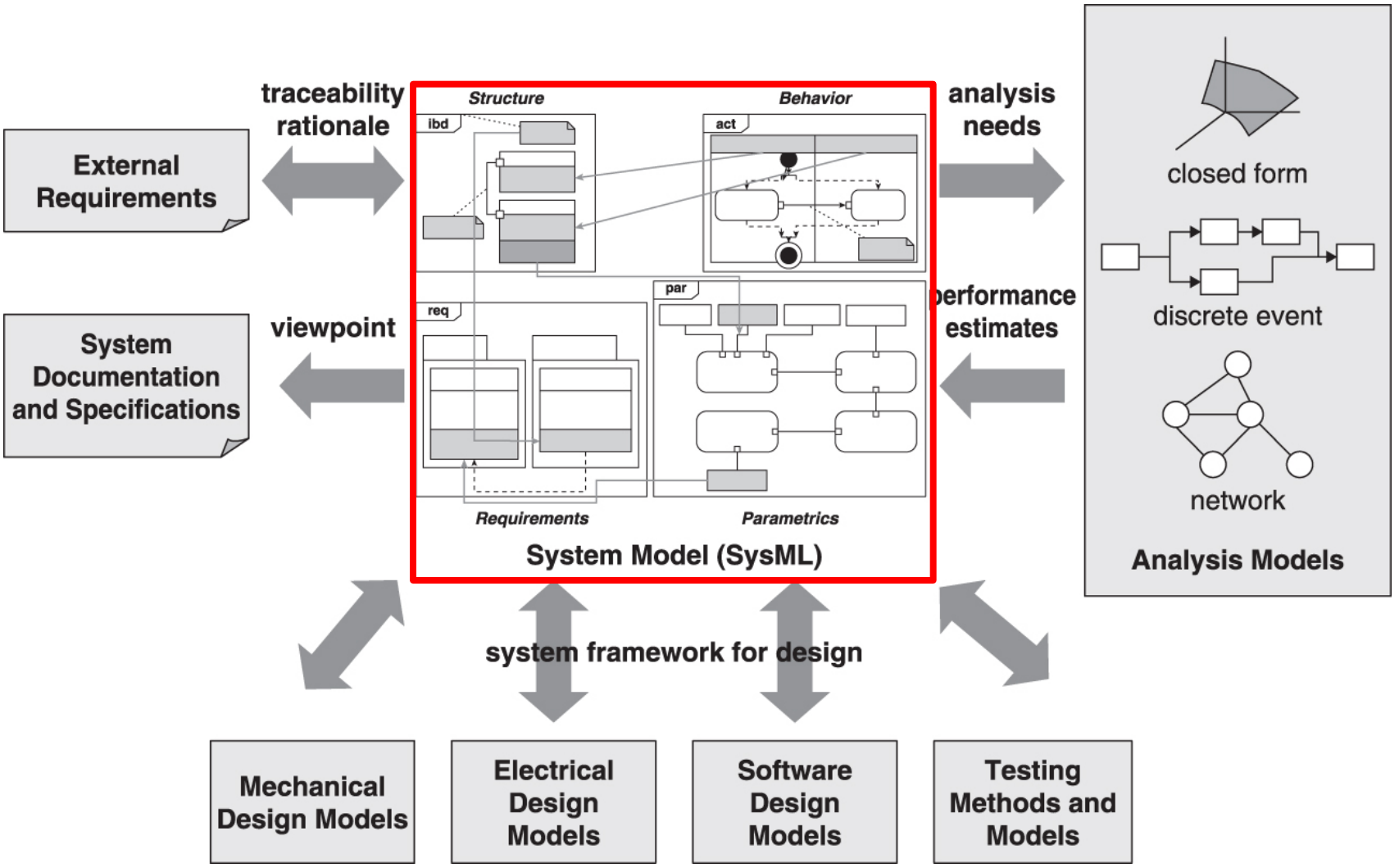
- Defines the preliminary driving requirements for the next-generation system modeling language and tools

"Evolving SysML and the System Modeling Environment to Support MBSE"

- By S. Friedenthal/R. Burkhart

http://www.omgwiki.org/OMGSysML/doku.php?id=sysml-roadmap:sysml_assessment_and_roadmap_working_group

System Model as an Integration Framework



© 2012-2014 by Sanford Friedenthal

Key SME requirements

models and tools are fully integrated across discipline-specific engineering tools

ability to answer questions such as the impact of a requirement or design change

automated requirements verification

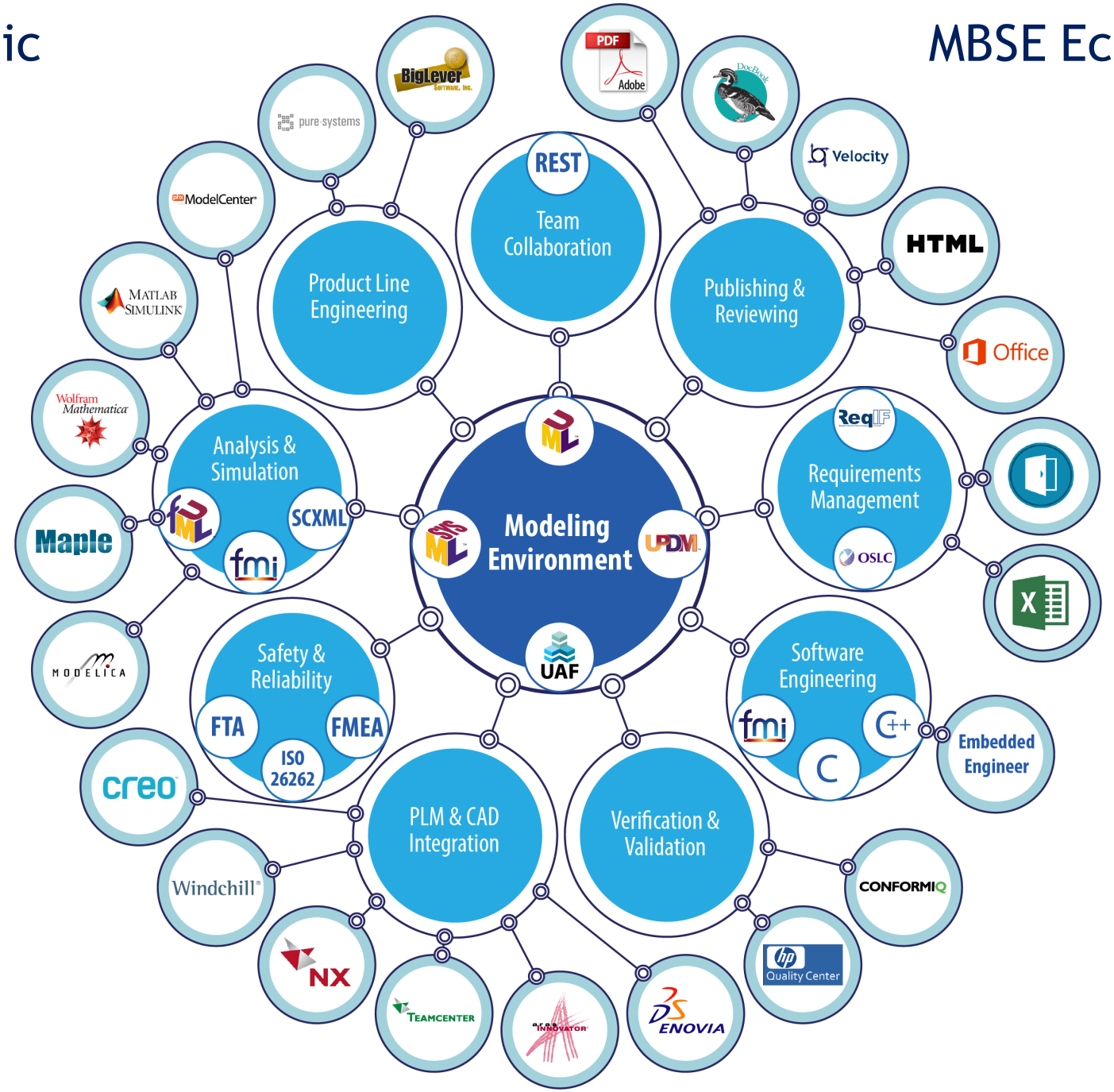
provide a simplified web interface to dynamically view the model from a diverse set of viewpoints

query the model and provide flexible reporting capability

include dynamic zoom, filtering, and traversal of model relationships

No Magic

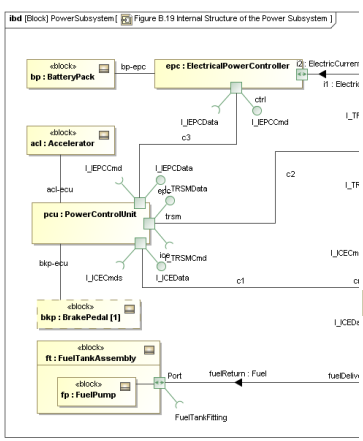
MBSE Ecosystem

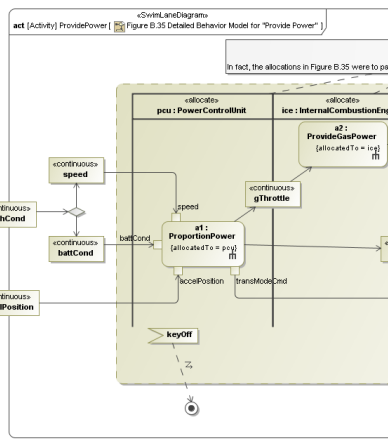


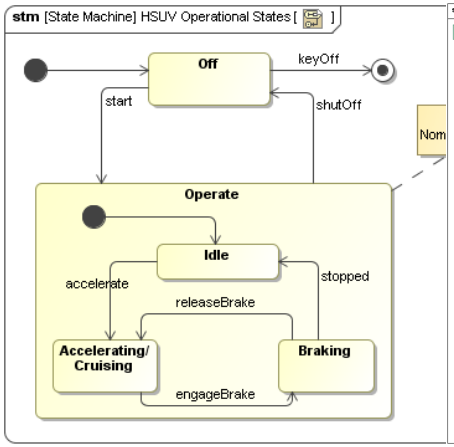
Cameo Systems Modeler

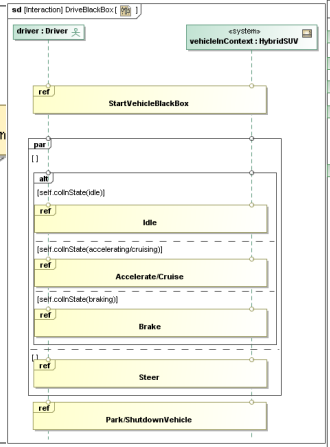
The best SysML implementation on the market

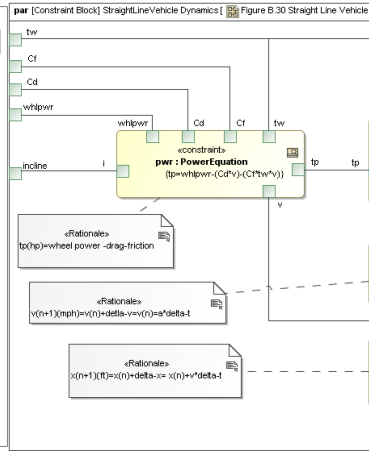
- Based on MagicDraw platform
- Full implementation of the latest SysML 1.4 spec
- Implementation of all SysML diagrams
- Most standard compliant SysML XMI file
- Model correctness and completeness checking
- Precise execution semantics











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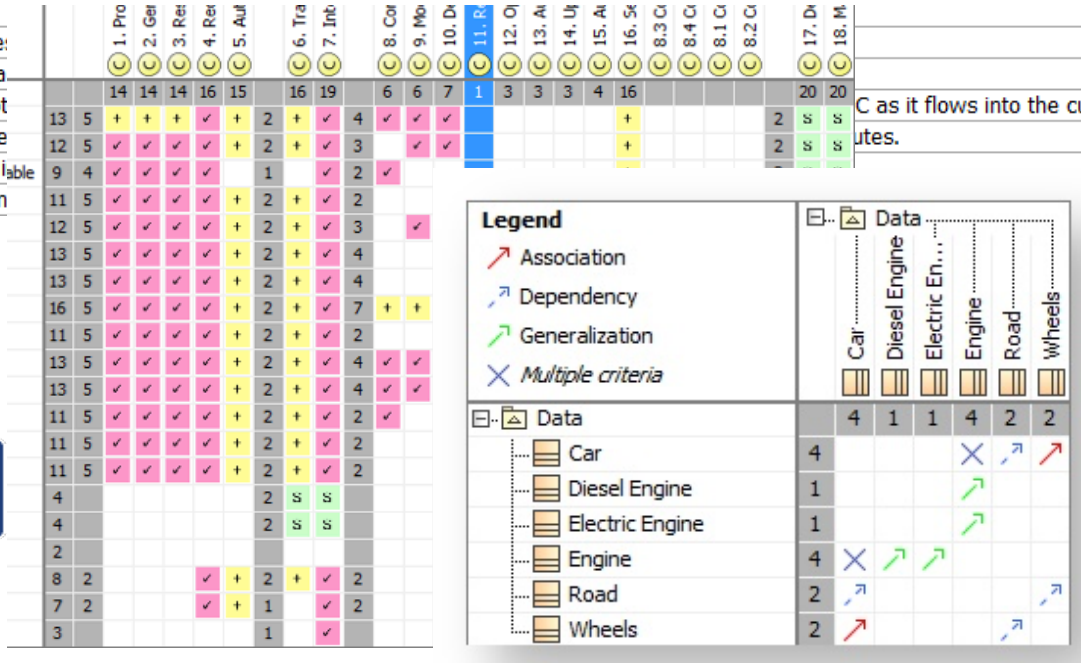
Various model representations

#	Id	Name	Text
1	UN20	Fresh Milk	I want fresh milk.
2	UN21	Footprint	The footprint must be less than 1.5 square meters.
3	UN22	Hygiene Requirements	The device must meet the health requirements.
4	UN23	Efficient Work	The devices must work efficiently after 1 year.
5	UN24	Failure Rate	The failure rate can not be higher than 1 time a month for max. 1 hours.
6	UN25	Money	The money must be kept safe.
7	UN26	Debit Card	I would like to pay by debit card.
8	UN27	Credit Card	I would like to pay by credit card.
9	UN28	Bills	The device must take bills up to 10 Euros.
10	UN29	Usability	The operation must be for all travelers and employees quick and easy to use.
11	UN30	UHT Milk	I want to UHT milk.
12	UN31	Freshly Ground	The coffee must be fre
13	UN32	Front Design	The front design is in a
14	UN33	Coffee Temperature	The coffee must be hot
15	UN34	Machine Maintenance	The machine should be
16	UN35	Security	The device should not i
17	UN36	Coffee Cup	I want to bring my own

Tabular representation



Matrix representation

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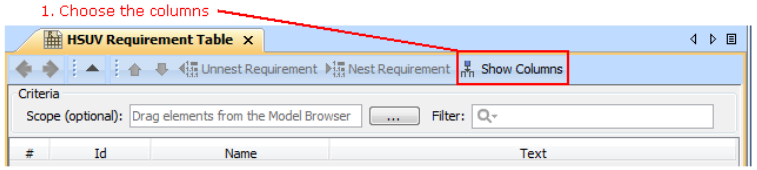
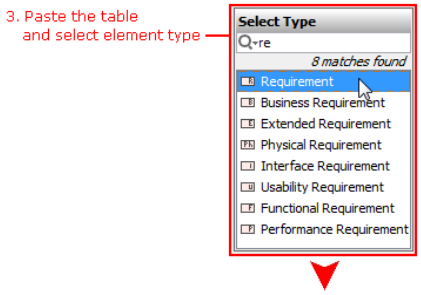
Requirements management

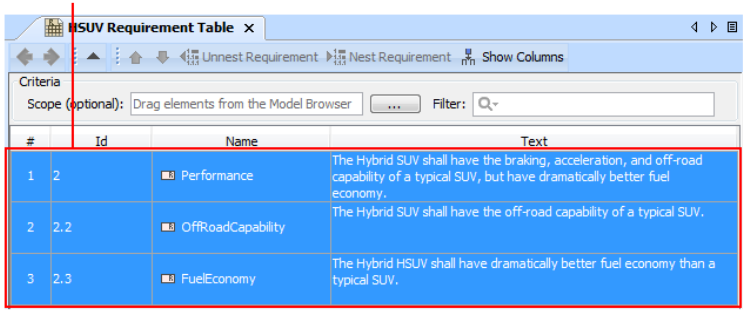
Importing text-based requirements

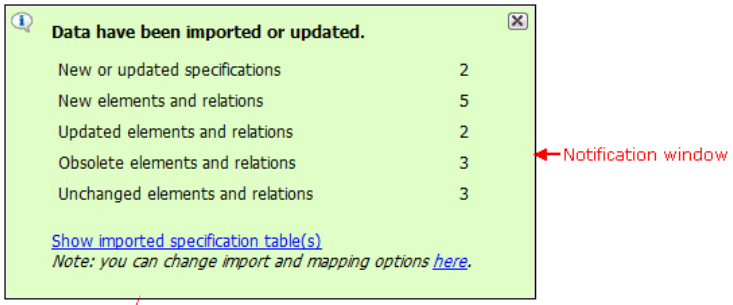


2. Copy the table from Excel

ID	Name	Text
2	Performance	The Hybrid SUV shall have the braking, acceleration, and off-road capability of a typical SUV, but have dramatically better fuel economy.
2.2	OffRoadCapability	The Hybrid SUV shall have the off-road capability of a typical SUV.
2.3	FuelEconomy	The Hybrid HSUV shall have dramatically better fuel economy than a typical SUV.

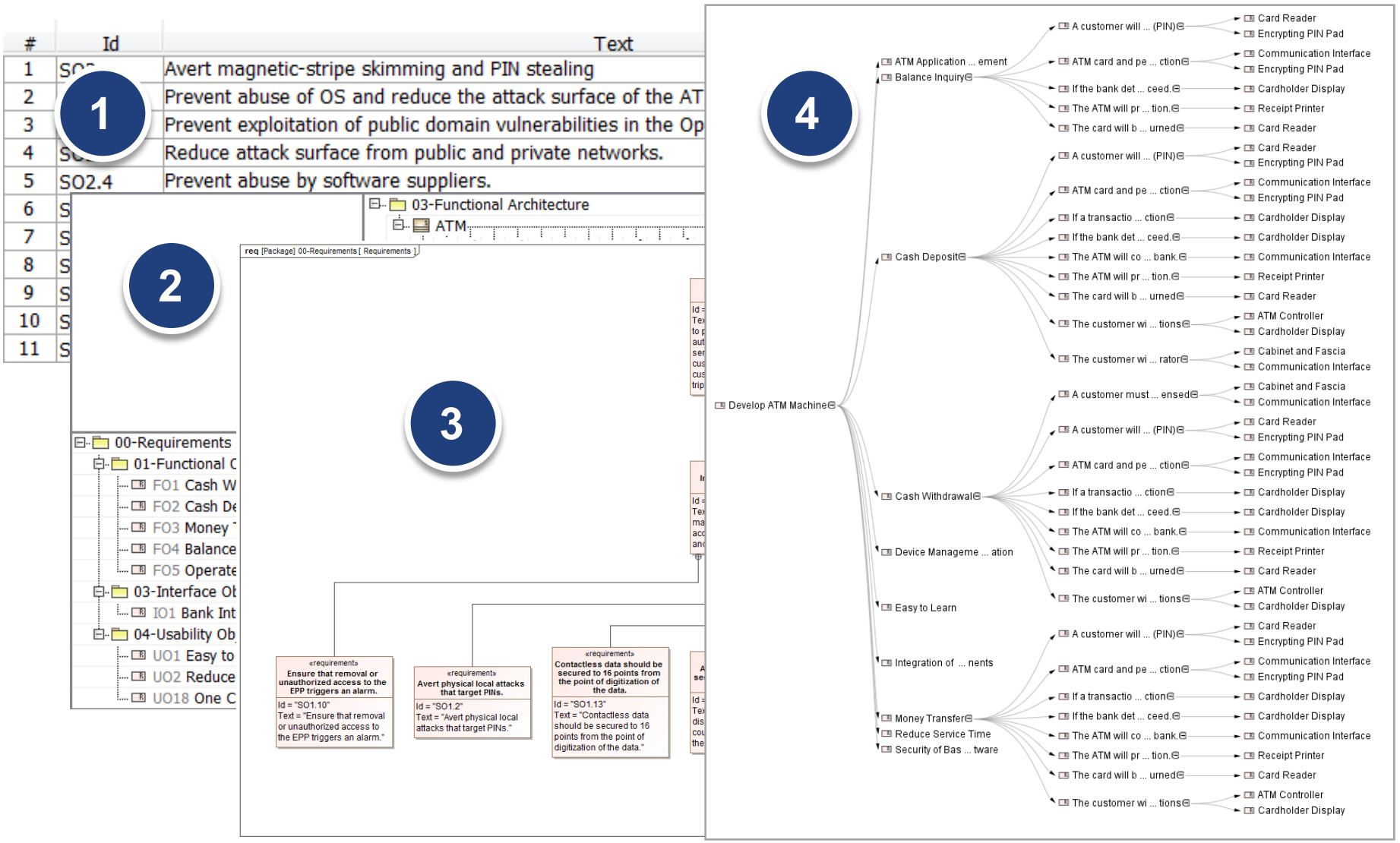






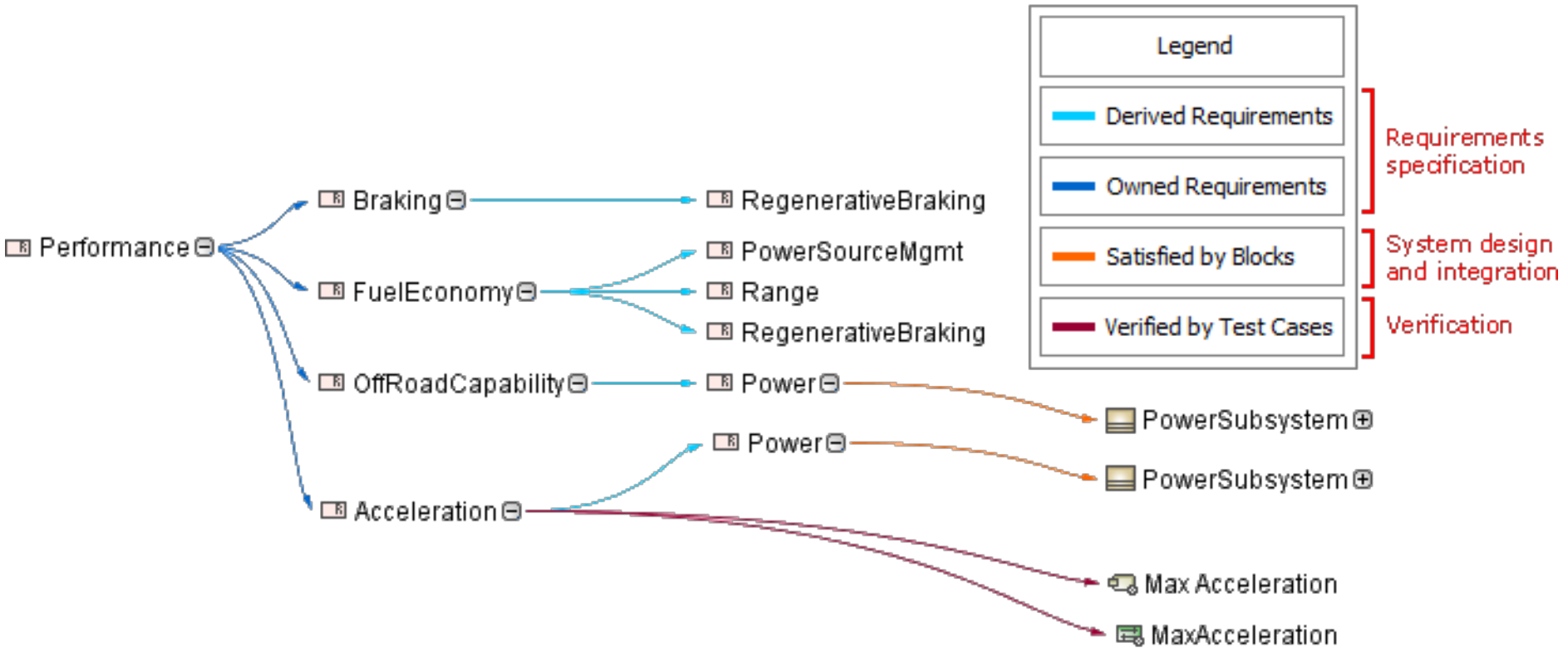
#	Hierarhy Id	Name	Status
1	1	Introduction	Updated
2	1.1	Scope	Unchanged
3	1.2	Asumptions(This Section Was Updated)	Obsolete
4	1.3	Exclusions	Obsolete
5	1.3.1	System Instances	Obsolete
6	2	Changes Made	Unchanged
7	2.1	Changes	Updated
8	3	Contents	Unchanged

Requirements in CSM

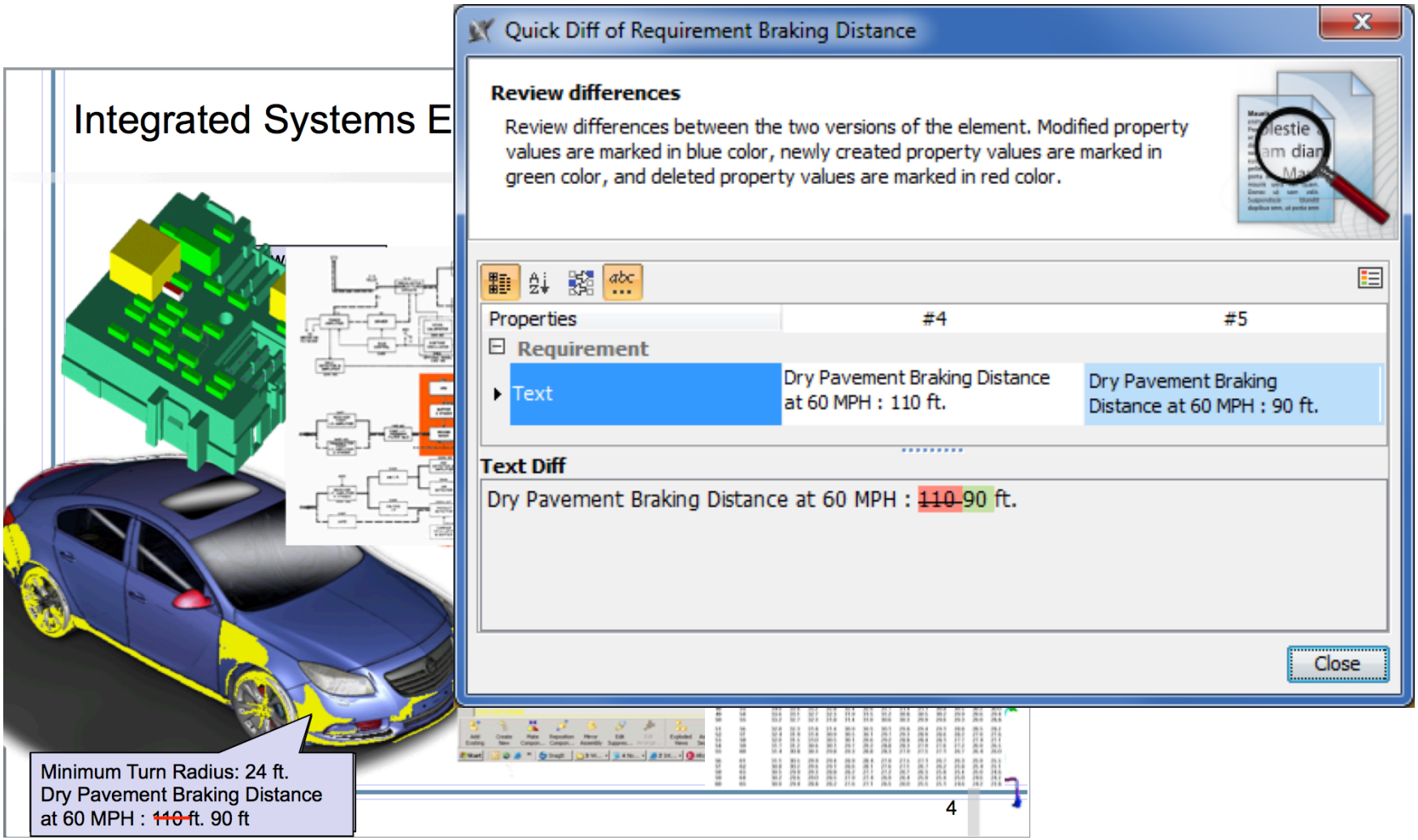


Traceability and Impact analysis

- Identification of the scope and impact of a change



Tracking changes



Coverage analysis

Use Cases | Data Metric Table | **Data Metric Table1** ×

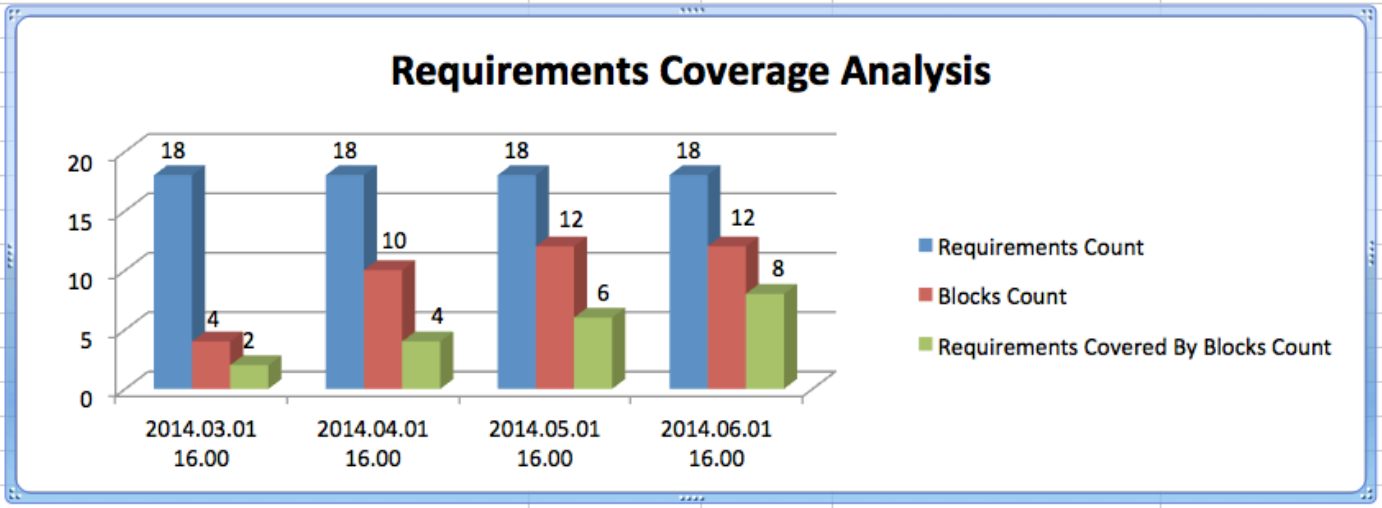
Calculate Metrics | Add Existing | Delete | Remove From Table | Show Metric Suites | Show Columns | Export

Criteria

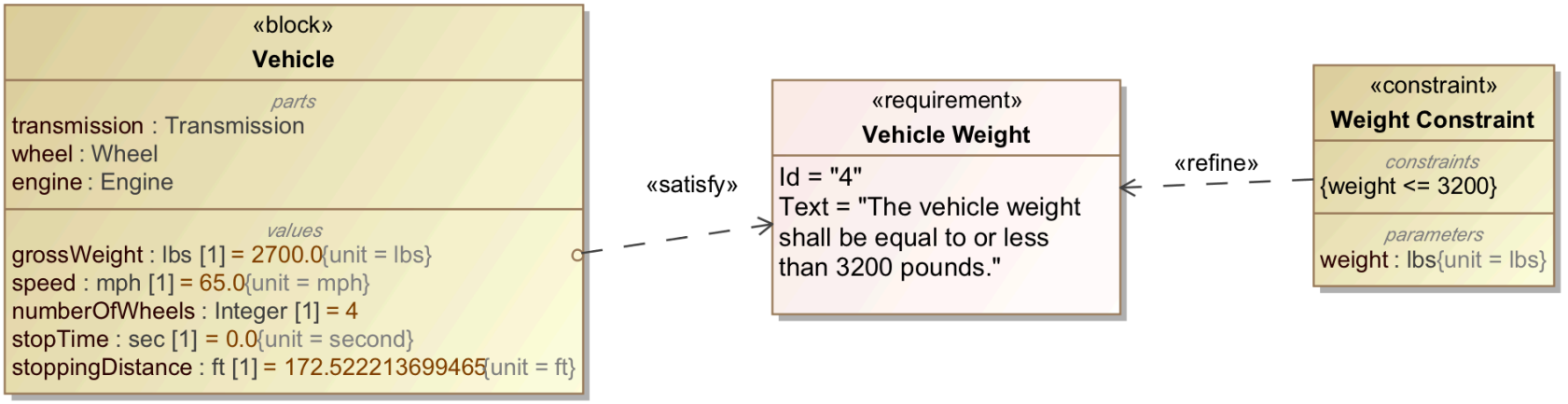
Metric Suite: Reqs Satisfied by Blocks ... Scope (optional): Drag elements from the Model B ... Filter:

#	Date	Requirements Count	Blocks Count	Requirements Covered By Blocks Count	Requiremets Covered By Blocks Percentage	Requirements Covered By Blocks Average
1	2014.03.01 16.00	18	4	2	11.11	1.00
2	2014.04.01 16.00	18	10	4	22.22	1.00
3	2014.05.01 16.00	18	12	6	33.33	1.50
4	2014.05.01 16.00	18	12	8	44.44	1.33

	A	D	E	F	G	H
1		Requirements Count	Blocks Count	Requirements Covered By Blocks Count	Requirements Covered By Blocks Percentage	Requirements Covered By Blocks Average
2	2014.03.01 16.00	18	4	2	11.11	1
3	2014.04.01 16.00	18	10	4	22.22	1
4	2014.05.01 16.00	18	12	6	33.33	1.5
5	2014.06.01 16.00	18	12	8	44.44	1.33



Requirements Verification



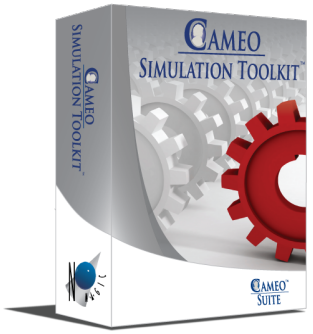
#	Name	Gross Weight : Lbs	Speed : Mph	Number Of Wheels : Integer	Stopping Distance : Ft	Required Stop Distance : Ft	SD Verification : Verdict Kind	: Weight Constraint	: SD Constraint
1	vh1	2800.0	65.0	4	178.9119253179637	176.54869701553358	fail	pass	fail
2	vh2	3300.0	65.0	5	168.68838672836577	176.54869701553358	pass	fail	pass
3		3200.0	65.0	4	204.4707717919585	176.54869701553358	fail	pass	fail
4		2700.0	65.0	4	172.522213699465	176.54869701553358	pass	pass	pass
5		2700.0	65.0	4	172.522213699465	176.54869701553358	pass	pass	pass
6	vehicle UT	3500.0	65.0	4	223.6399066474546	176.54869701553358	fail	fail	fail
7	vehicle UT1	2700.0	65.0	4	172.522213699465	176.54869701553358		pass	pass

2	Gross Weight : Lbs	Speed : Mph	Number Of Wheels : Integer	Stopping Distance : Ft	Required Stop Distance : Ft	SD Verification : Verdict Kind	: Weight Constraint	: SD Constraint
3	2800	65	4	178.9119253	176.548697	fail	pass	fail
4	3300	65	5	168.6883867	176.548697	pass	fail	pass
5	3200	65	4	204.4707718	176.548697	fail	pass	fail
6	2700	65	4	172.5222137	176.548697	pass	pass	pass
7	2700	65	4	172.5222137	176.548697	pass	pass	pass
8	3500	65	4	223.6399066	176.548697	fail	fail	fail
9	2700	65	4	172.5222137	176.548697		pass	pass

Integrated simulation and analysis

Cameo Simulation Toolkit

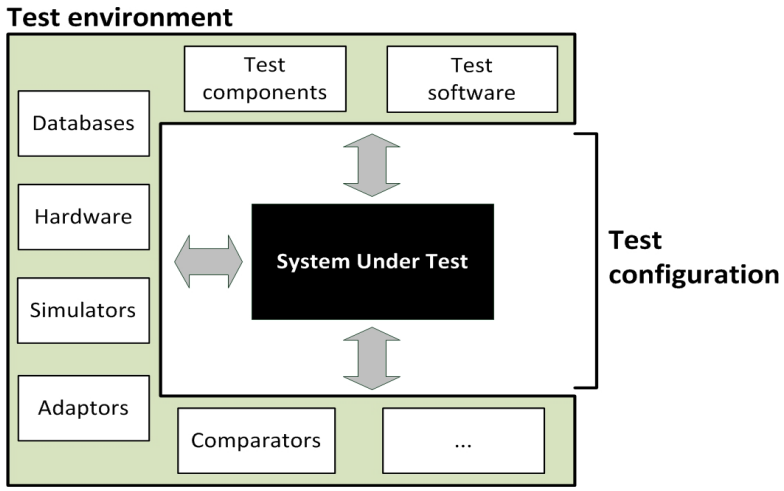
- Model execution framework and infrastructure:
  - Model debugging and animation environment
  - Pluggable engines, languages and evaluators
  - User Interface prototyping support
  - Model driven configs and test cases

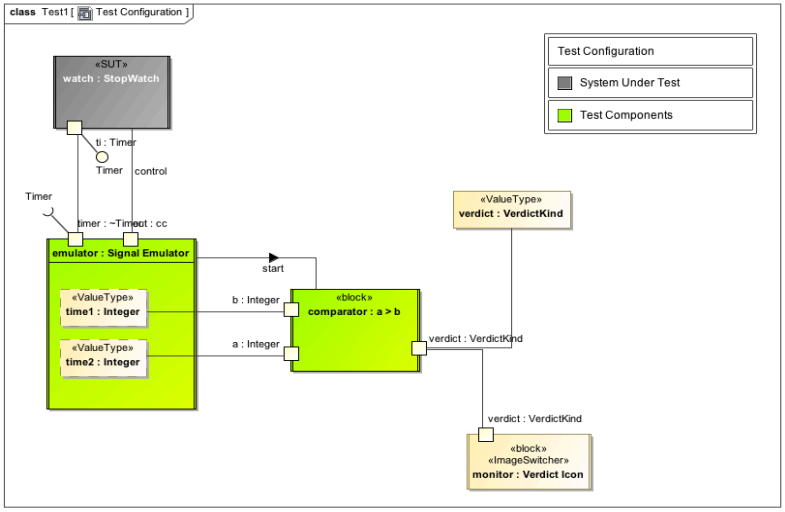


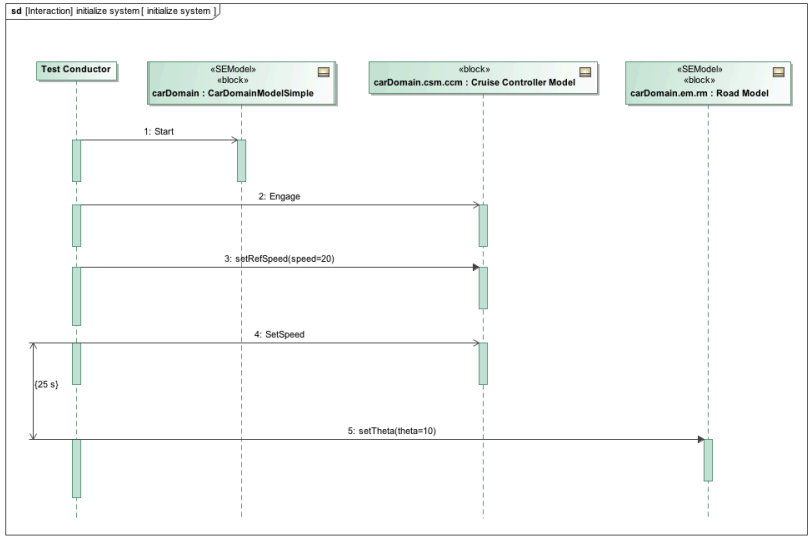
- The standard based model execution of:
  - Activities (OMG fUML standard)
  - Composite structures (OMG PSCS)
  - Statemachines (W3C SCXML standard)
  - Actions/scripts (OMG ALF, JSR223 standard)
  - Parametrics (OMG SysML standard)
  - Sequence diagrams (OMG UML Testing Profile)

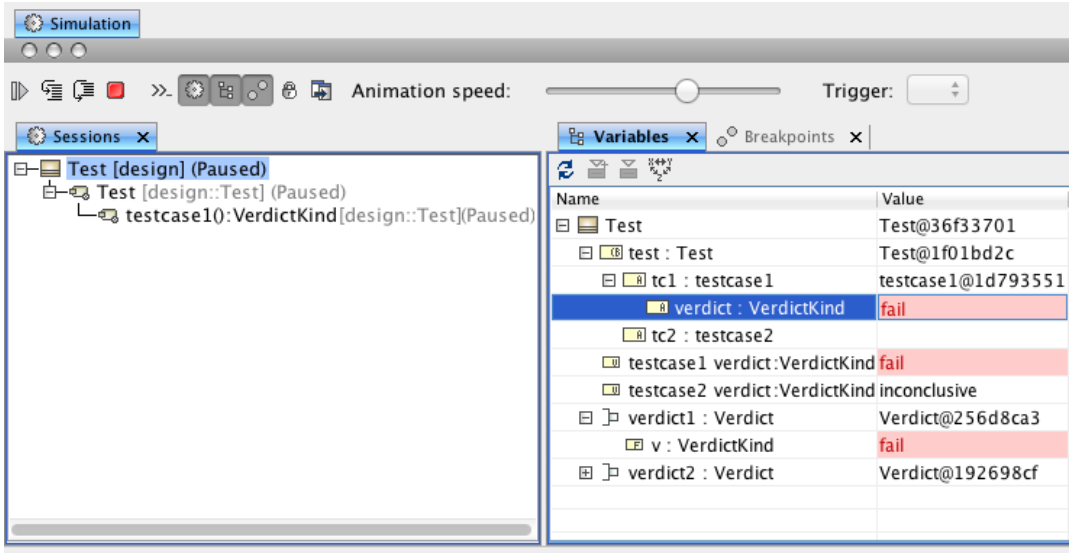
OBJECT MANAGEMENT GROUP

Model-based testing









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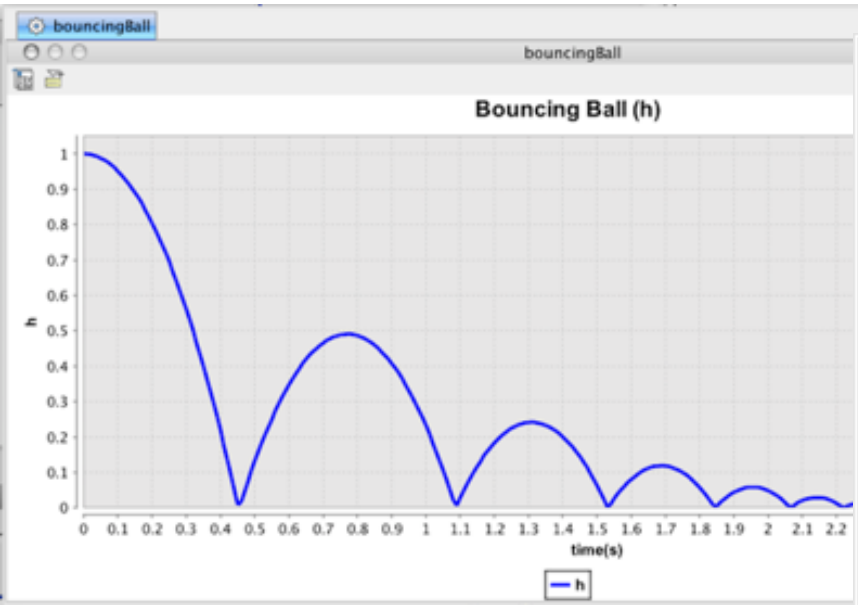
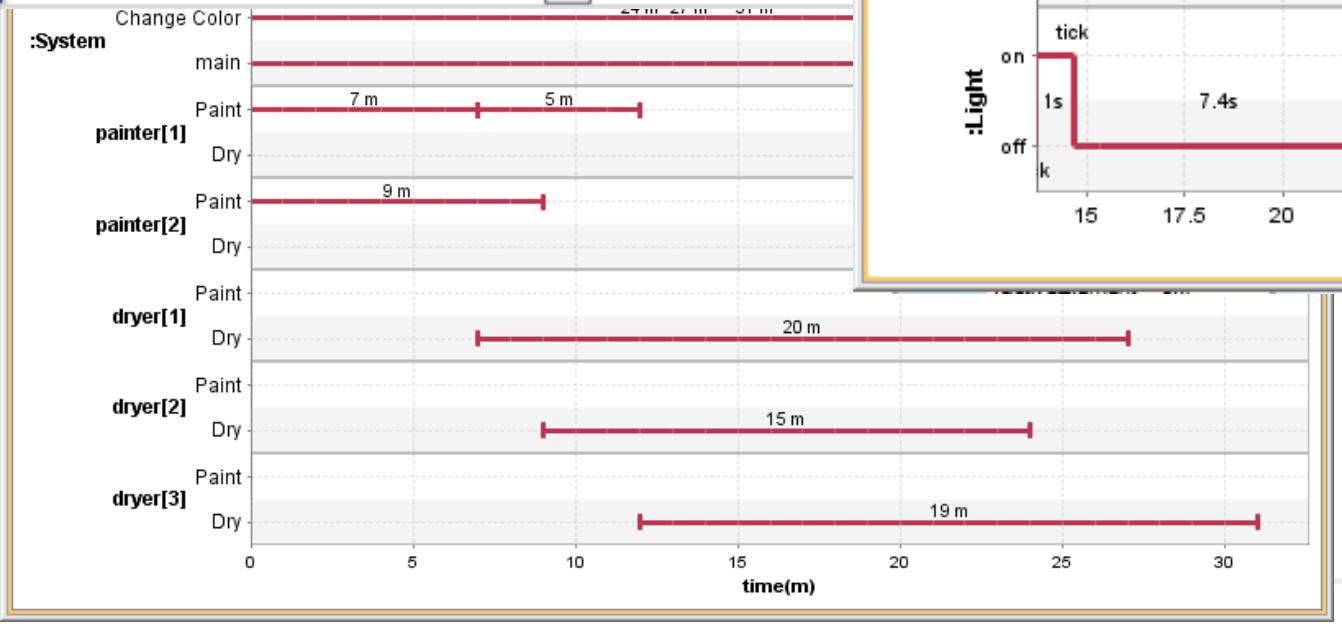
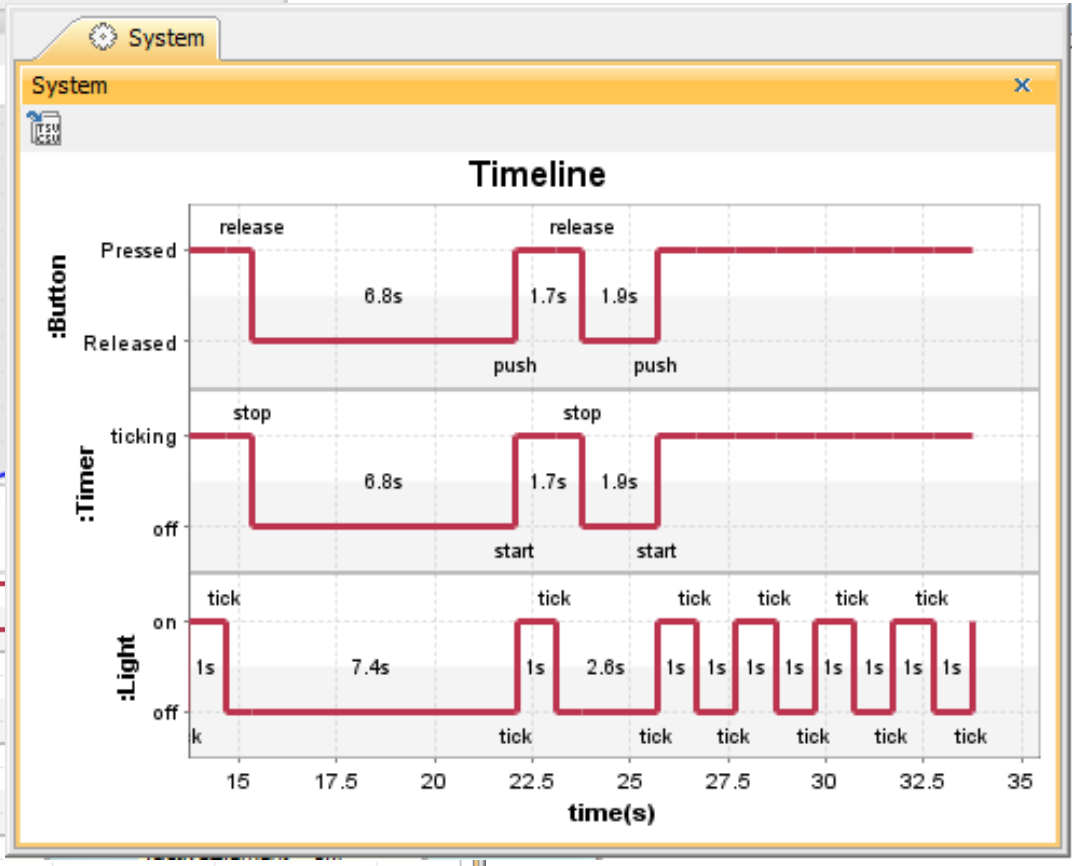
Timelines

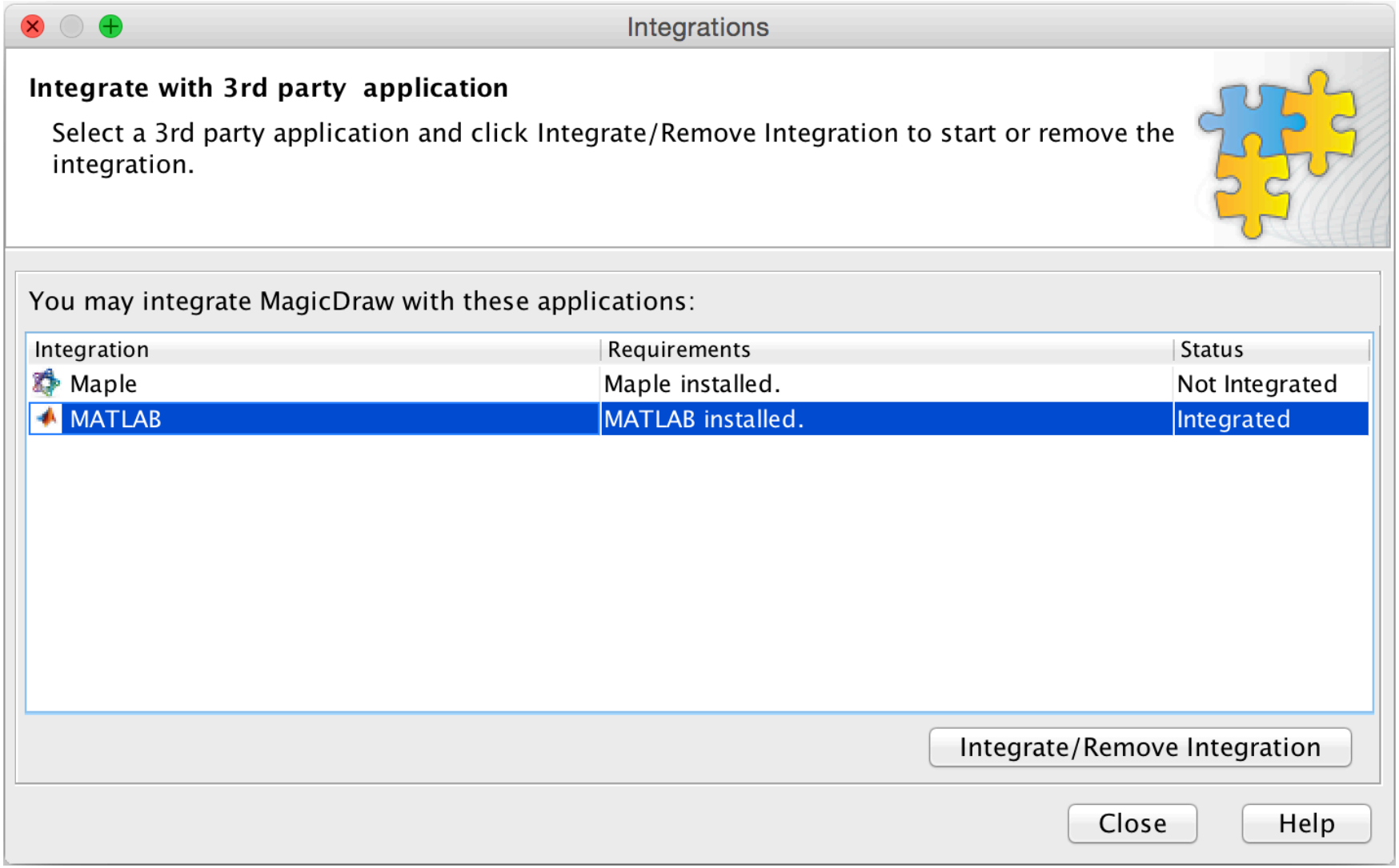

bouncingBall
bouncingBall
Bouncing Ball (h)
h
time(s)
h


Change Color
:System
main
Paint
painter[1]
Dry
7 m
5 m
Paint
painter[2]
Dry
9 m
Paint
dryer[1]
Dry
20 m
Paint
dryer[2]
Dry
15 m
Paint
dryer[3]
Dry
19 m
0
5
10
15
20
25
30
time(m)


System
System
Timeline
:Button
Pressed
Released
release
release
6.8s
1.7s
1.9s
push
push
:Timer
ticking
off
stop
stop
6.8s
1.7s
1.9s
start
start
:Light
on
off
tick
1s
7.4s
2.6s
15
17.5
20
22.5
25
27.5
30
32.5
35
time(s)

Integration of analytical models

One click Integration

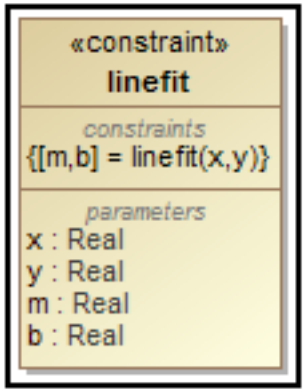


Matlab in SysML diagrams

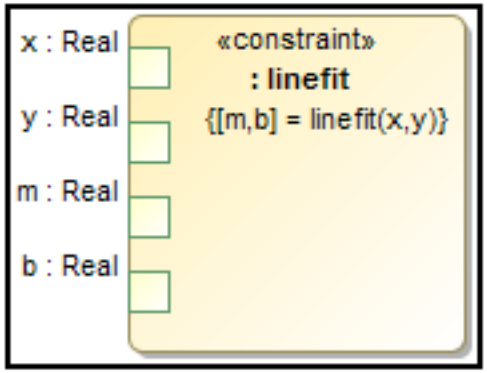
Wrap mathematical expressions into...

```
% linefit.m
% Least-squares fit of data to y=m*x+b
function [m, b] = linefit(x, y)
x = x( : );
y = y( : );
A = [x ones(size(x))];
c = (A' * A)(A' * y);
m = c(1);
b = c(2);
end
```

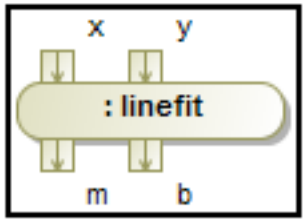
Constraint Block



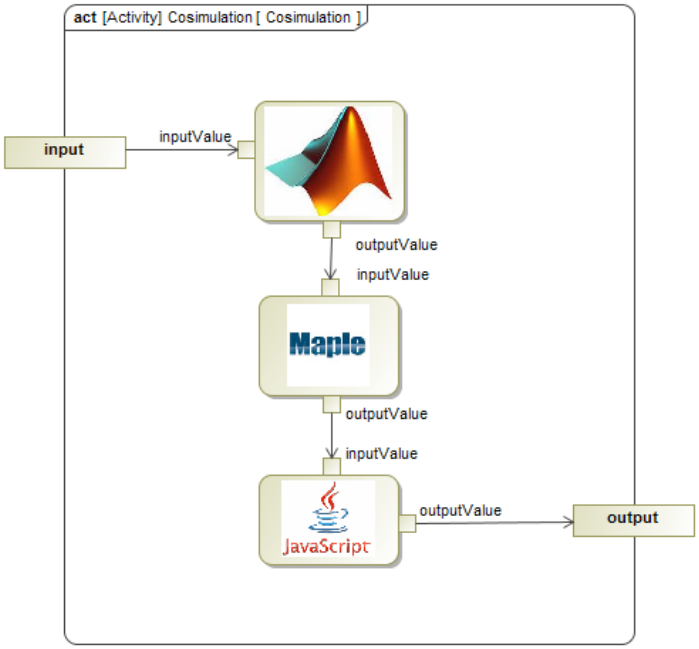
Constraint Property

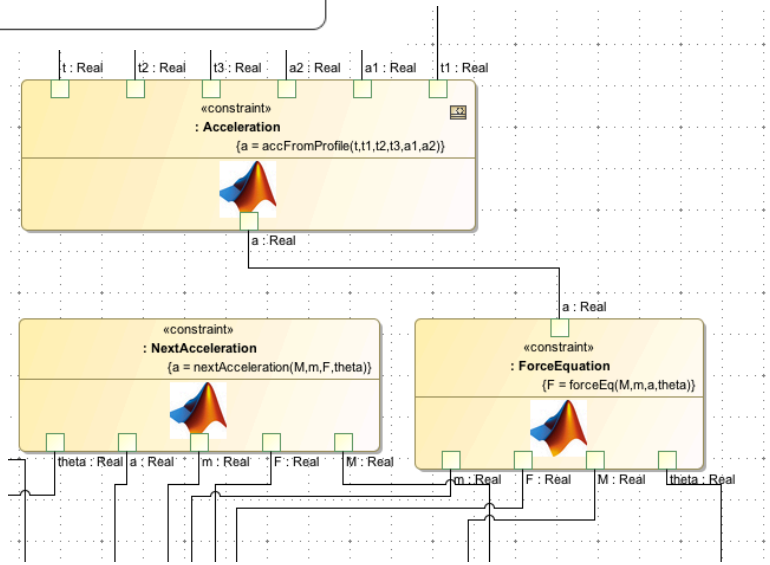


Call Behavior Action



Wrappers





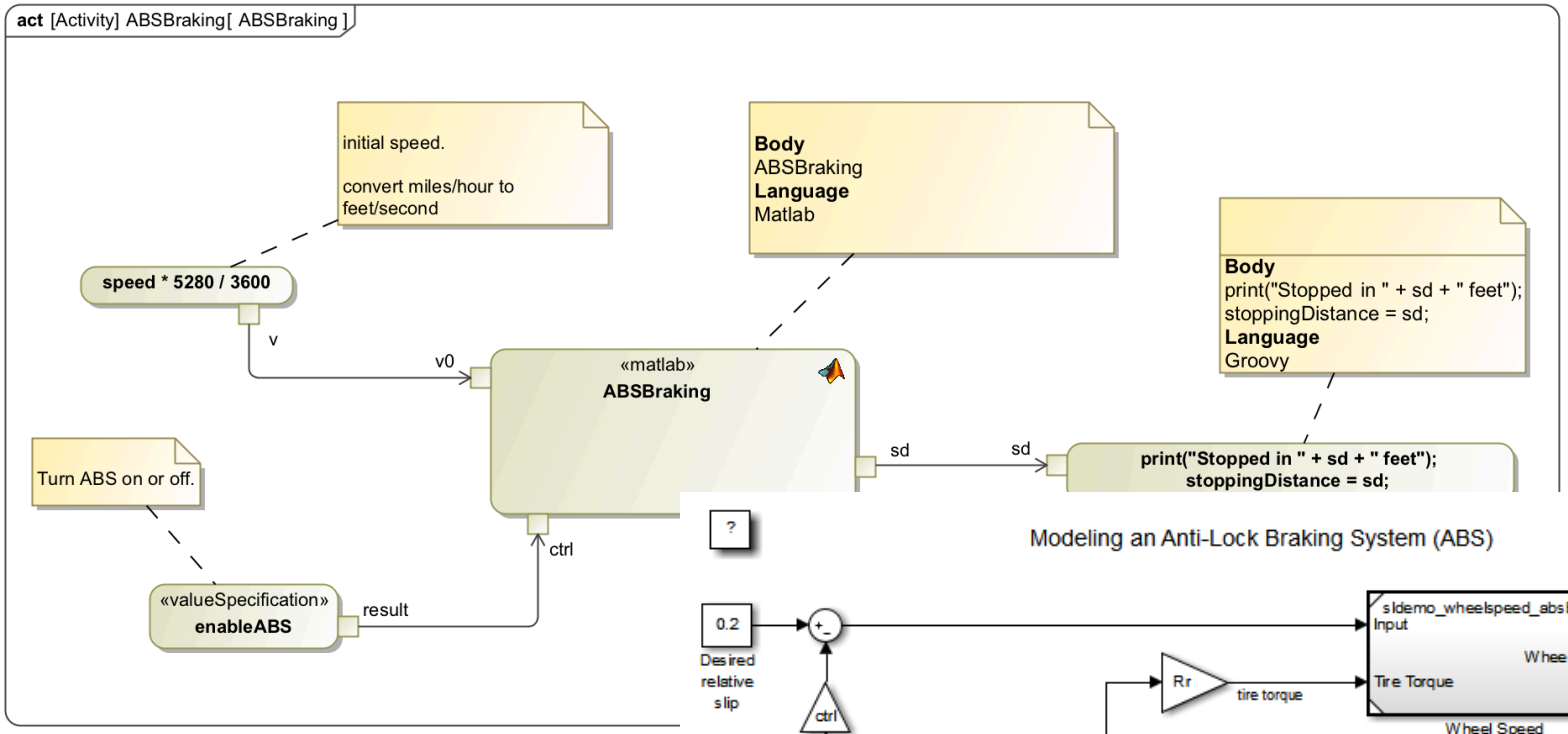
Math engines

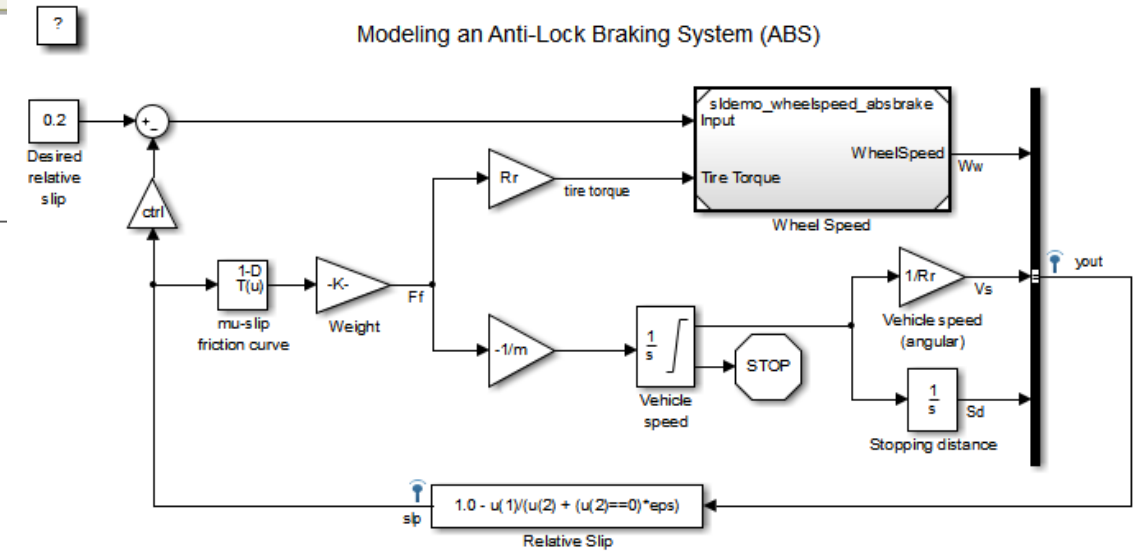
- Matlab/Simulink
- Mathematica
- Maple
- Open Modelica

Scipting

- Javascript
- Python
- Groovy
- Ruby

Simulink model integration





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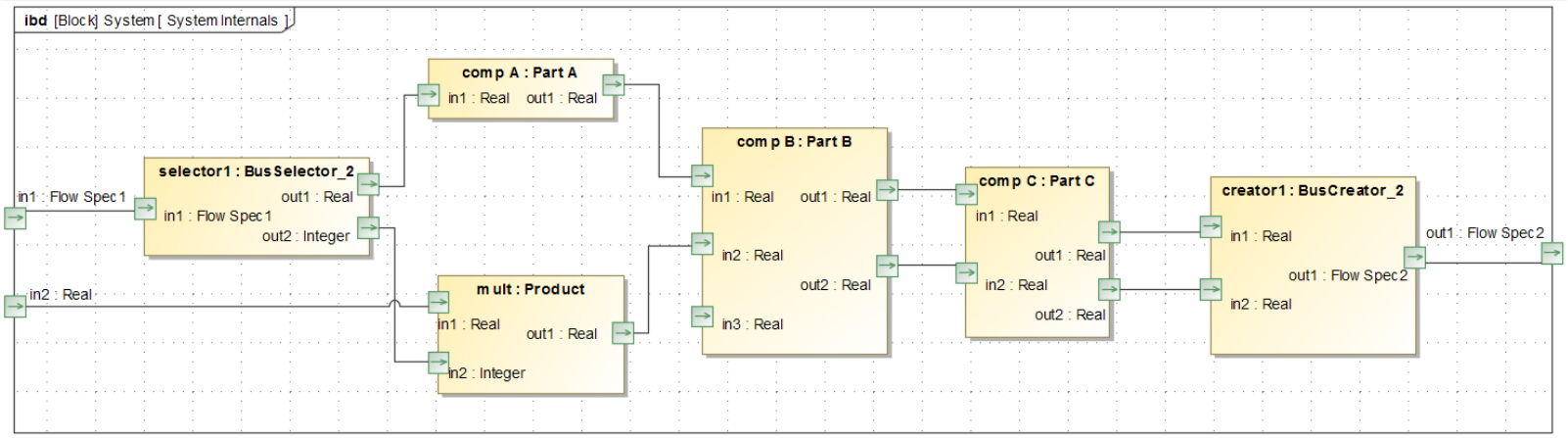
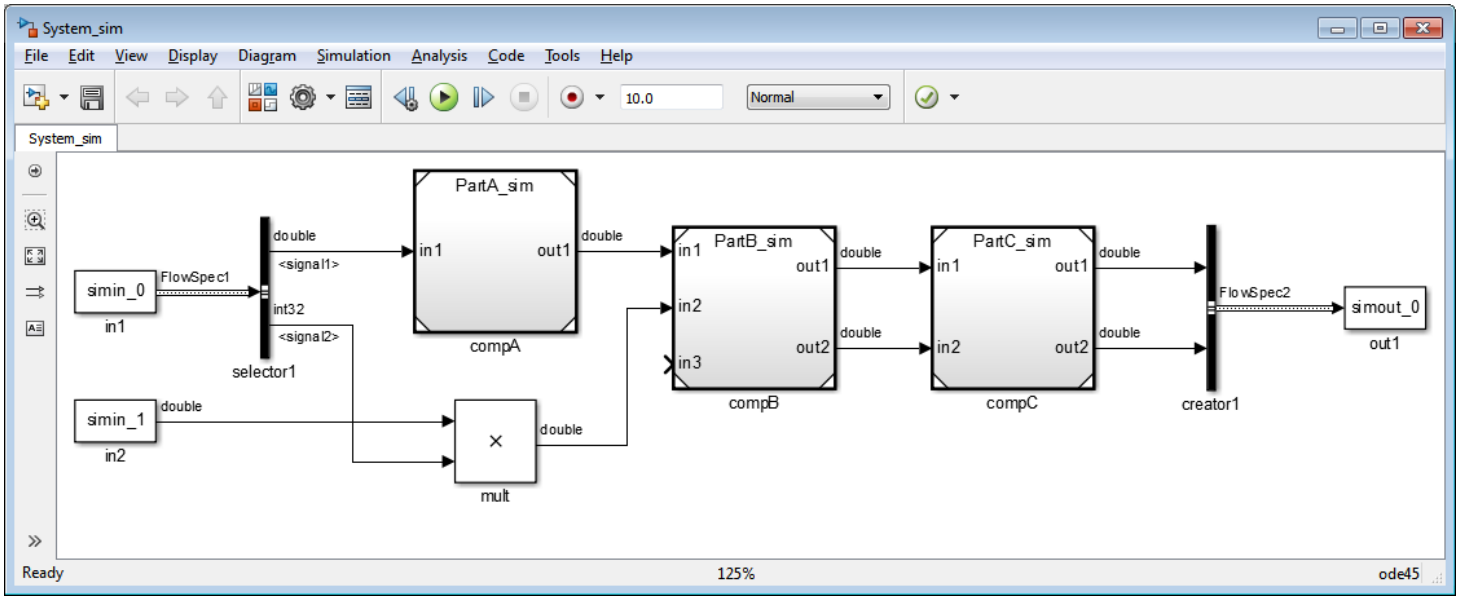
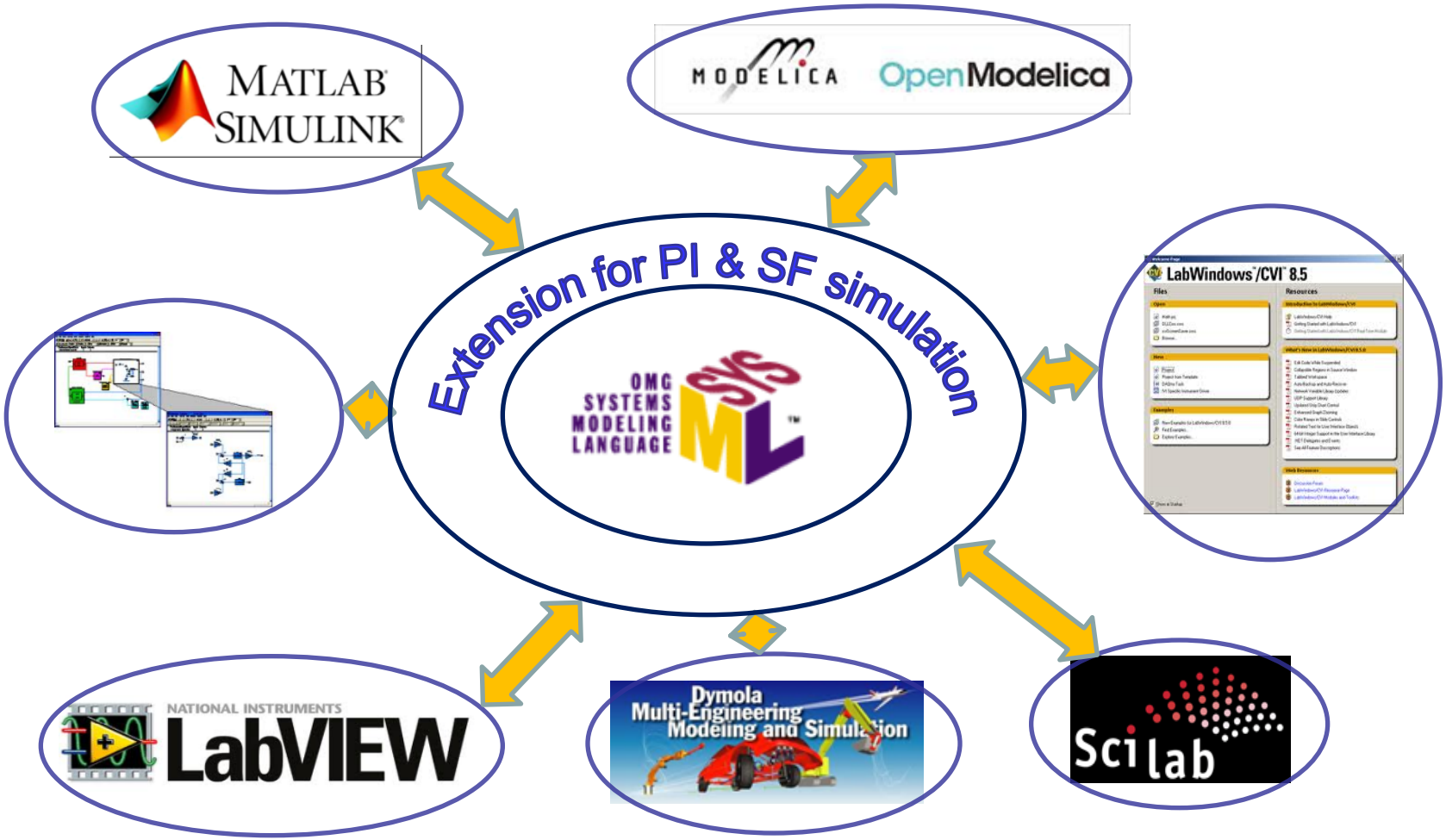
SysML – Simulink transformation





Reduce Specialized Mappings



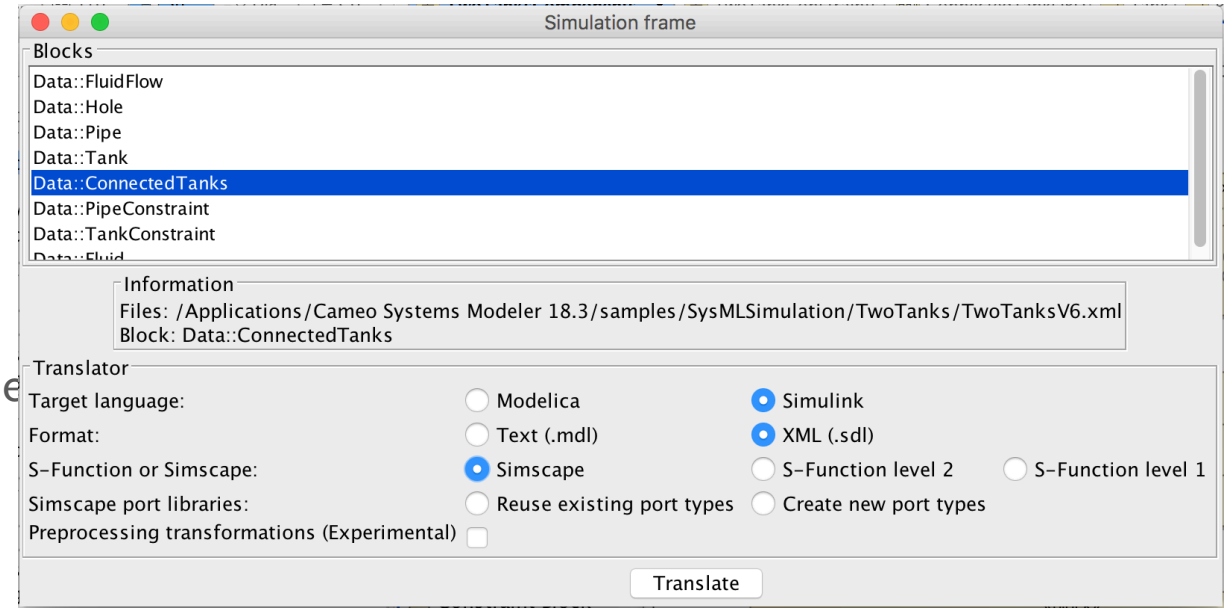
Extend SysML with a general simulation profile.

SysML 2 Simulation

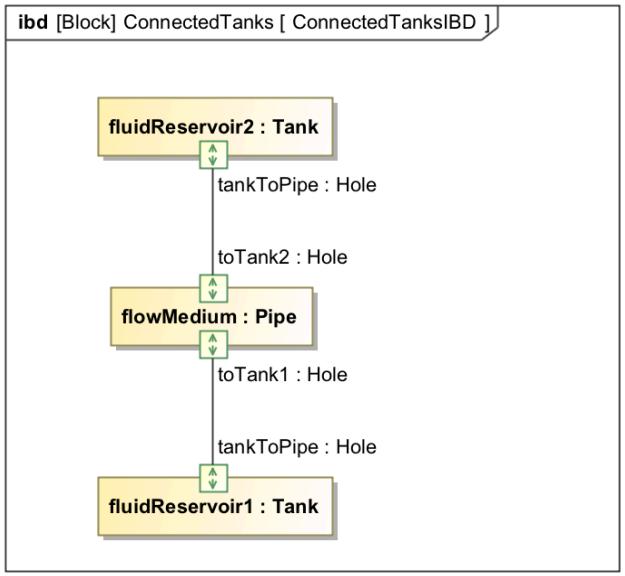
SysML Extension for Physical Interaction and Signal Flow Simulation (SysPISF)

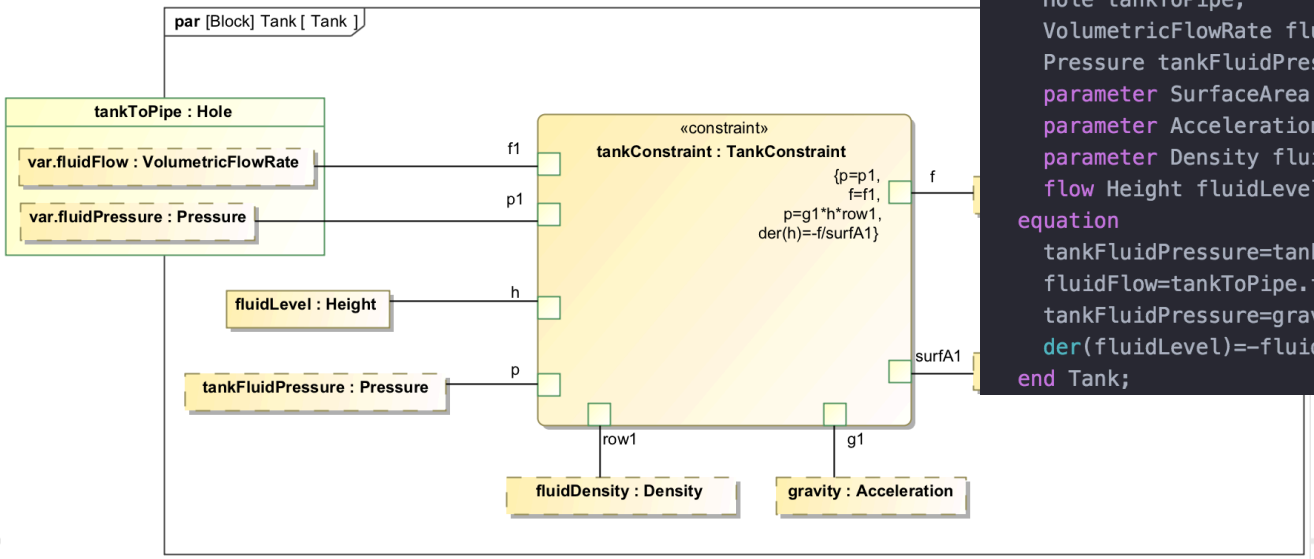
- SysML mapping to Modelica, Matlab, Simulink, Stateflow, Simscape
- Supports:
  - BDD for definitions
  - IBD for connections
  - Ports, flows, units
  - Parametric diagrams
  - Statemachines
  - Primitive block librarie

Free plugin for 18.0-18.5



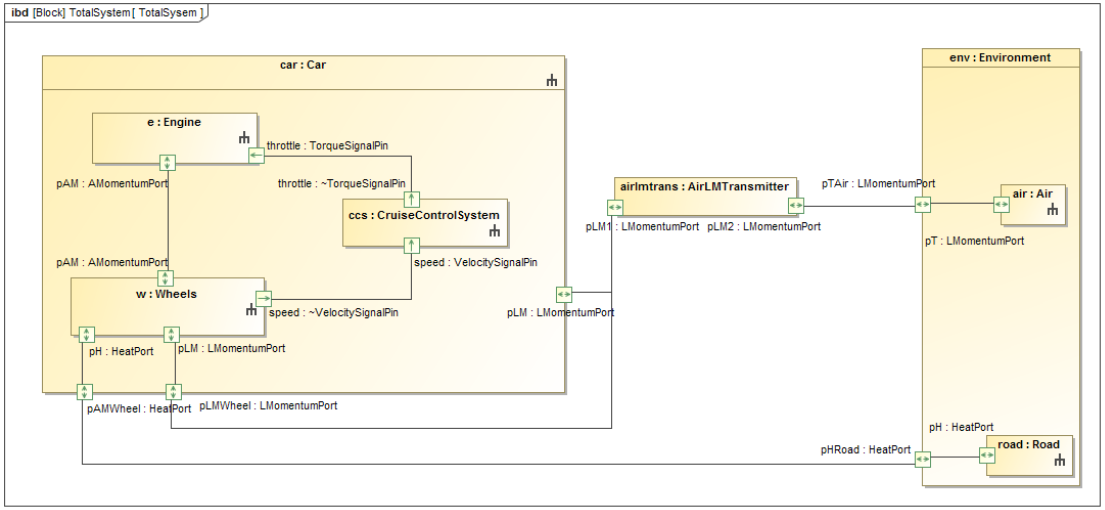
SysML 2 Modelica example





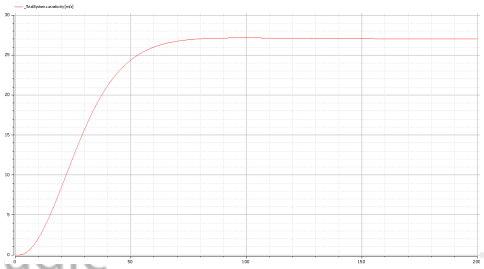

```
model ConnectedTanksModel
  ConnectedTanks _ConnectedTanks;
  model ConnectedTanks
    Pipe flowMedium;
    Tank fluidReservoir1(fluidLevel.start=40.0,fluidLevel.fixed=true);
    Tank fluidReservoir2(fluidLevel.start=15.0,fluidLevel.fixed=true);
  equation
    connect(flowMedium.toTank1,fluidReservoir1.tankToPipe);
    connect(fluidReservoir2.tankToPipe,flowMedium.toTank2);
  end ConnectedTanks;
  connector Hole
    flow VolumetricFlowRate fluidFlow;
    Pressure fluidPressure;
  end Hole;
  type Pressure=Real(unit="kg/((s^2)*m)");
  type VolumetricFlowRate=Real(unit="(m^3)/s");
  model Tank
    Hole tankToPipe;
    VolumetricFlowRate fluidFlow;
    Pressure tankFluidPressure;
    parameter SurfaceArea surfaceAreaTank(start=4.0,fixed=true);
    parameter Acceleration gravity(start=9.8,fixed=true);
    parameter Density fluidDensity(start=10.0,fixed=true);
    flow Height fluidLevel;
  equation
    tankFluidPressure=tankToPipe.fluidPressure;
    fluidFlow=tankToPipe.fluidFlow;
    tankFluidPressure=gravity*fluidLevel*fluidDensity;
    der(fluidLevel)=-fluidFlow/surfaceAreaTank;
  end Tank;
```

SysML to Simulink/Modelica

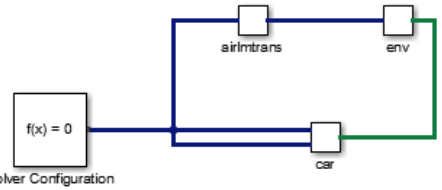


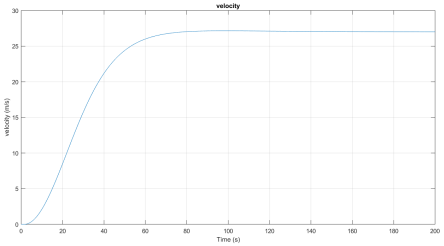
Modelica

```
4   model TotalSystem
5     Car car(g = g, slope = slope, w.velocity.start = 0.0,
    w.velocity.fixed = true, e.torque.start = 0.0, e.torque.fixed =
    true);
6     parameter Real g(start = 9.81, fixed = true);
7     parameter Real airdensity(start = 1.2, fixed = true);
8     parameter Real slope(start = 0.0, fixed = true);
9     Environment env;
10    AirLMTransmitter airlmtrans(crossSectionalArea = frontArea,
  airdensity = airdensity);
11    parameter Surface frontArea(start = 10.0, fixed = true);
12  equation
13    connect(car.pLMWheel, car.pLM);
14    connect(env.pHRoad, car.pAMWheel);
15    connect(car.pLM, airlmtrans.pLM1);
16    connect(airlmtrans.pLM2, env.pTAir);
17  end TotalSystem;
```



Simulink/Simscape



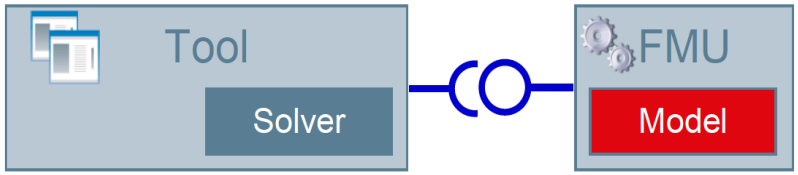


FMI – Functional Mockup Interface

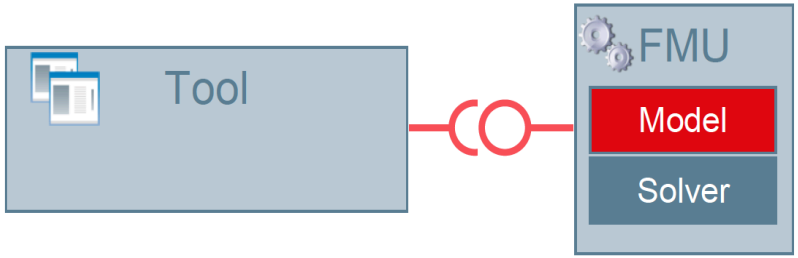
- Open standard for model exchange and co-simulation of dynamic models
- The FMI development was initiated by Daimler AG
- Developed as part of the ITEA2 MODELISAR project (2008 - 2011; 29 partners, Budget: 30 Mill. €).
- The first version, FMI 1.0, was published in 2010, followed by FMI 2.0 in July 2014.
- Since 2012 FMI is developed as Modelica Association Project.
- FMI is currently supported by 84 tools

Functional Mock-up Interface

- The Functional Mock-up Interface (**FMI**) is a **tool independent standard** for
  - **Model Exchange (ME)**



  - **Co-Simulation (CS)**

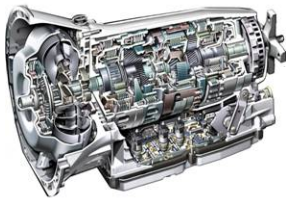


- The FMI defines an interface to be implemented by an executable called Functional Mock-up Unit (**FMU**)

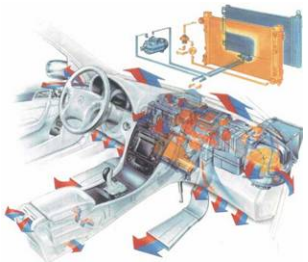
FMI : A Business Model Innovation

- Exported FMUs don't require a license of an authoring tool
- Separate model authoring and execution

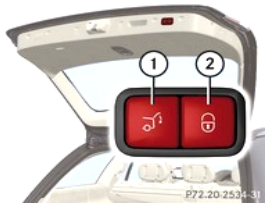
Engine
with ECU



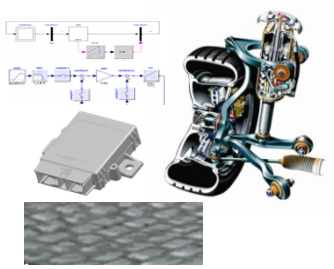
Gearbox
with ECU



Thermal
systems



Automated
cargo door



Chassis components,
roadway, ECU (e.g. ESP)

etc.

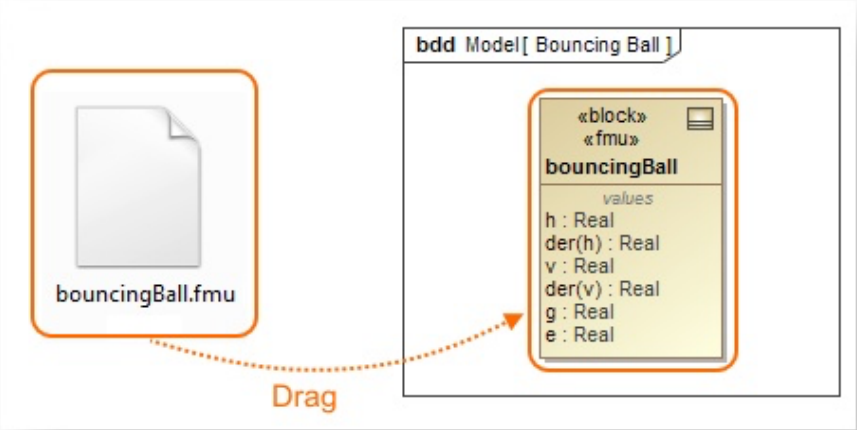
functional mockup interface for model exchange and tool coupling

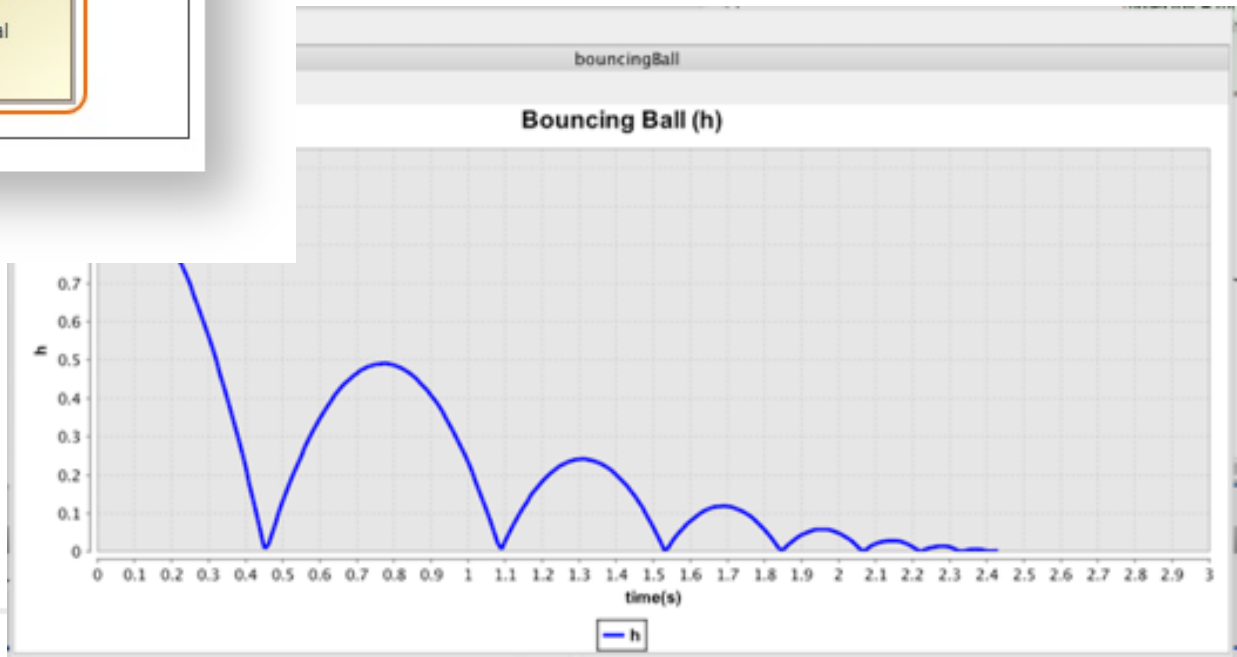
courtesy Daimler

Source: https://www.fmi-standard.org/

FMI import

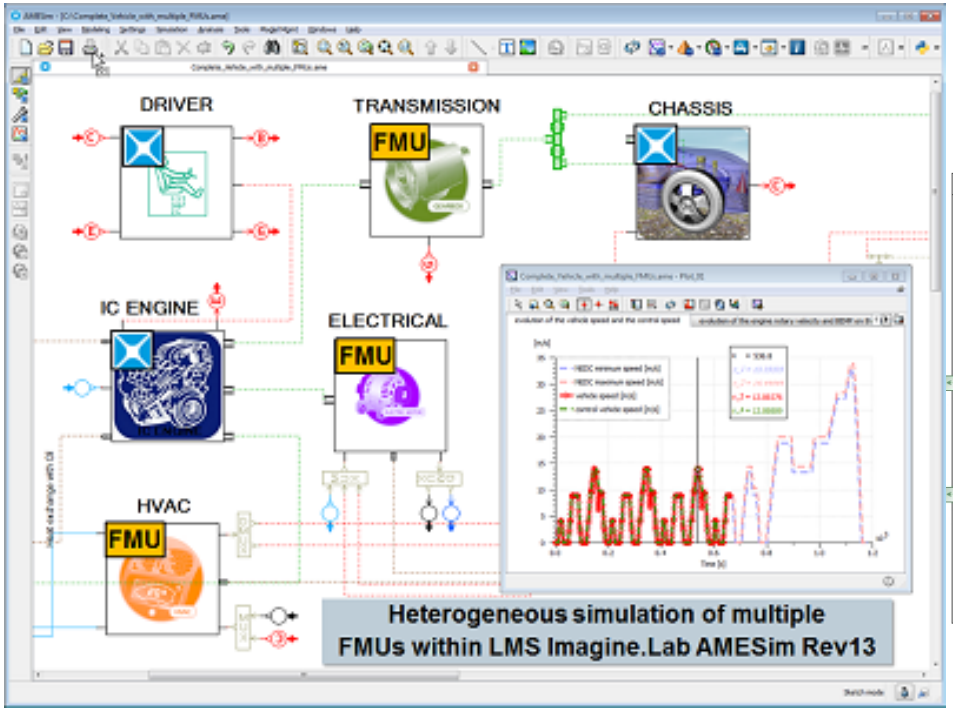
Tools supporting FMI	FMI Version	ModelExchange		CoSimulation		Notes
		Export	Import	Slave	Master	
Cameo Simulation Toolkit	FMI_1.0		Available		Available	FMUs can be imported, represented, connected and co-simulated in SysML models.

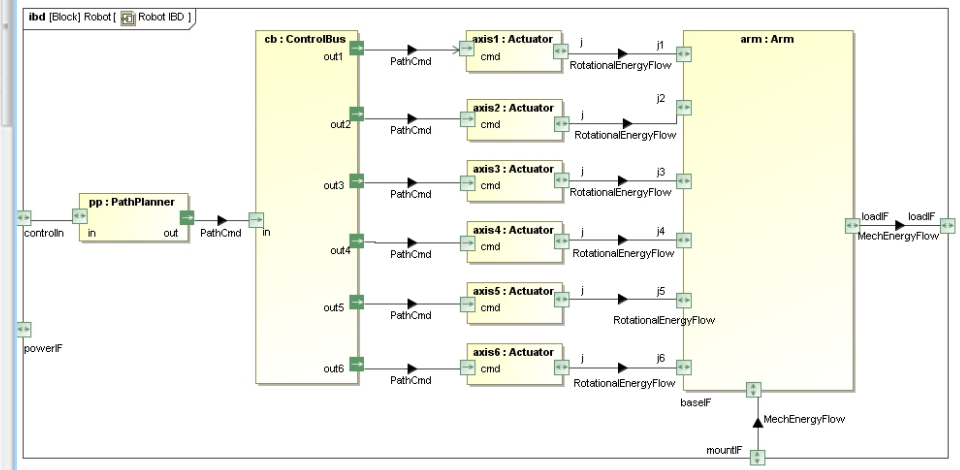




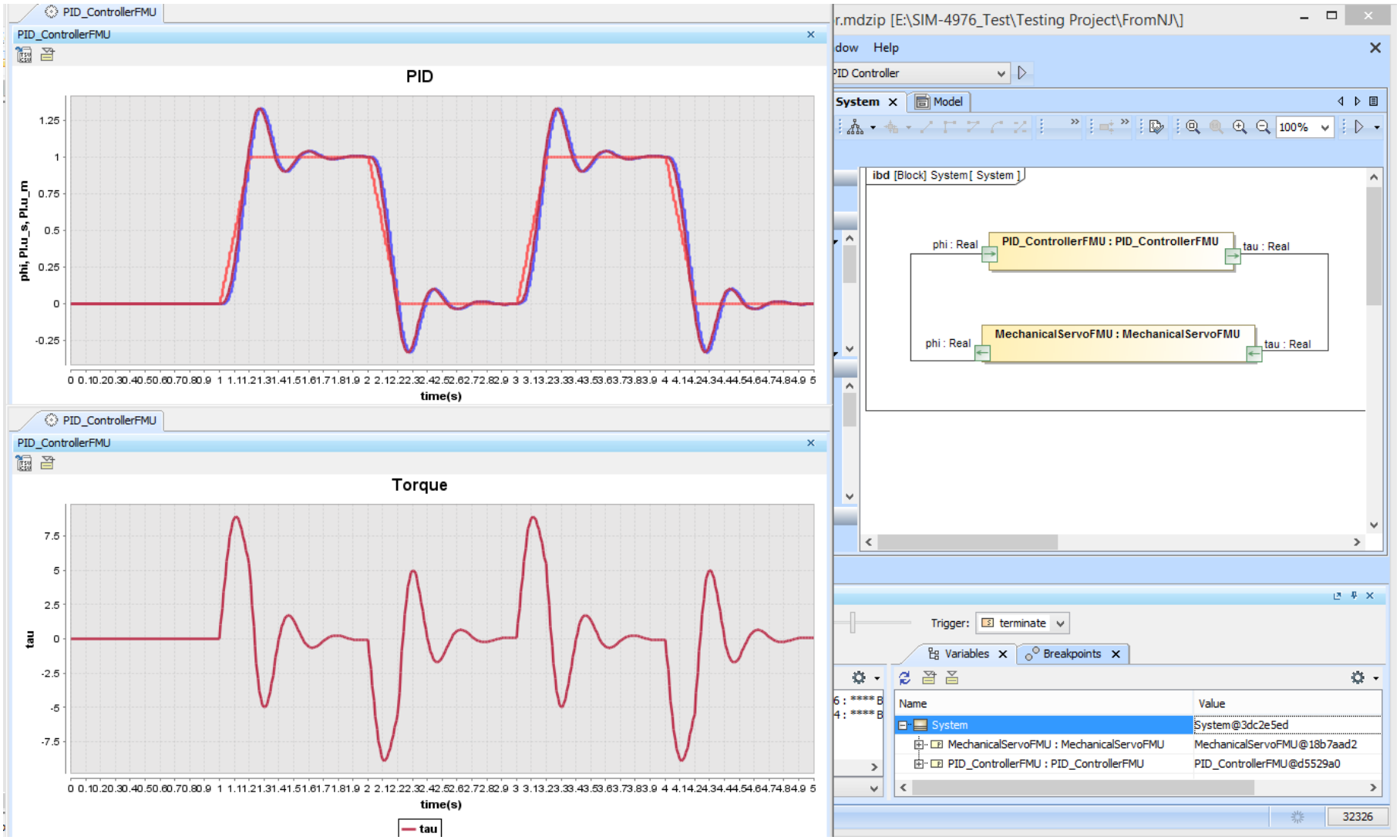
FMI connections

- Wrapping FMU as Block
- IBD for co-simulation assembly
- Cameo Simulation Toolkit as orchestrator



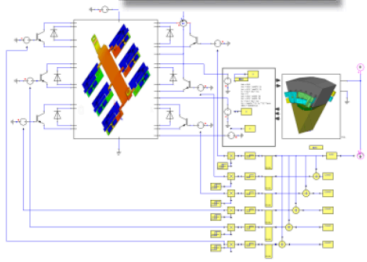


FMI co-simulation in SysML environment



SCADE SUITE™

ANSYS



SIM PACK

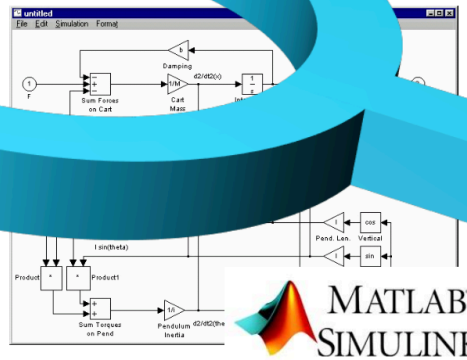
DASSAULT SYSTEMES

C/C++

Wolfram SystemModeler™

AUTOSAR Builder™

QTronic
SIMULATION FOR ENGINEERING

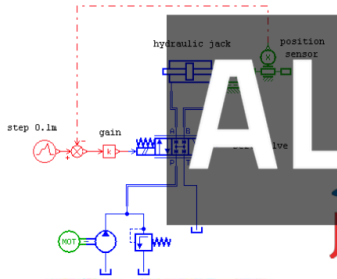


Excel

MATLAB SIMULINK

OpenModelica

IPG AUTOMOTIVE



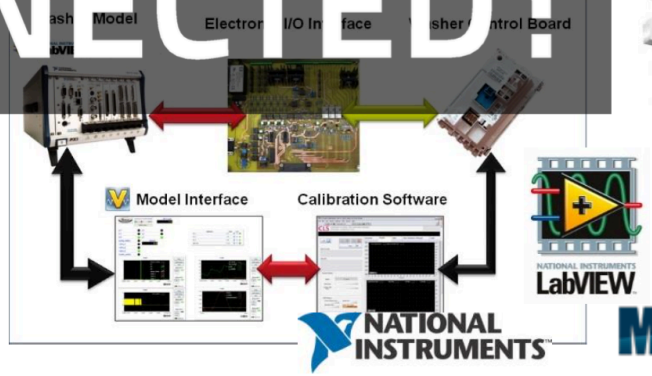
Java

Adams

MSC Software

LMS
A Siemens Business

SIMULATION X
Powered by ITI



LabVIEW

NATIONAL INSTRUMENTS

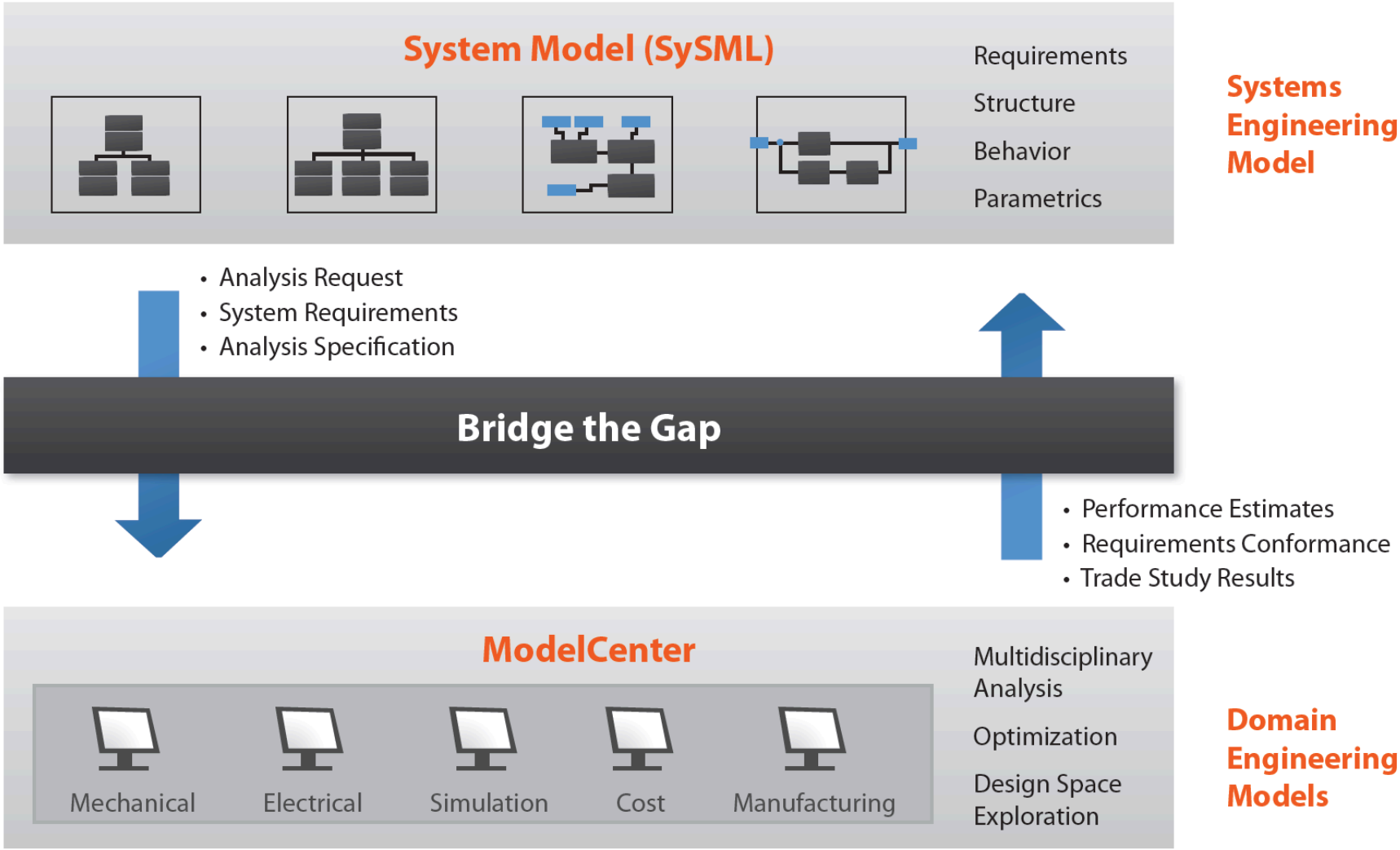
python

MapleSim

Modelon

ALL CONNECTED!

Model Center



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Model Center (2)

Modeling and Simulation Tools

Abaqus Adams ANSYS Catia LS-DYNA MSCNastran NX NXNastran ProE

Product Design

- Given design parameters, predicts performance characteristics:
  - How much will it weigh?
  - How high can it fly?
  - What will it cost?
- Useful for designing hardware

- Matlab*
- Mathcad*
- Excel*
- In-house
- CAD
- ANSYS*
- Fluent
- Price*
- Seer*
- ACEIT*

Simulation

- Given performance characteristics, predicts how a system will react to various stimulus over time
  - Hit rate
  - Access times
  - Throughput
- Useful for designing systems

- Flames*
- STK*
- OpNet
- ProModel
- Arena
- Simulink*
- Extend*
- Vensim*

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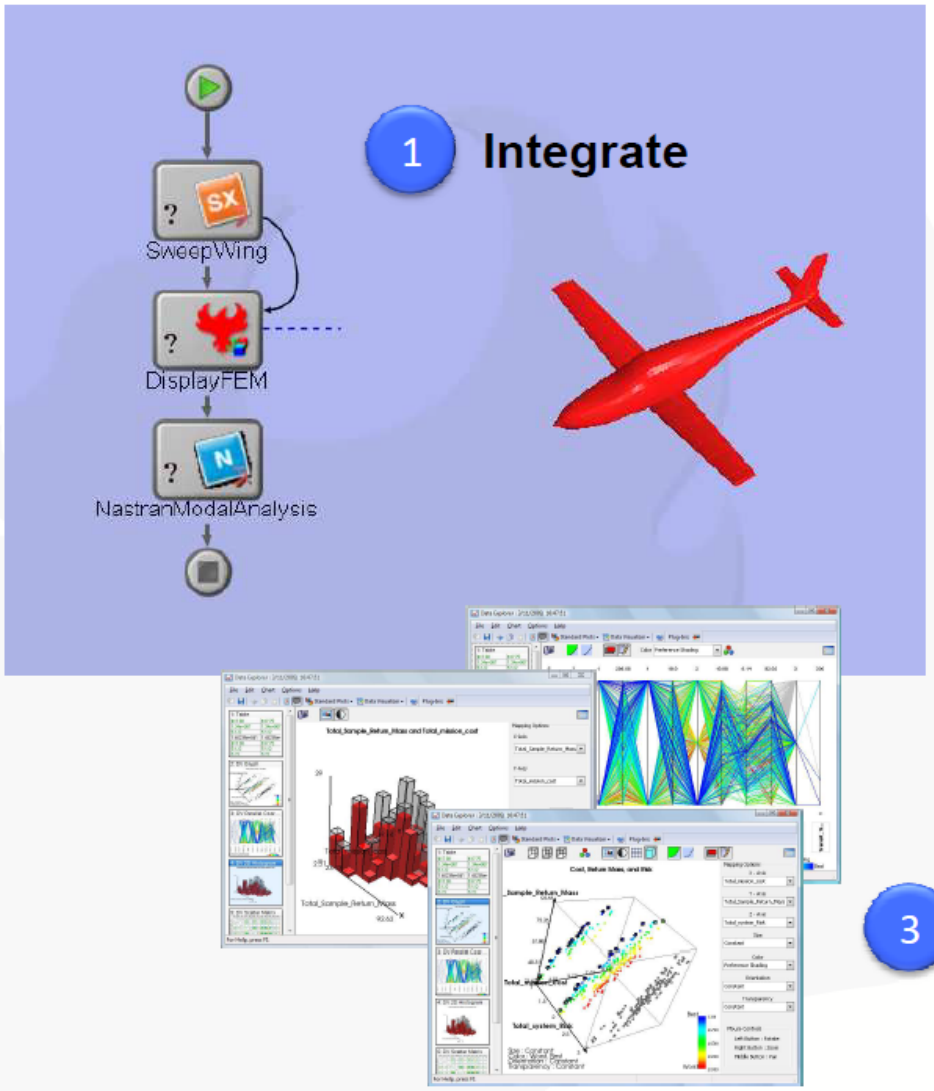
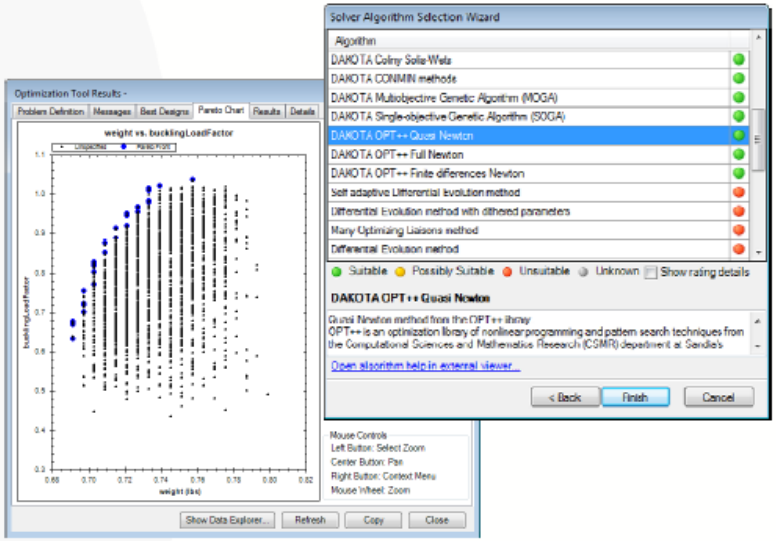
Model Center (3)



ModelCenter

2 **Automate (DOE, Optimization)**



3 **Visualize and Find Better Designs**

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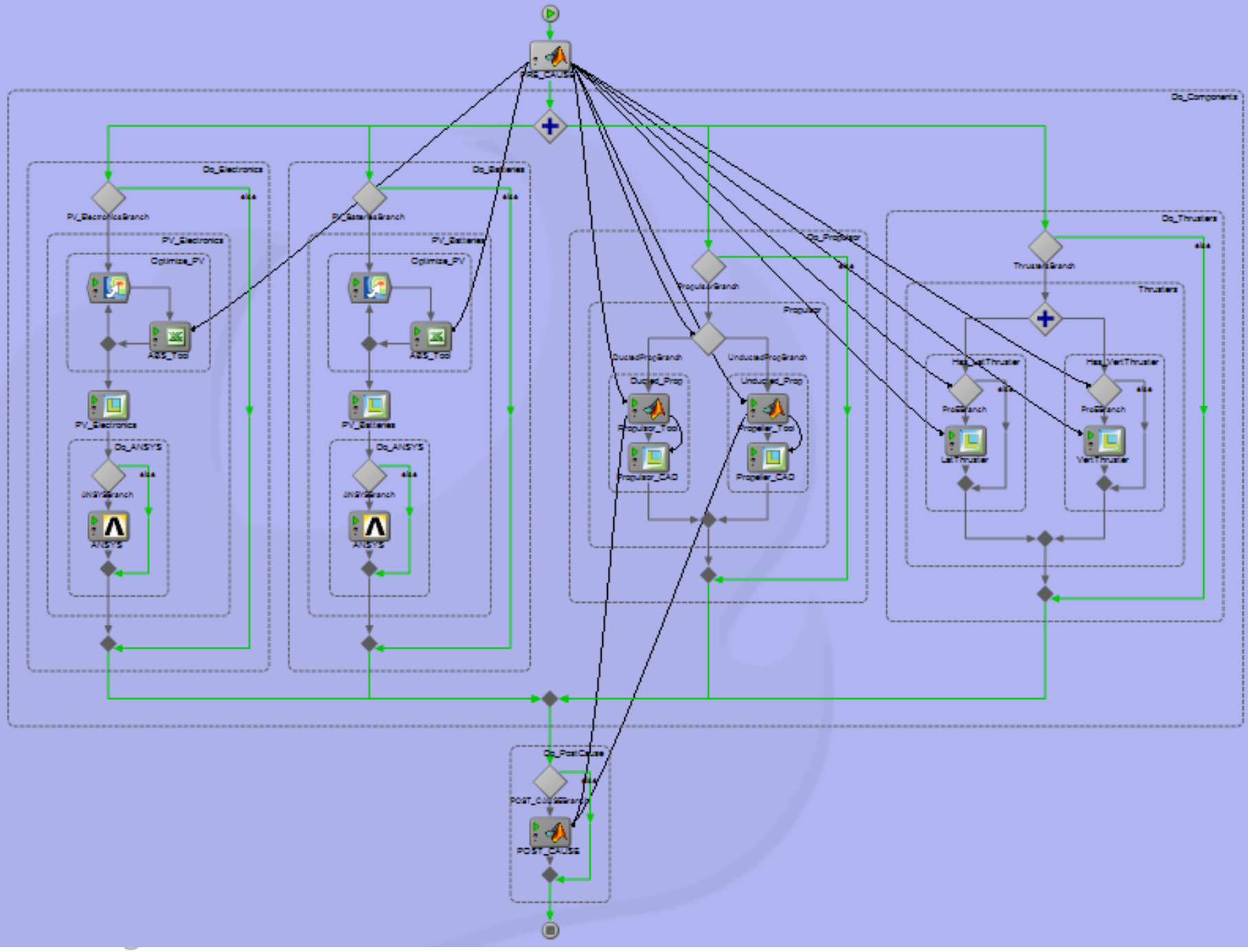
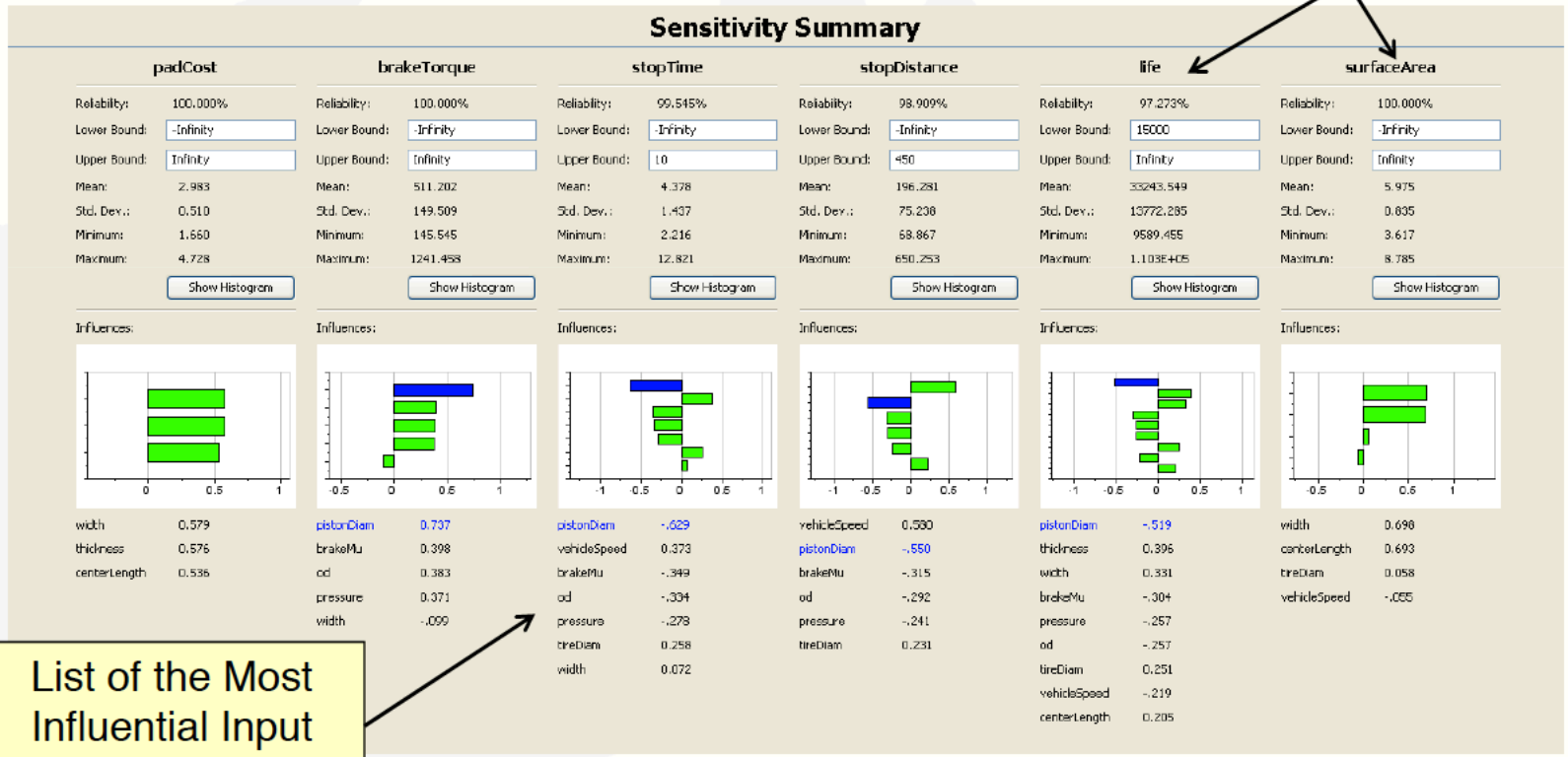

PRE_CAUSE
Do_Components
Do_Electronics
PV_ElectronicsBranch
PV_Electronics
Optimize_PV
ABS_Tool
PV_Electronics
Do_ANSYS
ANSYSBranch
ANSYS
Do_Batteries
PV_BatteriesBranch
PV_Batteries
Optimize_PV
ABS_Tool
PV_Batteries
Do_ANSYS
ANSYSBranch
ANSYS
Do_Propulsor
PropulsorBranch
Propulsor
DuctedPropBranch
Ducted_Prop
Propulsor_Tool
Propulsor_CAD
UnductedPropBranch
Unducted_Prop
Propeller_Tool
Propeller_CAD
Do_Thrusters
ThrustersBranch
Thrusters
Has_LatThruster
ProbeBranch
LatThruster
Has_VertThruster
ProbeBranch
VertThruster
Do_PostCalcs
POST_CALCS

Model Center (5)

Shows the most influential input variables for each output variable

Sensitivity Analysis

Output Variables



List of the Most Influential Input Variables

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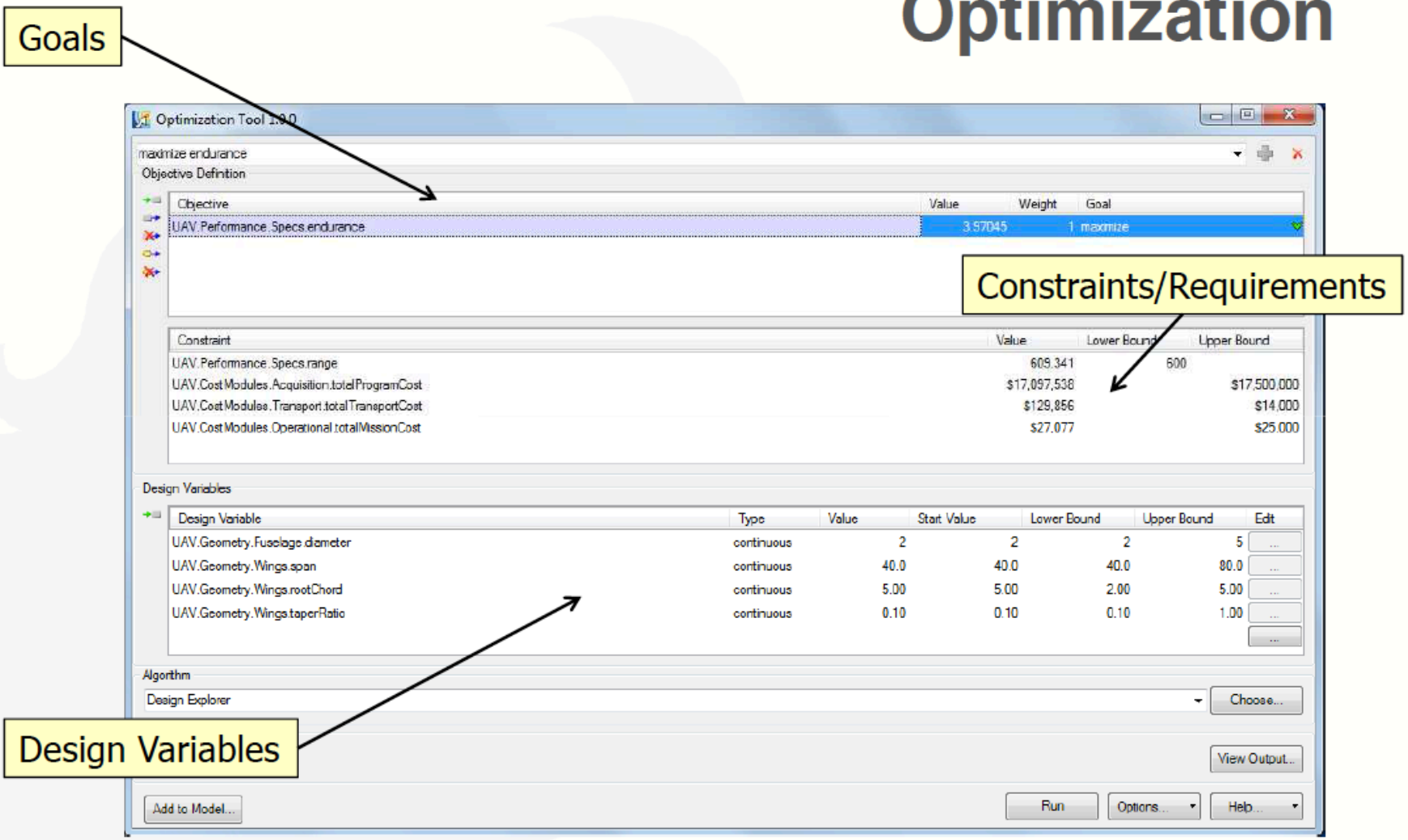
Model Center (6)

Optimization



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Model Center (7)

Algorithms

- Nelder-Mead
- Hooke-Jeeves
- EVOLVE
- SwarmOps
  - Differential Evolution method
  - Differential Evolution method with dithered parameters
  - Self adaptive Differential Evolution method
  - Local Unimodal Sampling method
  - Many Optimizing Liaisons method
  - Pattern Search method
  - Particle Swarm Optimization method
  - Random sampling method
- DOT
  - Broydon-Fletcher-Goldfarb-Shanno (BFGS) variable metric method
  - Fletcher-Reeves (F.R.) conjugate gradient method
  - Modified Method of Feasible Directions (MMFD)
  - Sequential Linear Programming (SLP)
  - Sequential Quadratic Programming (SQP)
- BIGDOT
  - Sequential Unconstrained Minimization Technique (SUMT)
- DAKOTA
  - Asynchronous Parallel Pattern Search
  - Coliny COBYLA
  - Coliny DIRECT
  - Coliny Evolutionary Algorithm
  - Coliny Pattern Search
  - Coliny Solis-Wets
  - CONMIN methods
  - Multi-objective Genetic Algorithm (MOGA)
  - NCSU DIRECT
  - OPT++ Polak-Ribiere conjugant gradient
  - OPT++ Finite differences Newton
  - OPT++ Full Newton
  - OPT++ Parallel direct search
  - OPT++ Quasi Newton
  - Single-objective Genetic Algorithm (SOGA)
- Boeing
  - Design Explorer
  - SQP Gradient Optimizer
- Darwin
- NSGA II

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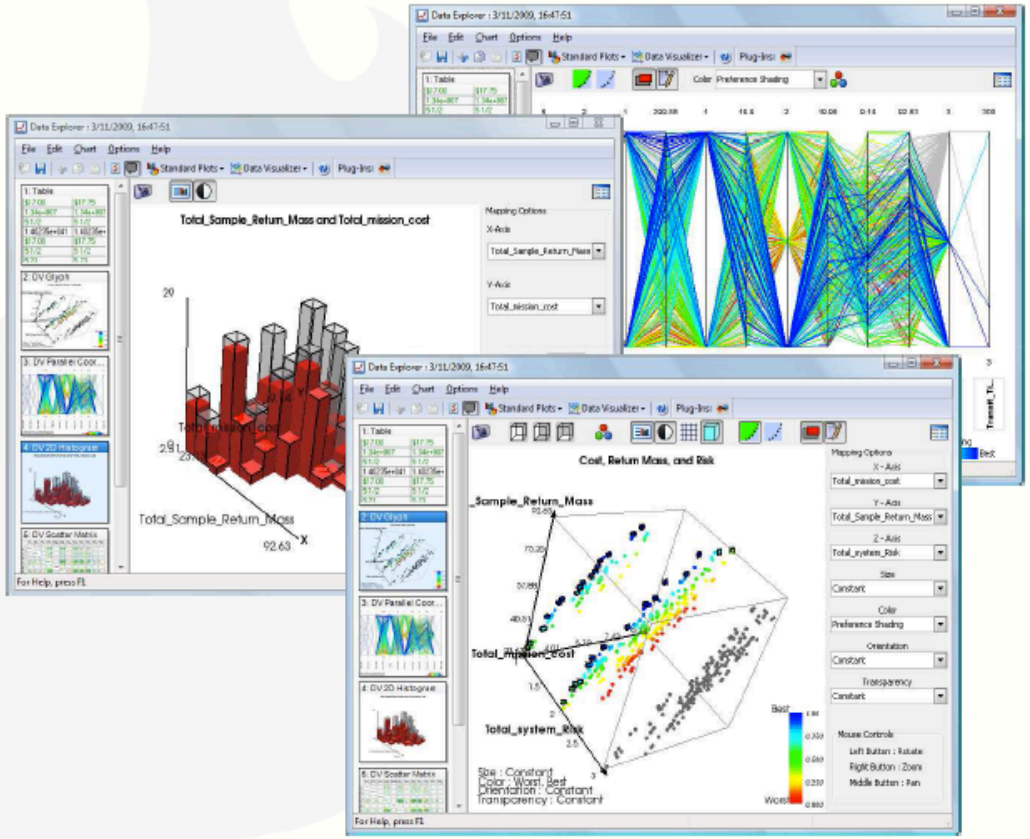
Model Center (8)

Multidimensional Data Visualization

- Multi-dimensional glyph plots, parallel coordinates plots, scatter matrices, histograms, etc.
- Identify variable relationships
- Identify key variables
- Define goals and quickly visualize the resulting multi- dimensional Pareto fronts
- Interactive brush the data to understand the impact of constraints
- Graphical optimization



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Model Center: MBSE Analyzer

Phoenix Integration MBSE Analyzer

Analyzer Edit View Tools Help

Welcome | Review Requirements | Manage Constraint Blocks | Manage Parametric Diagrams | Evaluate Designs

Requirements

Bookmark: <none>

Select a Subject to Analyze

- Data
  - Analysis
  - DesignBaselines
  - Requirements
  - Structure

Requirement	Text	Status	Margin
Pad Dimensions::Pad Center Thickness	The Pad Center Thickness shall be between .2 and .45 inches.	Unknown	
Pad Dimensions::Pad Width	The Pad width shall be between 1.5 and 2.5 inches	Unknown	
Pad Dimensions::Pad Center Length	The Pad Center Length shall be between 3 and 5.5 inches.	Unknown	
Performance::Stopping Distance	Four braking wheels shall be capable of stopping the vehicle from 60 miles ...	Pass	5.78 ft
Performance::Brake Heating	Braking at 60 miles per hour shall not generate more than 53 kW of heat at...	Pass	0.296 kw
	e of at least 36,000 miles under norma...	Pass	15.8 mi
	or less than 3200 pounds.	Unknown	
	diameter	Unknown	
	n diameter.	Unknown	

MagicDraw Plugin

File Edit Help

Project File: C:\MagicDrawExamples\CarBrakeDemo\CarBrakeDemo.mdzip Load...

Select a Subject to Analyze

- Data
  - Analysis
  - DesignBaselines
  - Requirements
  - Structure
    - Brake
    - Caliper
    - Engine
    - Pad
    - Rotor
    - Tire
    - Transmission
    - Vehicle
      - engine
      - par_VehicleAnalysis
      - transmission
      - wheel

Parametric Diagrams | Selection Filter

- Vehicle
  - par_VehicleAnalysis

Property	Units	Original	New	Margin
Vehicle.grossWeight	lb	3200.0	3200.0	
Vehicle.numberOfWheels	integer	4.0	4.0	
Vehicle.speed	mph	60.0	60.0	
Vehicle.wheel.brake.caliper.diameter	in	1.5	1.5	
Vehicle.wheel.brake.caliper.frictionForce	lb	30.0	30.0	
Vehicle.wheel.brake.caliper.pressure	psi	1000.0	1000.0	
Vehicle.wheel.brake.caliper.springForce	lb	50.0	50.0	
Vehicle.wheel.brake.pad.brakeMU	real	0.8	0.8	
Vehicle.wheel.brake.pad.centerLength	in	3.0	3.0	
Vehicle.wheel.brake.pad.thickness	in	0.275	0.275	
Vehicle.wheel.brake.pad.width	in	2.0	2.5	
Vehicle.wheel.brake.rotor.od	in	11.0	11.0	
Vehicle.wheel.tire.diameter	in	22.0	22.0	
Vehicle.wheel.tire.tireMU	real	0.9	0.9	
Vehicle.stopTime	s	3.959628	4.192547	
Vehicle.stoppingDistance	ft	174.223616	184.472064	4.47 ft
Vehicle.wheel.brake.torque	ft-lb	506.143751	478.024654	
Vehicle.wheel.brake.caliper.cost	usd	73.0	77.5	
Vehicle.wheel.brake.caliper.normalForce	lb	1687.145838	1687.145838	
Vehicle.wheel.brake.pad.cost	usd	3.3	4.125	
Vehicle.wheel.brake.pad.effectiveRadius	in	4.5	4.25	
Vehicle.wheel.brake.pad.heat	kw	52.704007	49.776006	3.22 kw
Vehicle.wheel.brake.pad.life	mi	36015.789222	47667.956324	1.17e+04 mi
Vehicle.wheel.brake.pad.surfaceArea	in^2	6.0	7.5	
Vehicle.wheel.brake.rotor.cost	usd	61.3	61.3	

Reset Values | Create Components | Run Now | Save | Save As...

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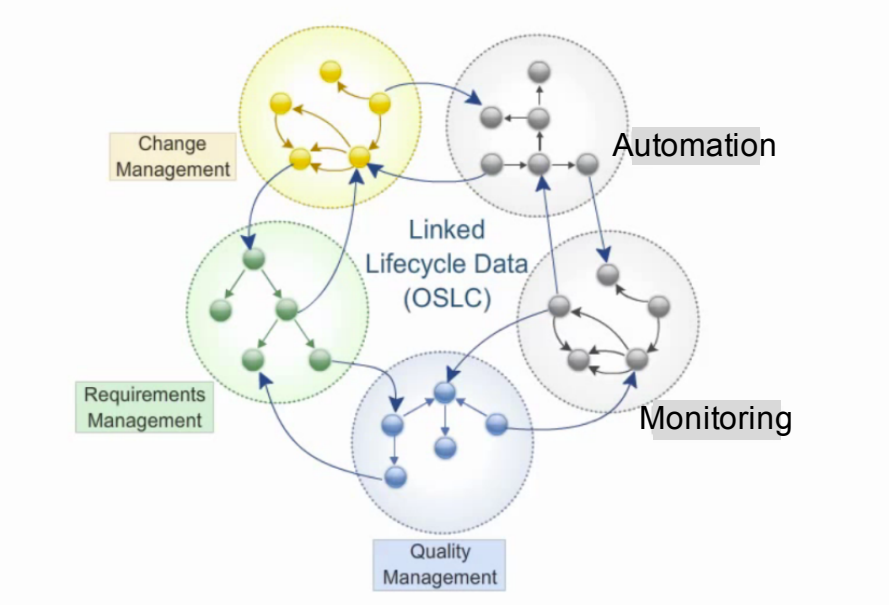
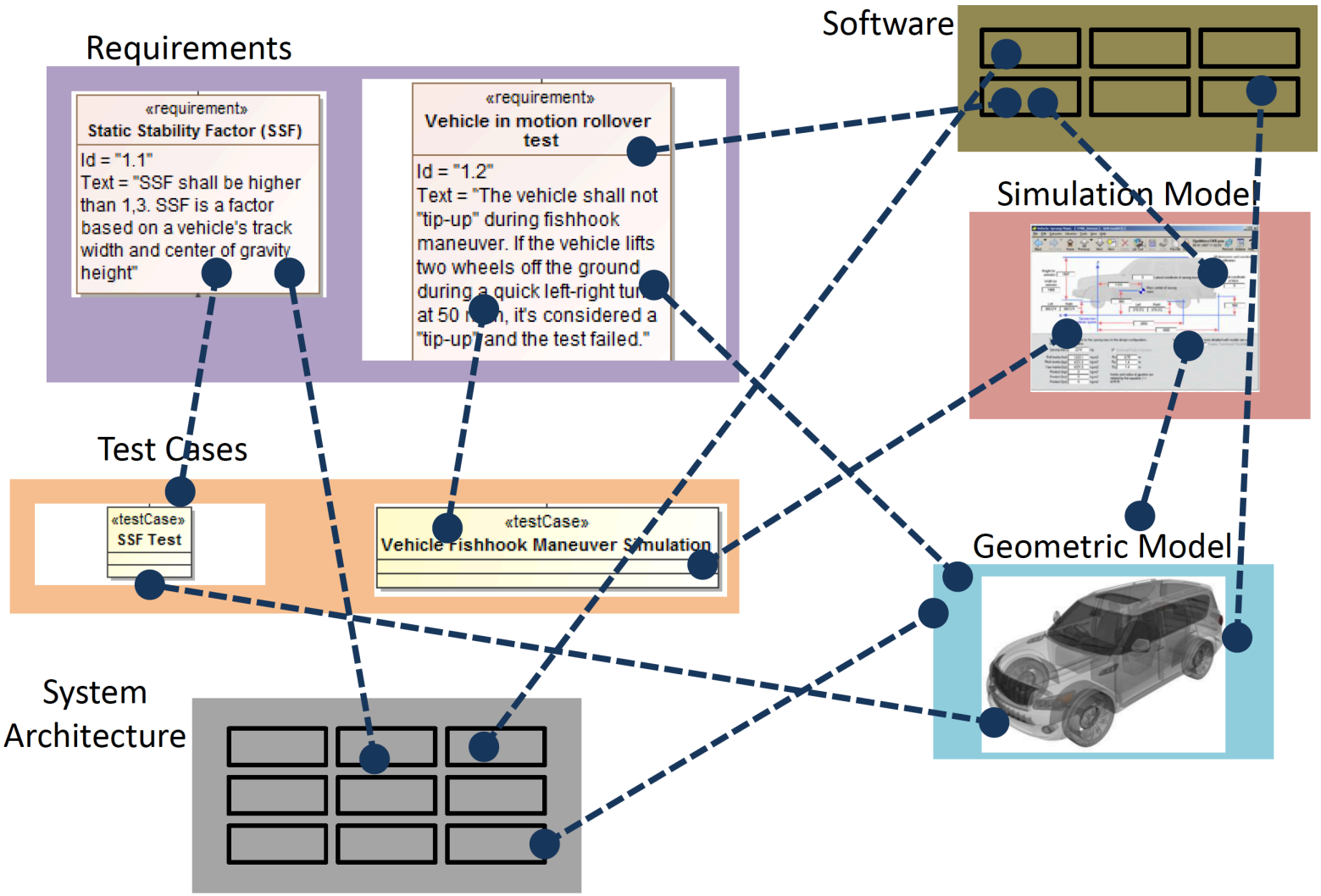
OSLC
Open Services for Lifecycle Management



Relationships among engineering data

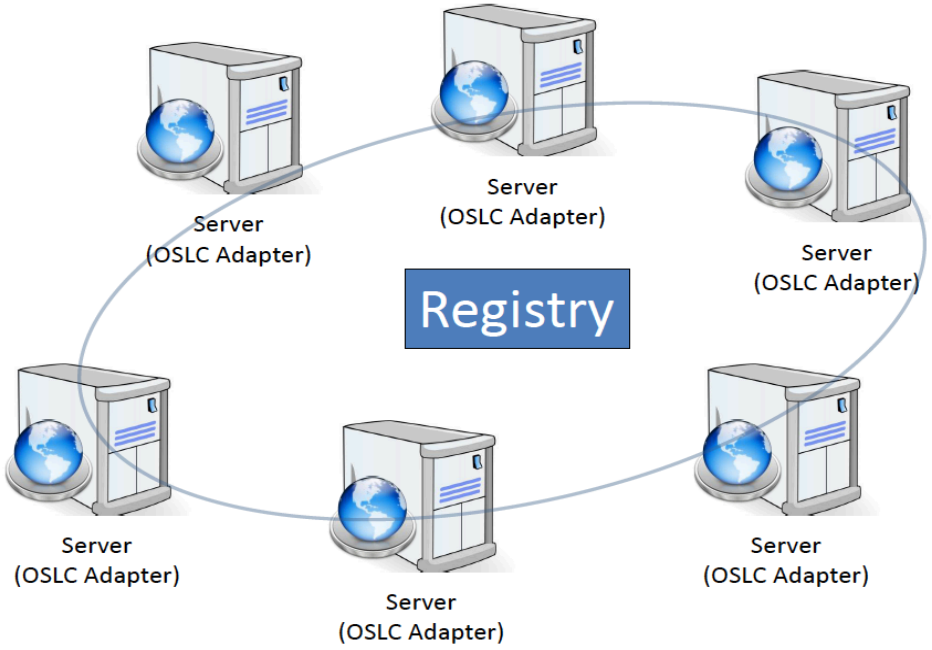


Credits: Axel Reichwein, Koneksys

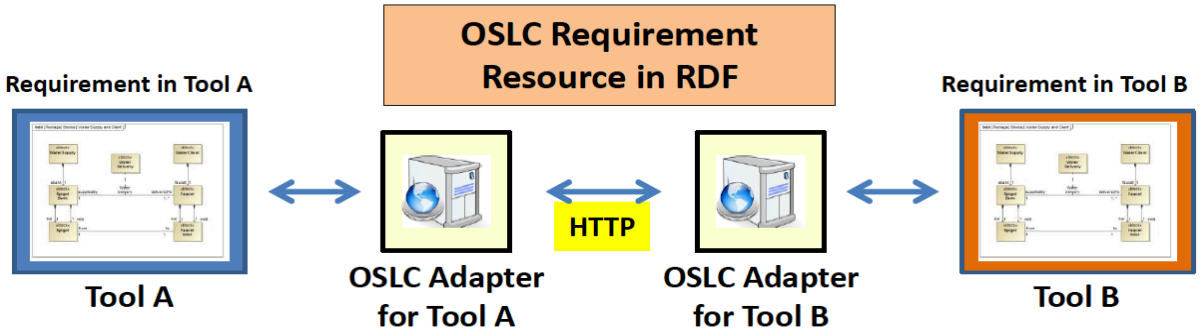
Open Services for Lifecycle Management (OSLC)

- OSLC = Reusing the Web for tool integration
- Based on **Linked Data** and **Representational State Transfer (REST)**
- Initiated by IBM
- Adopted by many tool vendors
- Managed by OASIS

OSLC Service & Resource Registry



Interoperability Through OSLC



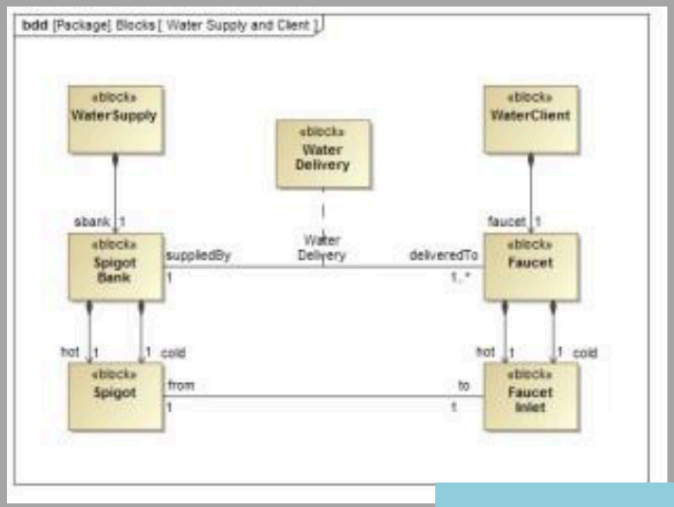
OSLC4MBSE Working Group

- Definition of new RDF vocabularies for engineering data
- Bridge between systems engineering and OSLC communities

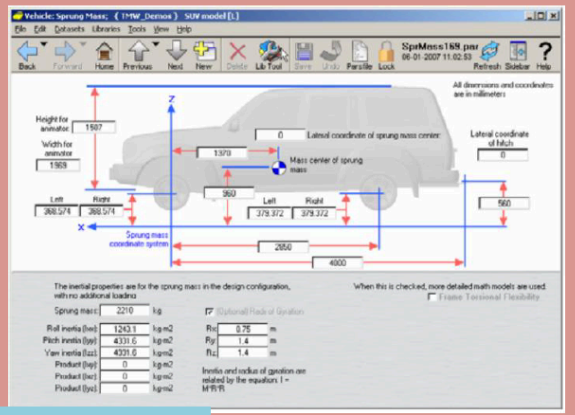
Domain	Status
Core	2.0
Architecture Management	2.0
Asset Management	2.0
Automation	2.0
Change Management	2.0
Performance Monitoring	2.0
Quality Management	2.0
Reconciliation	2.0
Requirements Management	2.0
Reporting	Converge
Estimation and Measurement	Converge
ALM/PLM Interoperability	Draft
Configuration Management	Scope

Missing OSLC specifications

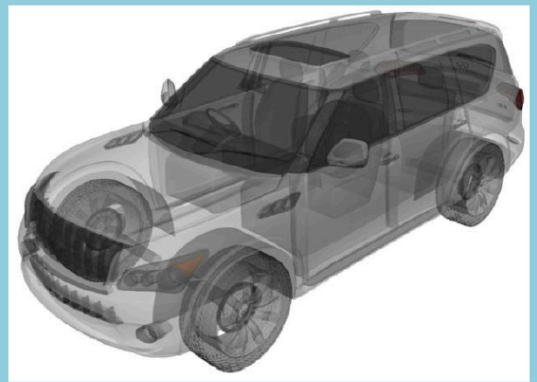
System Architecture



Dynamic Simulation



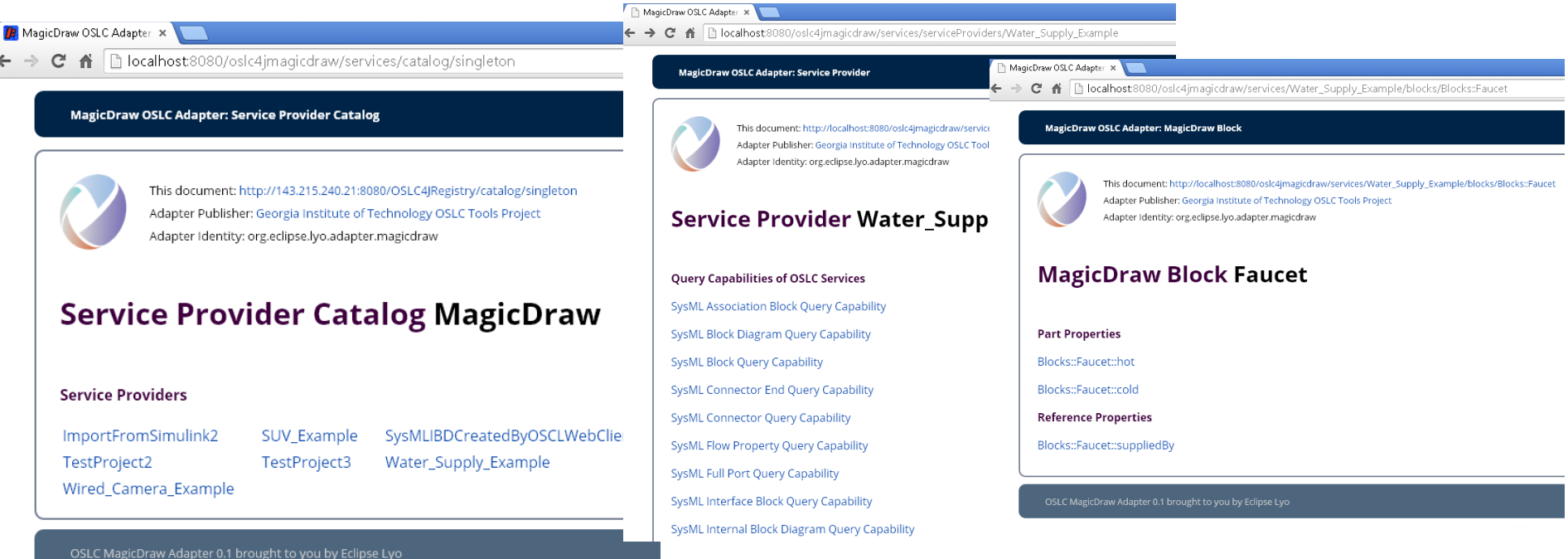
3D Geometry (CAD)



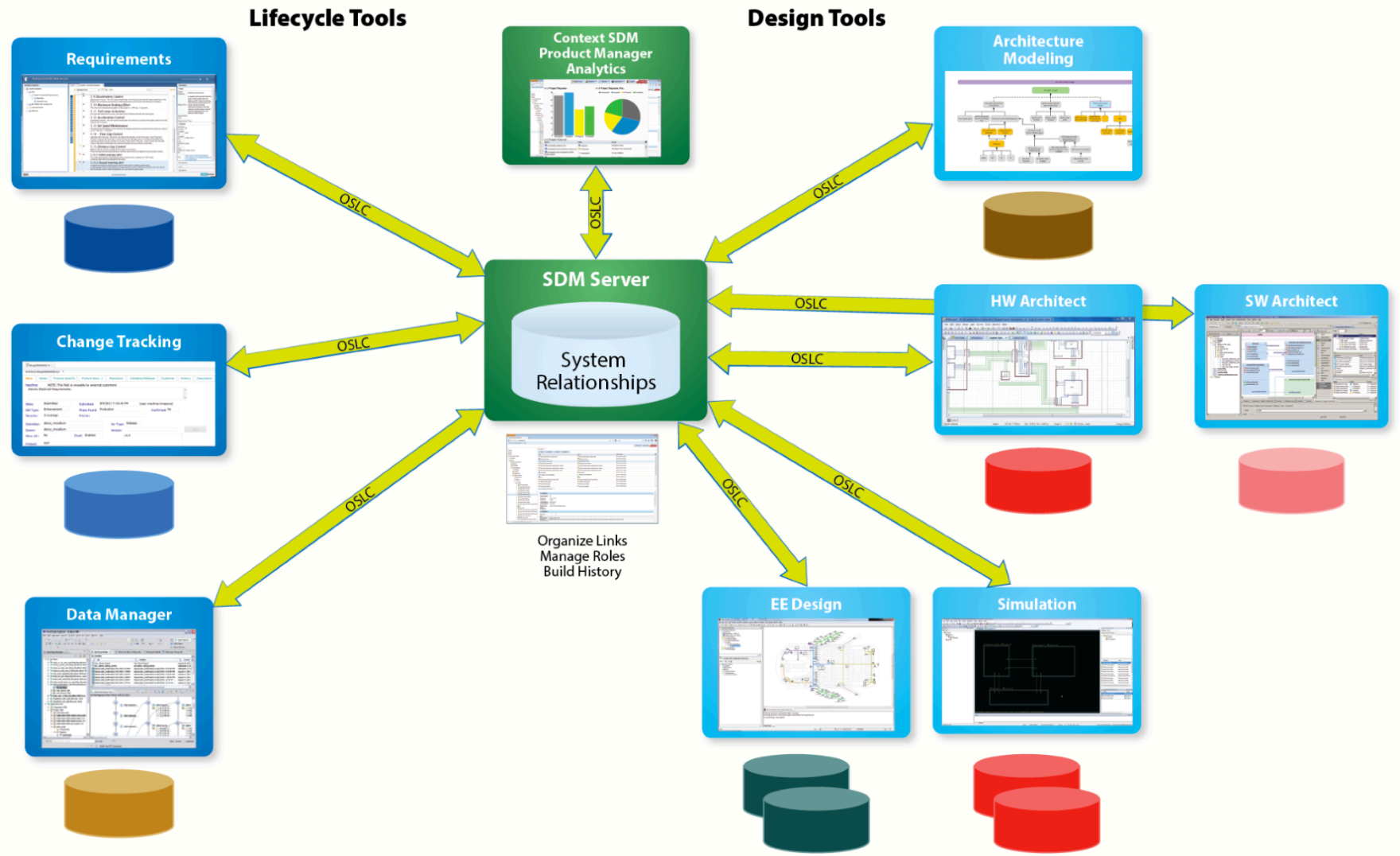
MagicDraw as OSLC data provider

Open-source MagicDraw OSLC adapter

- http://wiki.eclipse.org/Lyo/MagicDraw
- MagicDraw as content provider
- Access SysML elements as OSLC resources
- Add Blocks to SysML models
- Browse projects and diagrams on a web browser

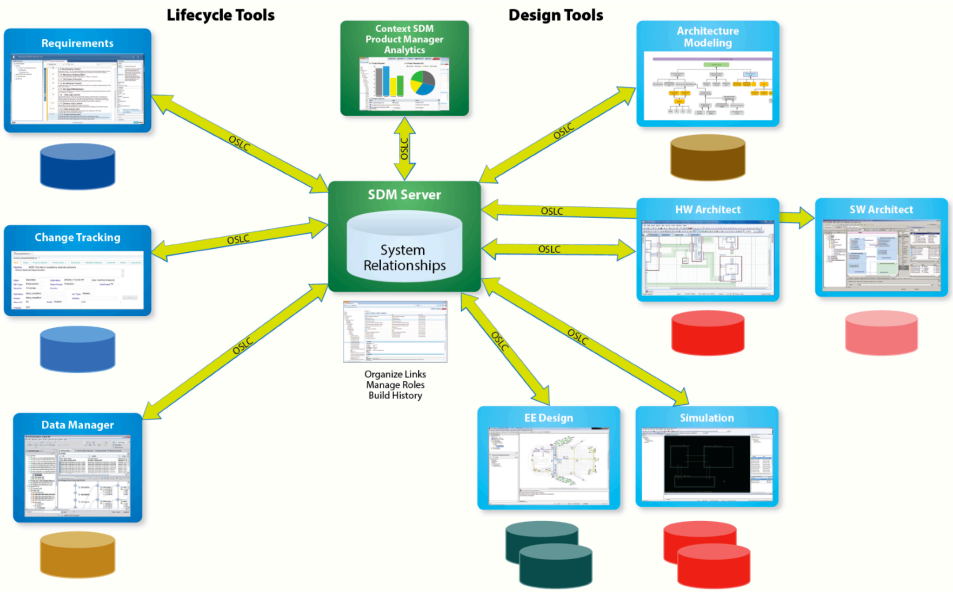


Mentor Graphics Context®
System Design Management (SDM) platform

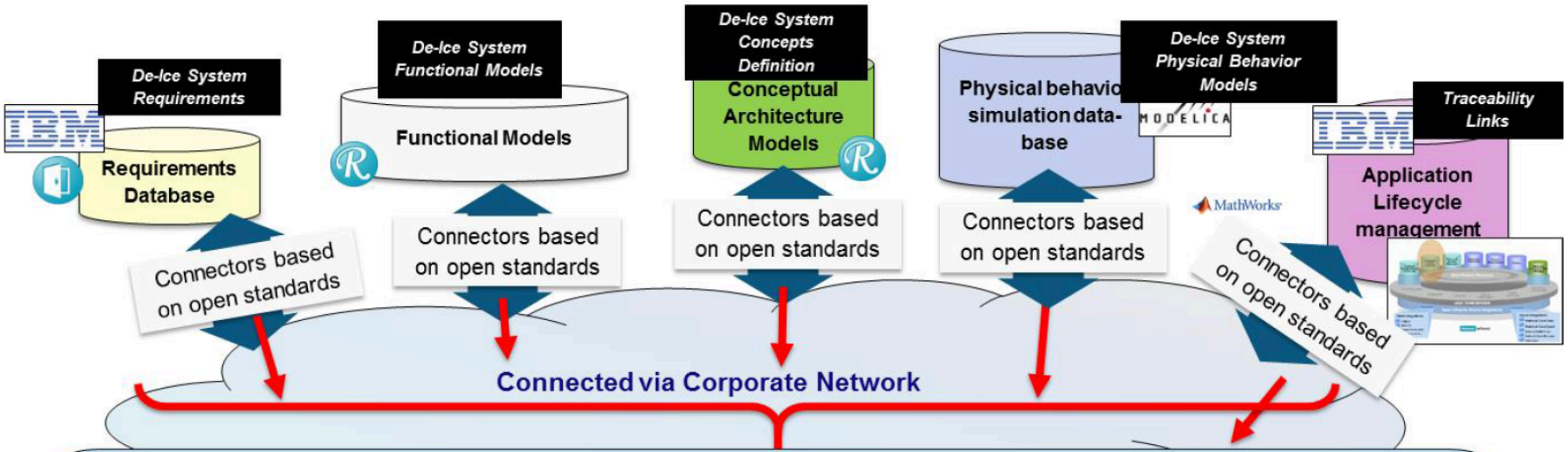


Plugins for Context SDM

Vendor Name	Tool Name	Category of Tool (Design/lifecycle)	Type of tool
Mentor Graphics	**SystemVision**	Design	Modeling/simulation
Mentor Graphics	**System Designer**	Design	Schematic/block design
Mentor Graphics	**Xpedition**	Design	PCB layout solution
Mentor Graphics	**Capital family**	Design	Electric/wire harness design & Synthesis
Mentor Graphics	**Volcano VSA family**	Design	Dev. of in-vehicle networks and comm.
Mentor Graphics	**Sourcery CodeBench**	Design	Comprehensive IDE environment for embedded code uses.
Mentor Graphics	**Additional tools**	Design	To be integrated with Context & OSLC
OneFact	**BridgePoint**	Design	UML creation, execution Compliers
IBM	**Rational Rhapsody**	Design	System modeling tool
Sparx	**Enterprise Architect**	Design	UML & SysML modeling tool family
MathWorks	**Matlab/Simulink**	Design	Math design and simulation tools
Cadence	**Virtuoso**	Design	Design and simulation for IC
Isograph	**Reliability Workbench**	Analysis	Fault tree analysis and modeling
EPRI	**CAFTA**	Analysis	Math fault modeling tool
IBM	**Rational DOORS**	Lifecycle	Requirements management tool
IBM	**RELM**	Lifecycle	System lifecycle coordination tool
IBM	**Rational ClearQuest**	Lifecycle	Tracking tool
Cognition	**Cognition Cockpit**	Lifecycle	Requirements management tool
Polarion	**Polarion Requirements**	Lifecycle	Requirements & project management
Apache	**Subversion (SVN)**	Lifecycle	Open source revision management capability
Allassian	**Jira**	Lifecycle	Tracking tool
Allassian	**Confluence**	Lifecycle	Collaboration tool
IBM	**ClearCase**	Lifecycle	Revision management
IBM	**Rational Team Concert**	Lifecycle	Change and revision management
IBM	**Rational Quality Manager**	Lifecycle	Test management
Adobe	**PDF**	Other	Document handling
Microsoft	**Visio**	Other	Selected diagram import
Microsoft	**Word**	Other	Requirements access & report generation
Microsoft	**Excel**	Other	Data access
Microsoft	**Project**	Other	Bi-directional data access

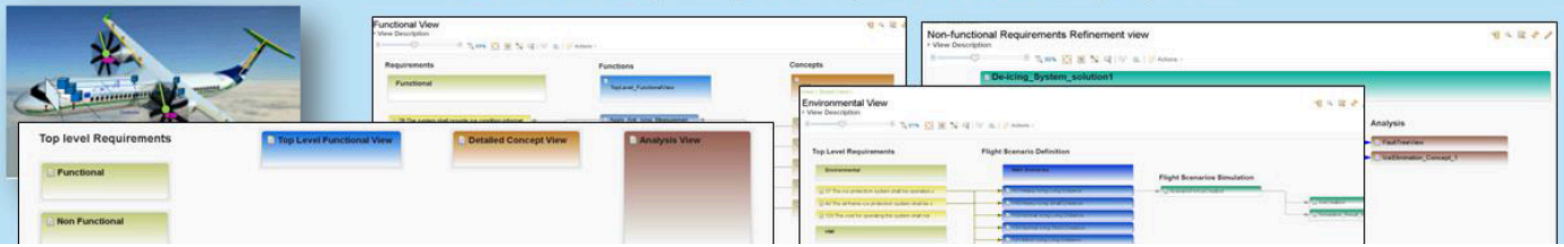


Implementation example (CRYSTAL)



Current CRYSTAL Demonstrator (based on IBM RELM)

- Focus on "Change Impact Analysis EM"
- Show Traceability Links between Artefacts of De-Icing System
- Assess change request impact on De-Icing System



PLM & MBSE Integration

PLM4MBSE Working group

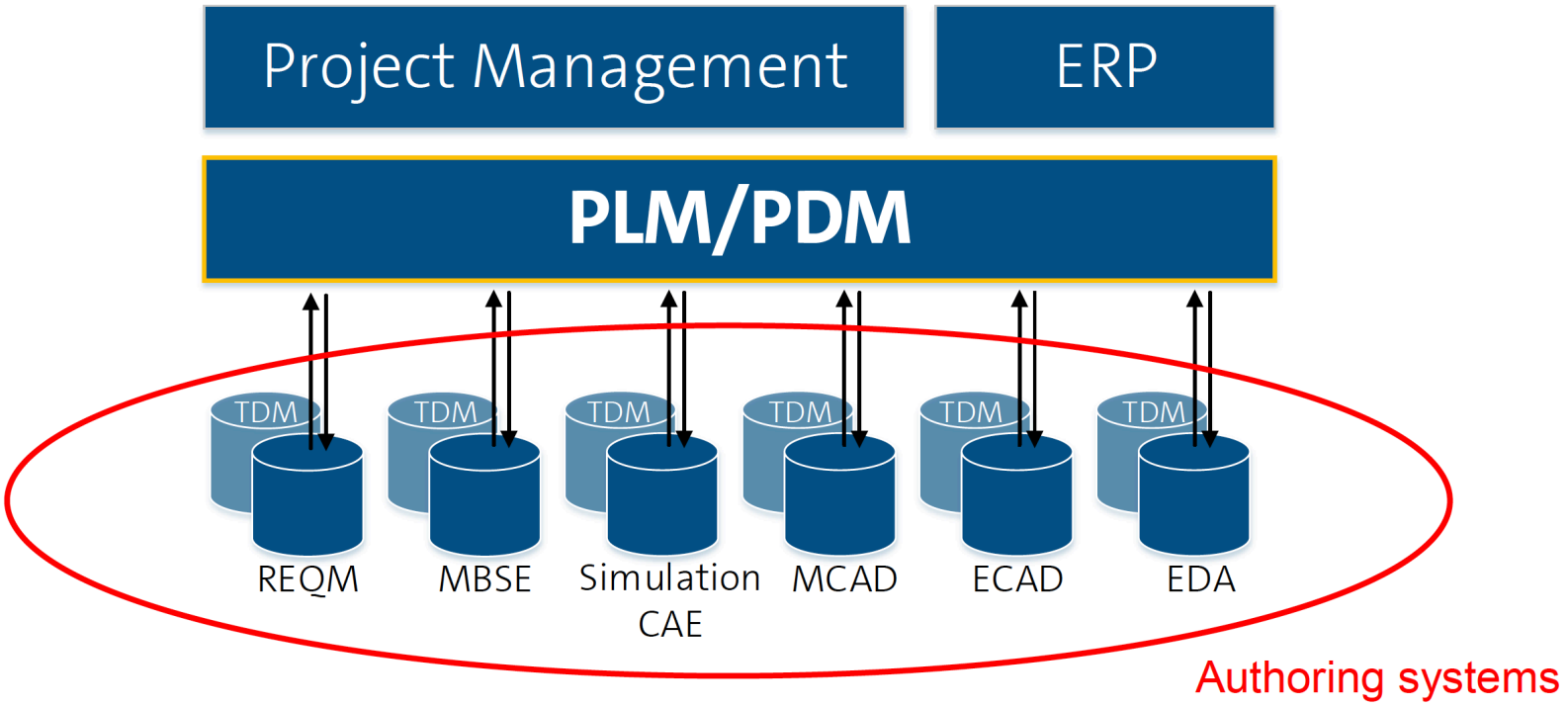
German INCOSE chapter and OMG

Major PLM and MBSE tool vendors:
Siemens TC, Dassault Enovia, PTC Windchill, Aras

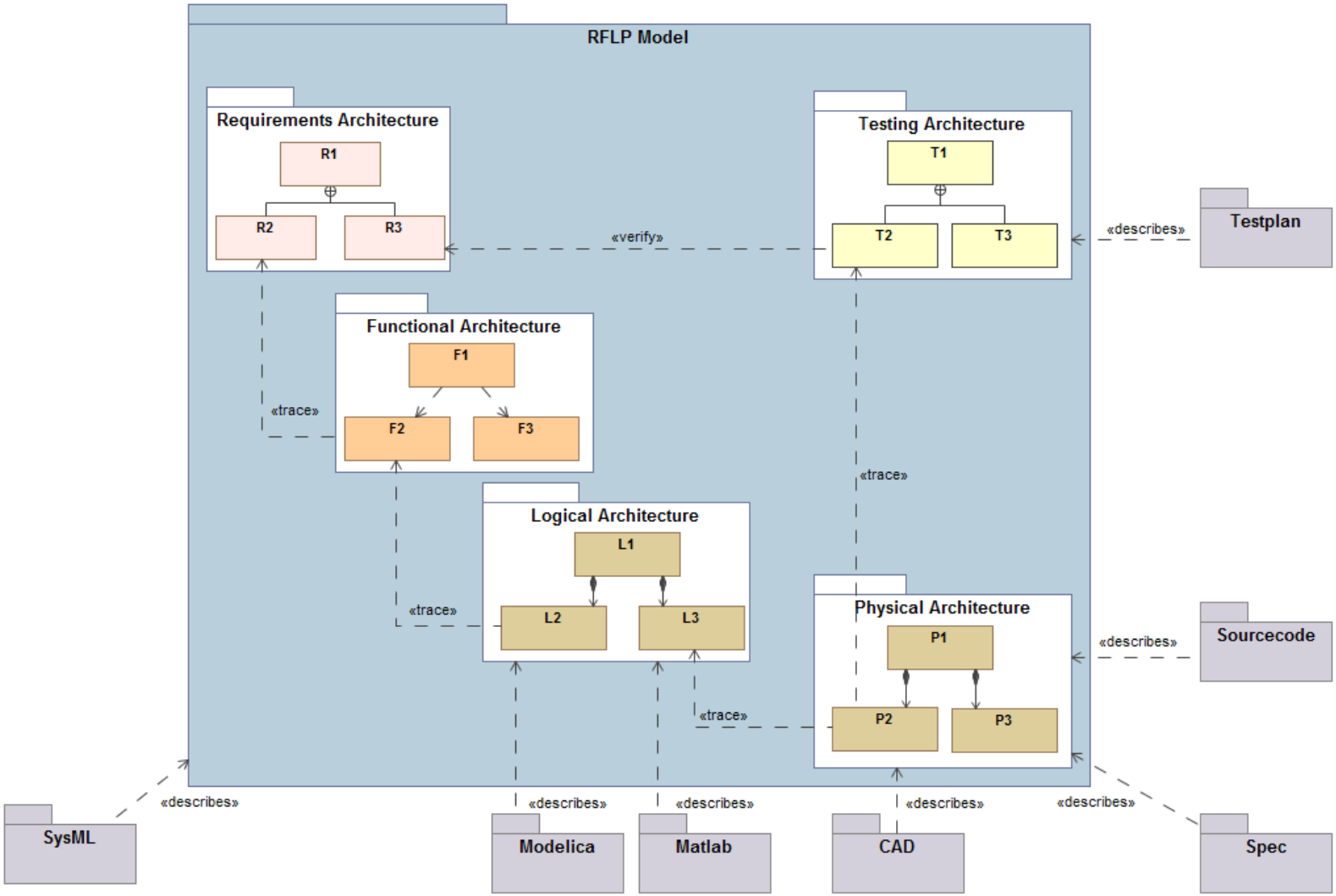
The aim of the working group is the development of requirements for MBSE authoring tools like SysML and Modelica and the architecture and interfaces of PLM systems for improved cross-disciplinary cooperation in the product development process.

Identification of potential standardization work and collaboration with organizations such as OMG (SysML, PLM Services, ReqIF), OASIS (OSLC, PLCS) and ProSTEP iViP (STEP, Smart Systems Engineering).

PLM Viewpoint



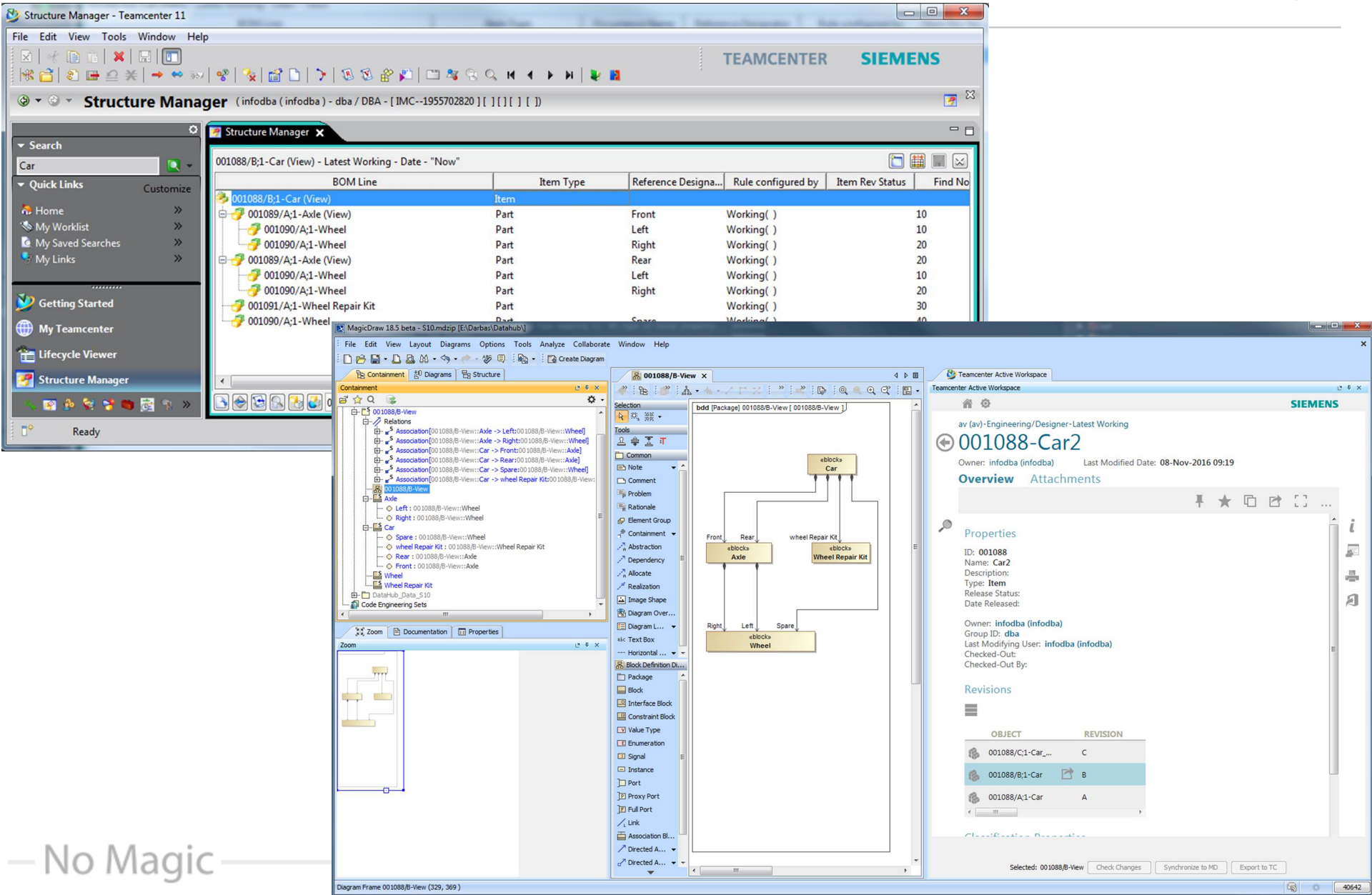
RFLP


RFLP Model
Requirements Architecture
R1
R2
R3
Testing Architecture
T1
T2
T3
«verify»
«describes»
Testplan
Functional Architecture
F1
F2
F3
«trace»
«trace»
Logical Architecture
L1
L2
L3
«trace»
Physical Architecture
P1
P2
P3
«describes»
Sourcecode
«trace»
«describes»
SysML
«describes»
Modelica
«describes»
Matlab
«describes»
CAD
«describes»
Spec

PLM and MagicDraw integrations

- **Aras Innovator**
  - Made by XPLM on Aras side, available
- **Dassault Enovia**
  - Made at Dassault side, using Reqtify mapping tool
  - DesignSync integration to TeamworkServer
- **Siemens TeamCenter**
  - Based on DataHub
  - TC window inside MD

SIEMENS Teamcenter integration

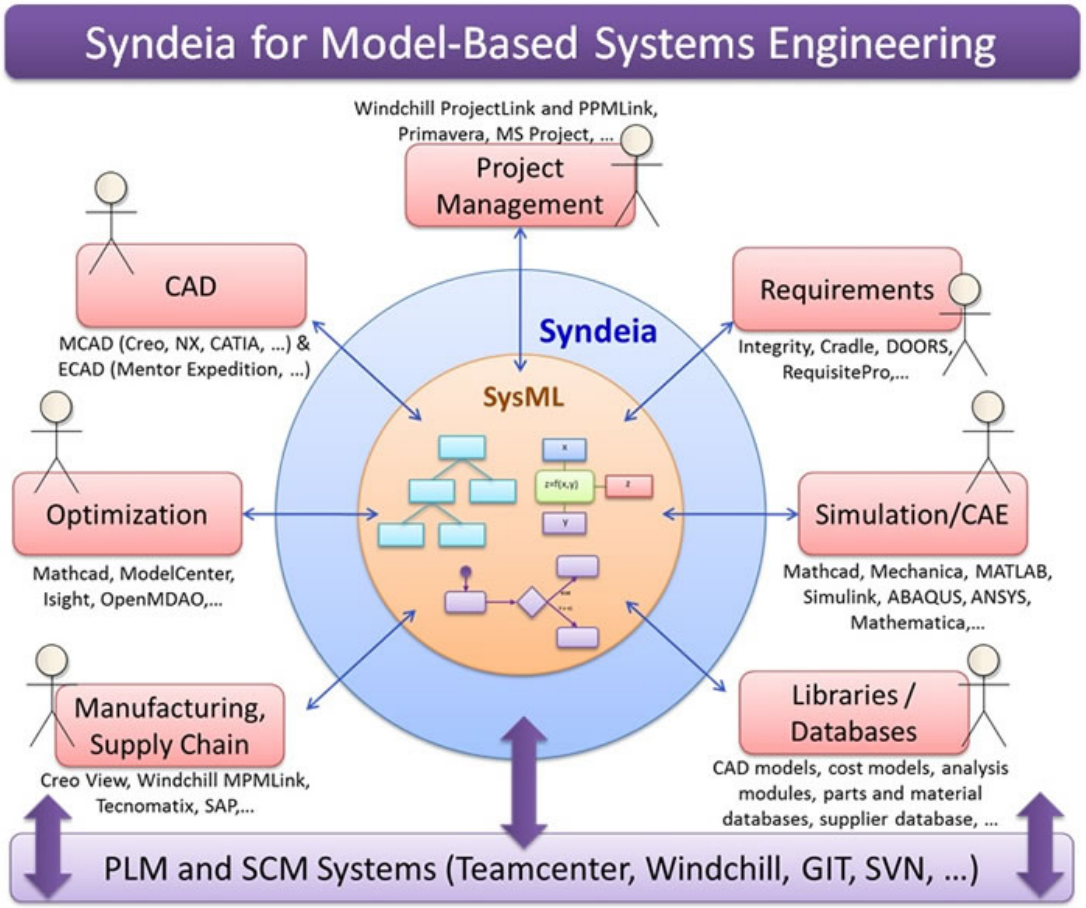


No Magic

Syndeia for MagicDraw

Connects and syncs MagicDraw models with:

- PLM (Teamcenter and Windchill)
- CAD (NX, Creo)
- SQL databases
- Simulink
- Requirements



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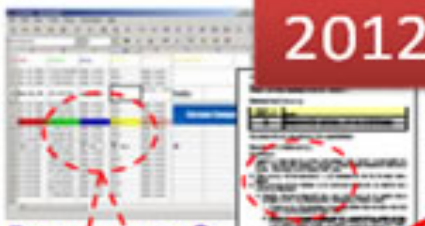
Syndeia creates and manages the TSM federation

TOTAL SYSTEM MODEL (TSM)

2012-07-12, 1000h US ET

B.20

CAD model
(Creo, NX, CATIA,...)



Documents &
Spreadsheets

Connections based on Reference, Data Map, Function Wrap, Model Transform, and Composite patterns

B1

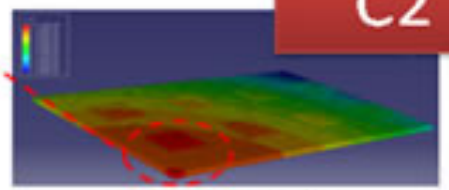
Requirement models

SysML

v35

MATLAB / Simulink &
Mathematica models

Rev 7



C2

CAE (FEA/CFD) models

Max *f(x,y)*
given:
- $g_1(x,y) < z_1$
- $g_2(x,y) > z_2$
- ...

v3

Optimization models

Other Artifacts and Databases

latest

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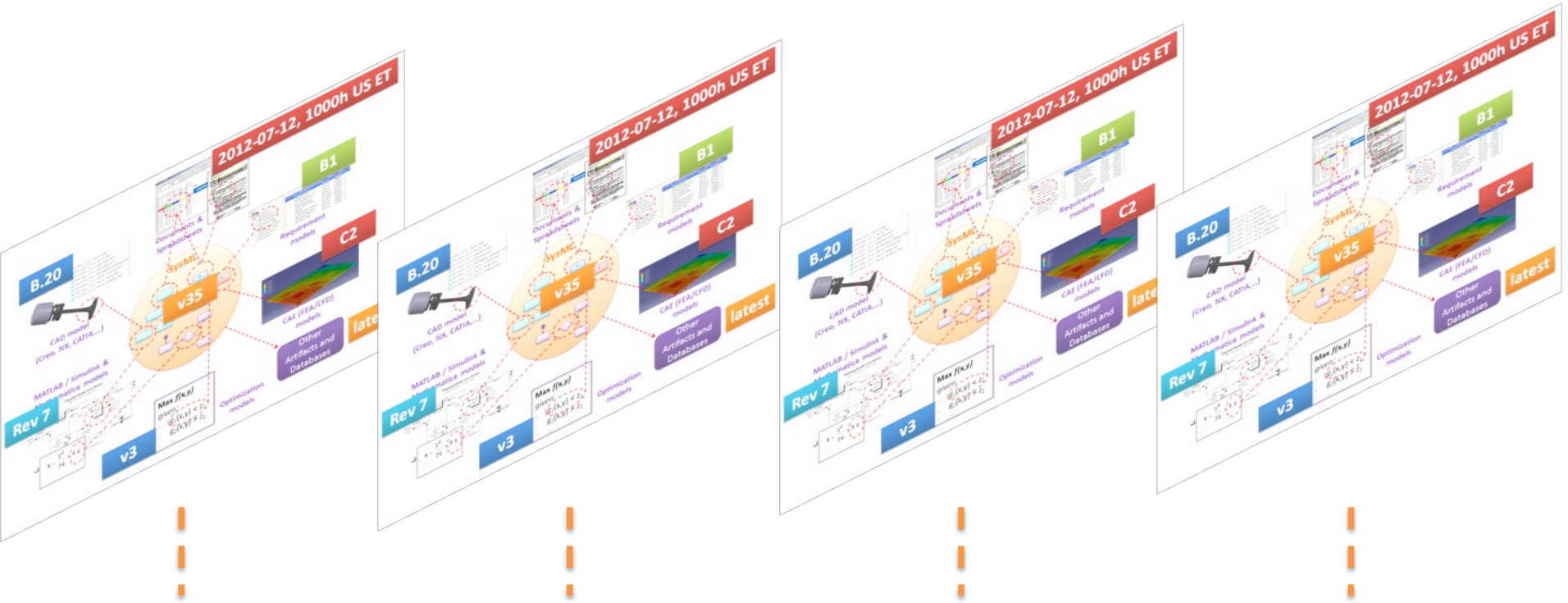
Total System Model History



T1 T2 T3 T4

(Baseline B1) ***(Baseline B2)***

Timeline

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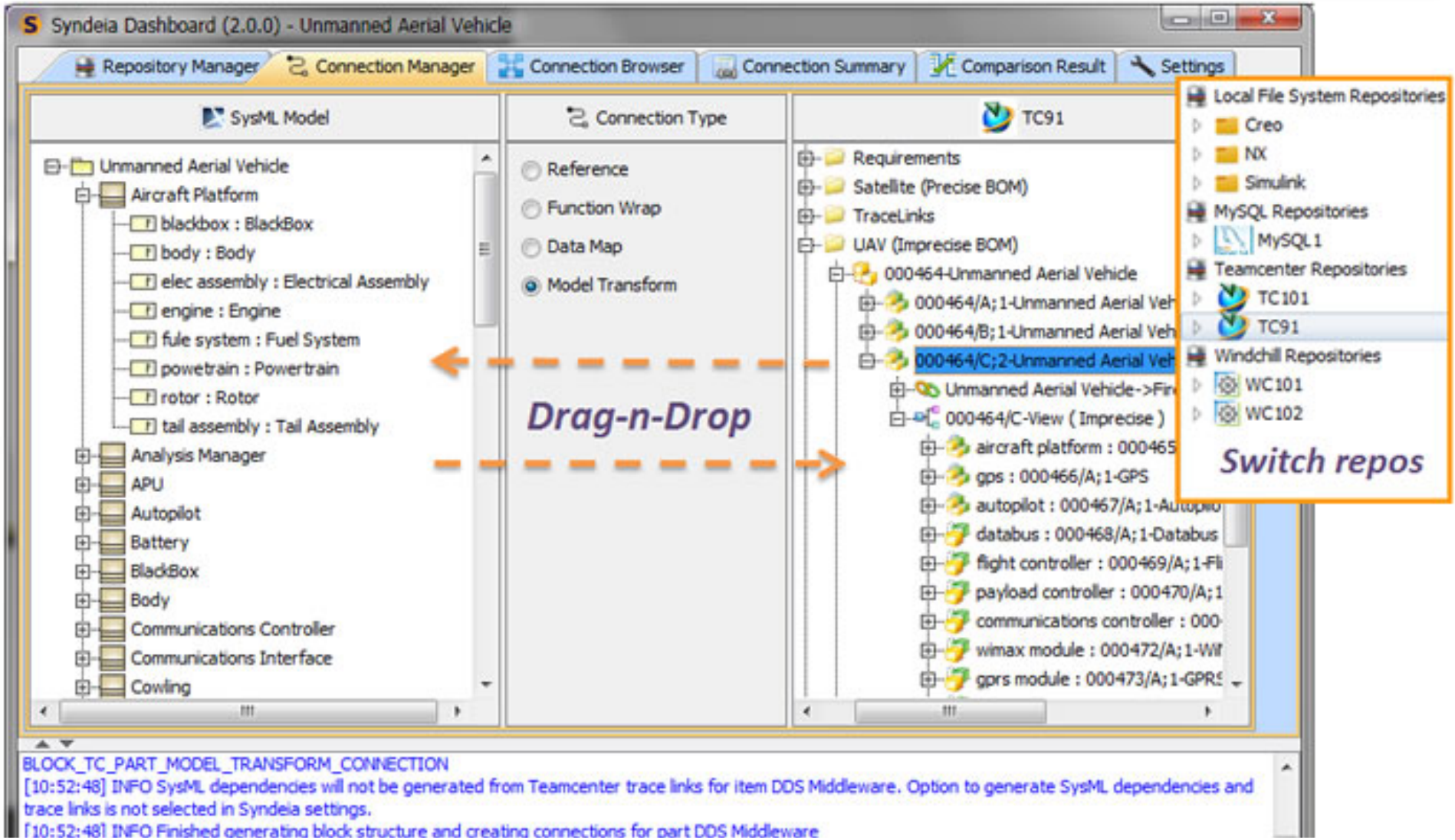
Browse and drag'n'drop



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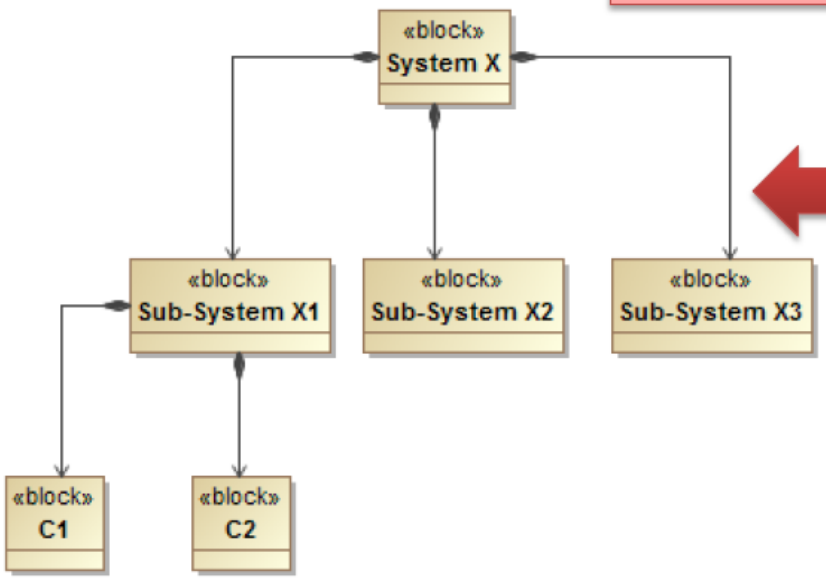
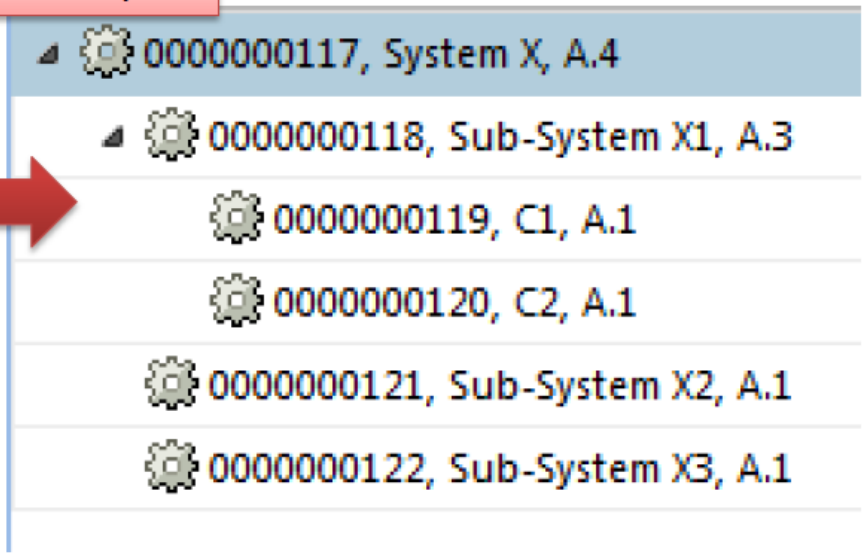
BOM <-> SysML

Generating PLM part structure from SysML block structure and vice versa

Auto-generation and sync





SysML model
block structure

Part structure (BOM) in PLM systems
(e.g. Windchill)

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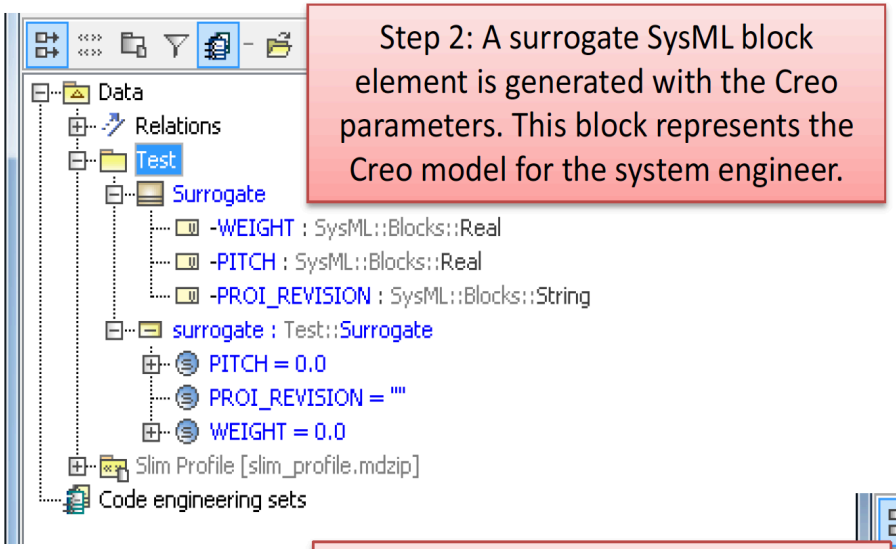
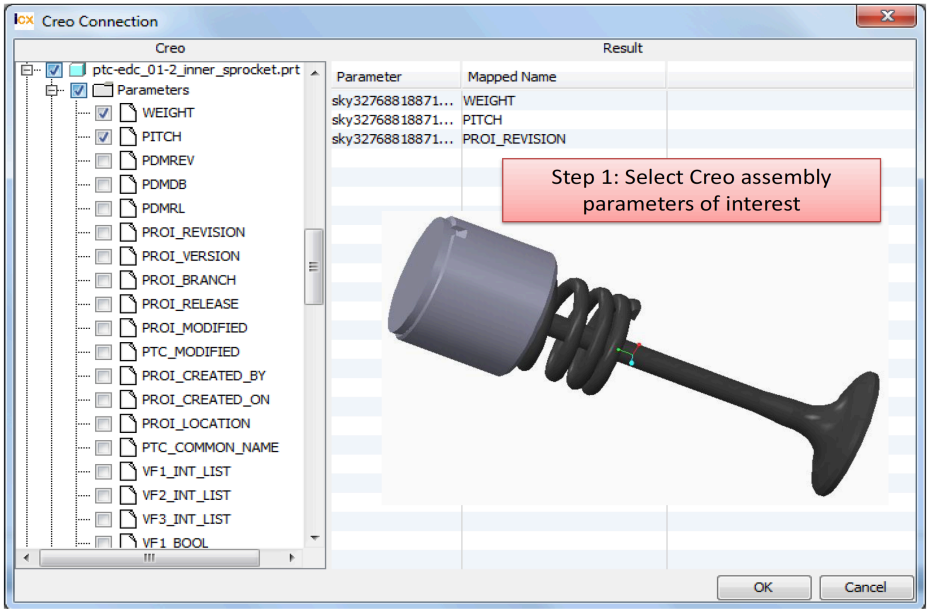
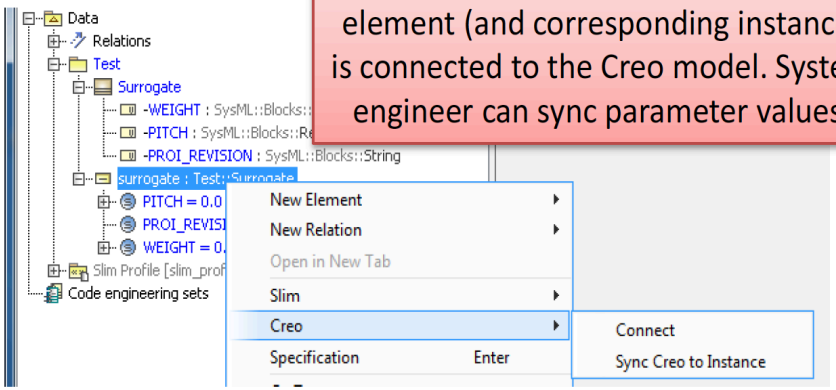
Reading geometrical data from CAD



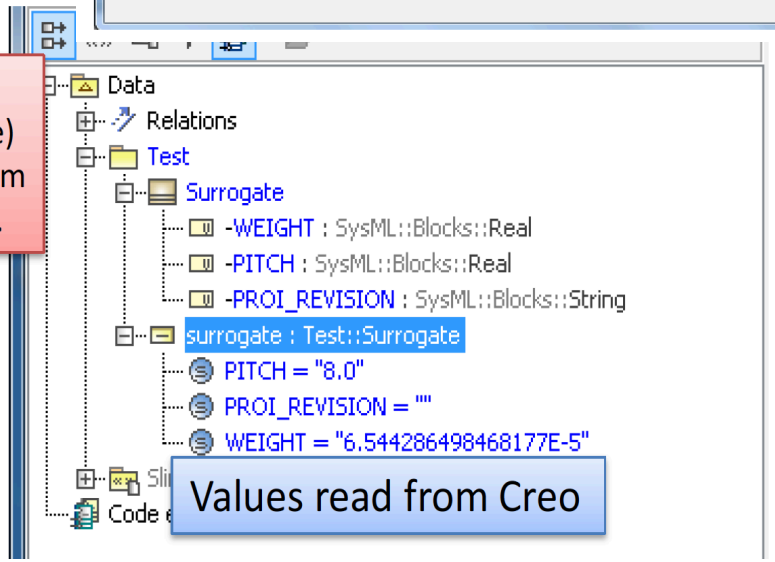
Step 2: A surrogate SysML block element is generated with the Creo parameters. This block represents the Creo model for the system engineer.



Step 1: Select Creo assembly parameters of interest

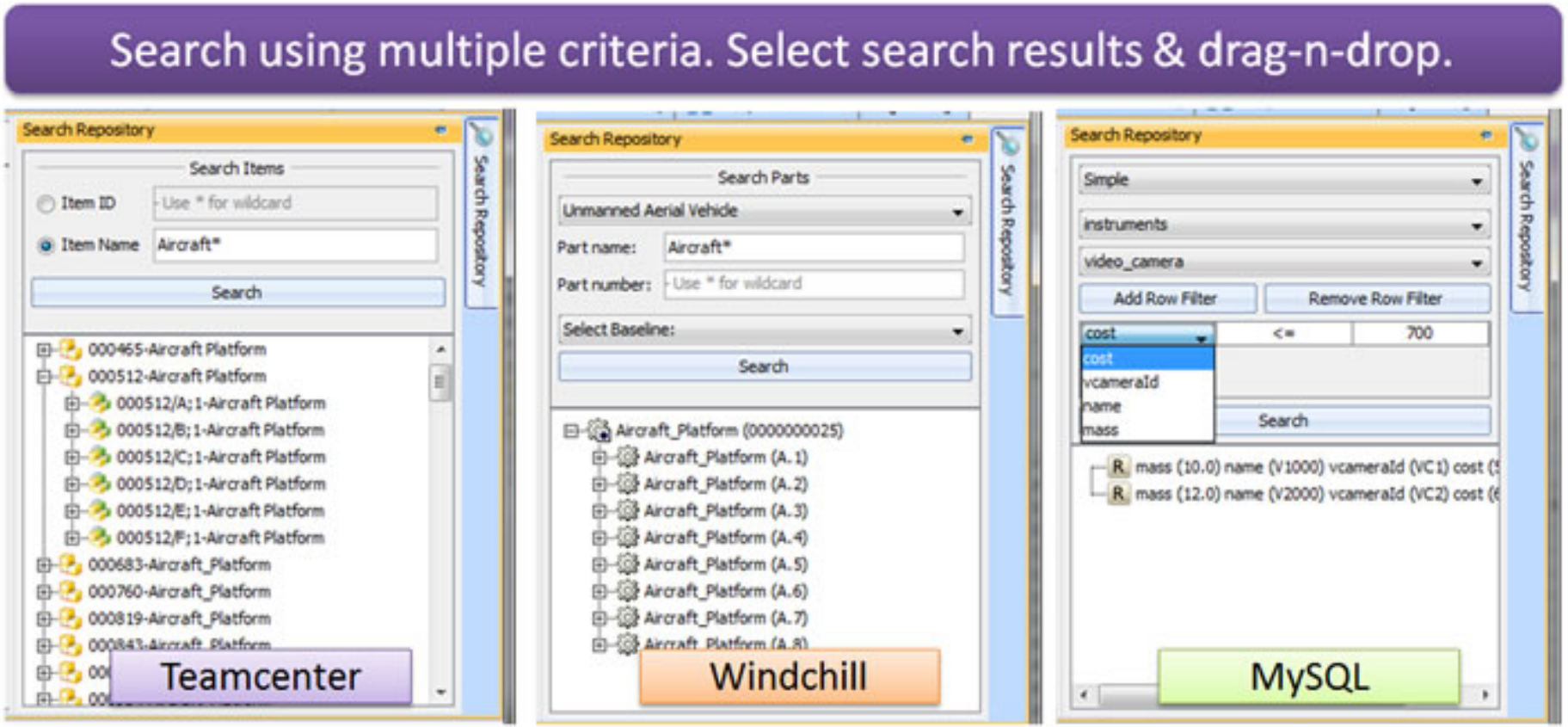


Step 3: The surrogate SysML block element (and corresponding instance) is connected to the Creo model. System engineer can sync parameter values.



Values read from Creo

Universal Search



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Central Model Repository

MagicDraw Teamwork Server

- **Global project repository**
  - Projects
  - Users
  - Permissions
- **Collaboration inside a project**
  - Locking/unlocking model elements
  - Seeing who has locked which elements
  - Submitting changes
- **Change management**
  - Versioning
  - Branching
  - Comparing
  - Merging

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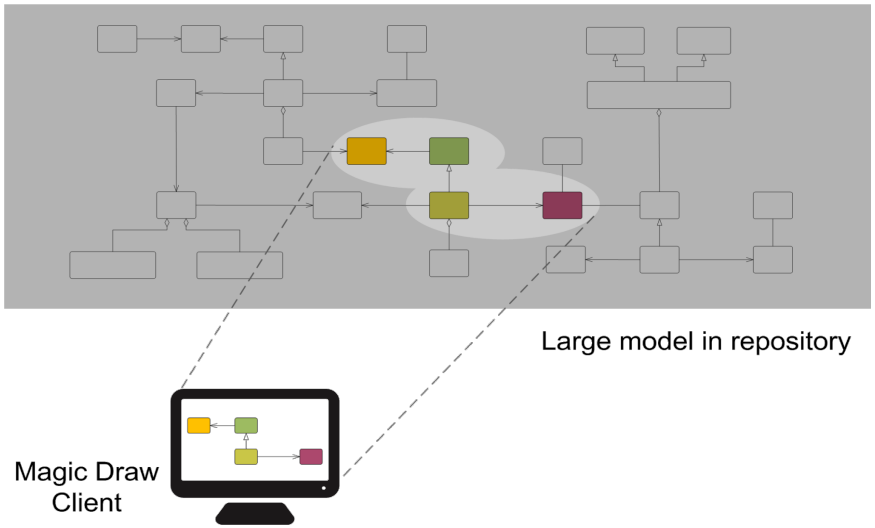
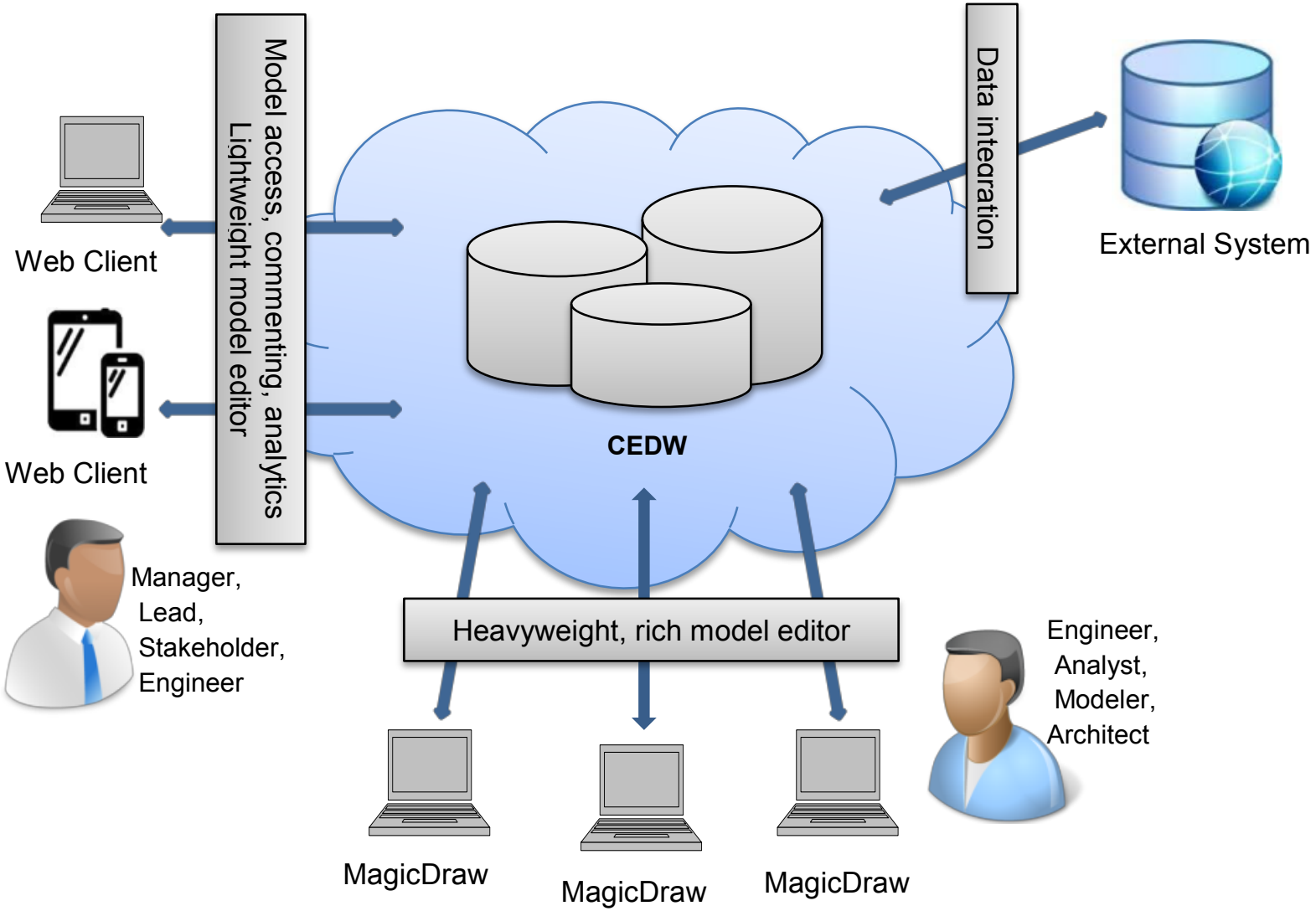
Teamwork Cloud (TWC)

- Next generation repository
  - Distributed, clustered, scalable database
  - Element-level version control
  - Partial, lazy loading to the client
  - Role-based access control
  - Delta commits
  - Server-side API and plugins
  - Web clients (RESTful API)
  - Linked data (OSLC)

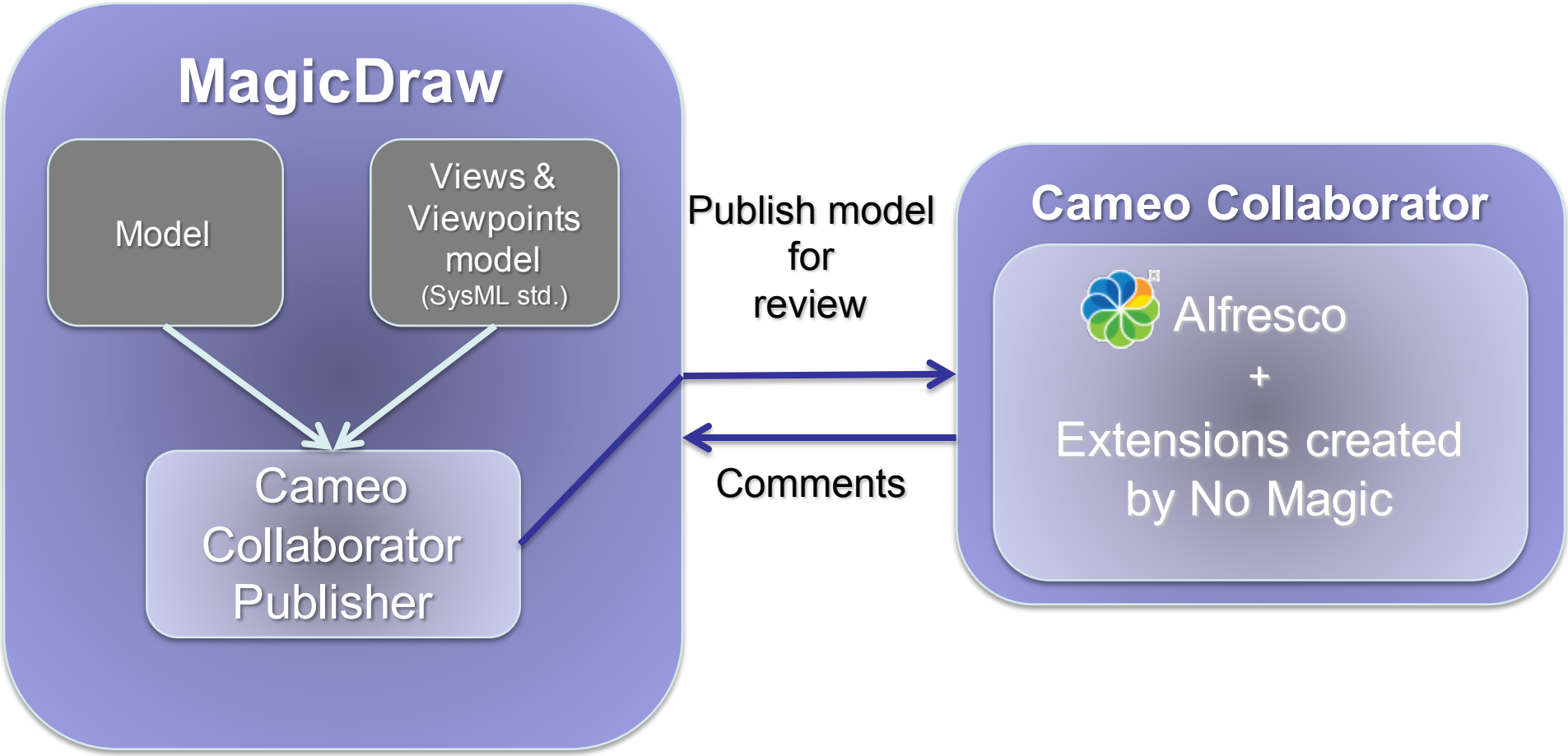


Teamwork Cloud (TWC)

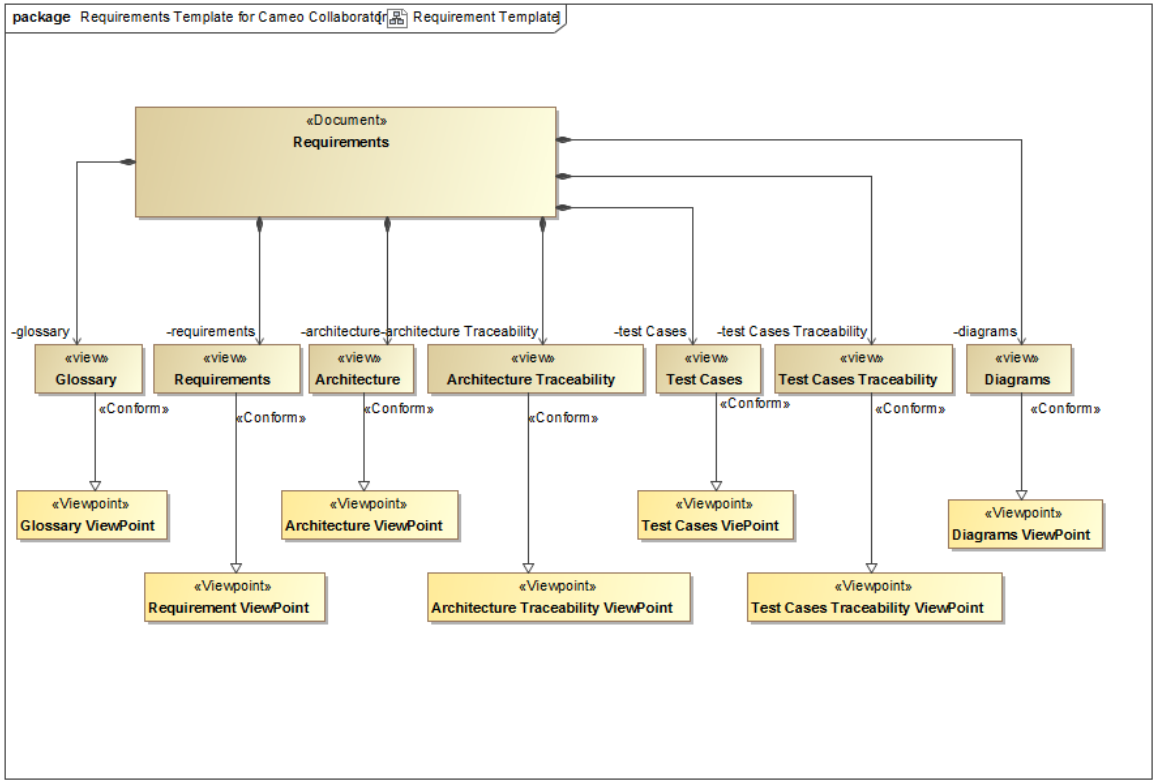


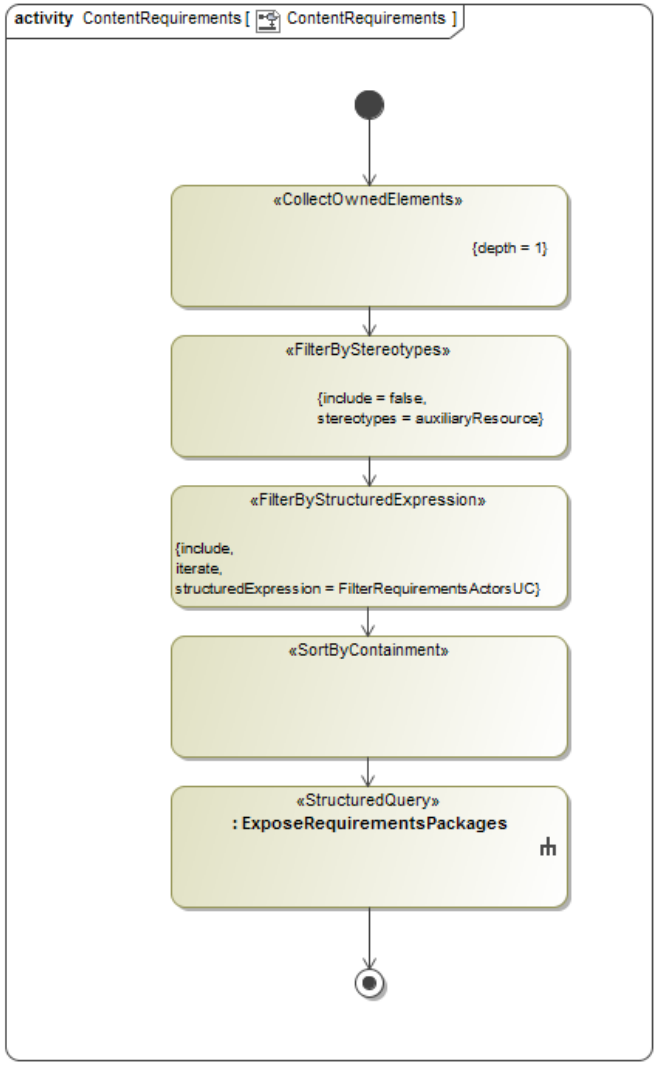
Model Publishing

Cameo Collaborator architecture

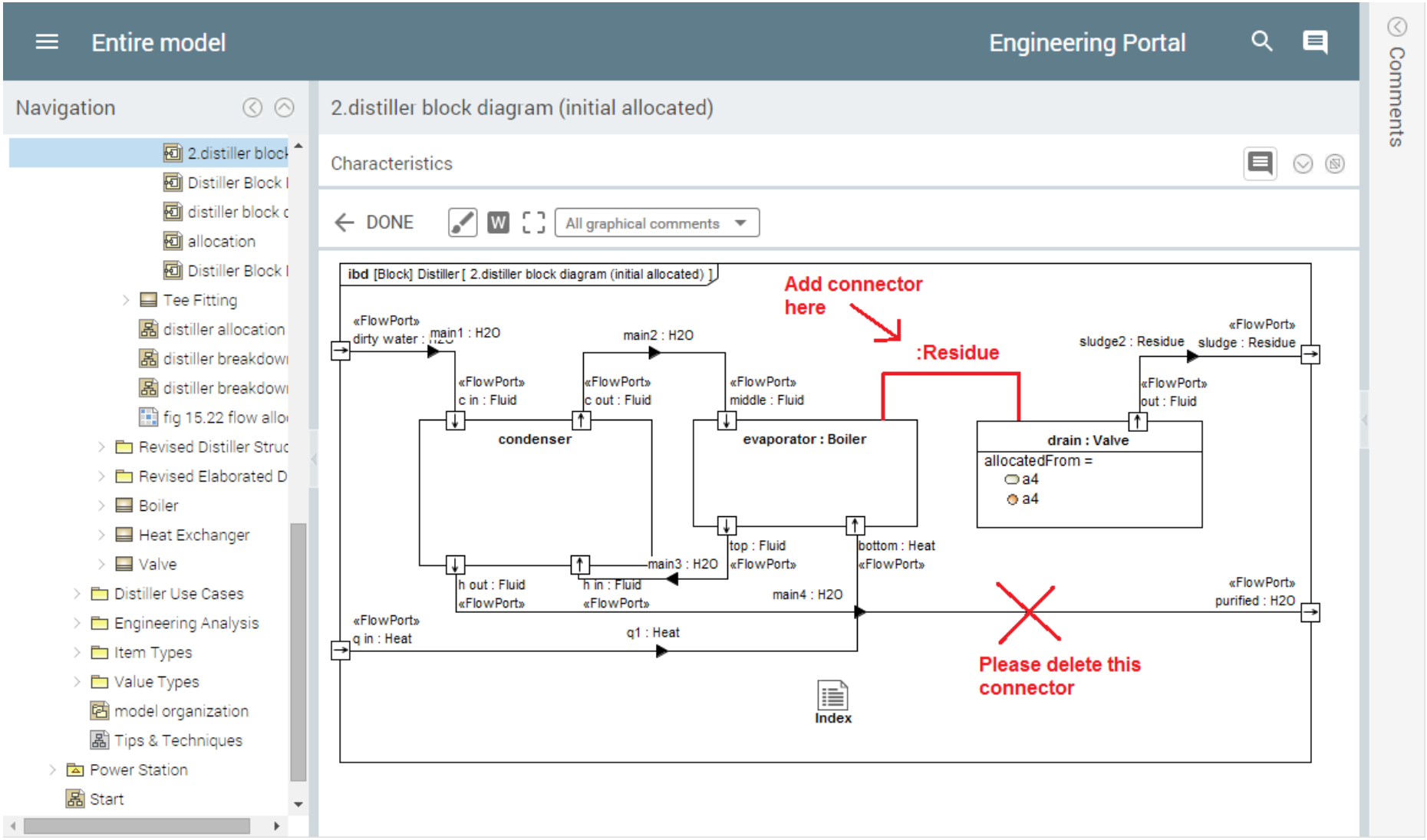


Views & Viewpoints

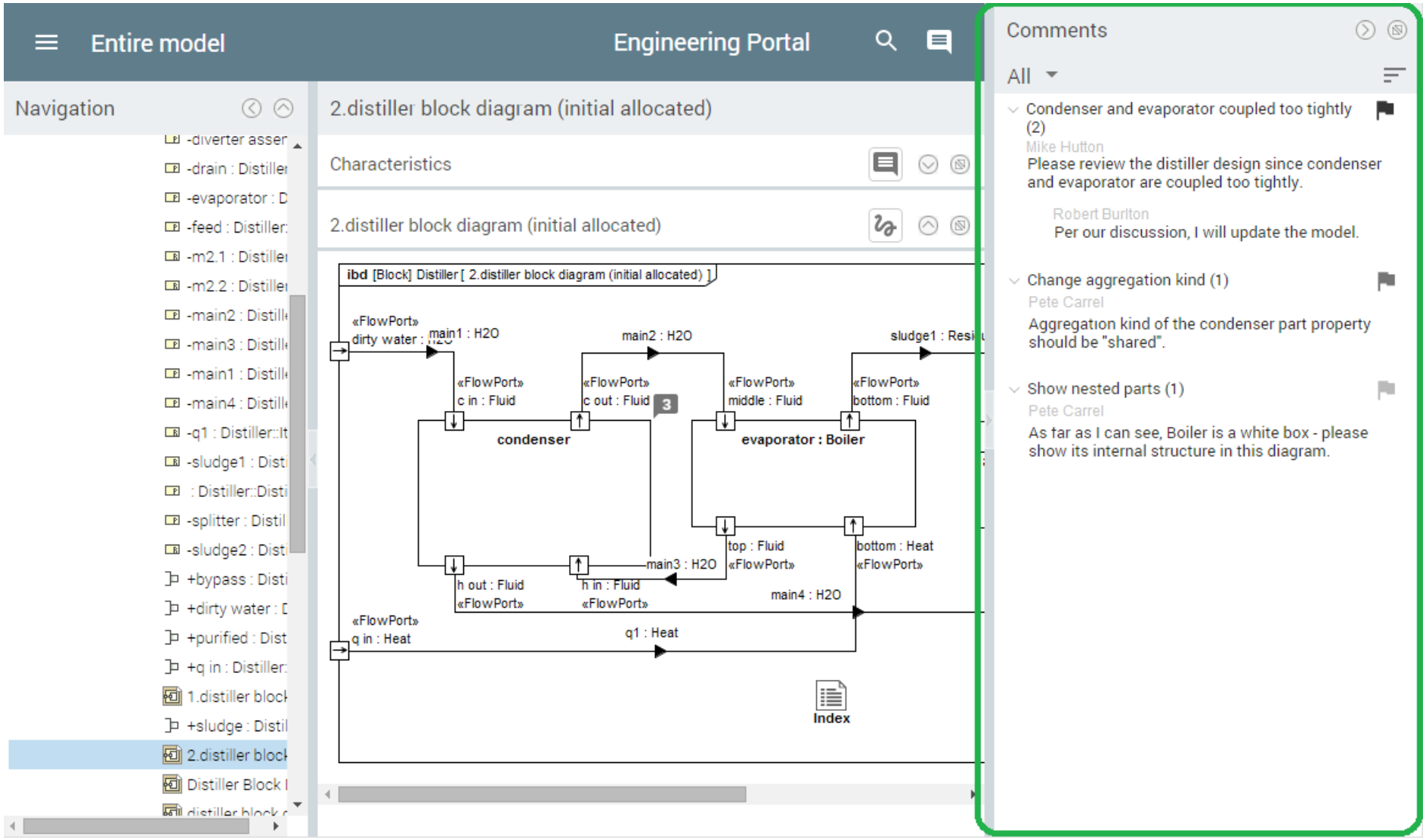




Graphical comments



Textual comments (continued)



NASA/JPL OpenMBEE example

National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology

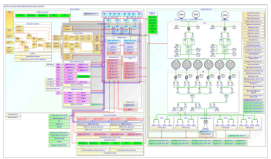
Europa System Model Framework

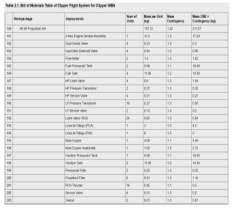
SysML Models
System, Programmatic, etc.

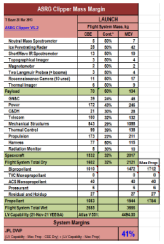
SysML

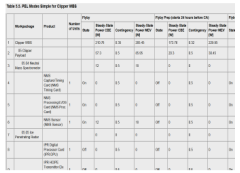
magicdraw

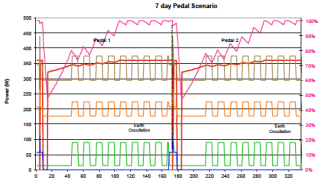
Block Diagram Viewpoints	Mass Equipment List Viewpoints	Mass Margin Viewpoints	Power Equipment List Viewpoints	Power Scenario Viewpoints	•••	Data Margin Viewpoints
Block Diagram	MEL Table	Mass Margin Analysis & Report	PEL Table	Power Margin Analysis		Data Margin Analysis &Report
DocWeb	DocWeb	Office Excel	DocWeb	DocWeb		Wolfram Mathematica











Automated Reporting

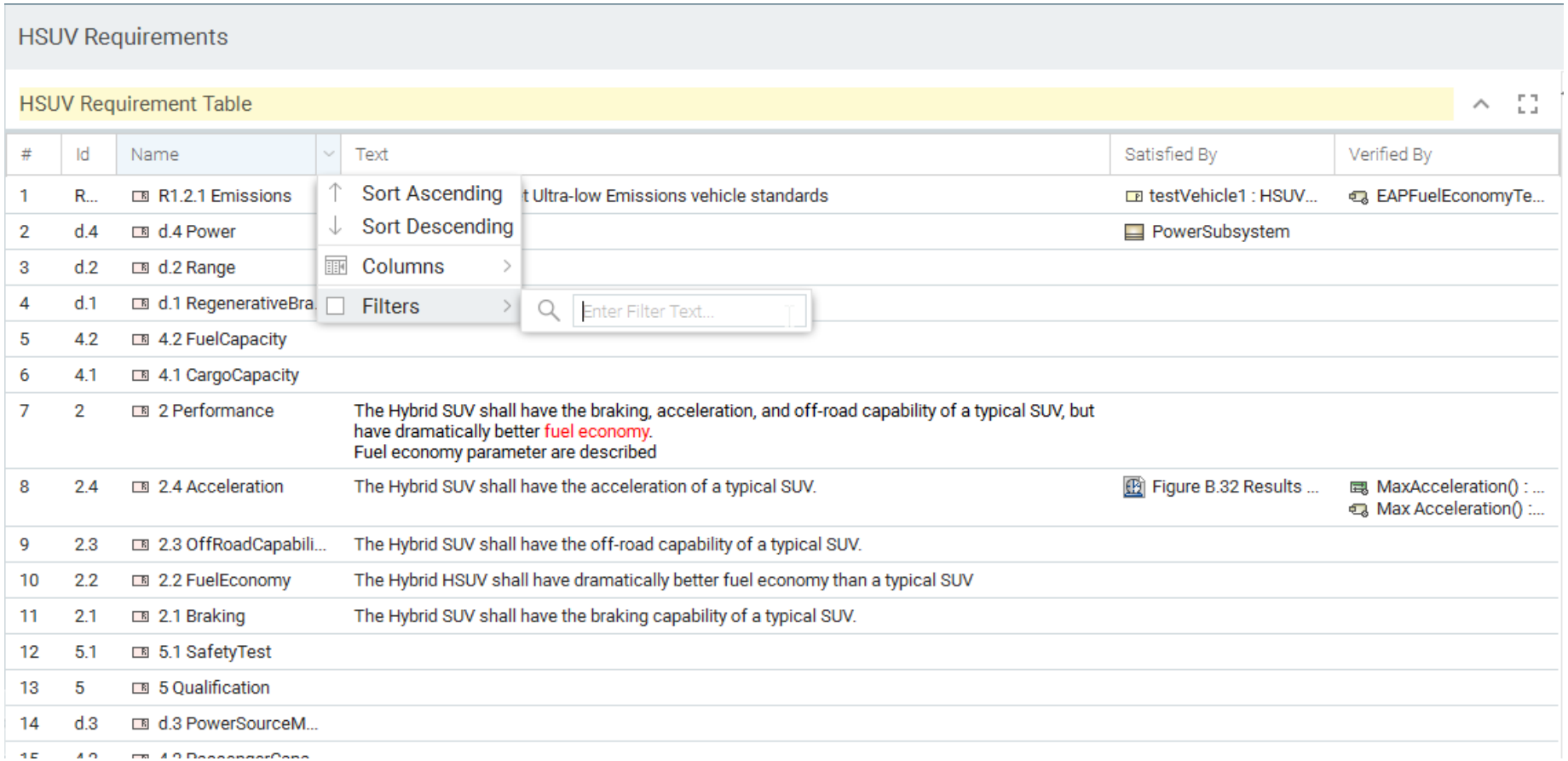
2.1.1. MEL: Bill of Materials Table

Table 2.1. Bill of Materials Table of Clipper Flight System for Clipper WBS

	Workpackage	Deployments	Num of Units	Mass per Unit (kg)	Mass Contingency	Mass CBE + Contingency (kg)
1	**4. Power Mode List**					
2						
3	**Table 4.1. PEL Table for Clipper WBS**					

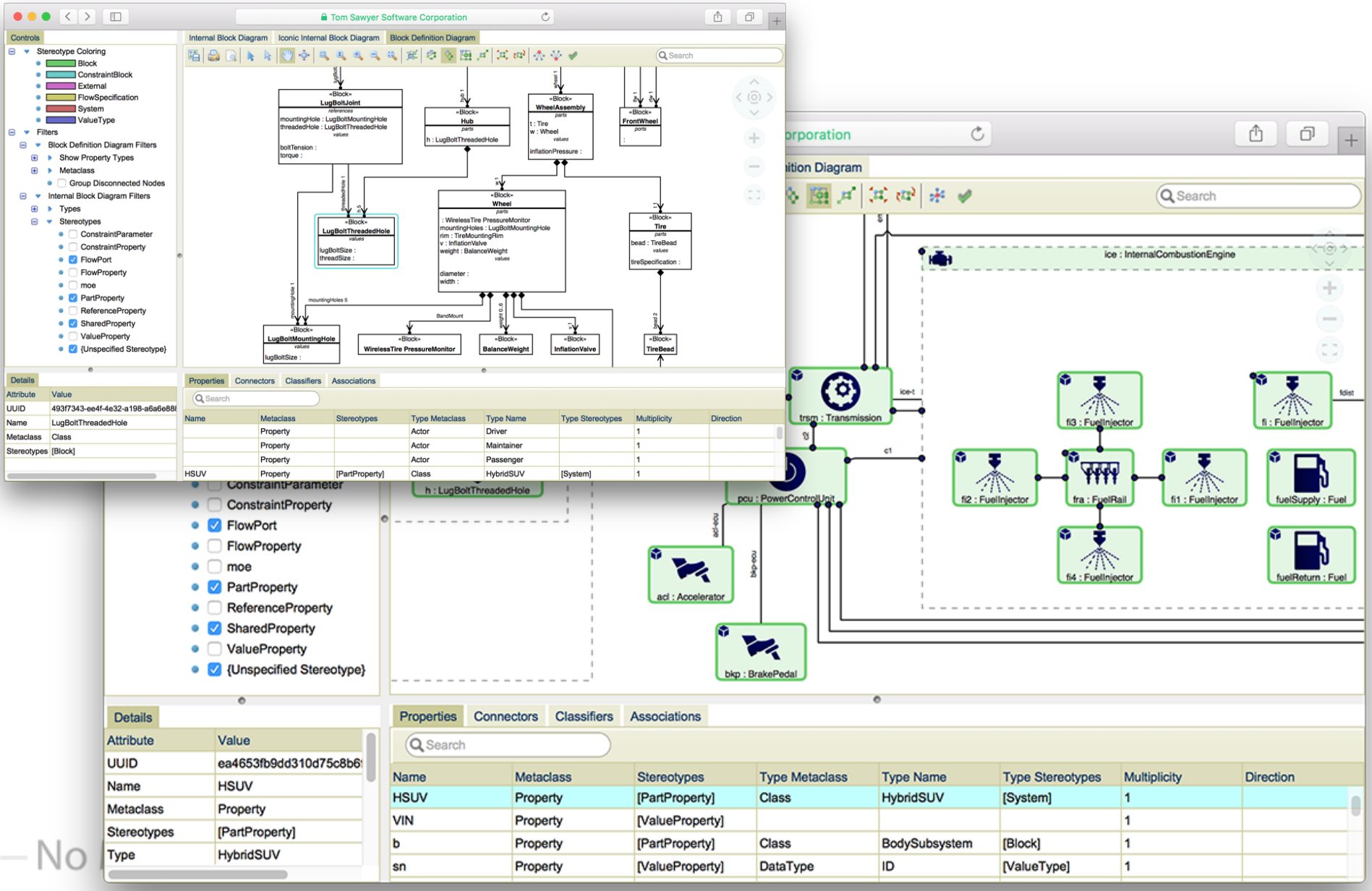
	Workpackage	Product	Power Mode	Avg Pwr CBE[W]	Contingency	Avg Pwr MEV[W]
1	Clipper WBS					
2	05 Clipper Payload					
3	05.04 Neutral Mass Spectrometer					
4		NMS Capture/Timing Card	Off	0	0.5	0
5			On	0	0.5	0
6			Standby	0	0.5	0
7		NMS Processing/LVDS Card	Off	0	0.5	0
8			On	0	0.5	0
9			Standby	0	0.5	0
10		NMS Sensor	Off	0	0.5	0
11			On	12	0.5	18
12			Standby	6	0.5	9
13	05.05 Ice Penetrating Radar					
14		IPR Digital Processor Card	Off	0	0.5	0
15			On	3.75	0.5	5.62

Dynamic editable and searchable tables

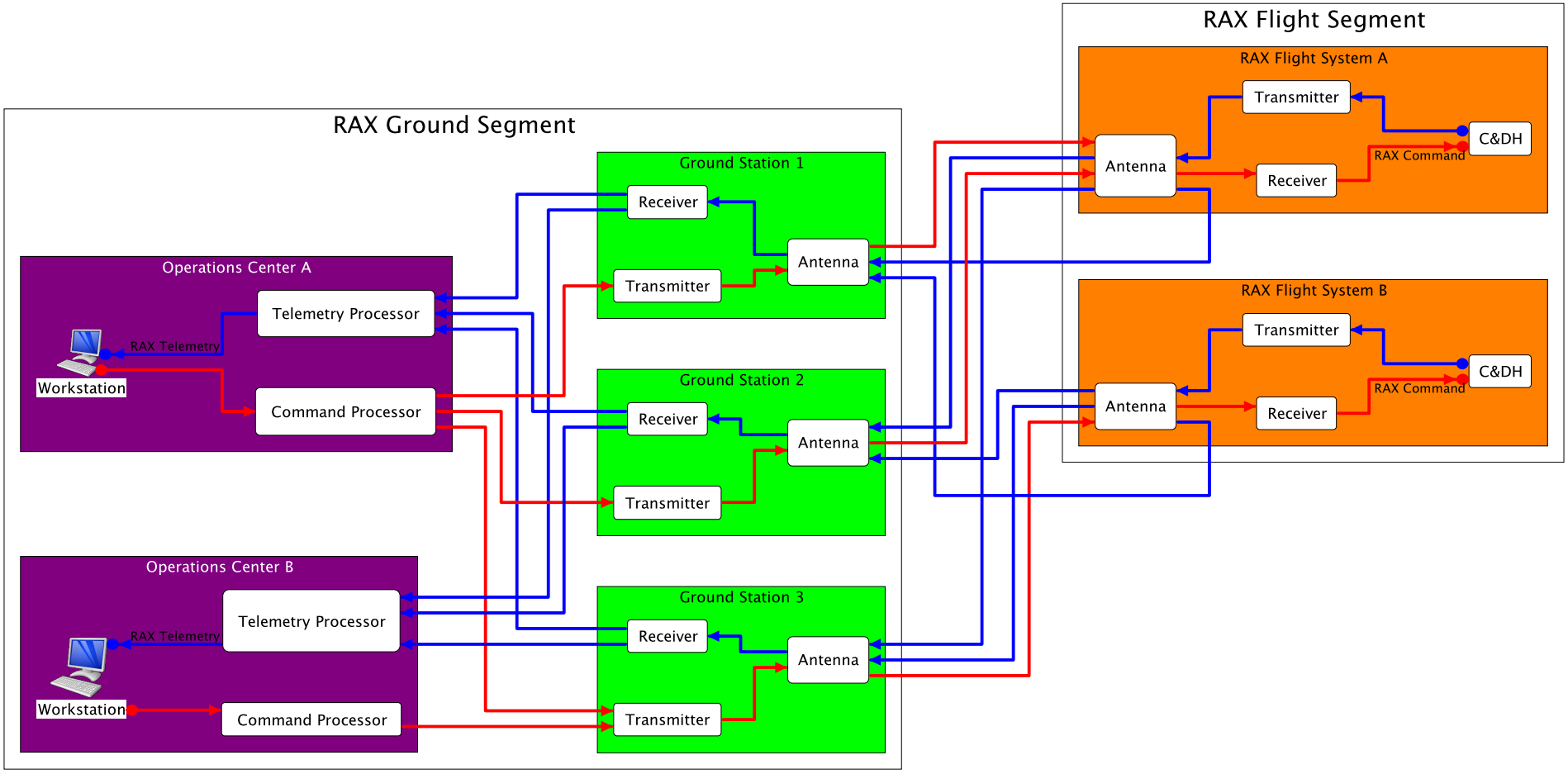


#	Id	Name	Text	Satisfied By	Verified By
1	R...	R1.2.1 Emissions	t Ultra-low Emissions vehicle standards	testVehicle1 : HSUV...	EAPFuelEconomyTe...
2	d.4	d.4 Power		PowerSubsystem	
3	d.2	d.2 Range			
4	d.1	d.1 RegenerativeBra...			
5	4.2	4.2 FuelCapacity			
6	4.1	4.1 CargoCapacity			
7	2	2 Performance	The Hybrid SUV shall have the braking, acceleration, and off-road capability of a typical SUV, but have dramatically better fuel economy. Fuel economy parameter are described		
8	2.4	2.4 Acceleration	The Hybrid SUV shall have the acceleration of a typical SUV.	Figure B.32 Results ...	MaxAcceleration() : ... Max Acceleration() :...
9	2.3	2.3 OffRoadCapabili...	The Hybrid SUV shall have the off-road capability of a typical SUV.		
10	2.2	2.2 FuelEconomy	The Hybrid HSUV shall have dramatically better fuel economy than a typical SUV		
11	2.1	2.1 Braking	The Hybrid SUV shall have the braking capability of a typical SUV.		
12	5.1	5.1 SafetyTest			
13	5	5 Qualification			
14	d.3	d.3 PowerSourceM...			

Tom Sawyer data visualization



How the Flows Traverse the Network



Source: S. Spangelo, D., L. Anderson, et al, *"CubeSat Challenge Team Using MBSE for Operational Analysis"*, 2013 INCOSE IW MBSE Workshop Proceedings

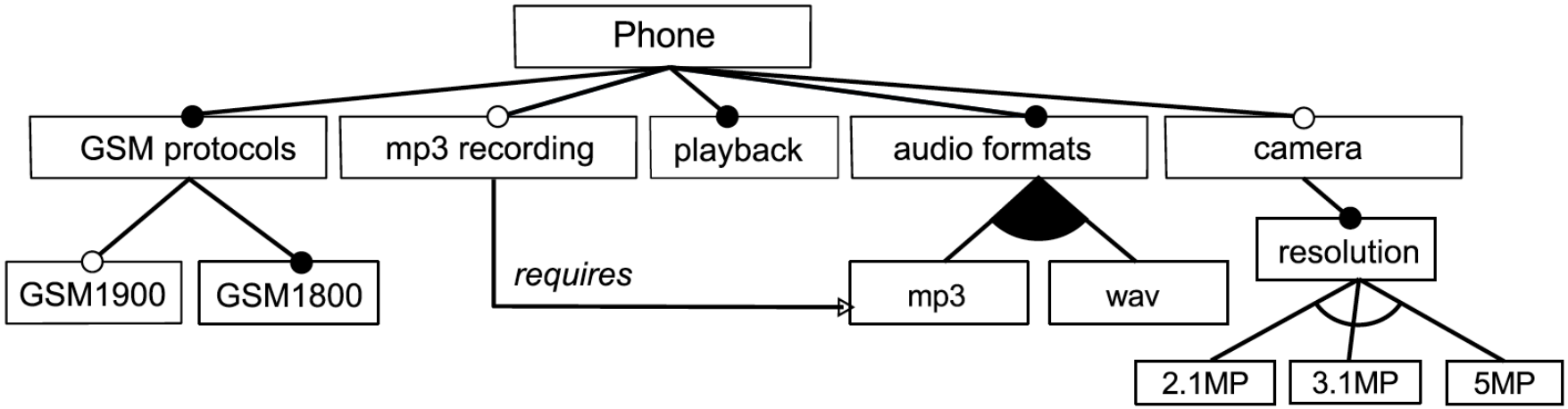
Other integration efforts

- **Conceptual models, ontologies**
  - Cameo Conceptual Modeler
- **Safety/Risk/Hazard analysis**
  - FMEA, fault trees (transportation, healthcare)
  - SafeML, Safety and Reliability Profile
- **Mechanical and CAD data**
  - MechML
- **Testing solutions**
  - UTP, Conformiq
- **Automotive and avionics applications**
  - AUTOSAR, ARINC 429
- **Ground, sea, air, and space assets, orbit analysis**
  - AGI System Tool Kit

Product Line Engineering

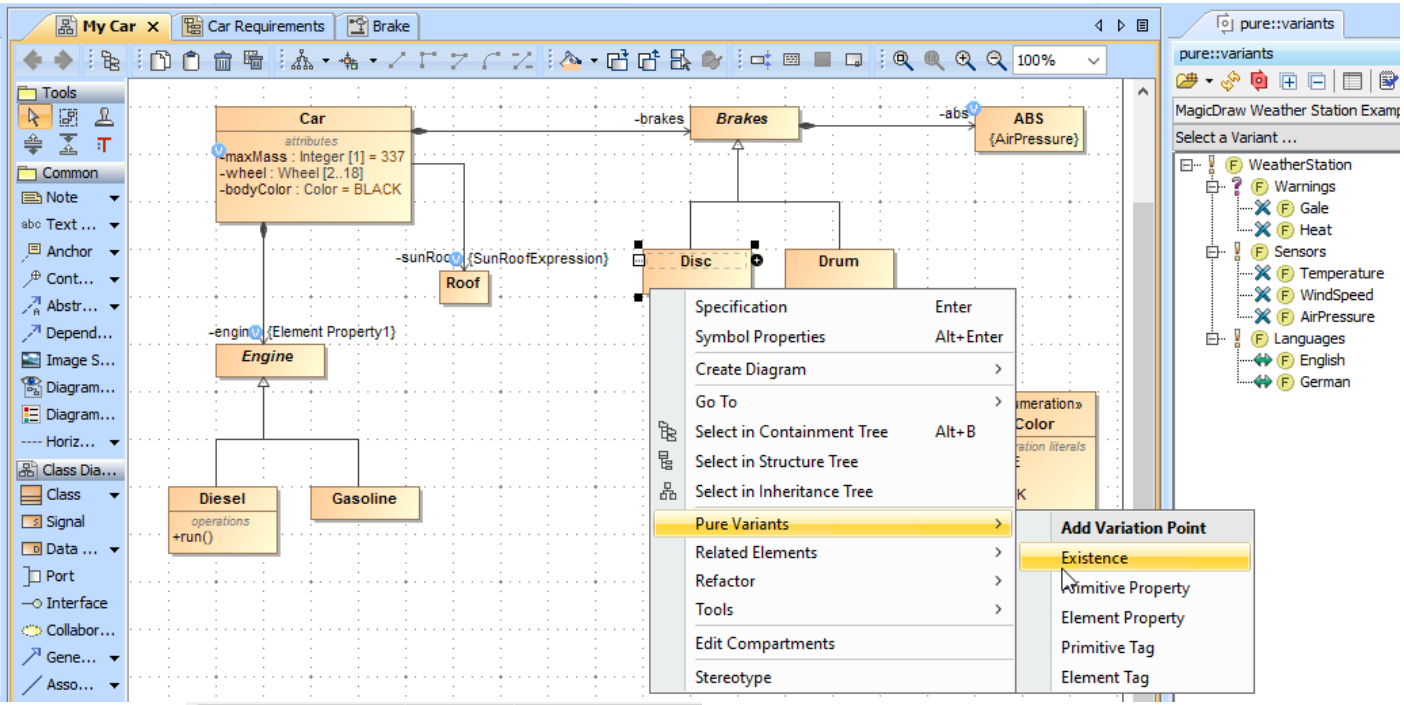
PLE – Product Line Engineering

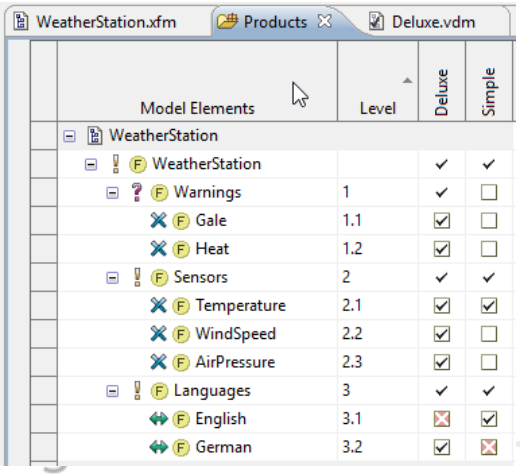
- Features model, product family
- Common vs Variation
- Alternative, optional, mandatory
- 150% vs 100% (superset vs subset) (family vs product)
- Variability Exchange Language

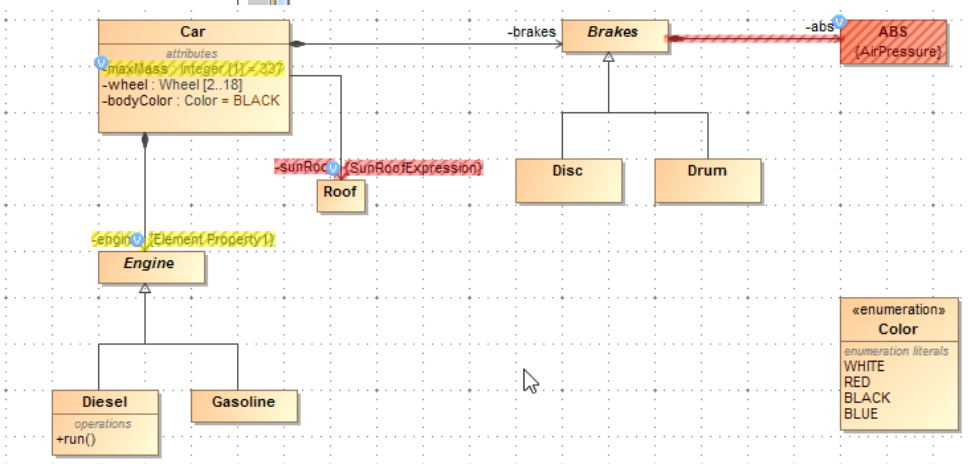


(a) Feature model in a tree notation—slightly adapted from FODA [42]

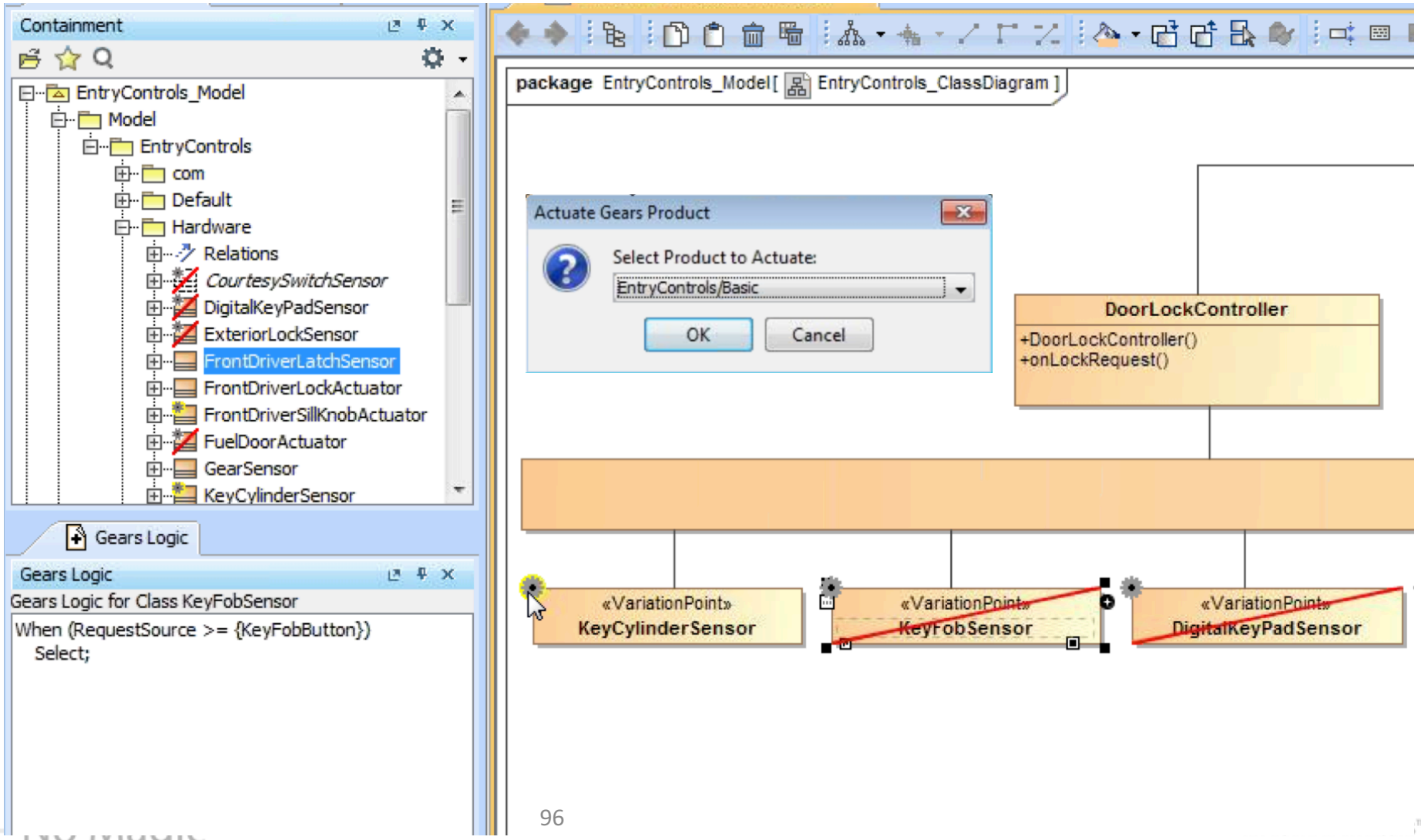
Pure::variants







BigLever Gears



Requirements variability (DOORS)

ID	VP		Gears Logic	Gears Variant	Gears Main Projection
12		**5.4.1.6 Key Fob Button**	When (RequestSource >= {KeyFobButton}) Select;		
22		The key fob shall have two buttons that, respectively, lock and unlock the car doors. Futurum in sollemnes fiant clari parum videntur nobis nunc qui typi modo, notare est Mirum lectorum consuetudium mutationem sequitur qui. Et decima quarta seacula per humanitatis formas litterarum! Parum videntur nobis nunc qui typi modo Eodem decima quinta et decima. Lectorum consuetudium mutationem sequitur qui dynamicus processus etiam est Claritas? Sollemnes fiant clari parum videntur nobis nunc qui typi. Futurum in sollemnes fiant clari parum videntur nobis nunc qui typi modo, humanitatis formas litter			
183		**5.4.1.7 Digital Key Pad**	When (RequestSource >= {DigitalKeyPad}) Select;		
186		The vehicle is equpped with a digital keypad on the exterior of the driver's door, convenient to the exterior latch handle. The key pad shall have five buttons labeled, respectively, "0-1", "2-3", "3-4", "5-6", "6-7", and "8-9".			

187		An operator shall be able to unlock the car doors by entering a _CODE_LENGTH_-digit code using the buttons.	When (true)
			Select
			{
			Apply "_CODE_LENGTH_" -> "@RequestSource.DigitalKeyPad@";
			}		

188		Each button must be depressed by a length of time (the duration of which is settable by a calibration parameter) in order for the button signal to be regarded as a legitimate button push. This is to avoid unintentional button pushes being interpreted as digits in the code.			
209		**5.4.2 Locking/Unlocking Available Inside the Vehicle**			**5.4.2 Locking/Unlocking Available Inside the Vehicle**
210		The vehicle shall contain at least one mechanism whereby front seat occupants can lock and unlock the door locks from within the vehicle.			The vehicle shall contain at least one mechanism whereby front seat occupants can lock and unlock the door locks from within the vehicle.
7		**5.4.3 Lock Status Indication**			**5.4.3 Lock Status Indication**
26		An unambiguous lock status indication shall provide a visual indication from inside the vehicle for the driver and occupants as to whether the doors are locked or unlocked.			An unambiguous lock status indication shall provide a visual indication from inside the vehicle for the driver and occupants as to whether the doors are locked or unlocked.

Variability Exchange Language

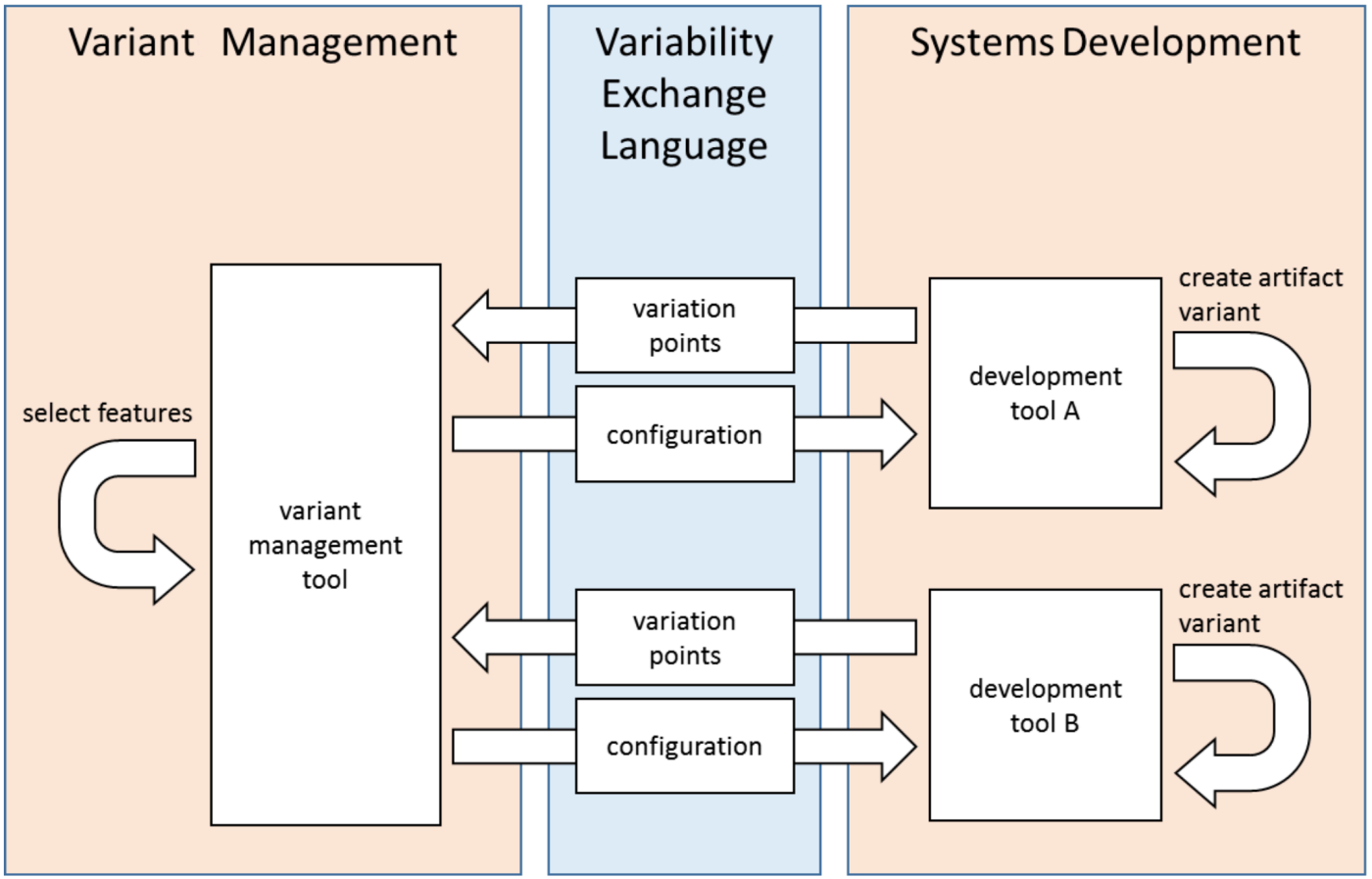


Figure 1: Use case for the *Variability Exchange Language*

Thank You!

Nerijus Jankevicius

No Magic Europe

E-mail: nerijus@nomagic.com

http://www.nomagic.com

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