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Paper Track 3, Rm 402, Session 4 (10 AM – 12 PM)

Satellites to Supply Chains, Energy to Finance — SLIM for Model-Based Systems Engineering

Part 1: Motivation and Concept of SLIM

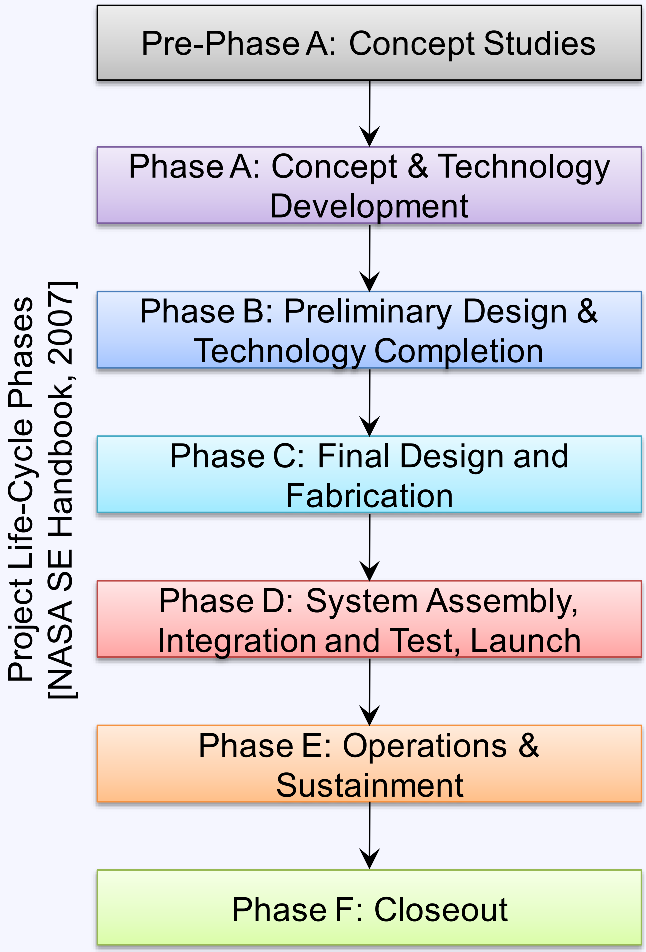
Manas Bajaj, PhD
Chief Systems Officer
www.InterCAX.com

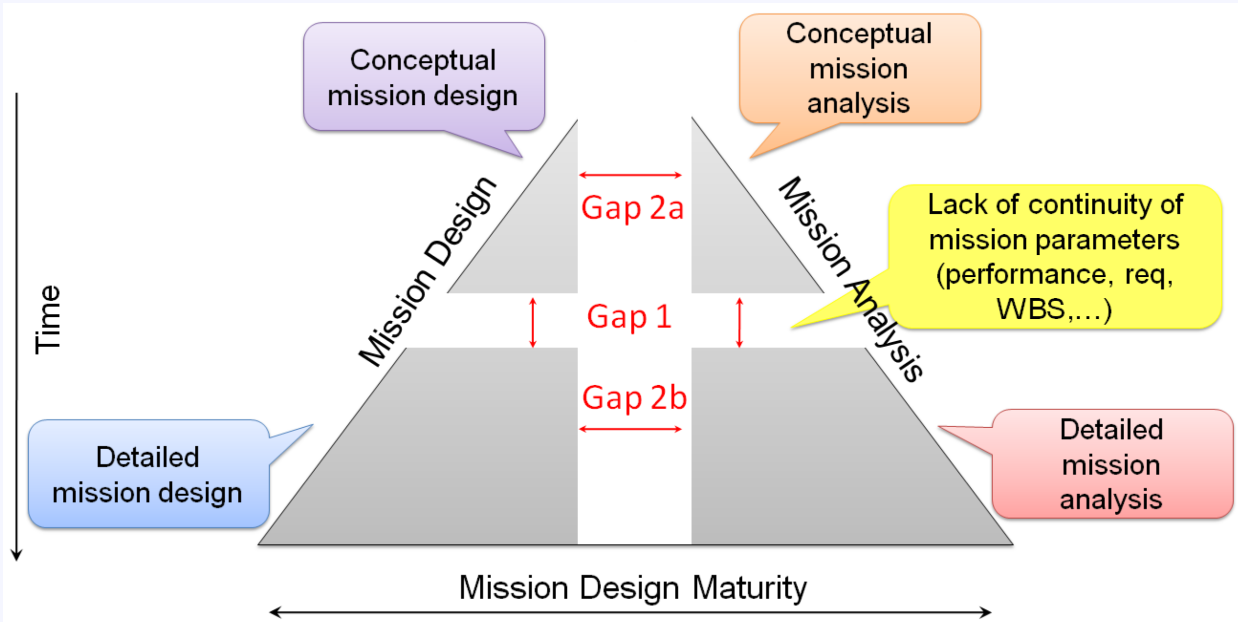
Co-Authors: Dirk Zwemer, Russell Peak (GIT), Alex Phung, Andy Scott, Miyako Wilson (GIT)

Contents

- Motivation
- What is SLIM?
  - Conceptual Architecture
  - Use Cases
- SLIM
  - Capabilities & Tools
  - Applications
- Experiences
- Questions / Comments

Motivation





Gap 1 = Disconnect between design and analysis activities across the phases, e.g. Pre-Phase A to Phase A, or Phase A to Phase B.

Gap 2 = Disconnect between design, analysis, verification activities within a given phase.

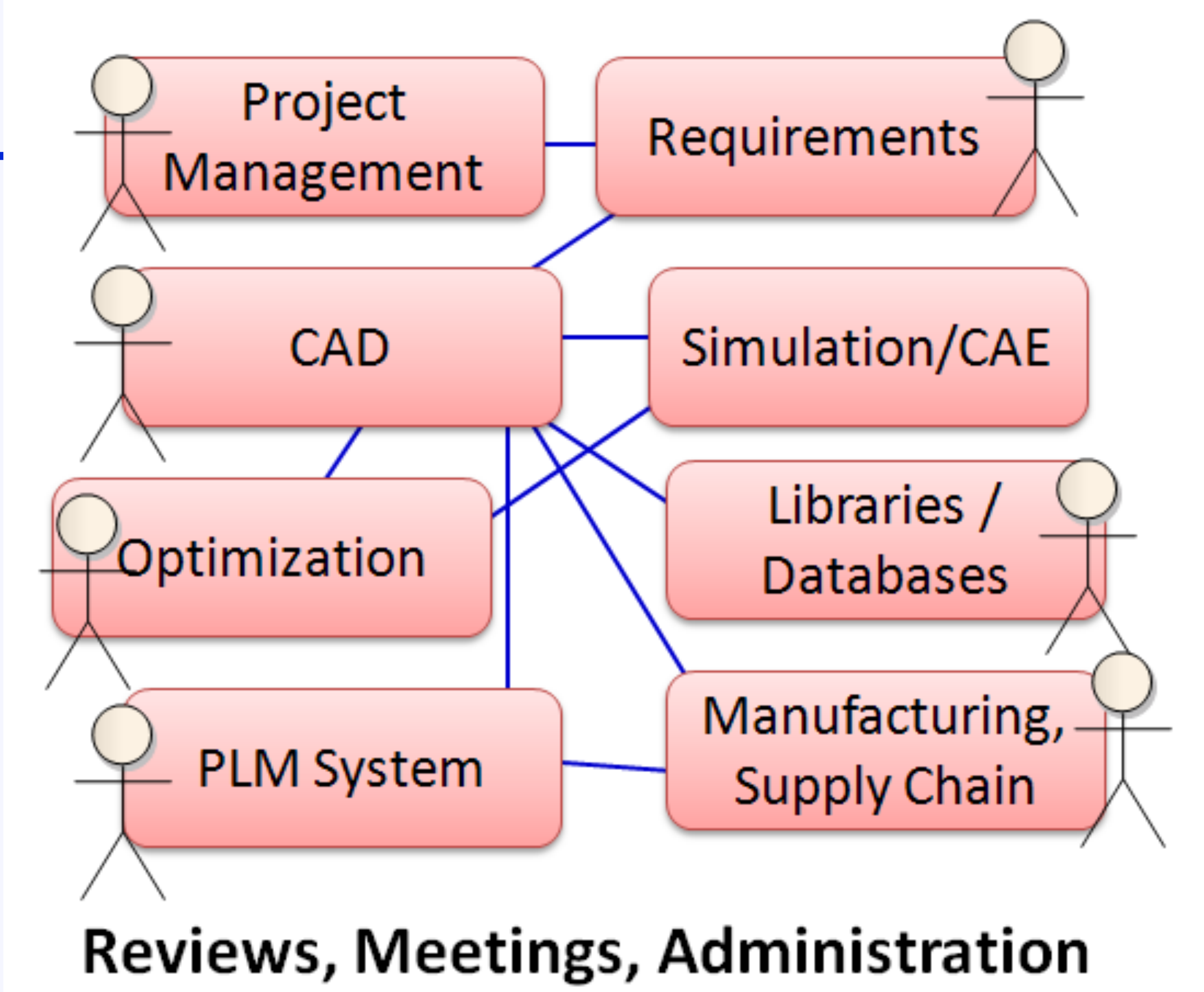
Challenges

- Document-based or ad-hoc **point-to-point linkages** between models in different tools

- No **unified definition** of the system, analyses, V&V tasks, and MoEs that are continuous through the development process

- How does one **propagate trade spaces, uncertainties, and risk** from one phase to another?

- How do we **manage abstract**, system-level design/analysis **with detailed** sub-system/component-level design/analyses (CAD/CAE)?


Project Management
Requirements
CAD
Simulation/CAE
Optimization
Libraries / Databases
PLM System
Manufacturing, Supply Chain
Reviews, Meetings, Administration

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What is SLIM?

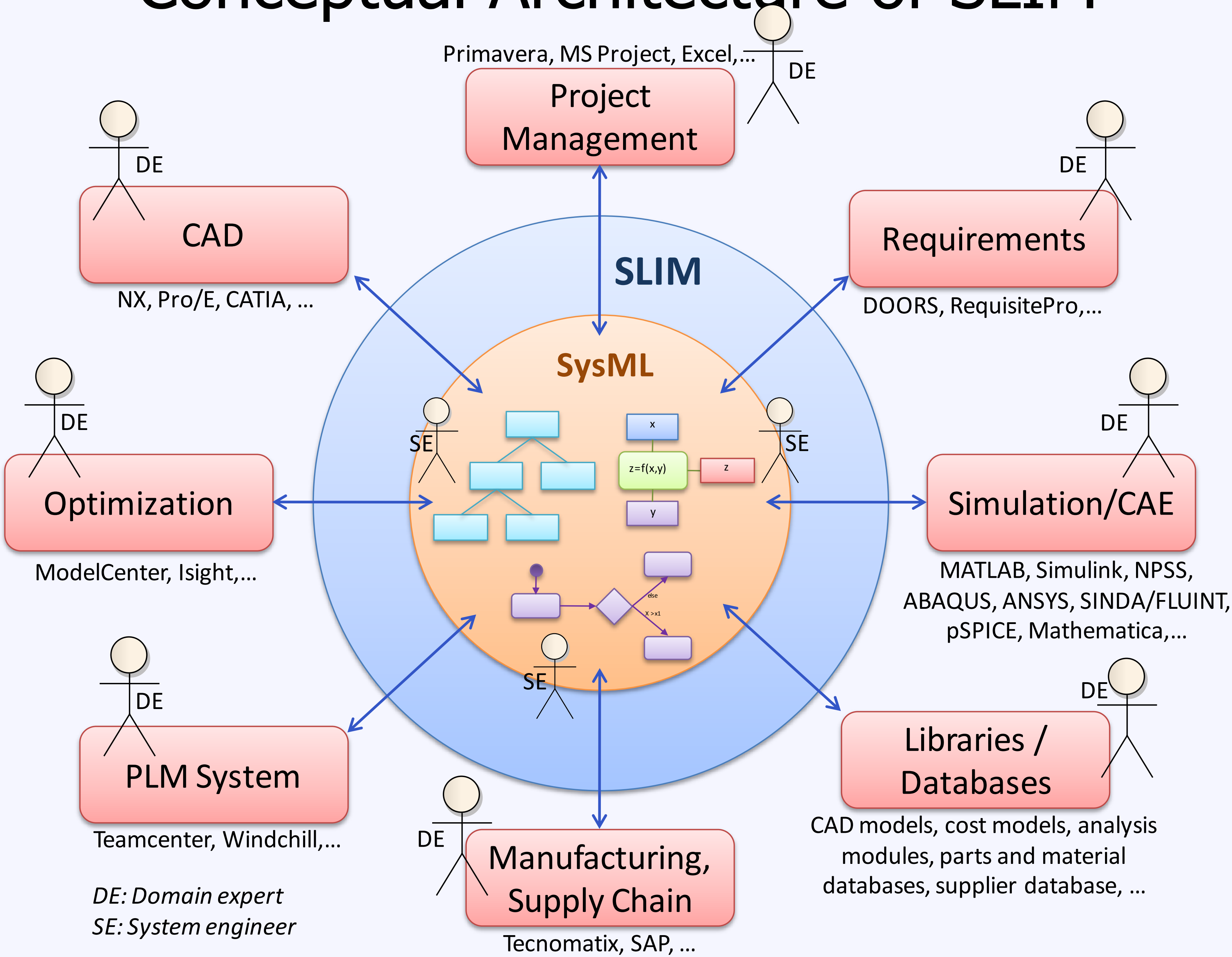
- **S**ystems **Li**fecycle **M**anagement

  model-based systems engineering (MBSE) with the foundations of product lifecycle management (PLM)

- Software environment for
  - integrated model-based (systems) engineering – MBE/MBSE
  - multi-disciplinary system development teams
  - end-to-end system design, analysis, and V&V

- Core philosophy
  - Use SysML as the front-end conceptual map of a system
  - Federate domain-specific tools/models from SysML
  - SysML model and domain models can “co-evolve”

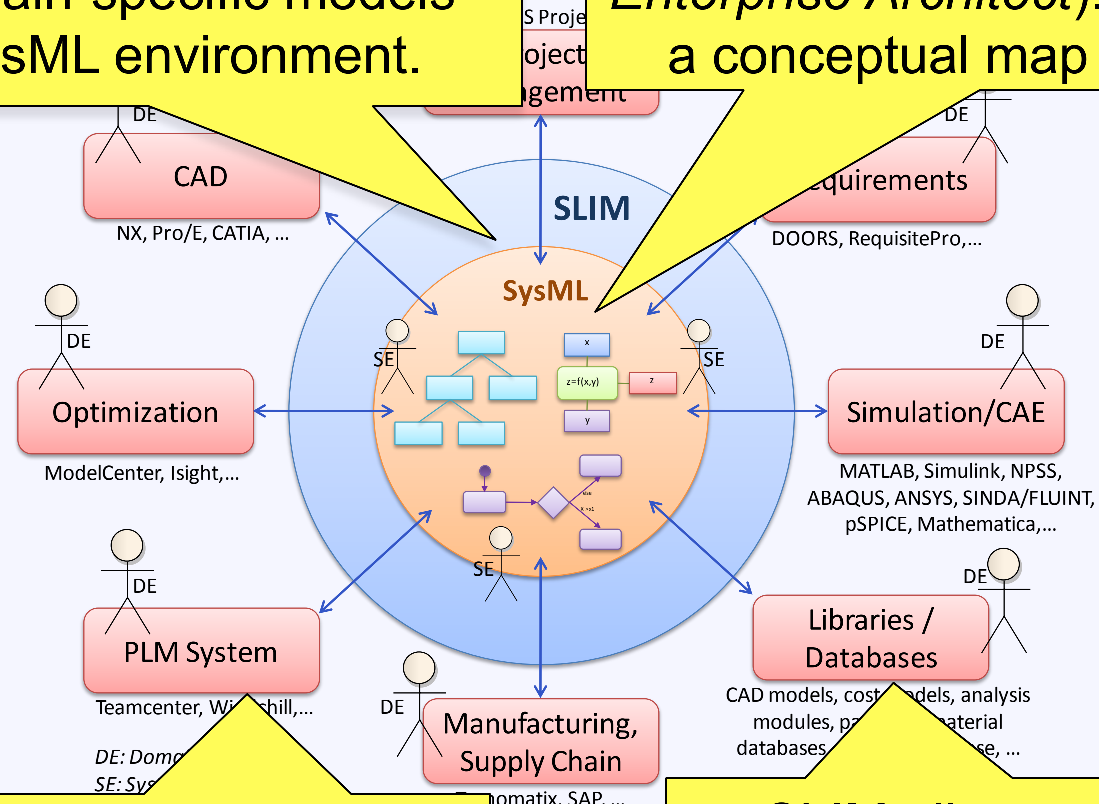
Conceptual Architecture of SLIM



Conceptual Architecture of SLIM

SLIM is deployed in the SysML environment. It provides tools to federate (visualize, connect, execute) domain-specific models from the SysML environment.

System engineers work directly in their SysML environment - *MagicDraw, Rhapsody, Artisan Studio, Enterprise Architect*). SysML model is a conceptual map of the system.



SLIM connects to models in enterprise PLM environments to enable configuration control of artifacts.

SLIM allows users to wrap external model libraries (CAD, CAE, MATLAB,..) as plug-and-play SysML objects.

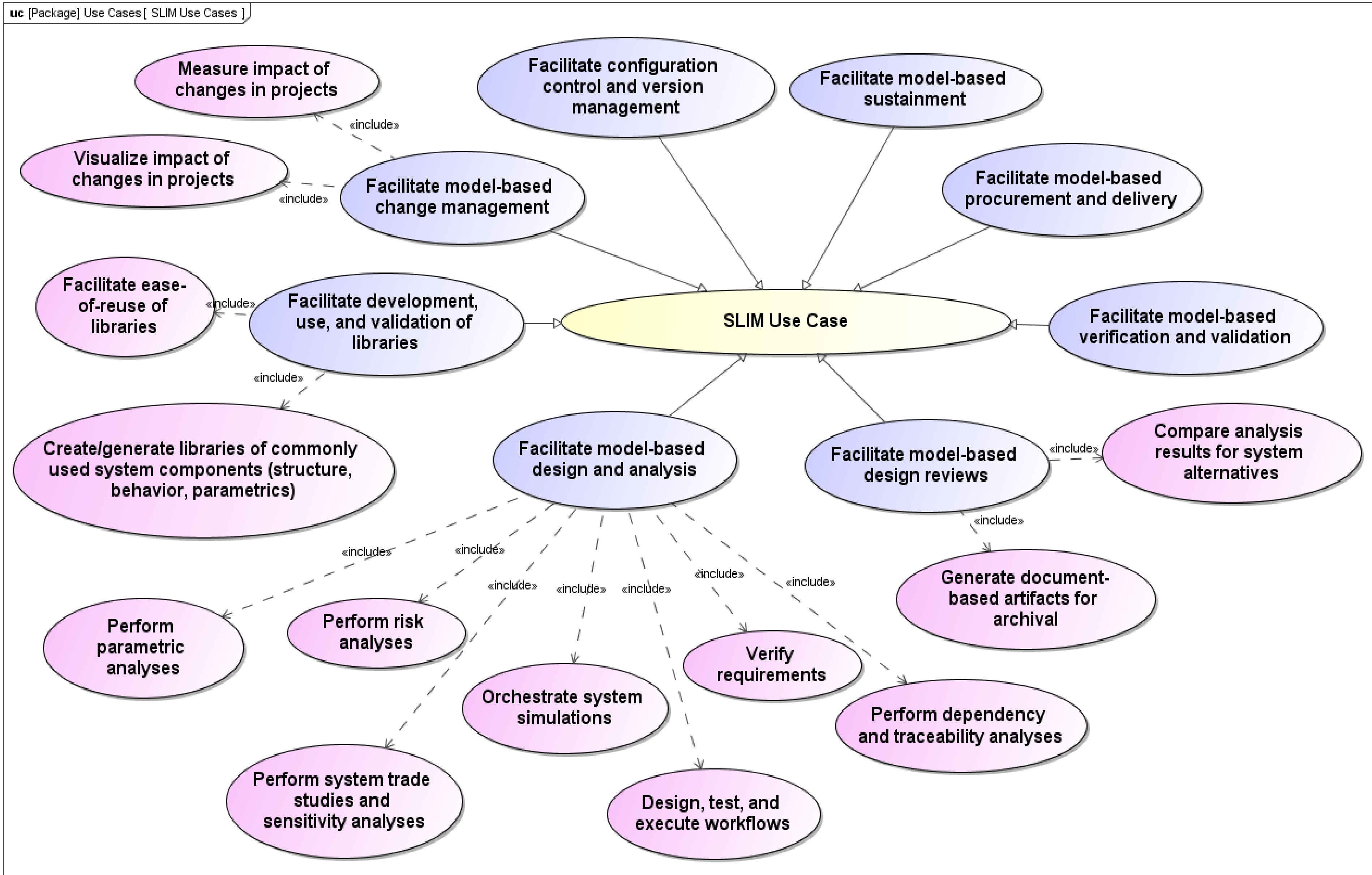
SLIM – Core Philosophy

- SysML-based system model is continuous through the development process

- SysML objects can
  - can be “connected” to domain-specific models
  - “control” domain-specific models
  - can “co-evolve” with domain-specific models

- SysML-based system model
  - is not a data repository
  - is a dashboard for orchestration SE design, V&V flows

SLIM – Systems Engineering Use Cases



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SLIM – Tools and Capabilities (cont.)

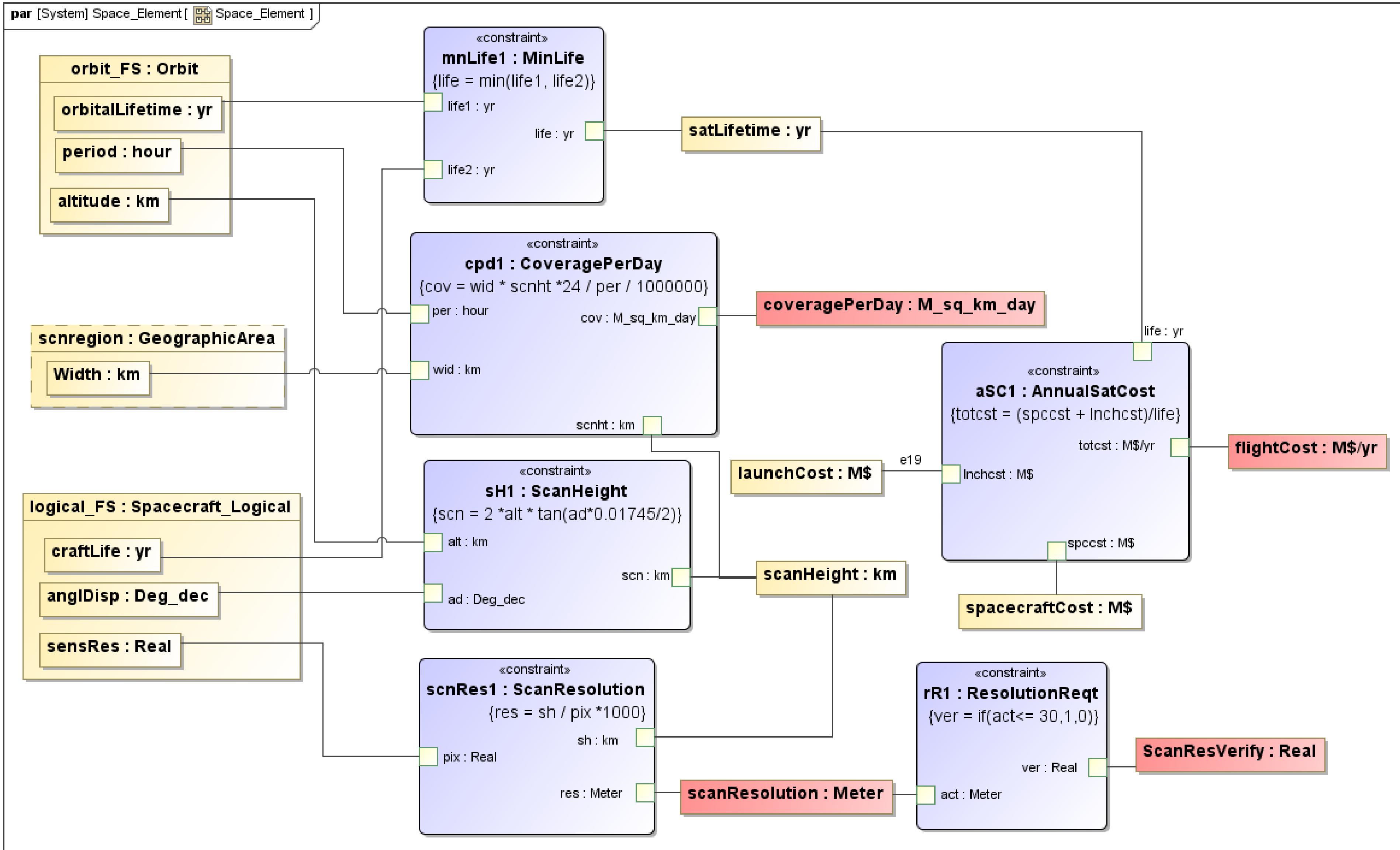
- SysML Analysis Tools
  - Parametric execution tool
  - Trade study tool
  - Risk analysis tool
  - Activity execution tool
- SysML Integration Tools
  - Excel interface
  - Database interface
  - MATLAB/Simulink interface
  - Mathematica interface
  - OpenModelica interface
  - CAD (NX) interface
  - STK interface
  - Plus tailored interfaces…
- SysML Visualization Tools
- SysML Libraries

SLIM – Tools and Capabilities Parametric execution and Trade study tool

SysML Parametrics provide a foundation to…

- Represent fine-grained math relationships between SysML model elements
- Wrap and connect any external model to SysML – CAD, CAE, MALTAB/Simulink, Spreadsheets, Databases,…
- Orchestrate Simulations, Trade Studies, Optimization, Requirements Verification, Risk Assessment, and more from SysML Models

SysML parametric model
Annual cost & feature resolution for FireSat



Parametric execution and Trade study tool

- Vary operational altitudes of two FireSats
- Compute annual cost and ground coverage
- Automatically Verify cost and coverage requirement
- Results generated by SLIM's parametric execution and trade study tool

COST requirement fails for these altitudes

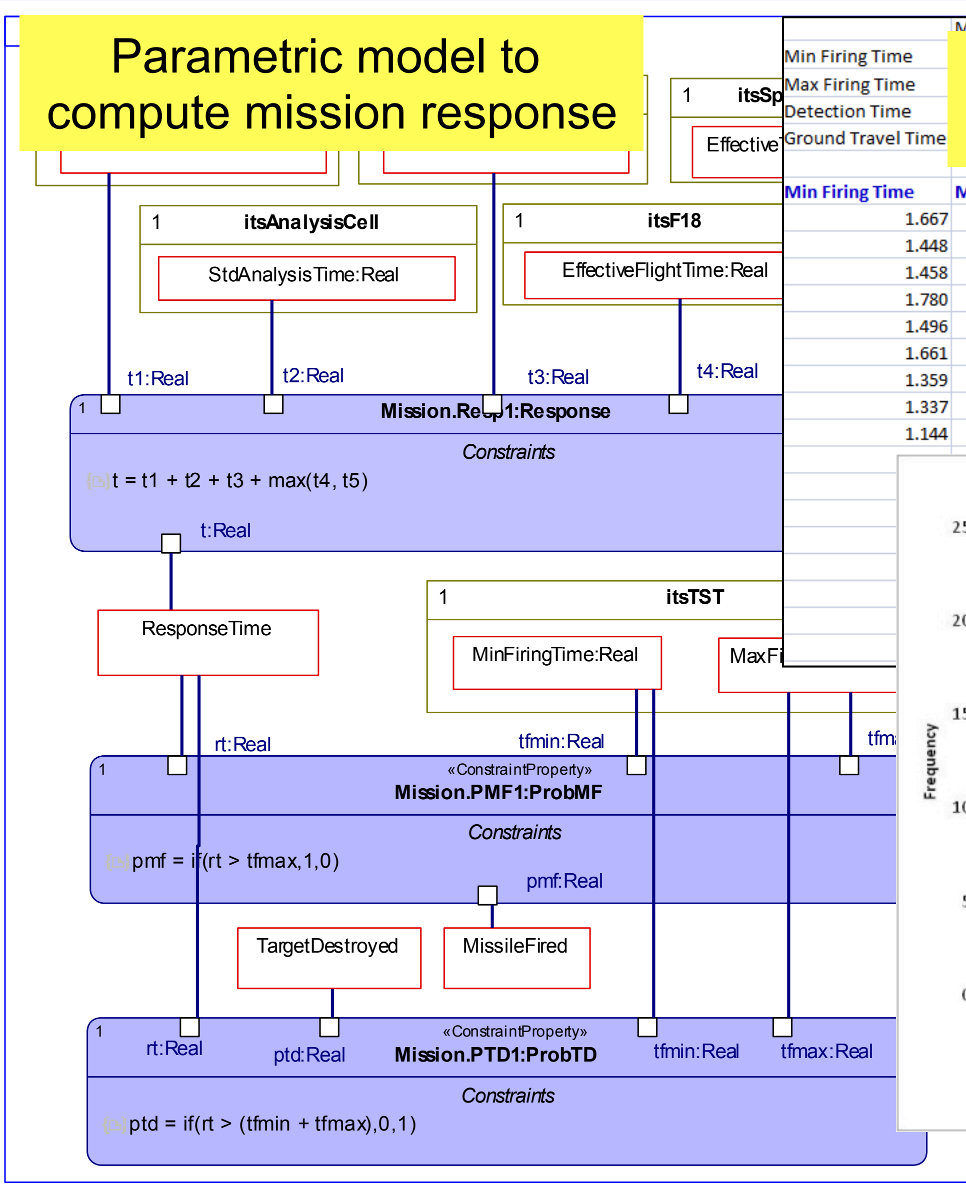
COVERAGE requirement fails for these altitudes

Satellite 1		Satelite 2						Satellite 1		Satellite 2	
Altitude	Ang. Aperture	Altitude	Ang. Aperture	Cost/yr.	Cost req.	Coverage/day	Coverage req.	Tgt. Resolution	Res. req.	Tgt. Resolution	Res. req.
km	deg	km	deg	M$/yr	1-pass, 0-fail	M sq km/day	1-pass, 0-fail	meters	1-pass, 0-fail	meters	1-pass, 0-fail
300	3	300	3	77.23	0	2.50	0	15.71	1	15.71	1
325	3	325	3	51.61	0	2.70	0	17.02	1	17.02	1
350	3	350	3	36.28	0	2.89	0	18.33	1	18.33	1
375	3	375	3	26.65	0	3.08	1	19.64	1	19.64	1
400	3	400	3	20.36	0	3.26	1	20.94	1	20.94	1
425	3	425	3	19.67	1	3.45	1	22.25	1	22.25	1
450	3	450	3	19.67	1	3.63	1	23.56	1	23.56	1
475	3	475	3	19.67	1	3.81	1	24.87	1	24.87	1
500	3	500	3	19.67	1	3.99	1	26.18	1	26.18	1
525	3	525	3	19.67	1	4.17	1	27.49	1	27.49	1
550	3	550	3	19.67	1	4.34	1	28.80	1	28.80	1
575	3	575	3	19.67	1	4.52	1	30.11	0	30.11	0
600	3	600	3	19.67	1	4.69	1	31.42	0	31.42	0

Risk Analysis Tool

Performing Monte Carlo simulations

Parametric model to compute mission response



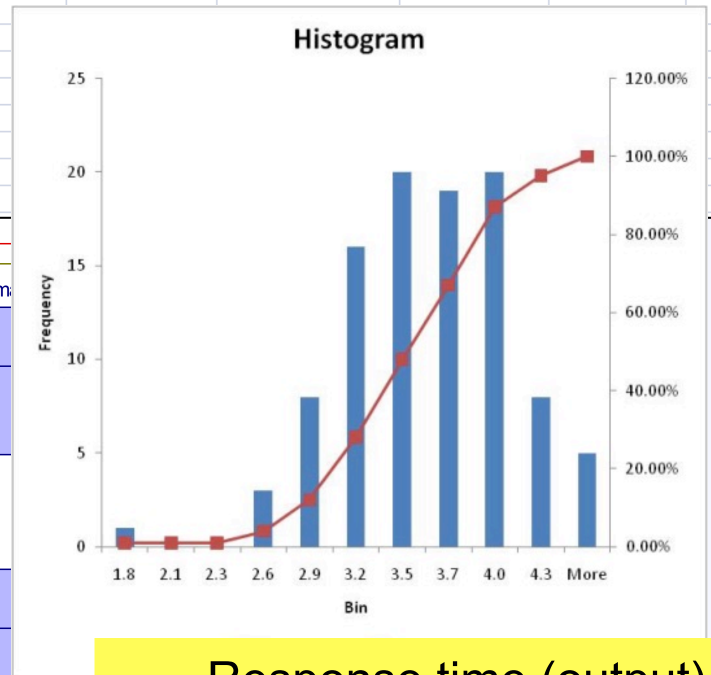
	Mean (hrs)	Variance (hrs)
Min Firing Time		
Max Firing Time		
Detection Time		
Ground Travel Time		

Trials based on probability distributions of input variables

0.36

1.00

Min Firing Time	MaxFiring Time	UAV Detection Time	SF Travel Time	MissileFired?	TSTDestroyed?	Response Time
1.667	2.881	4.145	2.072	0	1	2.34
1.448	2.465	4.780	1.643	0	1	2.45
1.458	2.544	3.804	2.518	0	1	2.37
1.780	2.590	4.450	1.510	0	1	2.36
1.496	2.400	4.258	2.562	1	1	2.50
1.661	2.813	3.328	2.387	0	1	2.22
1.359	2.387	4.095	2.812	1	1	2.53
1.337	2.961	3.797	2.155	0	1	2.28
1.144	2.206	3.559	1.358	0	1	2.14
					1	2.75
					1	1.83
					1	2.57
					1	2.72
					1	2.03
					1	2.23
					1	2.54
					1	2.15



Response time (output) probability distribution

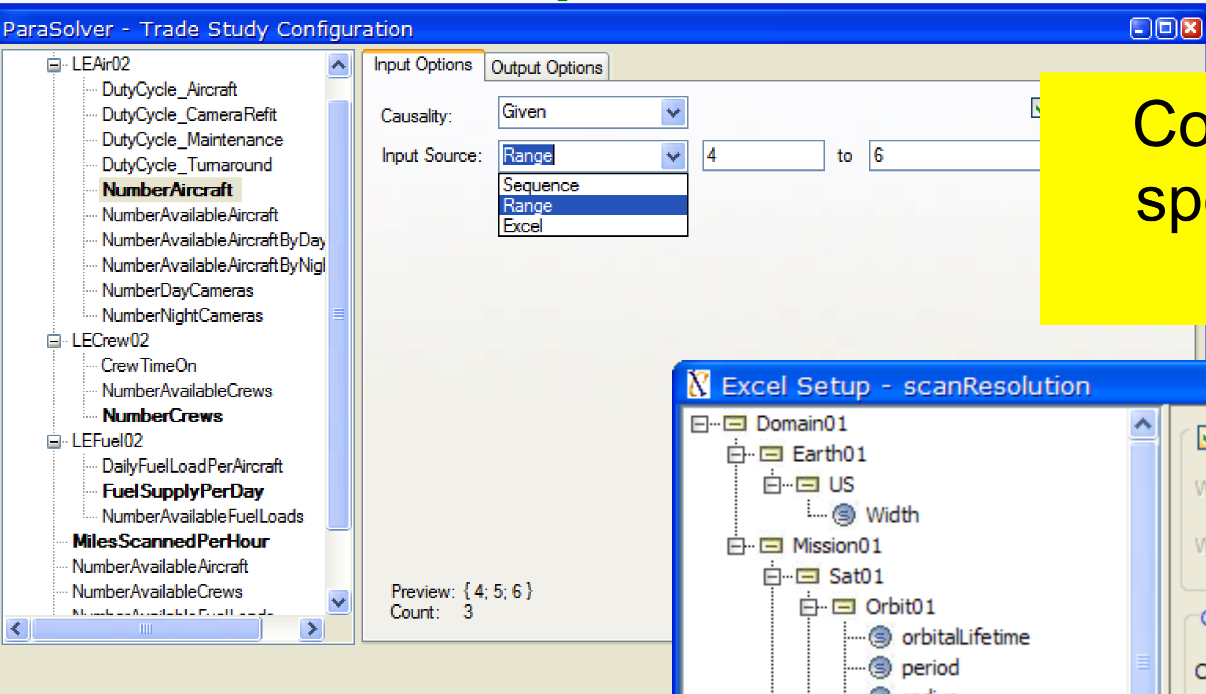
SLIM Analysis Tools

Available commercially as

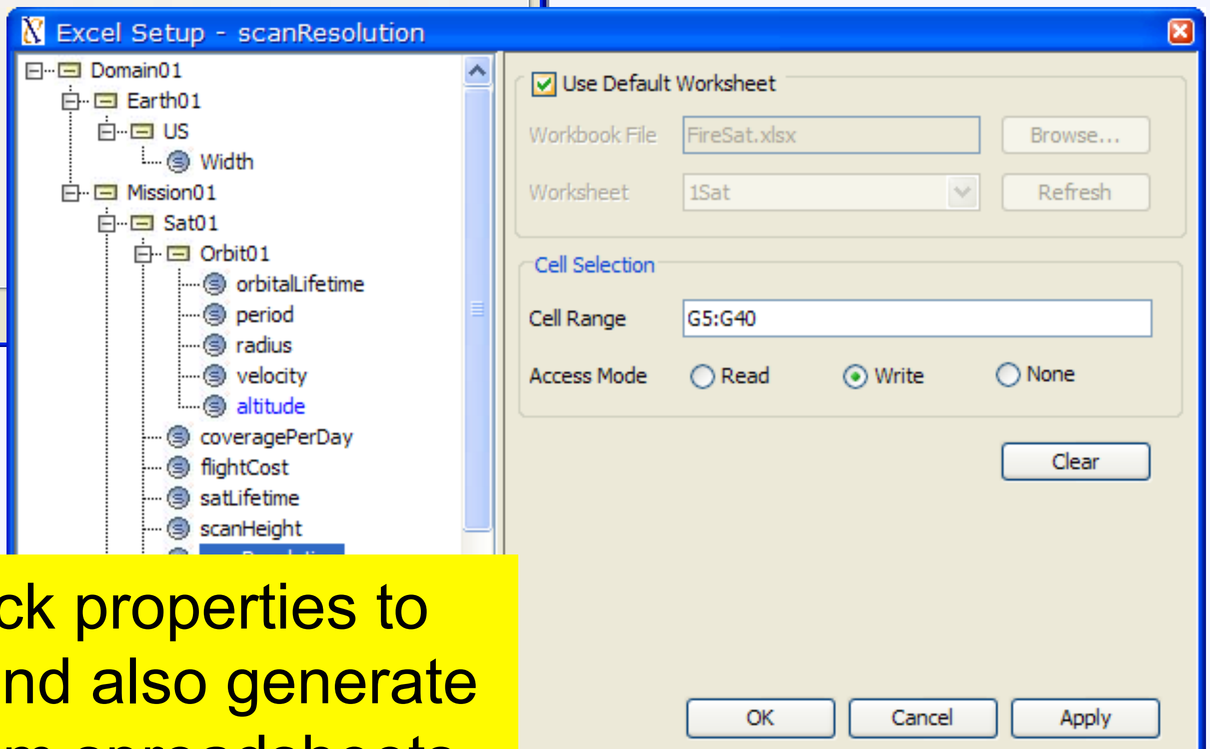
- ParaMagic® for MagicDraw
  - www.intercax.com/paramagic
- ParaSolver™ for Artisan Studio
  - www.intercax.com/parasolver
- Melody™ for Rhapsody
  - www.intercax.com/melody
- Solvea™ (beta) for Enterprise Architect
  - www.intercax.com/solvea

Excel Integration Tool

Data Sync and Model Generation



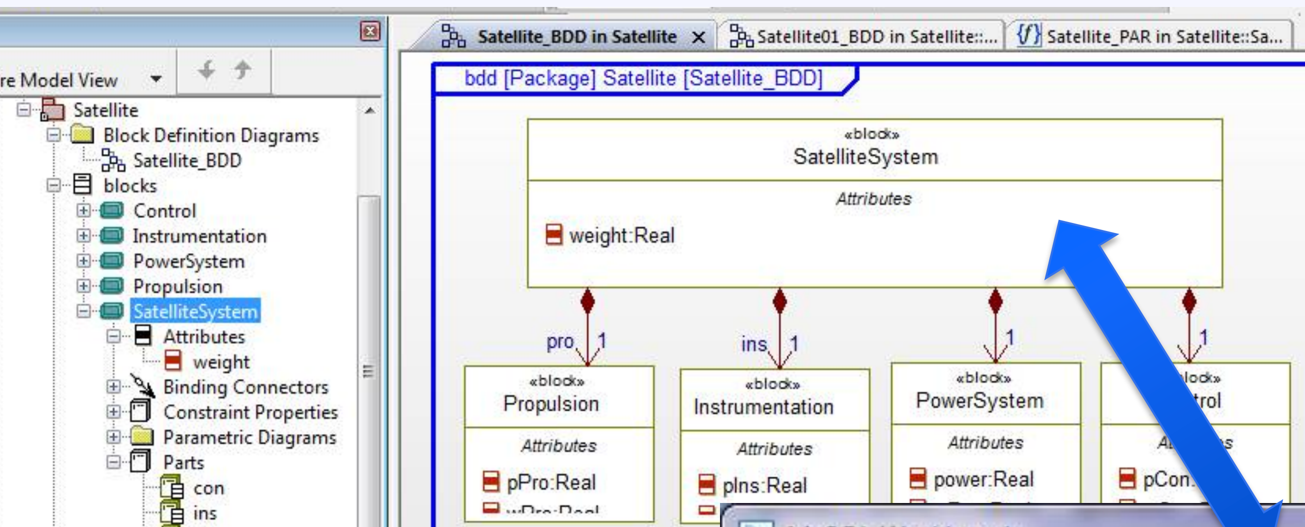
Configure trade studies, specify variable ranges, generate scenarios

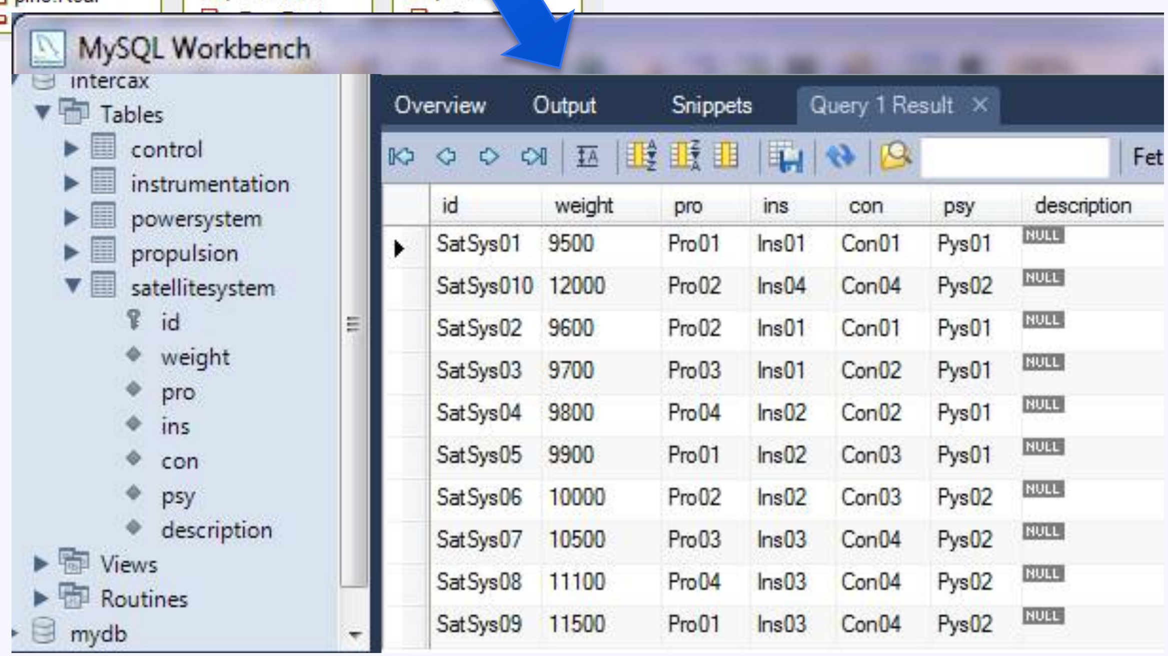


Connect SysML block properties to Excel spreadsheets and also generate SysML instances from spreadsheets

Database Integration Tool

Connect and control datasets from SysML models



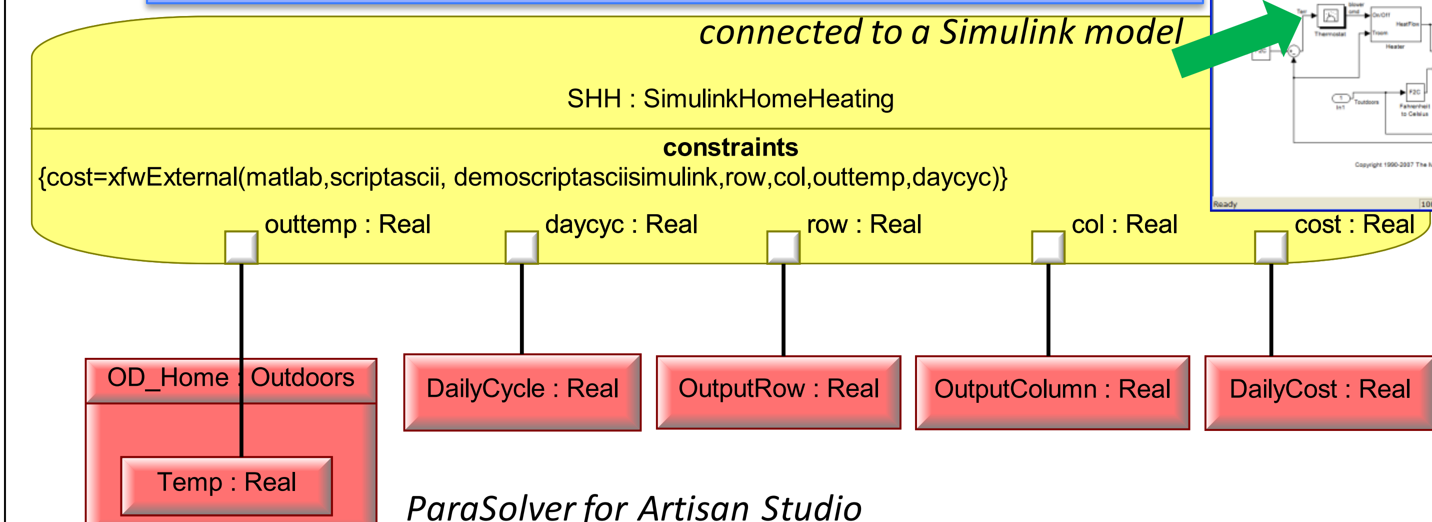


id	weight	pro	ins	con	psy	description
SatSys01	9500	Pro01	Ins01	Con01	Pys01	NULL
SatSys010	12000	Pro02	Ins04	Con04	Pys02	NULL
SatSys02	9600	Pro02	Ins01	Con01	Pys01	NULL
SatSys03	9700	Pro03	Ins01	Con02	Pys01	NULL
SatSys04	9800	Pro04	Ins02	Con02	Pys01	NULL
SatSys05	9900	Pro01	Ins02	Con03	Pys01	NULL
SatSys06	10000	Pro02	Ins02	Con03	Pys02	NULL
SatSys07	10500	Pro03	Ins03	Con04	Pys02	NULL
SatSys08	11100	Pro04	Ins03	Con04	Pys02	NULL
SatSys09	11500	Pro01	Ins03	Con04	Pys02	NULL

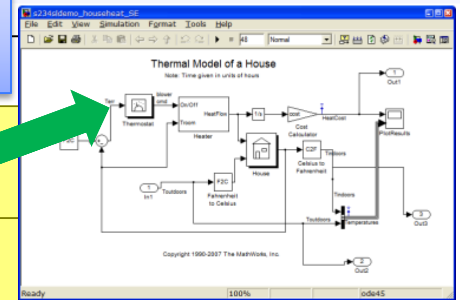
1. Initialize / sync db tables from block structure
2. Archive block instances in database tables
3. Execute SysML models (e.g. parametric) on db tables

MATLAB/Simulink/Mathematica Integration

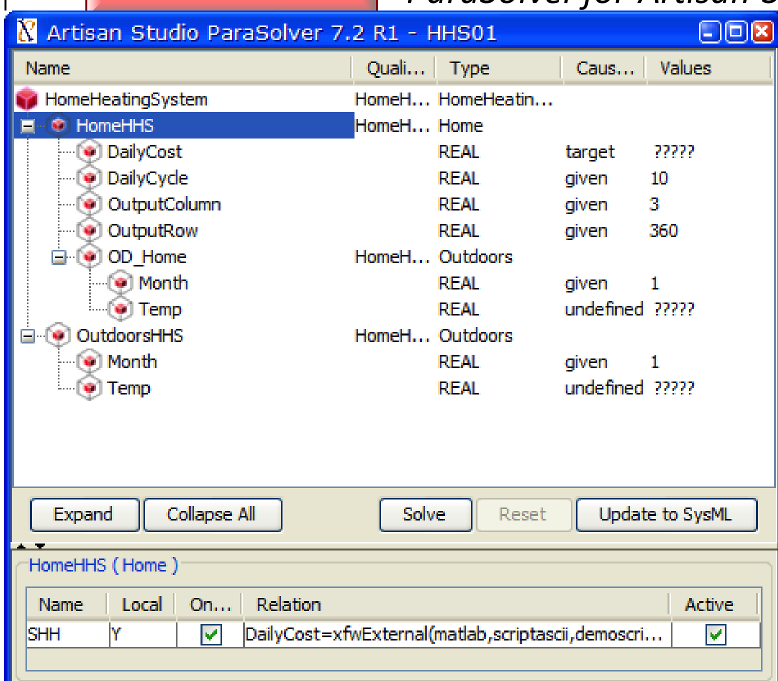
Wrap analysis models as SysML constraint blocks and use in the context of the system



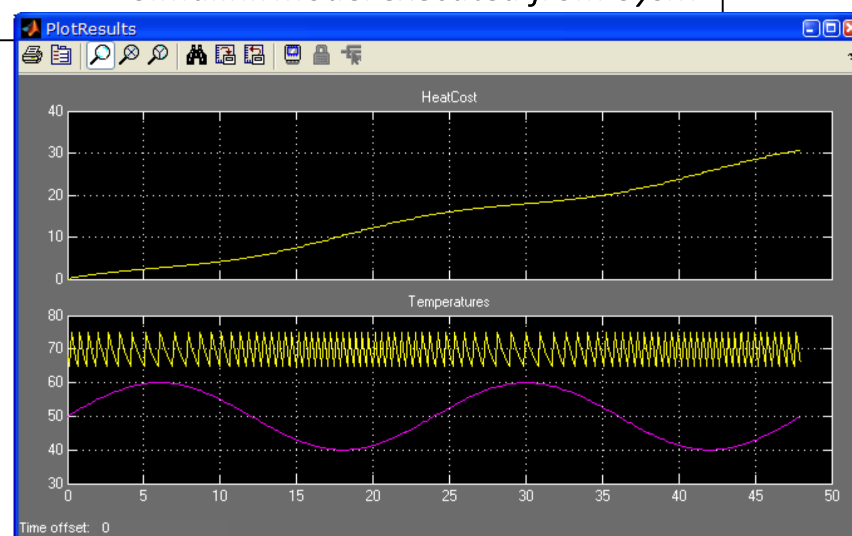
connected to a Simulink model



ParaSolver for Artisan Studio

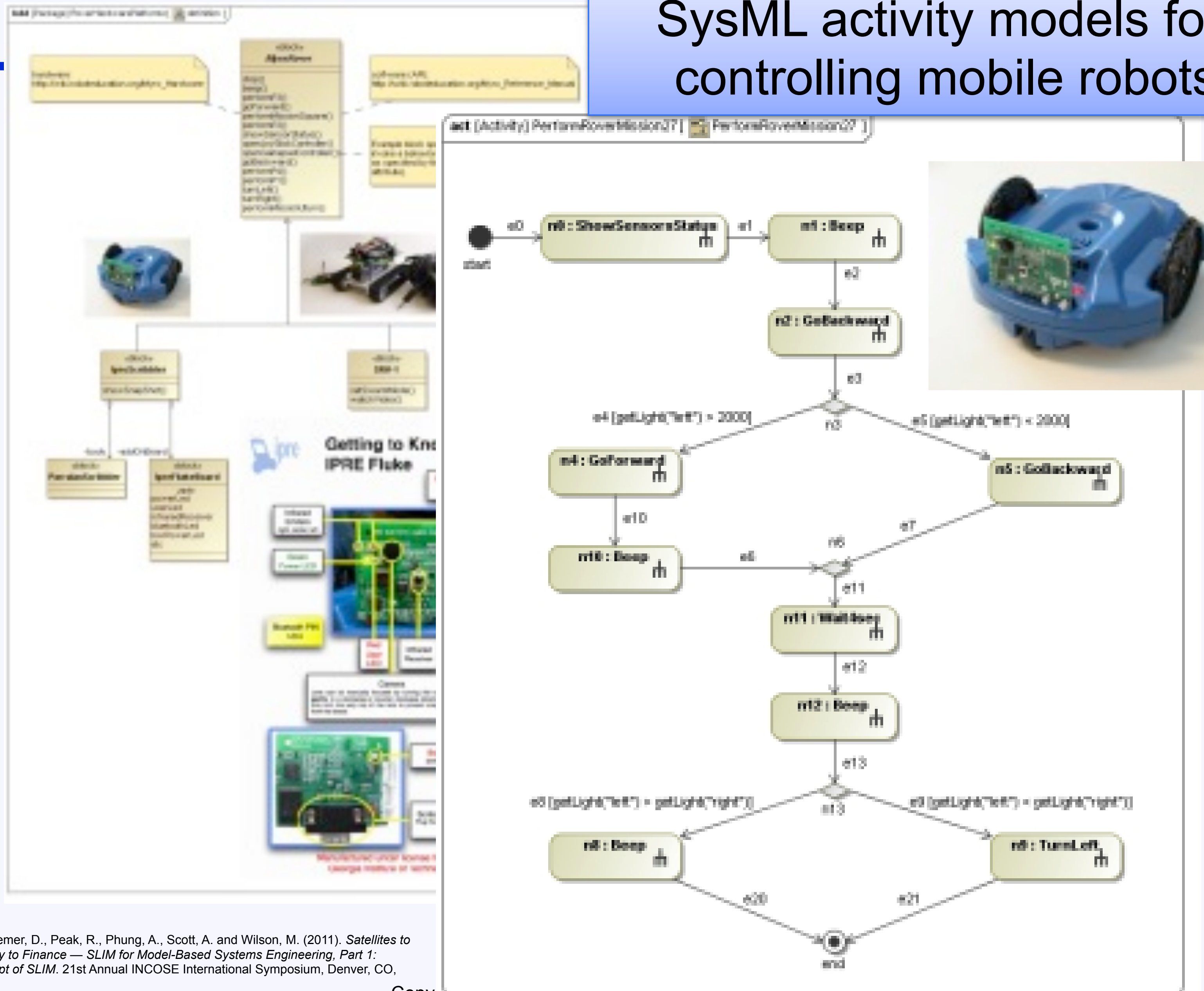


Simulink model executed from SysML



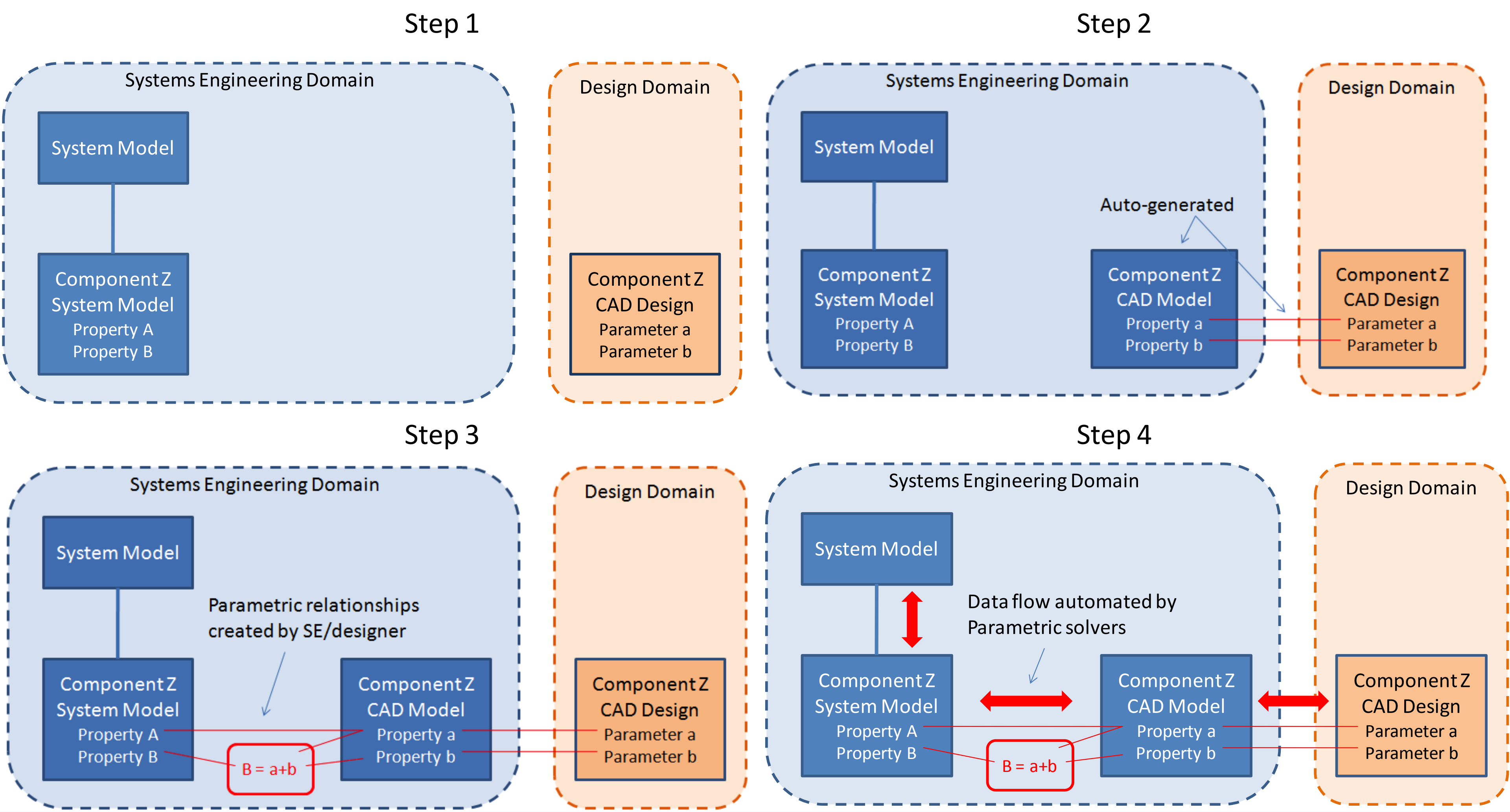
SysML Activity Execution Tool

SysML activity models for controlling mobile robots

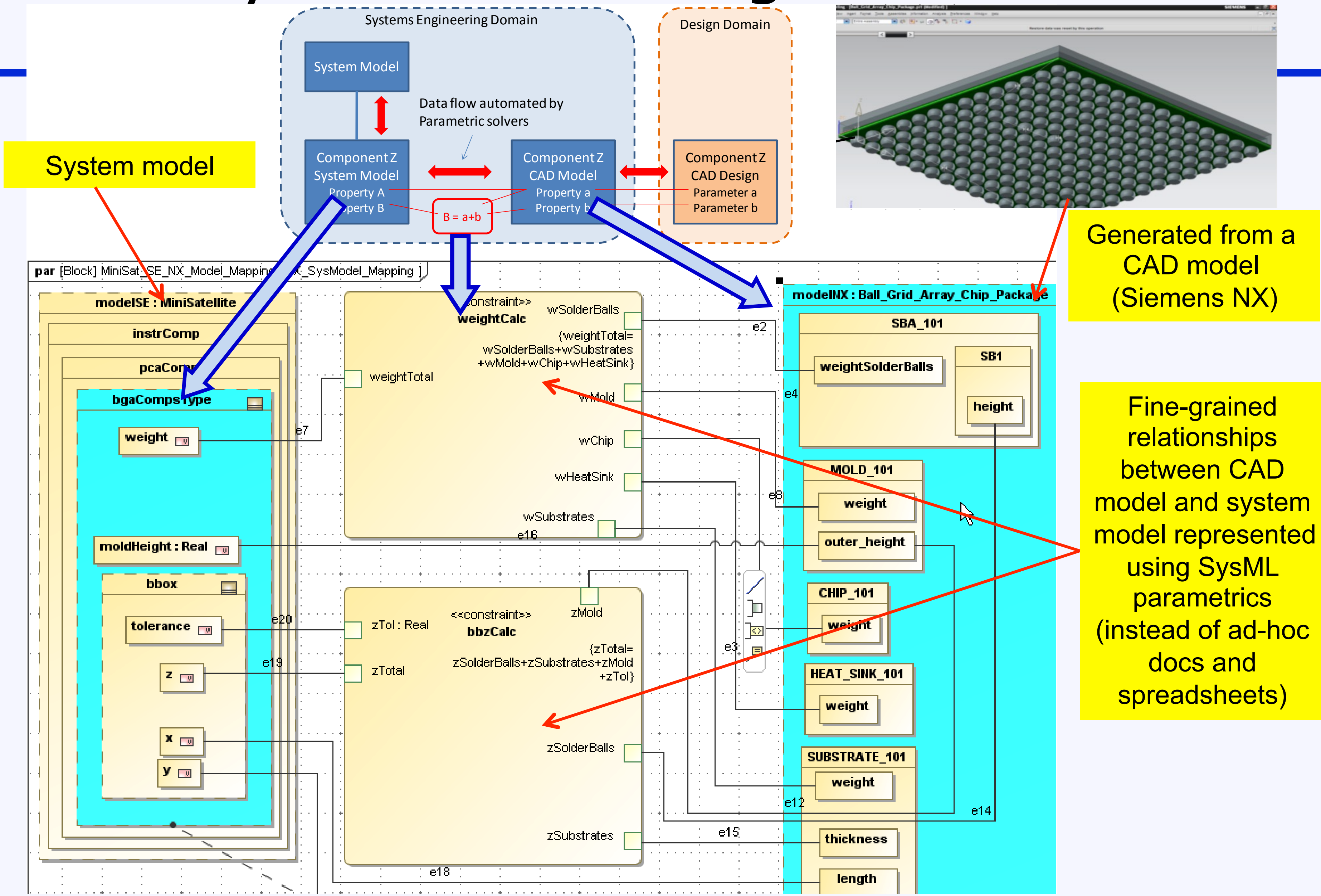


Source: Bajaj, M., Zwemer, D., Peak, R., Phung, A., Scott, A. and Wilson, M. (2011). *Satellites to Supply Chains, Energy to Finance — SLIM for Model-Based Systems Engineering, Part 1: Motivation and Concept of SLIM*. 21st Annual INCOSE International Symposium, Denver, CO, June 20-23, 2011.

SysML – CAD / STK Integration

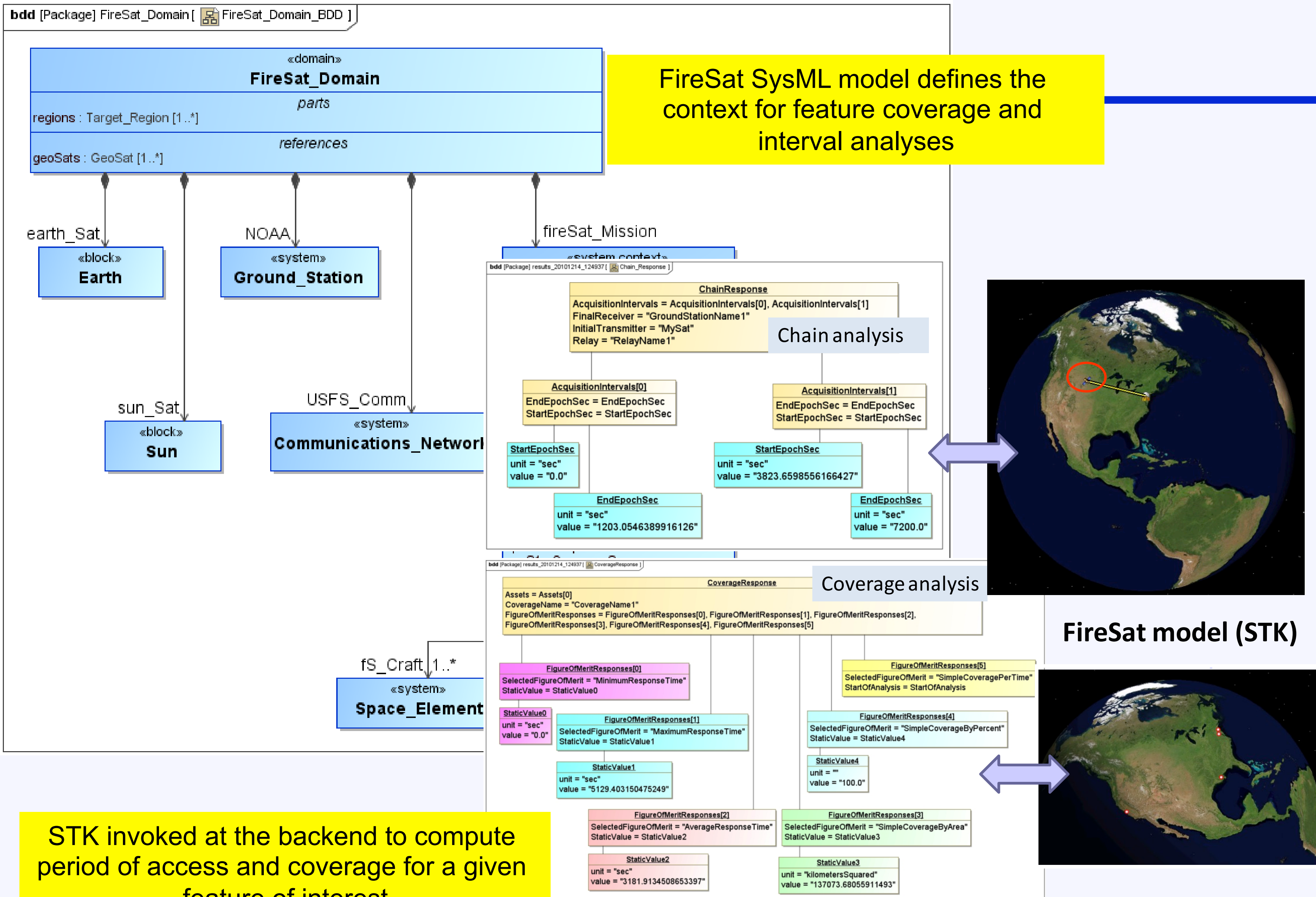


SysML – CAD Integration Tool



SysML – STK Integration Tool

FireSat SysML model defines the context for feature coverage and interval analyses



STK invoked at the backend to compute period of access and coverage for a given feature of interest

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Part 1

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Part 2: Applications of SLIM

Manas Bajaj, PhD
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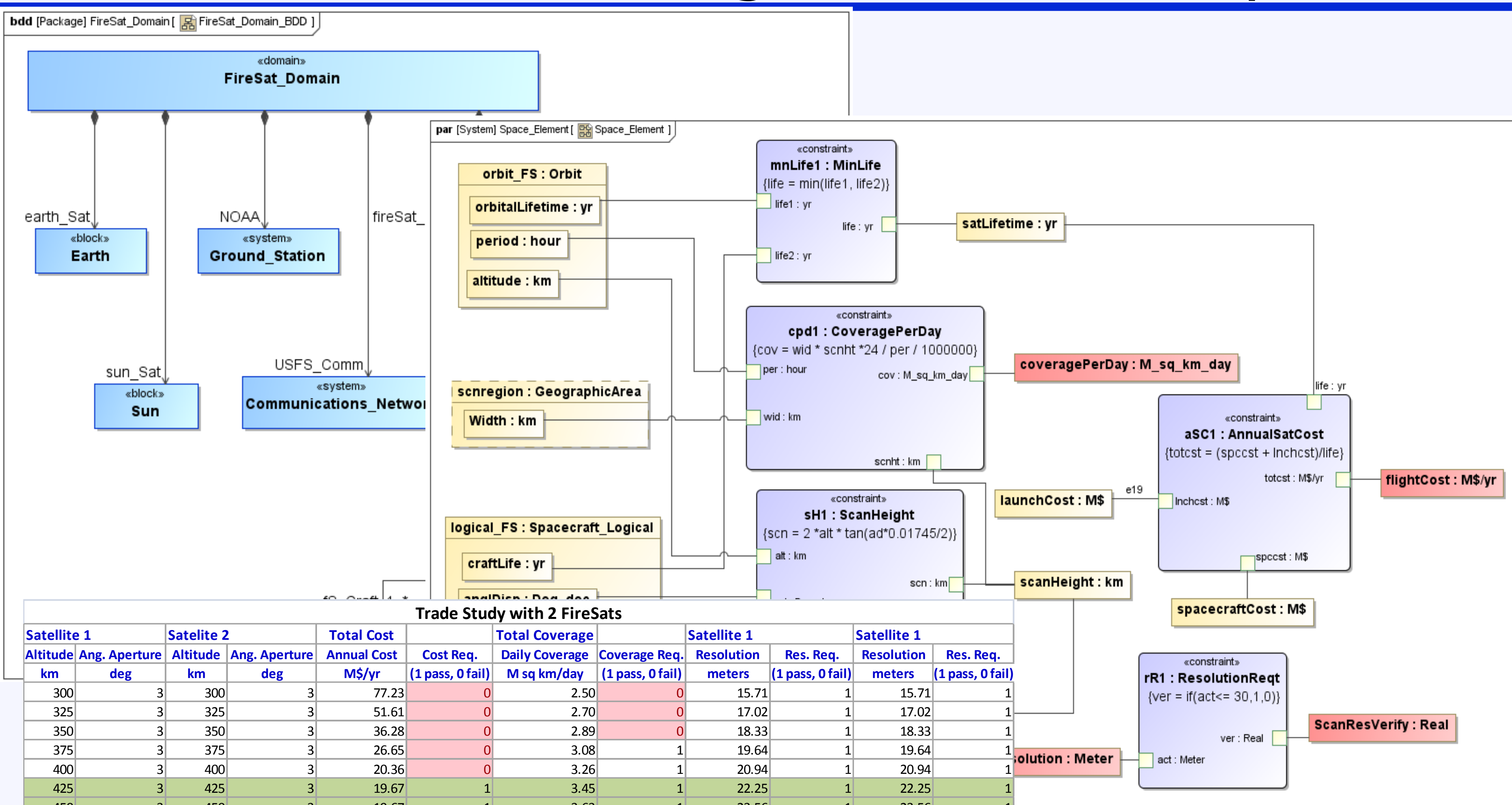
Space Systems

FireSat cost and coverage trades and reqt. verif.



Trade Study with 2 FireSats

Satellite 1		Satelite 2		Total Cost		Total Coverage		Satellite 1		Satellite 1	
Altitude	Ang. Aperture	Altitude	Ang. Aperture	Annual Cost	Cost Req.	Daily Coverage	Coverage Req.	Resolution	Res. Req.	Resolution	Res. Req.
km	deg	km	deg	M$/yr	(1 pass, 0 fail)	M sq km/day	(1 pass, 0 fail)	meters	(1 pass, 0 fail)	meters	(1 pass, 0 fail)
300	3	300	3	77.23	0	2.50	0	15.71	1	15.71	1
325	3	325	3	51.61	0	2.70	0	17.02	1	17.02	1
350	3	350	3	36.28	0	2.89	0	18.33	1	18.33	1
375	3	375	3	26.65	0	3.08	1	19.64	1	19.64	1
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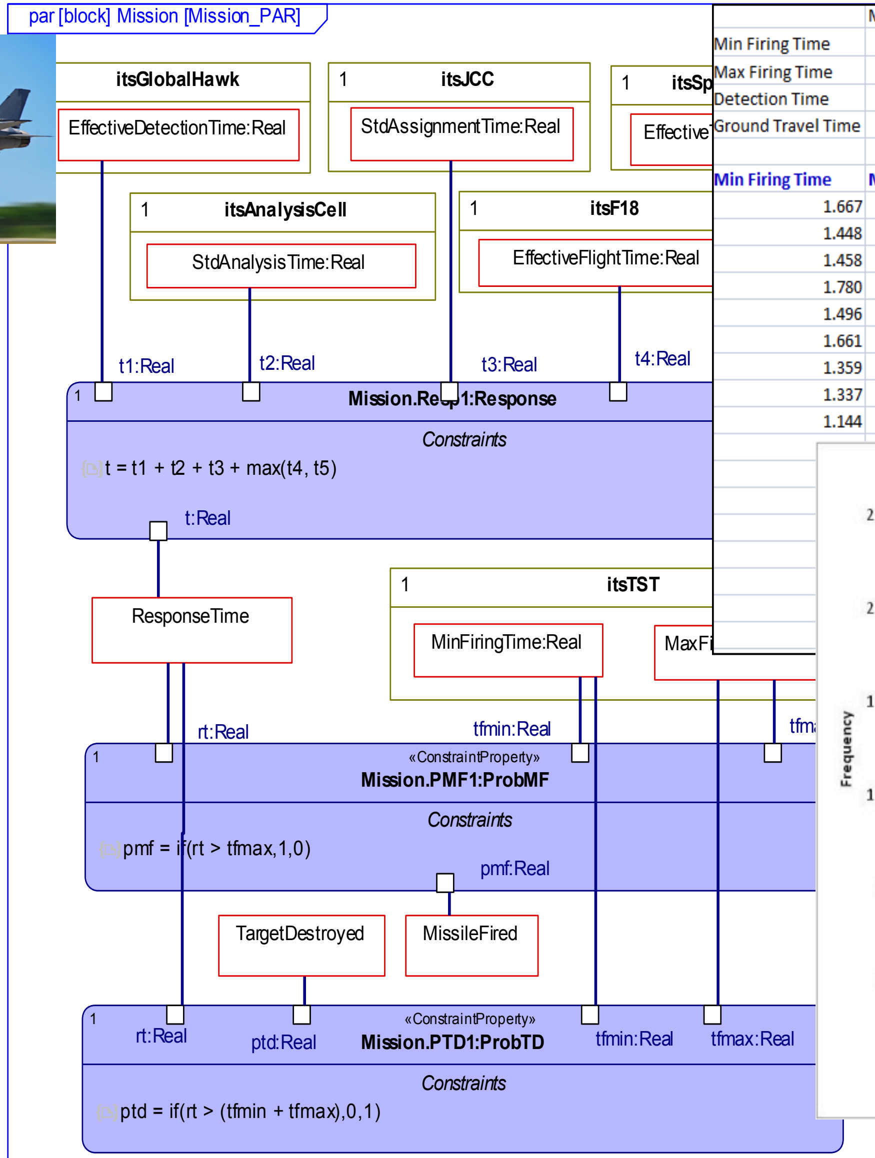
525	3	525	3	19.67	1	4.17	1	27.49	1	27.49	1
550	3	550	3	19.67	1	4.34	1	28.80	1	28.80	1
575	3	575	3	19.67	1	4.52	1	30.11	0	30.11	0
600	3	600	3	19.67	1	4.69	1	31.42	0	31.42	0

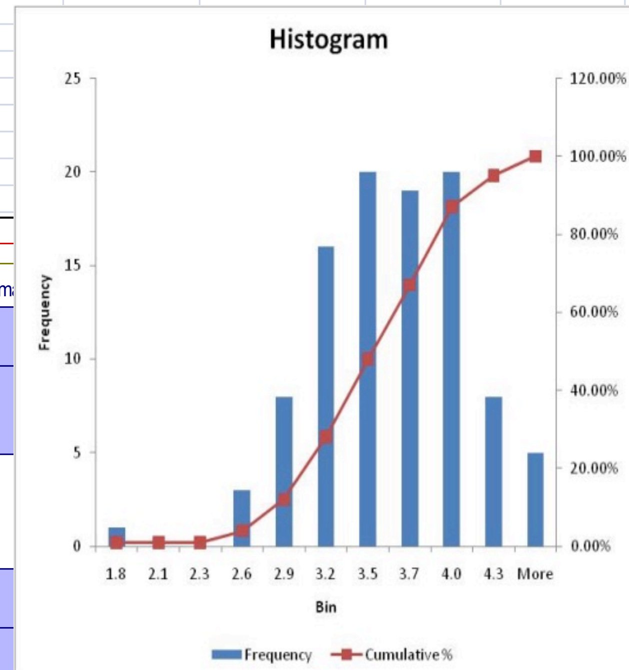
Military and Intelligence

Probability of mission success, mean response time



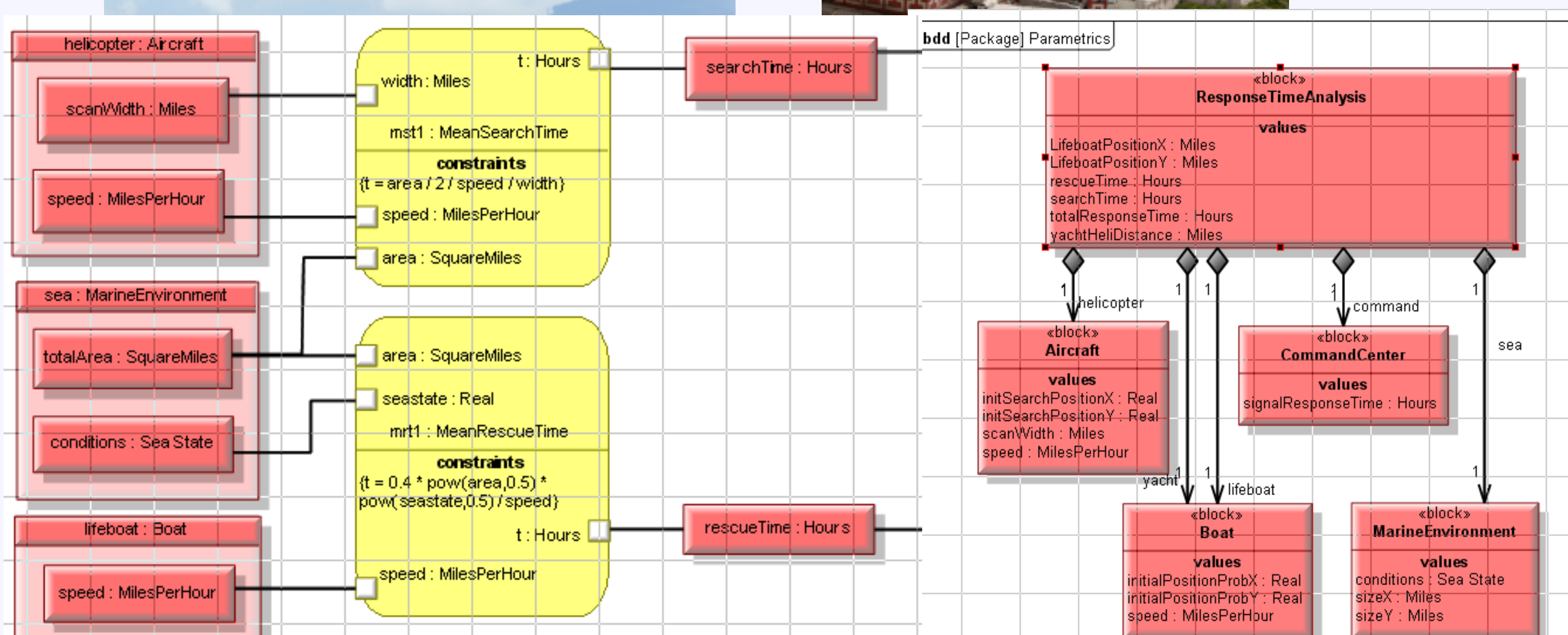
	Mean (hrs)	Variance (hrs)		
Min Firing Time	1.5	0.25	Mean Prob Missile Fired	0.36
Max Firing Time	2.5	0.25	Mean Prob TST Destroyed	1.00
Detection Time	4	1		
Ground Travel Time	2	0.5		

Min Firing Time	MaxFiring Time	UAV Detection Time	SF Travel Time	MissileFired?	TSTDestroyed?	Response Time
1.667	2.881	4.145	2.072	0	1	2.34
1.448	2.465	4.780	1.643	0	1	2.45
1.458	2.544	3.804	2.518	0	1	2.37
1.780	2.590	4.450	1.510	0	1	2.36
1.496	2.400	4.258	2.562	1	1	2.50
1.661	2.813	3.328	2.387	0	1	2.22
1.359	2.387	4.095	2.812	1	1	2.53
1.337	2.961	3.797	2.155	0	1	2.28
1.144	2.206	3.559	1.358	0	1	2.14
					1	2.75
					1	1.83
					1	2.57
					1	2.72
					1	2.03
					1	2.23
					1	2.54
					1	2.15

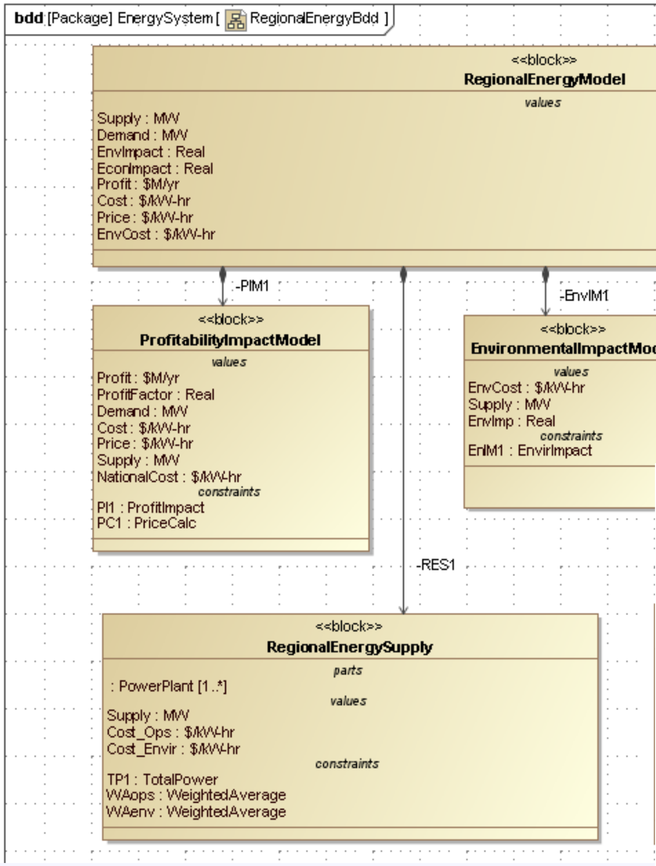


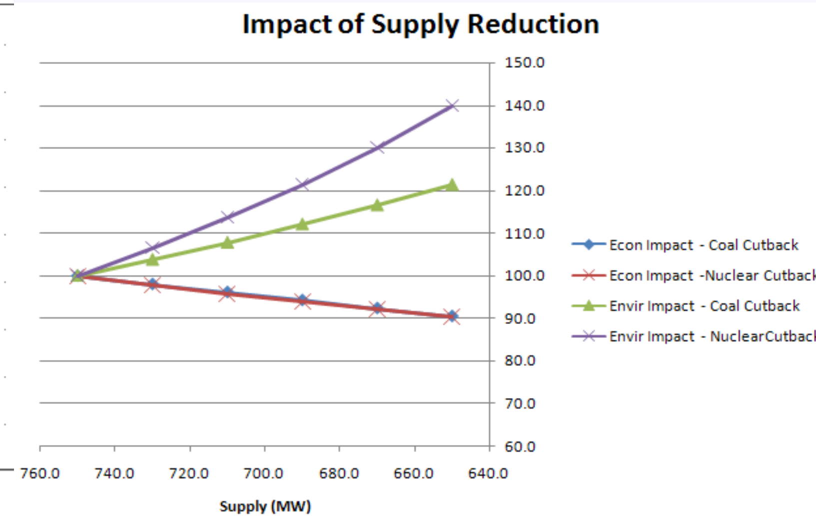
Disaster Response

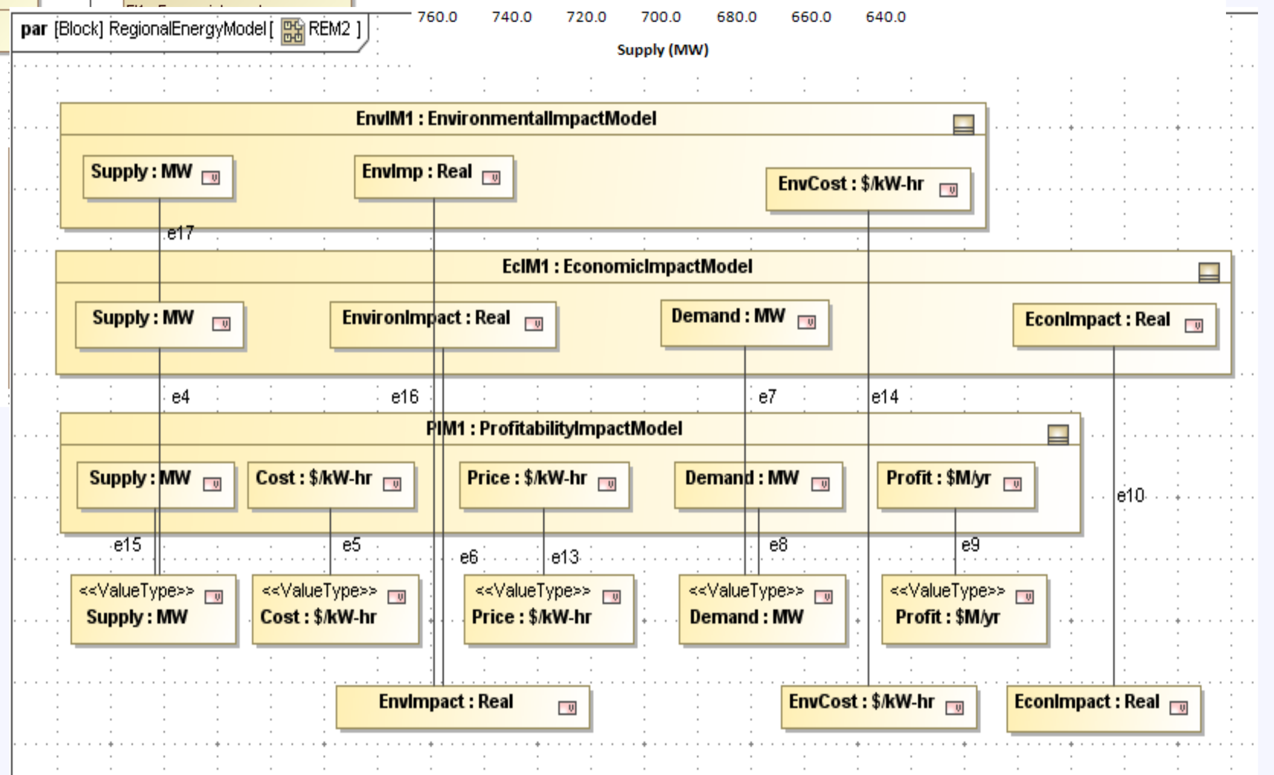
Search & rescue area coverage and response time



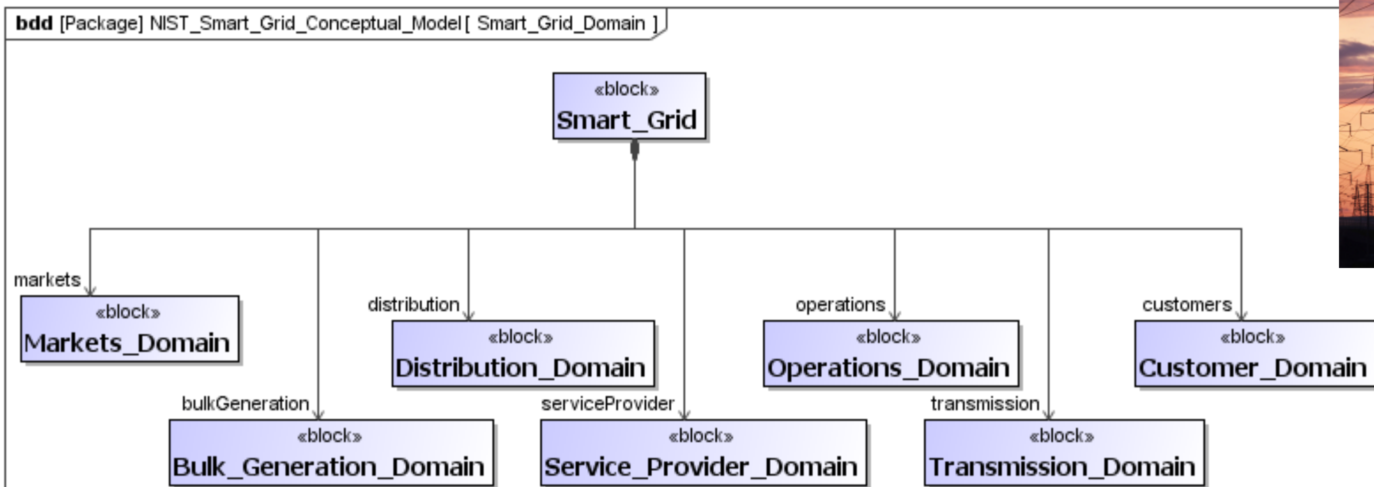
Energy Systems
Profitability, Environment, and Economy

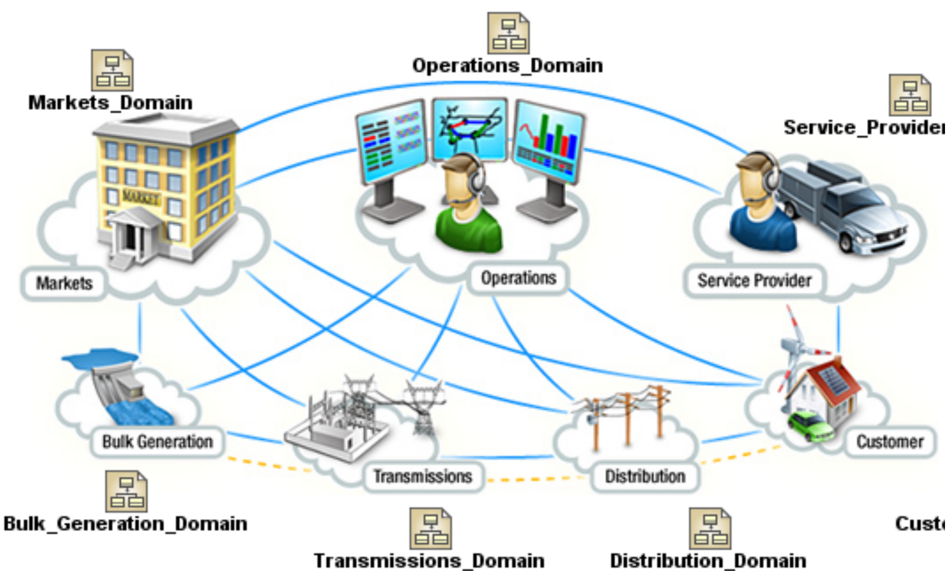


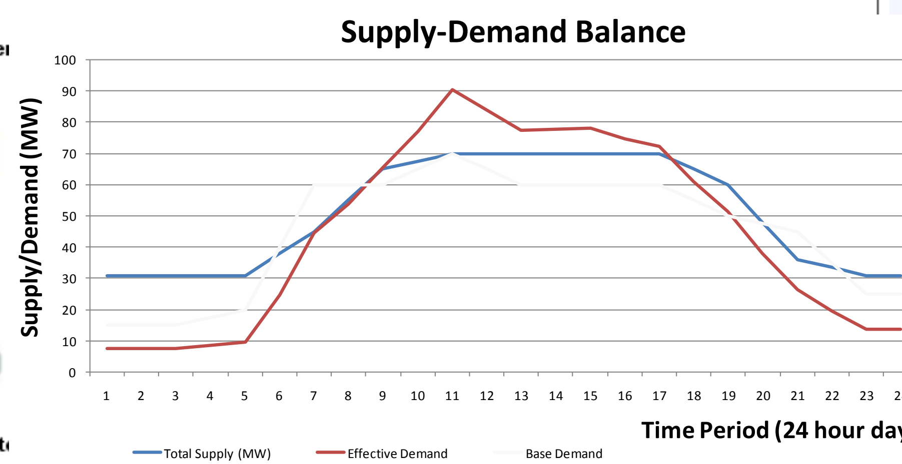




Smart Grid



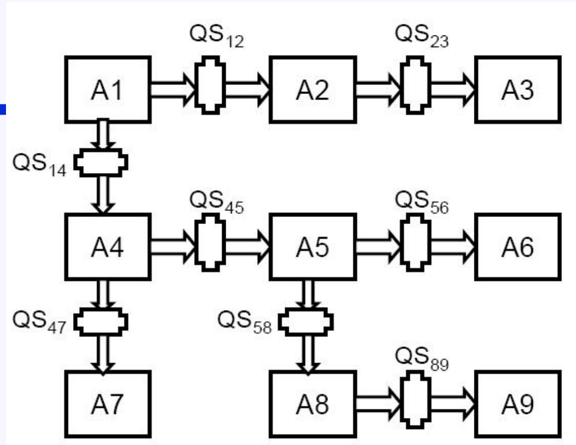


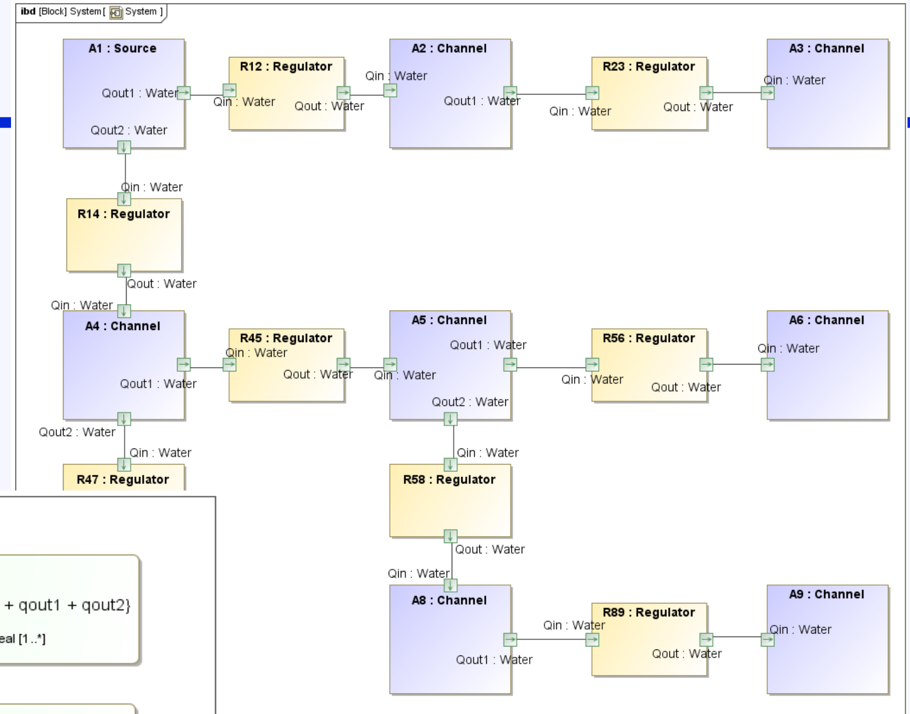


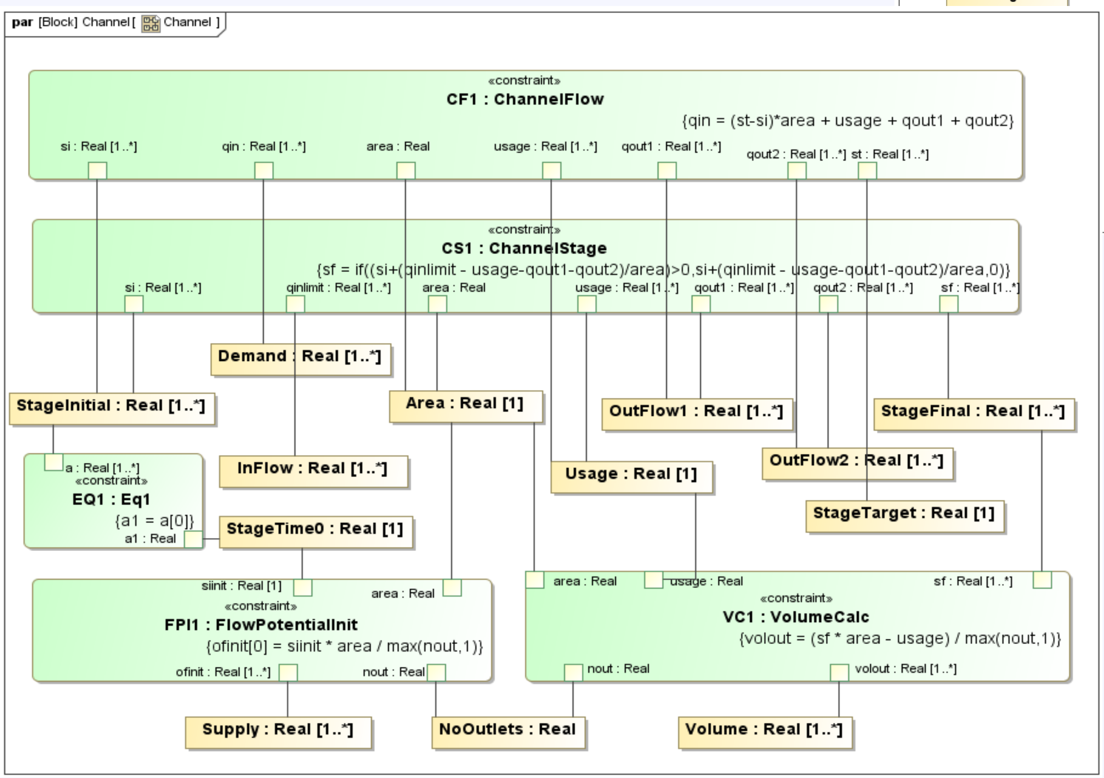
Daily Expense: SmartGrid $60,228 DumbGrid $66,477

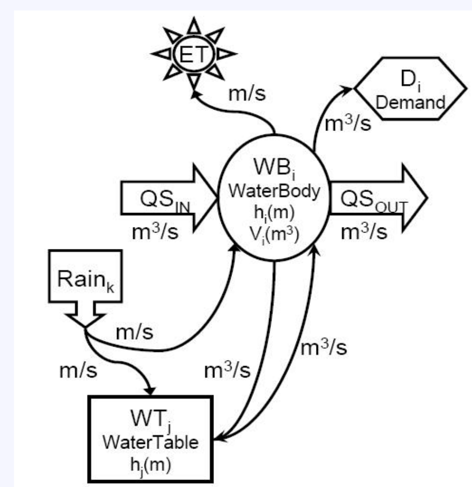
For more info, visit http://smartgrid.ieee.org/nist-smartgrid-framework

Infrastructure Systems



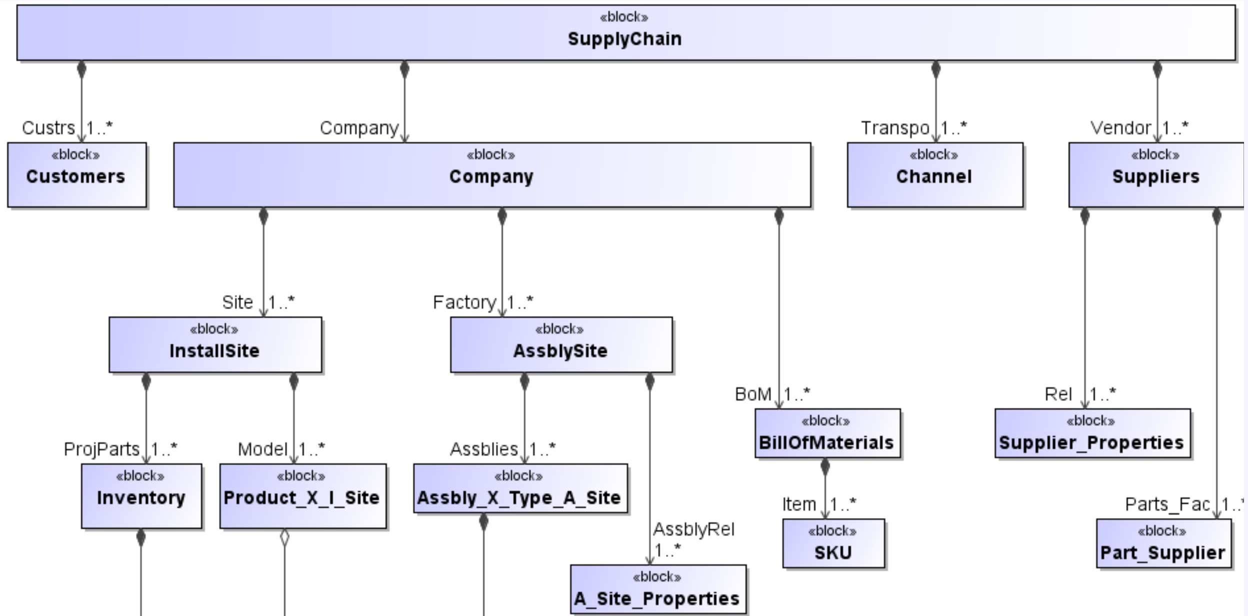


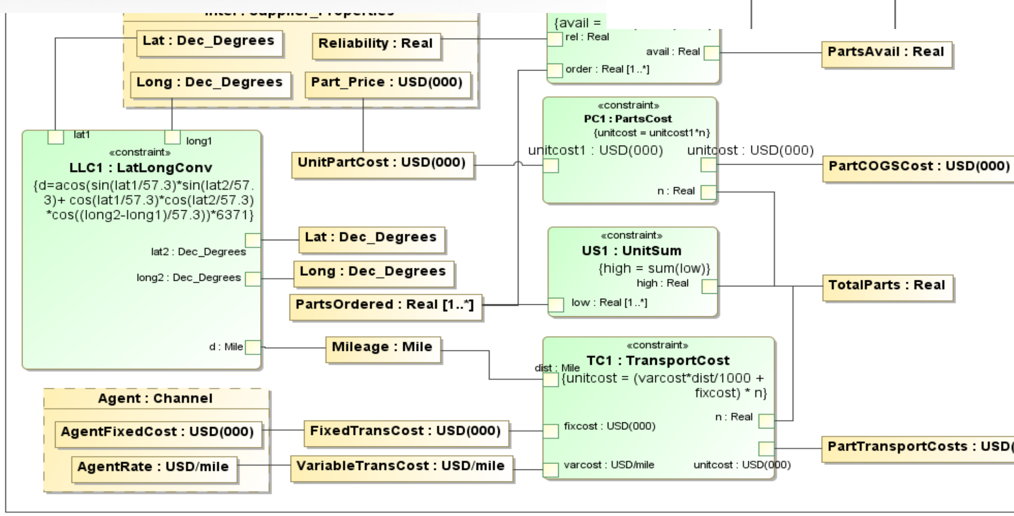


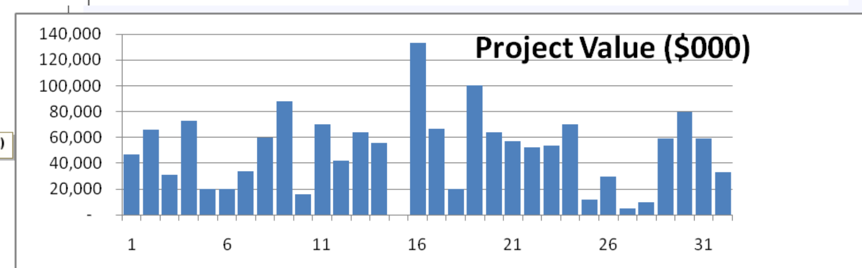


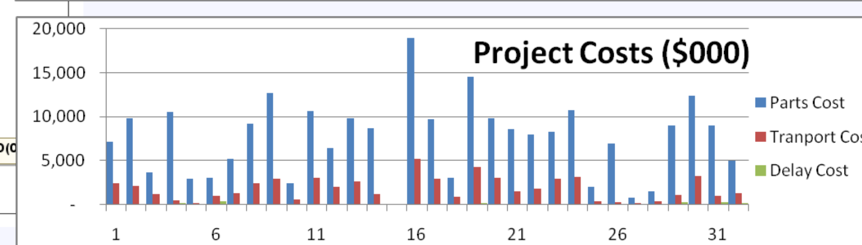
Manufacturing and Supply Chain

Computing value at risk, supply-demand balance



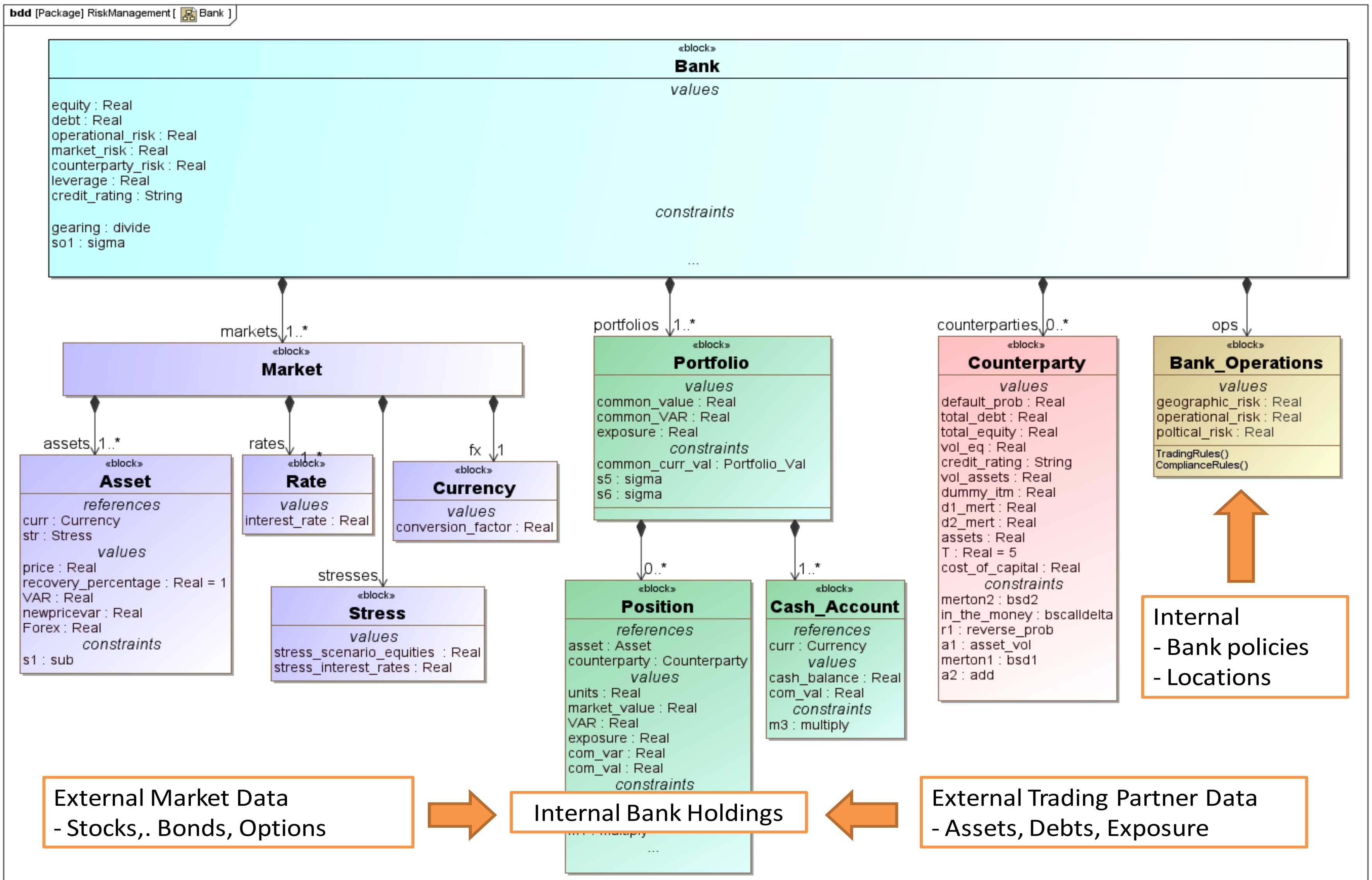






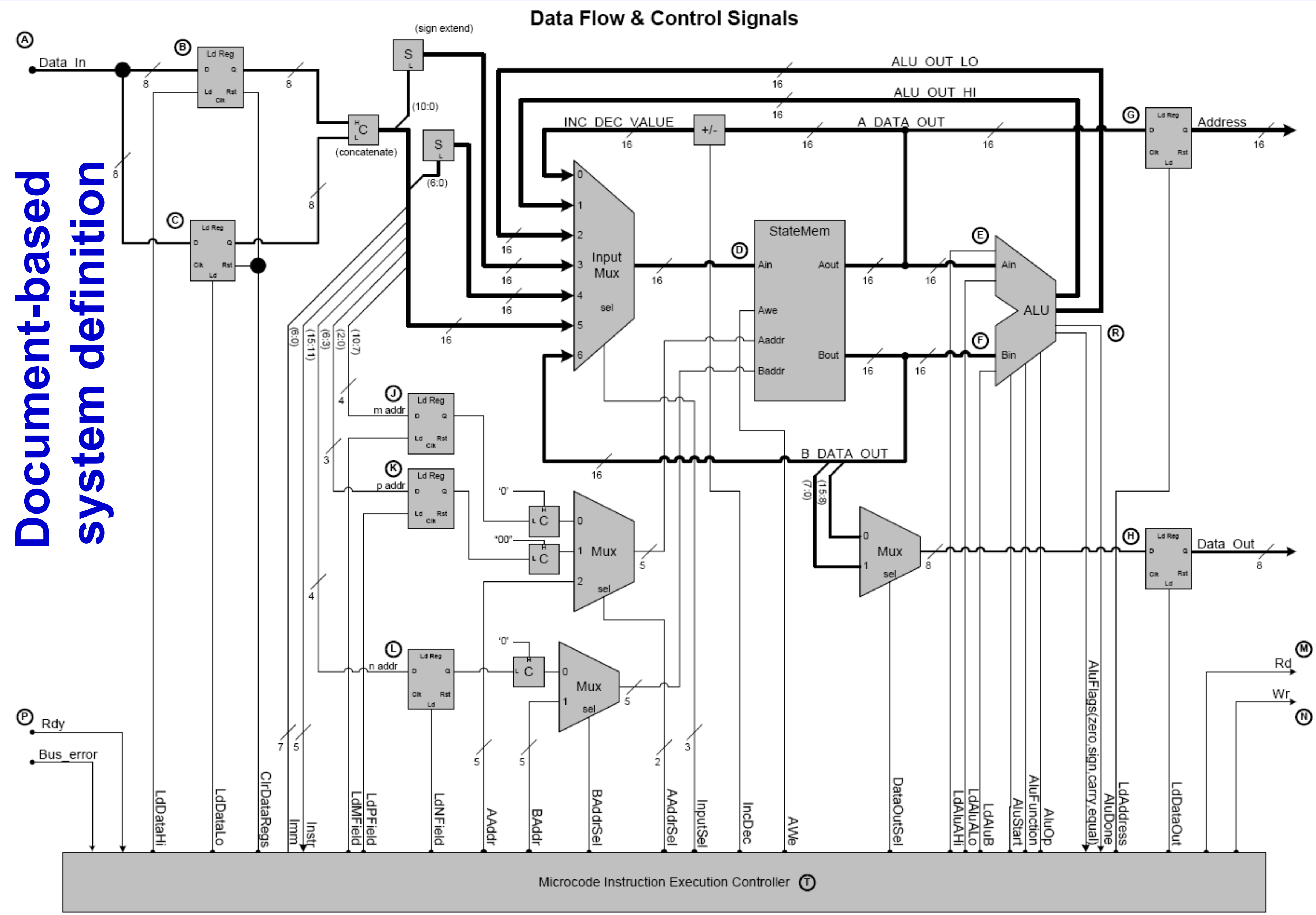
Banking and Financial Systems

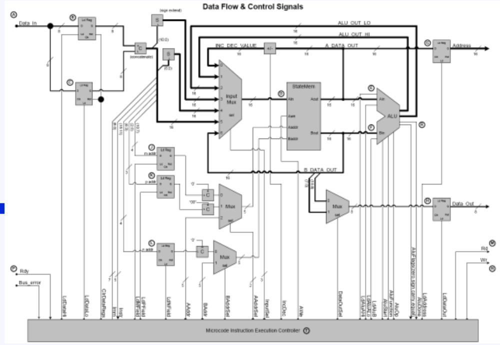
Computing risk and checking compliance



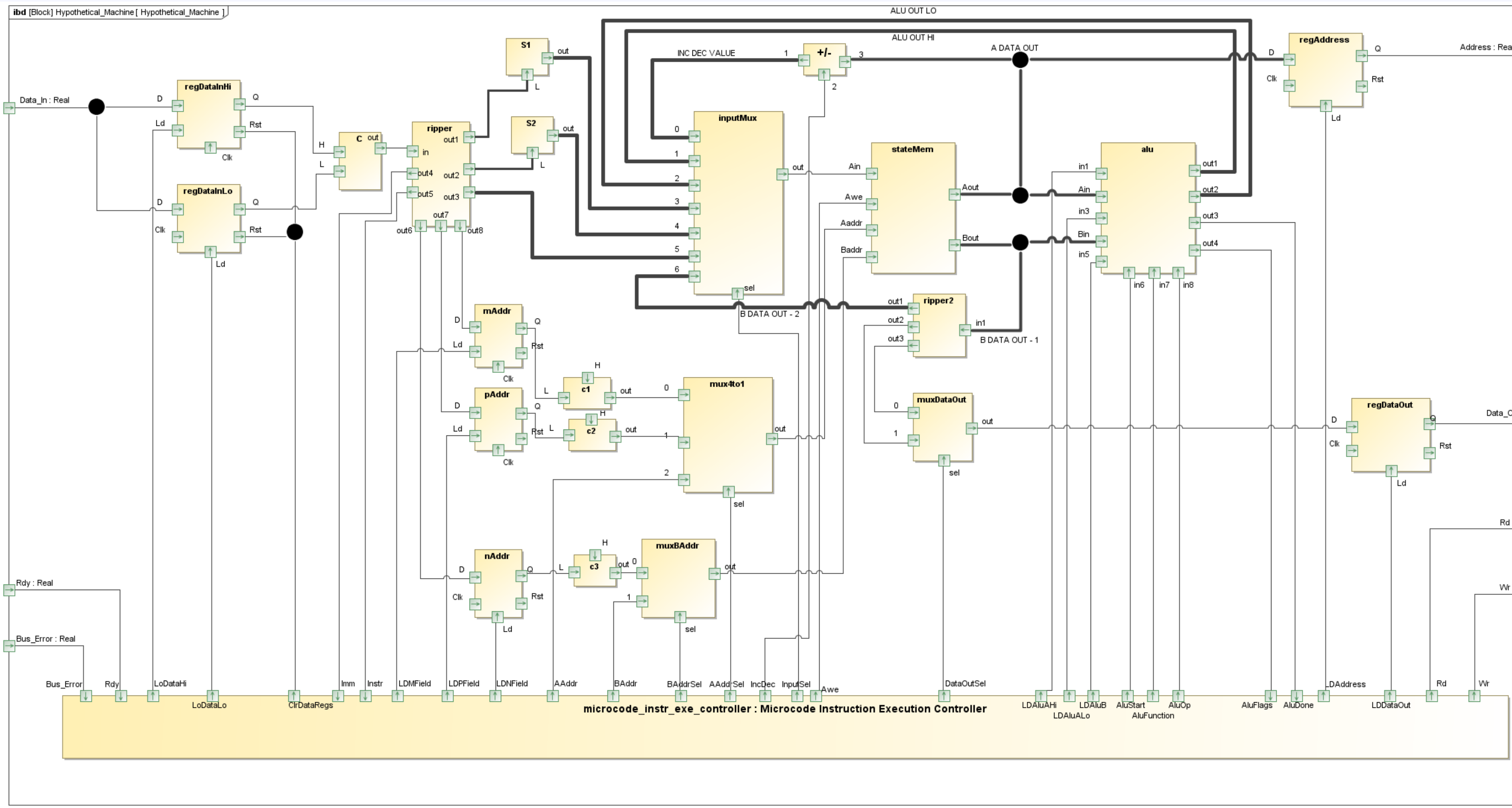
MBSE of Electronics Systems

Document-based system definition

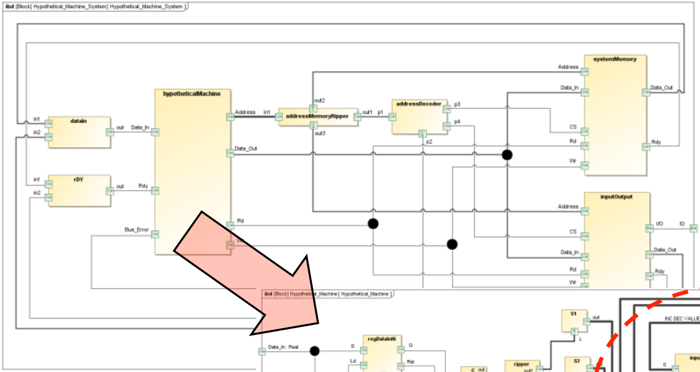


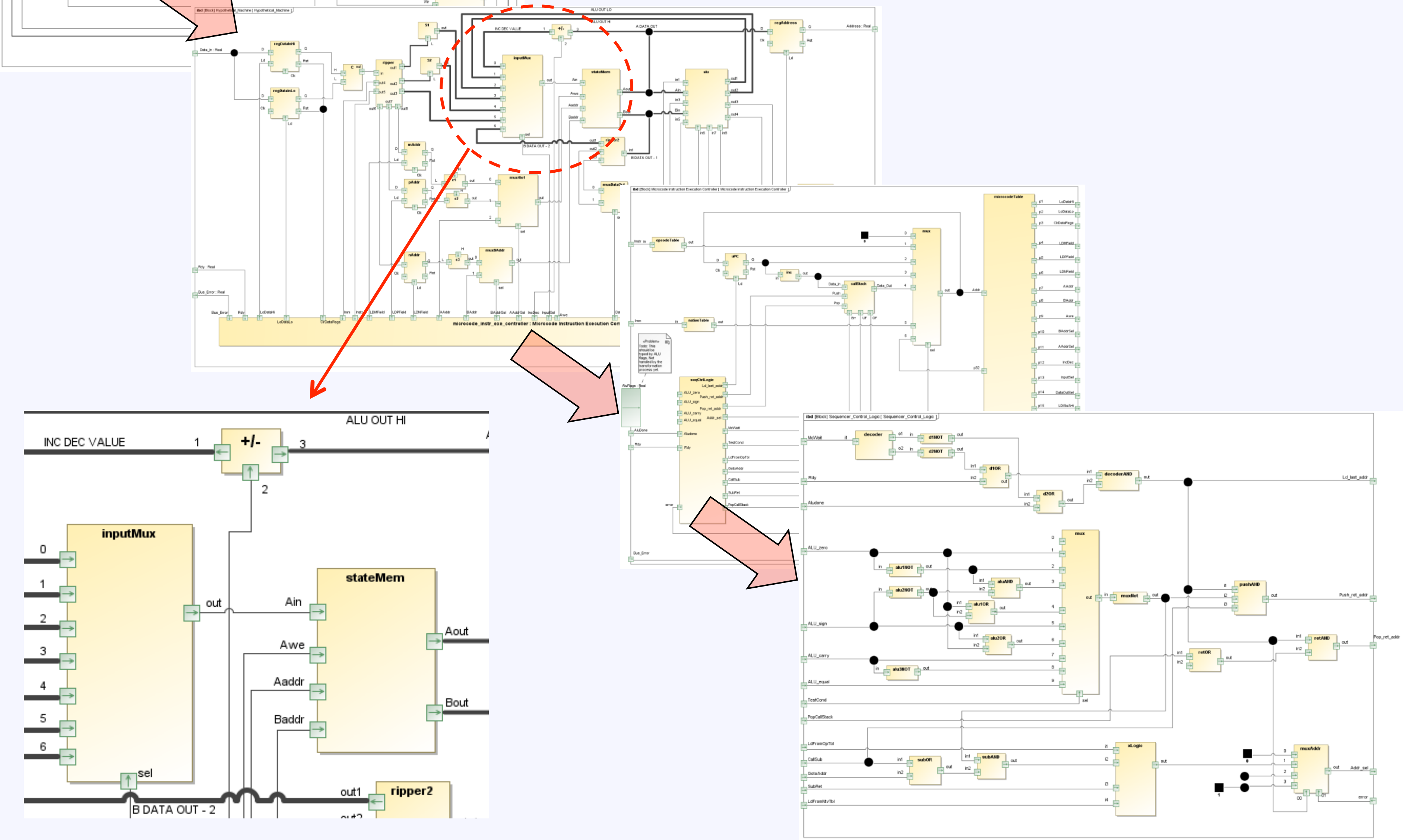


Model-Based System Definition



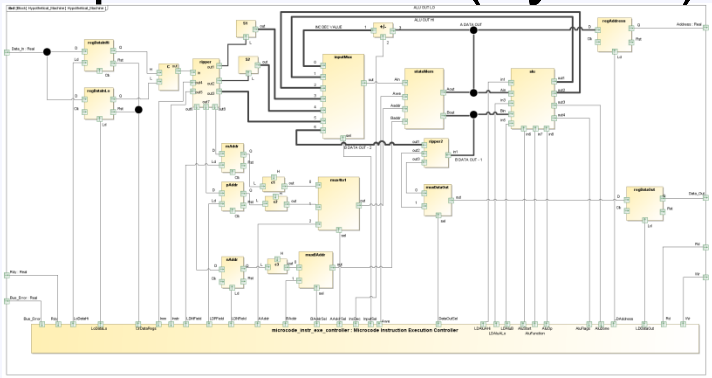
System Decomposition SysML IBDs



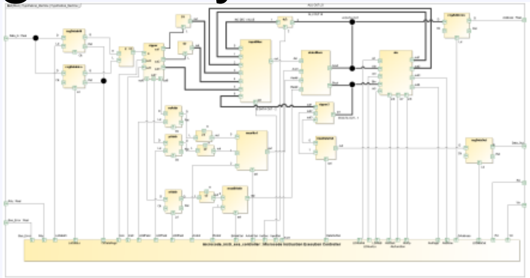


Generating Simulation Models SysML, XML, and Java

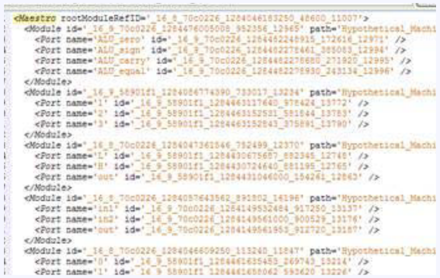
System Design Representation (SysML)



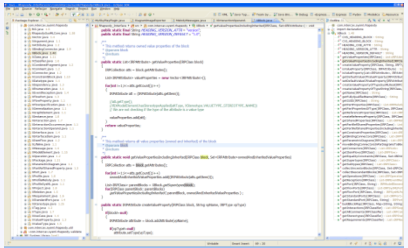
SysML-based Analytical Model + design-analysis relationships



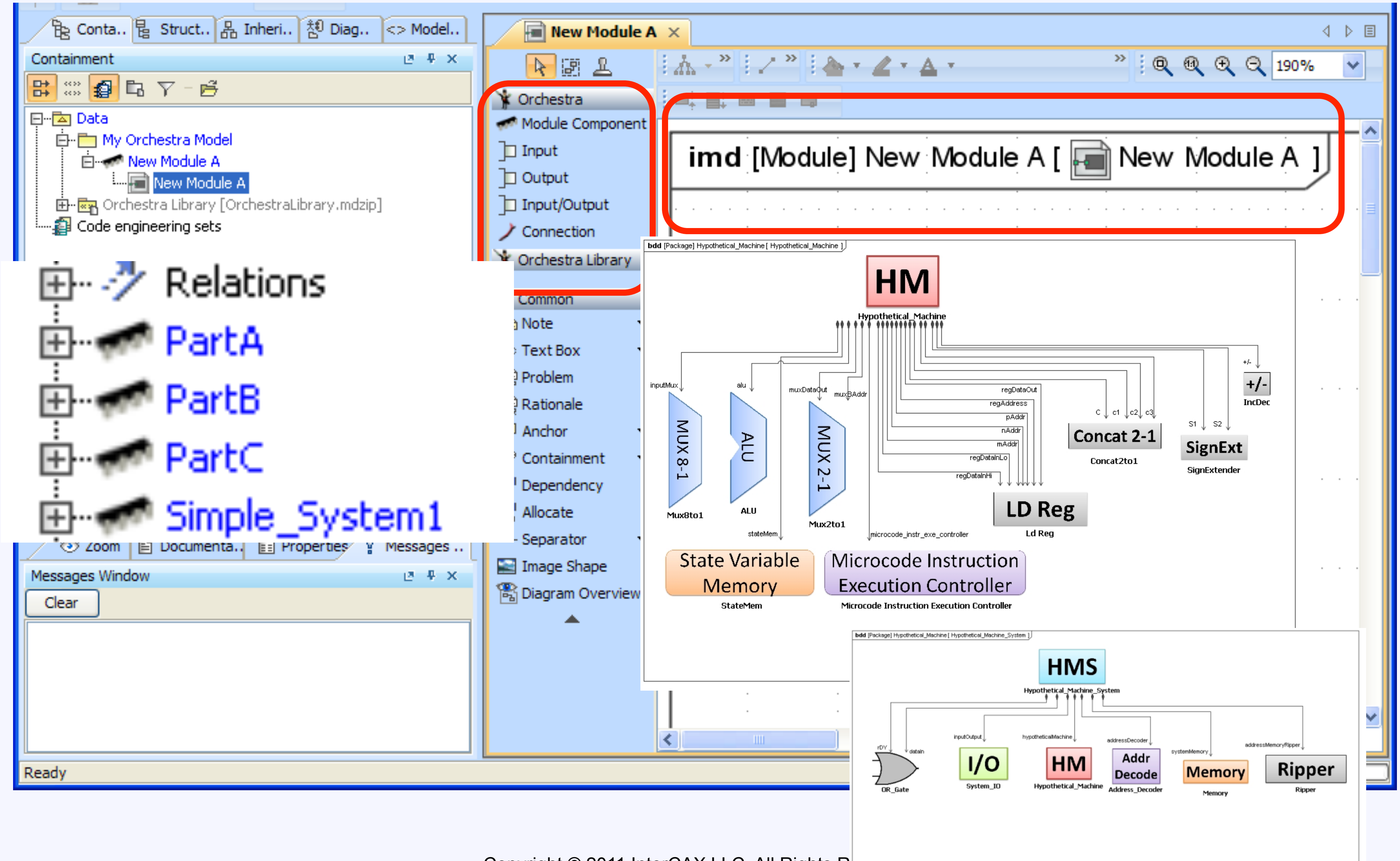
XML-based analytical model structure



Java-based simulation model



DSL Plugin Environment for Designers and Analysts



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Experiences

- Computing with SysML & Variable Topology
- Deployment for all 4 major SysML authoring tools
- SysML/MBSE for different applications
- SysML – X tool interoperability patterns
- Domain-specific MBSE

Contact

Manas Bajaj
manas.bajaj@intercax.com

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- SysML/MBSE – www.intercax.com/mbse
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