INCOSE International Workshop — IW2014
Presentation for Affordability Working Group
Monday January 27,2014

SysML Building Blocks for Cost Modeling: Towards Model-Based Affordability Analysis

Part of SERC RT46 Phase 2 [Contract # H98230-08-D-0171]
"-ilities" Tradespace and Affordability Program (ITAP)

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Jo Ann Lane – USC

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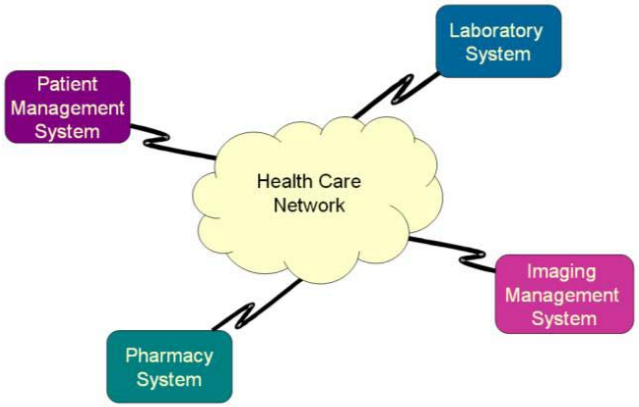
Contents

- SERC ITAP/RT46 project context & summary
- Leveraged bodies of work (BW_i)
  - BW2: Patterns for model interoperability (MIM)
  - BW1: Trade study capabilities (FACT)
  - BW3: Cost modeling capabilities (COSYSMO ...)
  - BW4: Implementation enablers (MBSE/SysML ...)
- Results from Stage 1 work (Oct-Dec 2013)
  - Building blocks and case study implementation
- Summary & observations
- Proposed future work
- Selected bibliography

SysML Building Blocks for Cost Modeling
Initial Work in RT46 Phase 2 (Oct-Dec 2013)

- Implemented reusable SysML building blocks
  - Based on SoS/COSYSMO SE cost (effort) modeling work by Lane, Valerdi, Boehm, et al.
- Successfully applied building blocks to healthcare SoS case study from [Lane 2009]
- Provides key step towards affordability trade studies involving diverse "-ilities" (*see MIM slides*)



Aspect	Formula	Calculated Effort
SoSE effort (Equation 5)	Effort = 38.55*[((SoS_{CR} / SoS_{Treq})* (SoS_{Treq})$^{1.06}$ * EM_{SOS-CR}) + (((SoS_{MR} / SoS_{Treq})* (SoS_{Treq})$^{1.06}$ * EM_{SOS-MR}*OSF)] /152 = 38.55*[((50 / 52) * (52)$^{1.06}$ * 2.50) + (20/52)*(52)$^{1.06}$* 0.47 * 10%)] / 152	40.41
Pharmacy System effort (Equation 4)	Effort = 38.55*[(1.0+$CS_{Softimp}$) * (($SoS_{CSatisc}$/$CS_{Treq(SoSE)}$)* ($CS_{Treq(SoSE)}$)$^{1.06}$* $EM_{CS-CRWSOSE}$) + ($CS_{Sam/Soft}$/$CS_{Treq(SoSE)}$) * ($CS_{Treq(SoSE)}$)$^{1.06}$ * $EM_{CSam/SOS}$] /152 = 38.55 *[(1.15) * ((50/70)*(70)$^{1.06}$ * 1.06 + (20/70) * (70)$^{1.06}$*0.72] / 152	22.02
Laboratory System effort (Equation 4)	Effort = 38.55*[(1.0+$CS_{Softimp}$) * (($SoS_{CSatisc}$/$CS_{Treq(SoSE)}$)* ($CS_{Treq(SoSE)}$)$^{1.06}$* $EM_{CS-CRWSOSE}$) + ($CS_{Sam/Soft}$/$CS_{Treq(SoSE)}$) * ($CS_{Treq(SoSE)}$)$^{1.06}$ * $EM_{CSam/SOS}$] /152 = 38.55 *[(1.15) * ((50/50)*(50)$^{1.06}$ * 1.06 + 0] / 152	19.55
Imaging System effort (Equation 4)	Effort = 38.55*[(1.0+$CS_{Softimp}$) * (($SoS_{CSatisc}$/$CS_{Treq(SoSE)}$)* ($CS_{Treq(SoSE)}$)$^{1.06}$* $EM_{CS-CRWSOSE}$) + ($CS_{Sam/Soft}$/$CS_{Treq(SoSE)}$) * ($CS_{Treq(SoSE)}$)$^{1.06}$ * $EM_{CSam/SOS}$] /152 = 38.55 *[(1.15) * ((50/50)*(50)$^{1.06}$ * 1.06 + 0] / 152	19.55
New infrastructure component effort (Equation 1)	Effort = 38.55*EM*(size)$^{1.06}$/152 = 38.55 * 1.0 * (100)$^{1.06}$ / 152	33.43
	Total Effort:	134.96

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MIM Panorama for Naval/Marine Vessels

Ship Design, Analysis, and Operation
(pro-forma)

MIM = Modeling Interoperability Method
[Peak et al. 2010]

Based on HMX 0.1
2008-02-20

c2. Optimization Templates

c0. Context-Specific Models

Legend
- Parametric associativity
- Tool & native model associativity
- Composition relationship (re-usage)

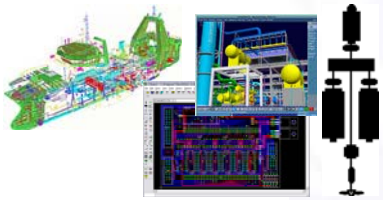
a0. Descriptive Resources

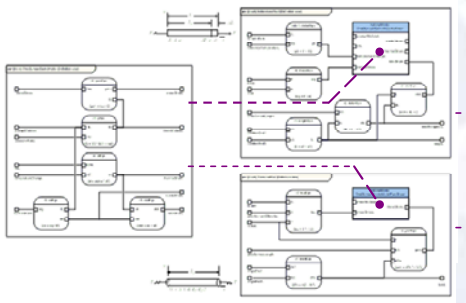
d0. Simulation Building Blocks

c1. Simulation Templates
(of diverse behavior & *fidelity*)

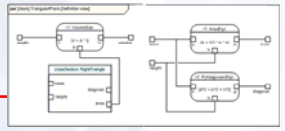
e0. Solver Resources

ECAD & MCAD Tools
Tribon, CATIA, NX, Cadence, ...





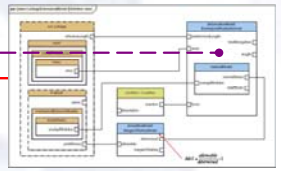
Evacuation Mgt.



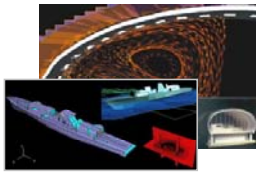
Evacuation Codes
Egress, Exodus, …

General Math
Mathematica, Maple, Matlab…

2D

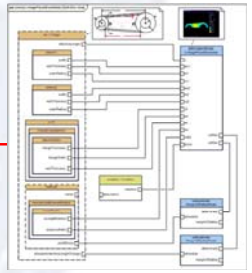


CFD
Flotherm, Fluent, …

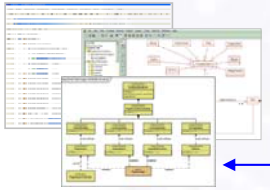


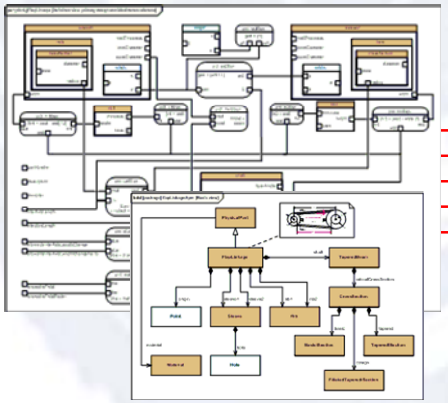
Propeller Hydro-dynamics

3D



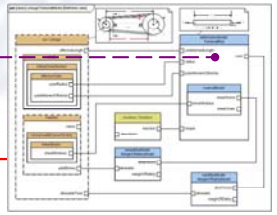
Systems & Software Tools
DOORS, E+ MagicDraw, Studio, Eclipse, …

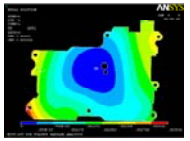




FEA
Abaqus, Ansys, Patran, Nastran, …

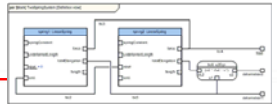
Damaged Stability





Operation Mgt. Systems

Navigation Accuracy



Discrete Event
Arena, Quest, …

Libraries & Databases
Classification Codes, Materials, Personnel, Procedures, …

b0. Federated Descriptive Models

MIM Panorama for Naval/Marine Vessels — FACT/ITAP RT46

Ship Design, Analysis, and Operation (pro-forma — for SERC RT46 Phase 2 report Dec 2013)

ITAP Future Work

Core Implementation Enabler:
BW4 SysML/MBSE/MBE

Tradespace Exploration (c2)
BW1 *FACT*

MIM Patterns (a0-e0)

BW2

c2. Trade Study Templates

c0. Context-Specific Models

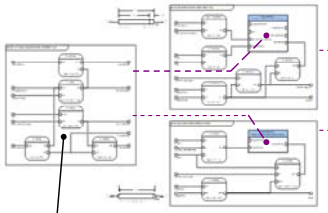
Legend
- Parametric associativity
- Tool & native model associativity
- Composition relationship (re-usage)

a0. Descriptive Resources

c1. Sim/Analysis Templates
(of diverse behavior & *fidelity*)

e0. Solver Resources

d0. Sim/Analysis Building Blocks



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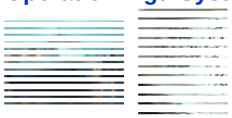

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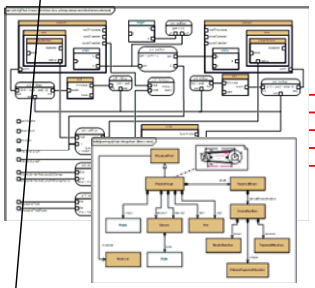
Classification Codes, Materials, Personnel, Procedures, …



b0. Federated Descriptive Models

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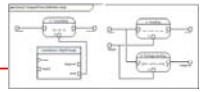

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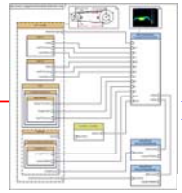

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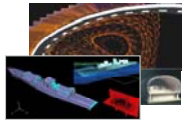

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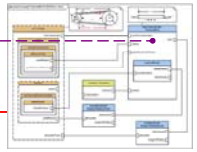

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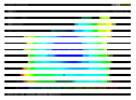

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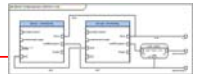


Discrete Event
Arena, Quest, …

2013-12 - Russell.Peak@gatech.edu

BW$_j$ = body of work j brought together in ITAP project

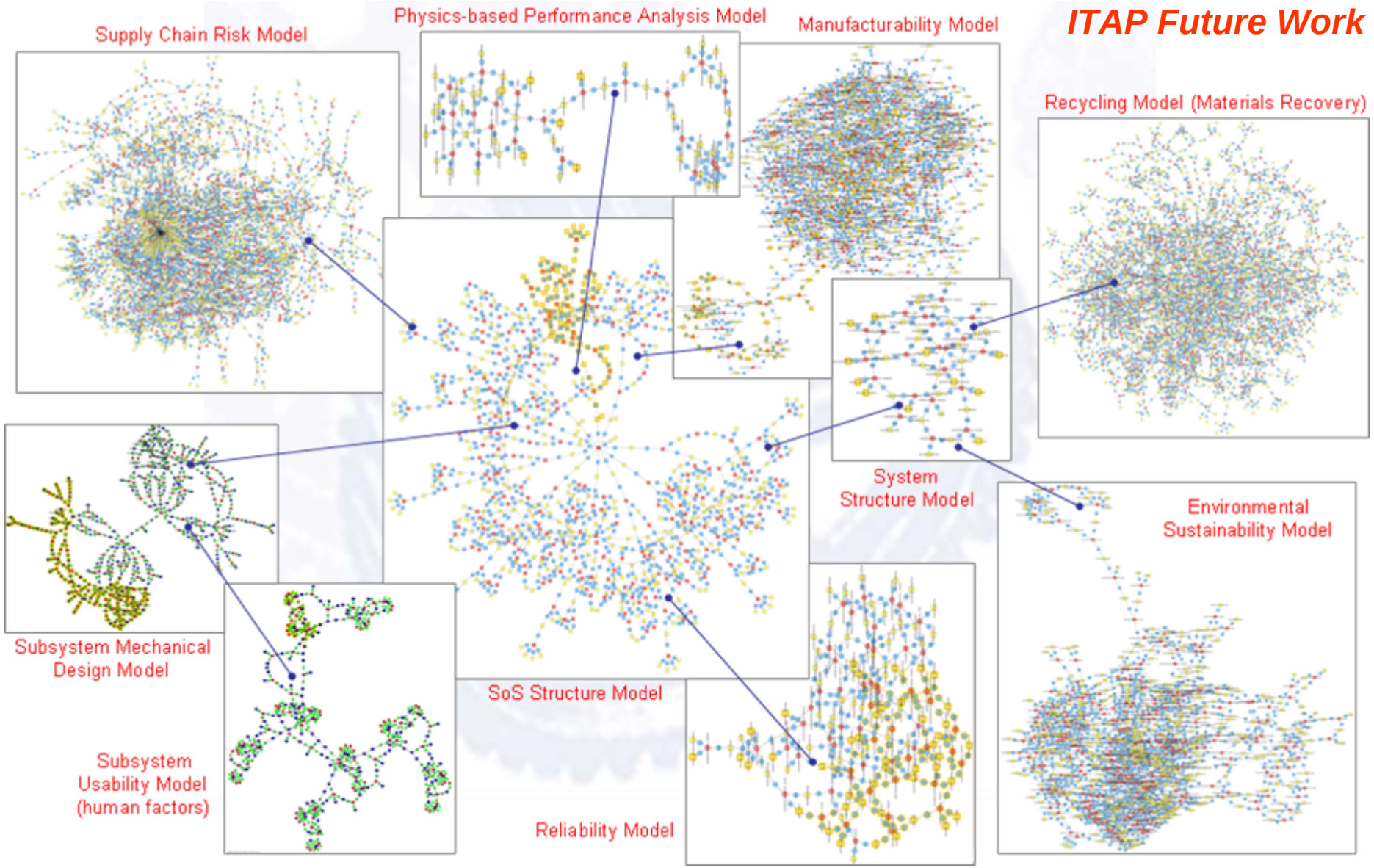
BW3 Cost Model Building Blocks (d0)
COCOMO, COSYSMO, etc.

Software Engr Cost Models

Systems Engr Cost Models

Trade Studies with Diverse "-ilities" [DNA Signature View]

Multi-Domain, Multi-Behavior, Multi-Fidelity, ... *(pro-forma)*



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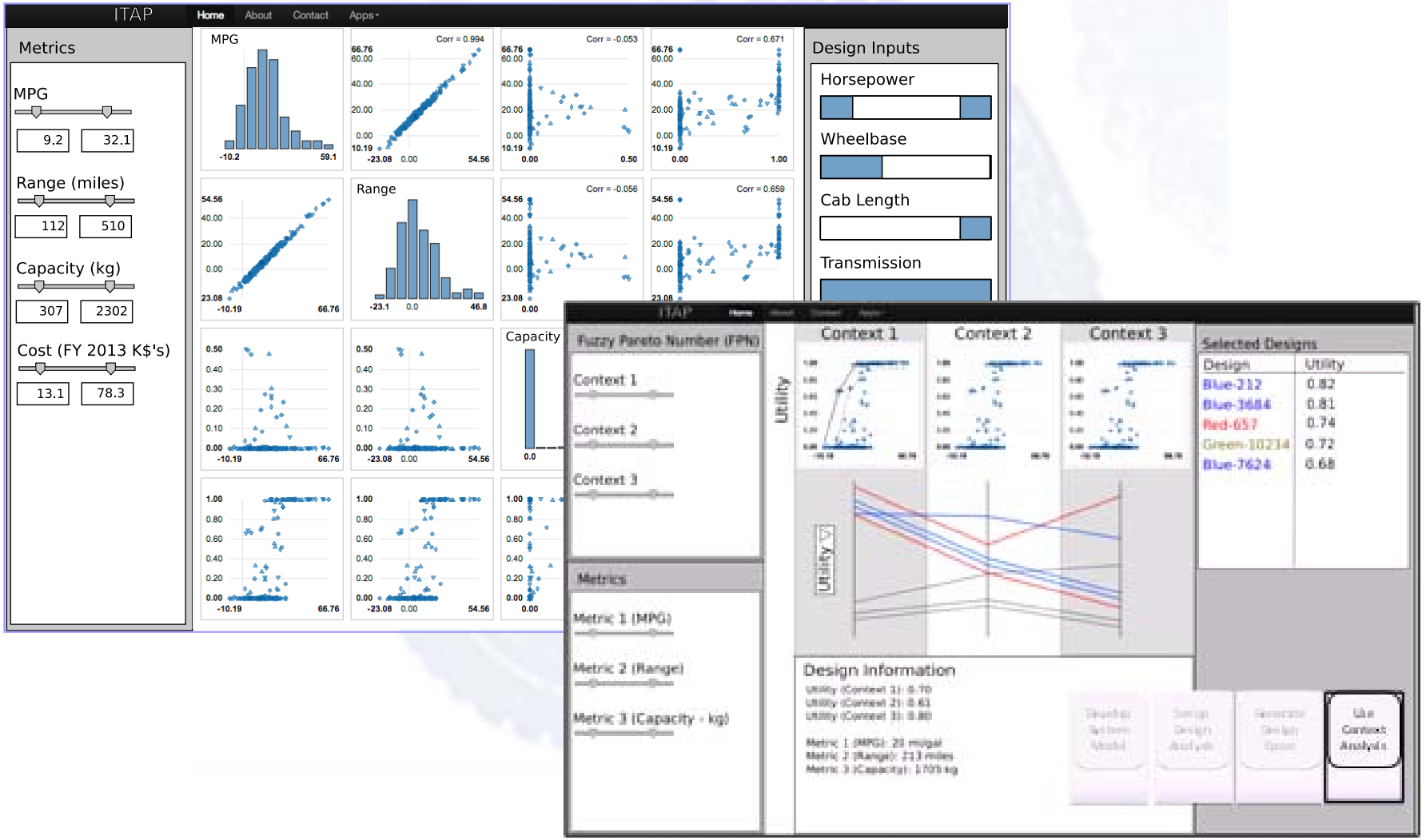
FACT Highlights

Contact: Tommer Ender et al. @ GTRI

ITAP Future Work (integrating cost modeling w/ FACT)

SysML-Based Environment for Advanced Trade Studies



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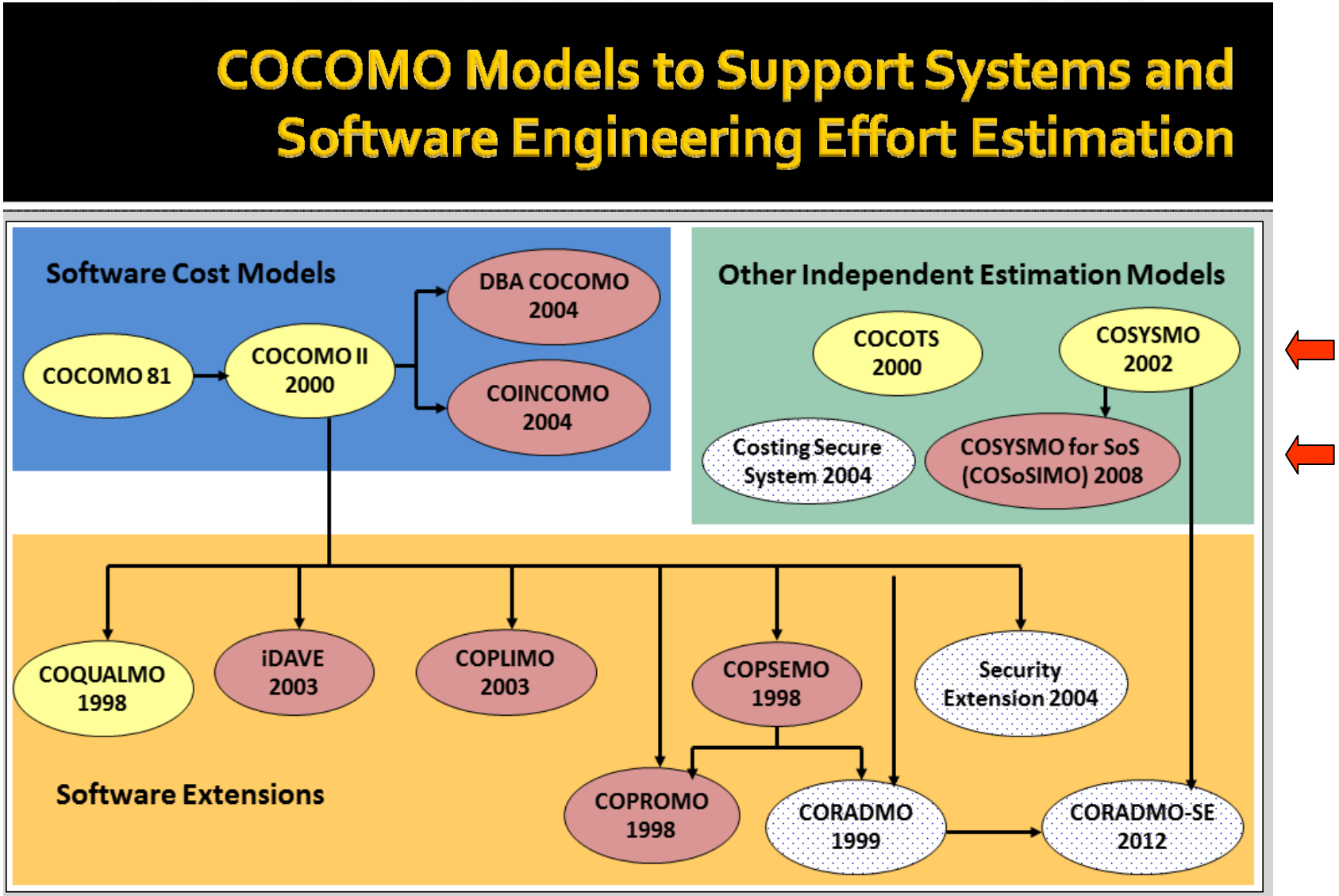
Cost/Effort Modeling Background



Cost/Effort Modeling: Further Applications

- Current RT46 work (for **SE effort modeling**):
  - COSYSMO (for single system-of-interest = SOI) - Valerdi et al.
  - COSYSMO+ (for systems-of-systems = SOS) - Lane et al.
- Potential future extensions (for **full system cost/effort modeling**):
  - Size Isn't Everything! Andy Nolan and Satpaul Sall (Rolls Royce), COCOMO Forum, 2010.
  - Proxy Estimation Costing for Systems (PECS), Reggie Cole (Lockheed), COCOMO Forum, 2012.
- Related work
  - Modeling "Should Cost" and "Will Cost" Using Model-Based Systems Engineering, Ricardo Valerdi, Dan Galorath, Quoc Do, COCOMO Forum, 2012. *[Shows SysML/Rhapsody interface with SEER-H]*

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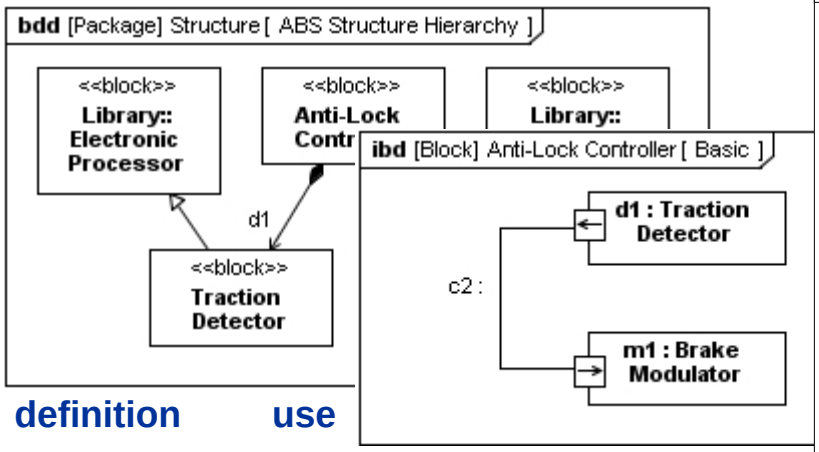
The 4 Pillars of SysML

Automotive Anti-Lock Braking System Example – www.omgsysml.org

1. Structure

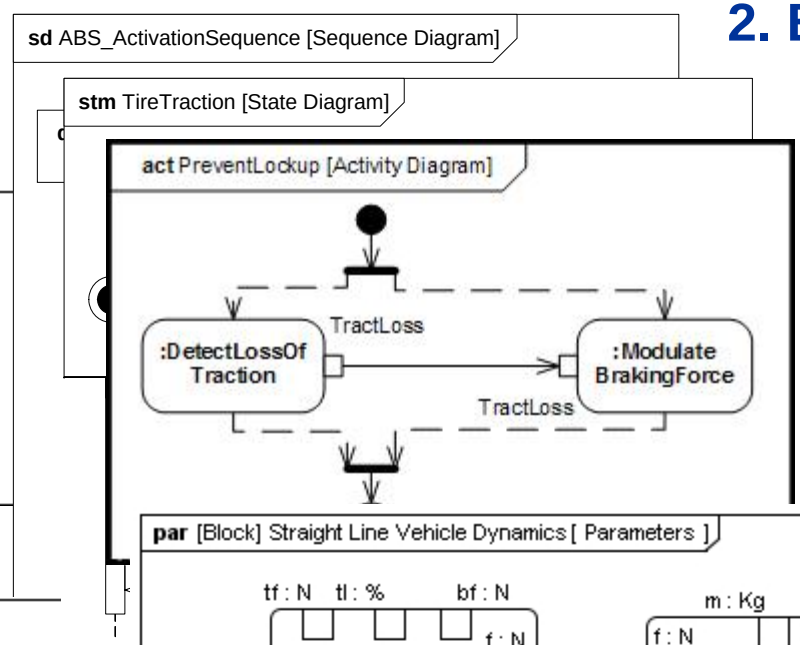


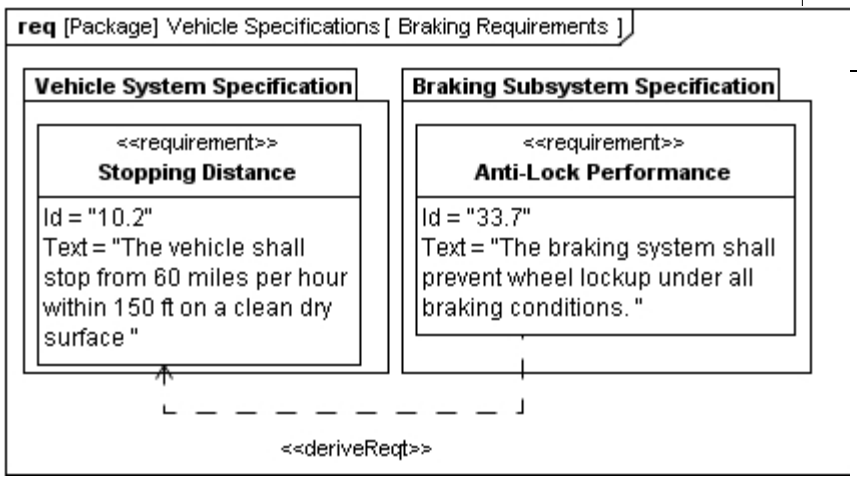
2. Behavior

interaction

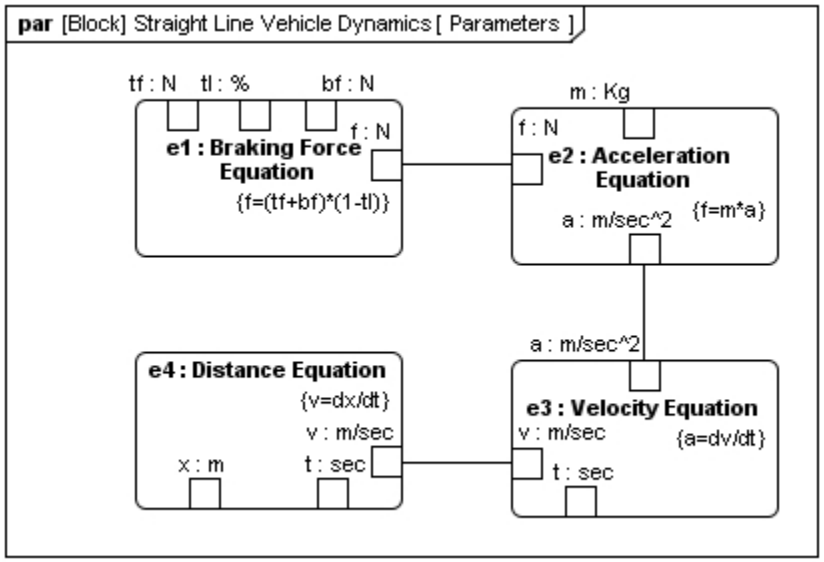
state machine

activity/ function





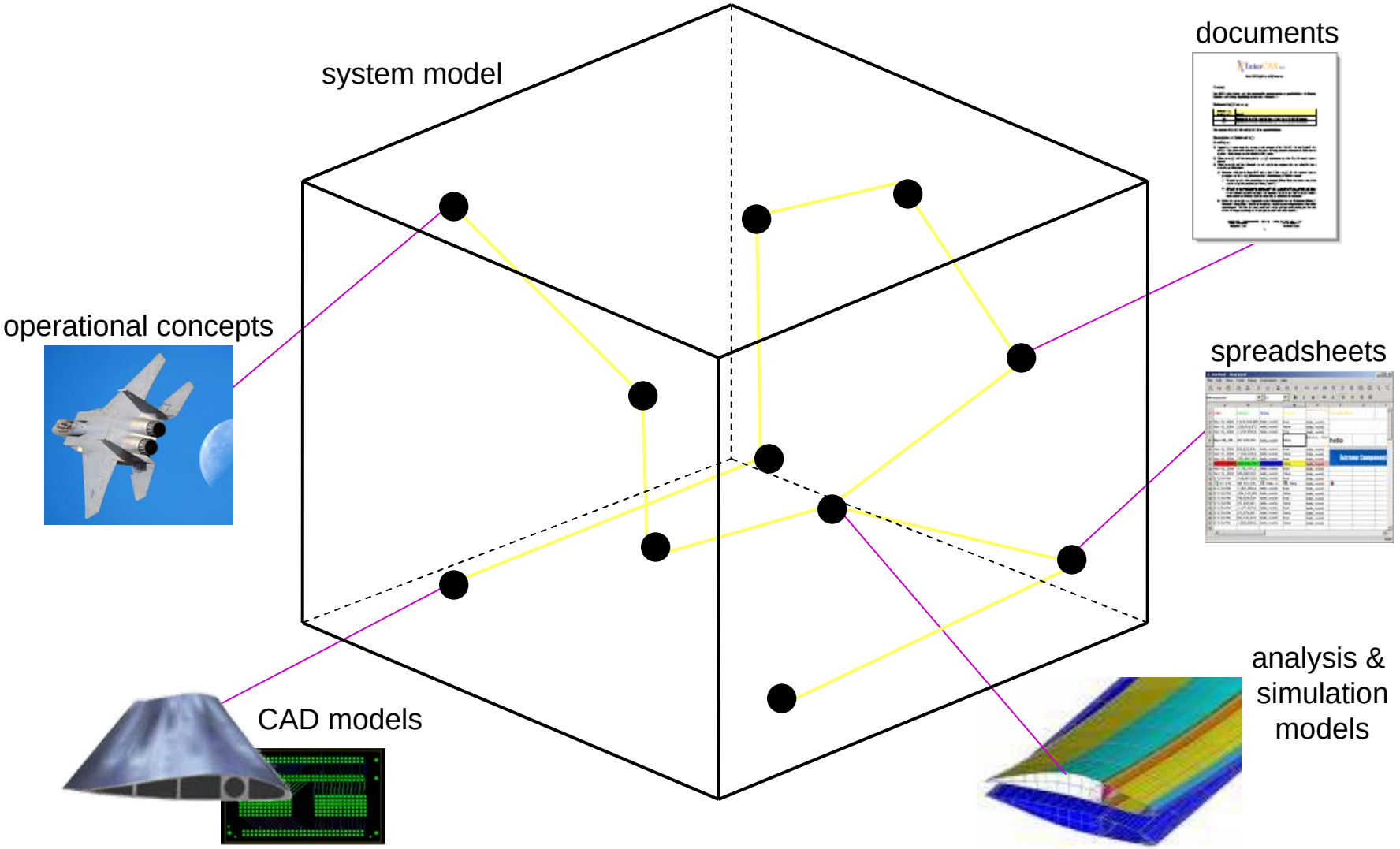
3. Requirements



4. Parametrics

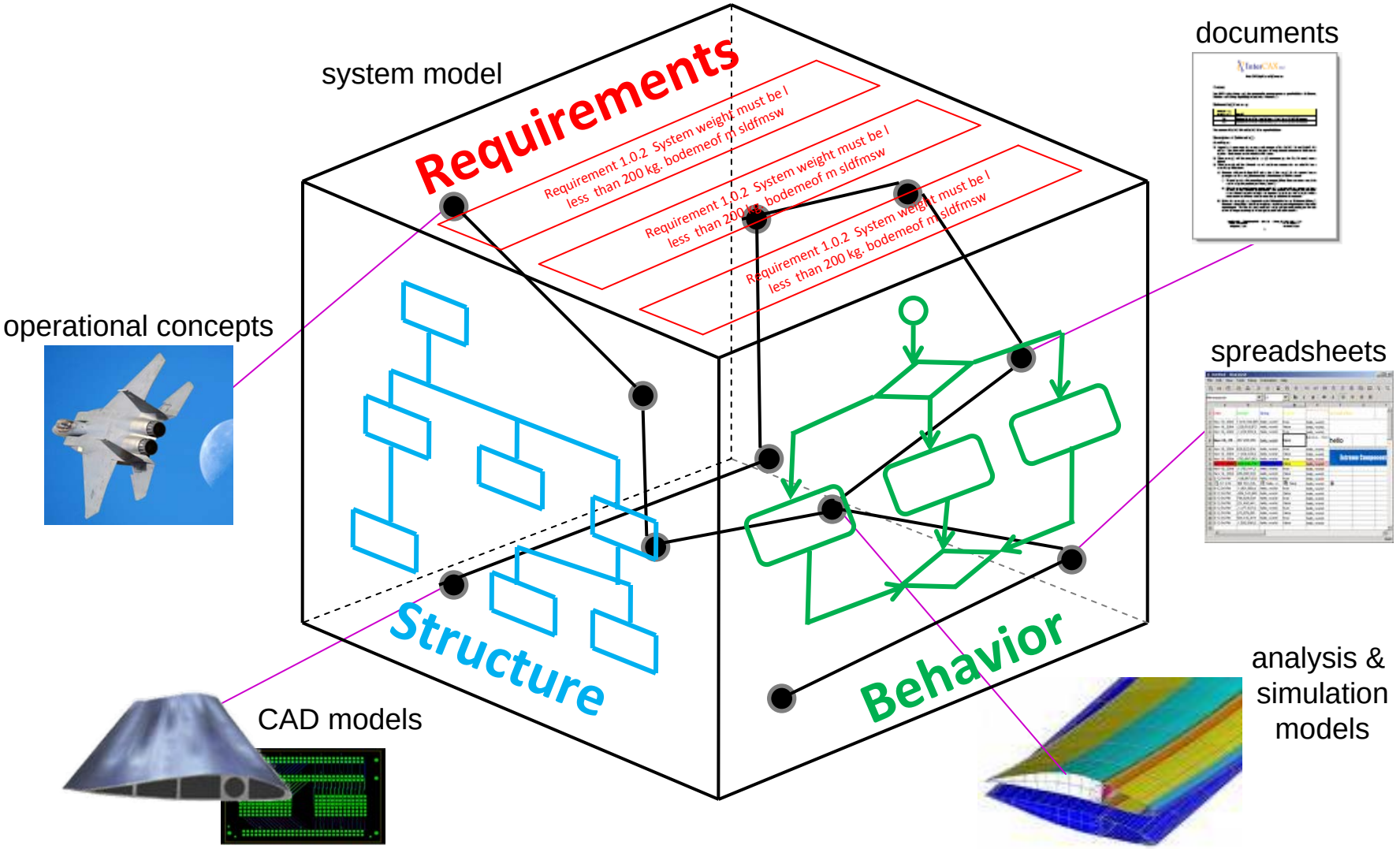
Developing Systems

Without SysML: Ad-Hoc, Disconnected, Inconsistent, Implicit



Developing Systems

With SysML: Unified, Connected, Consistent, Explicit



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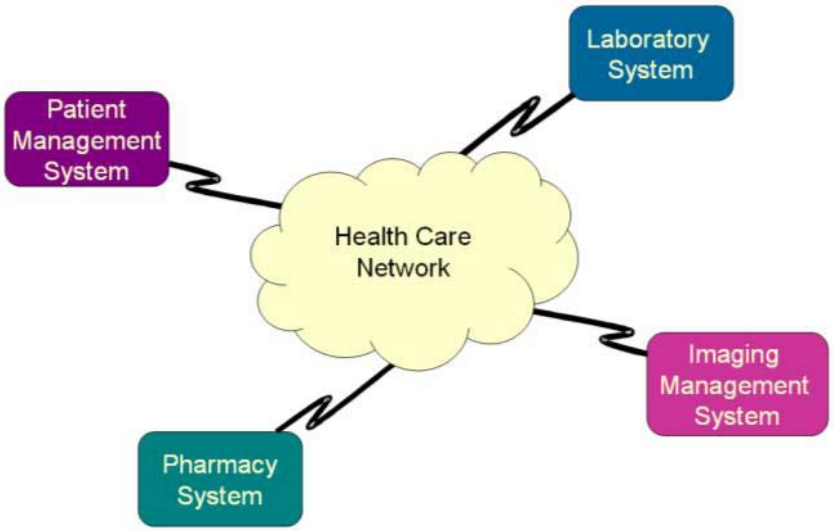
Healthcare SoS Case Study [Lane 2009]



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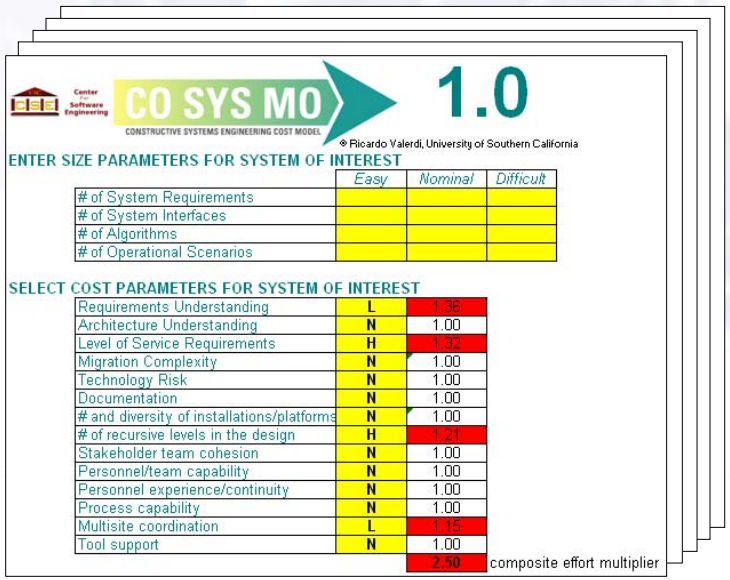
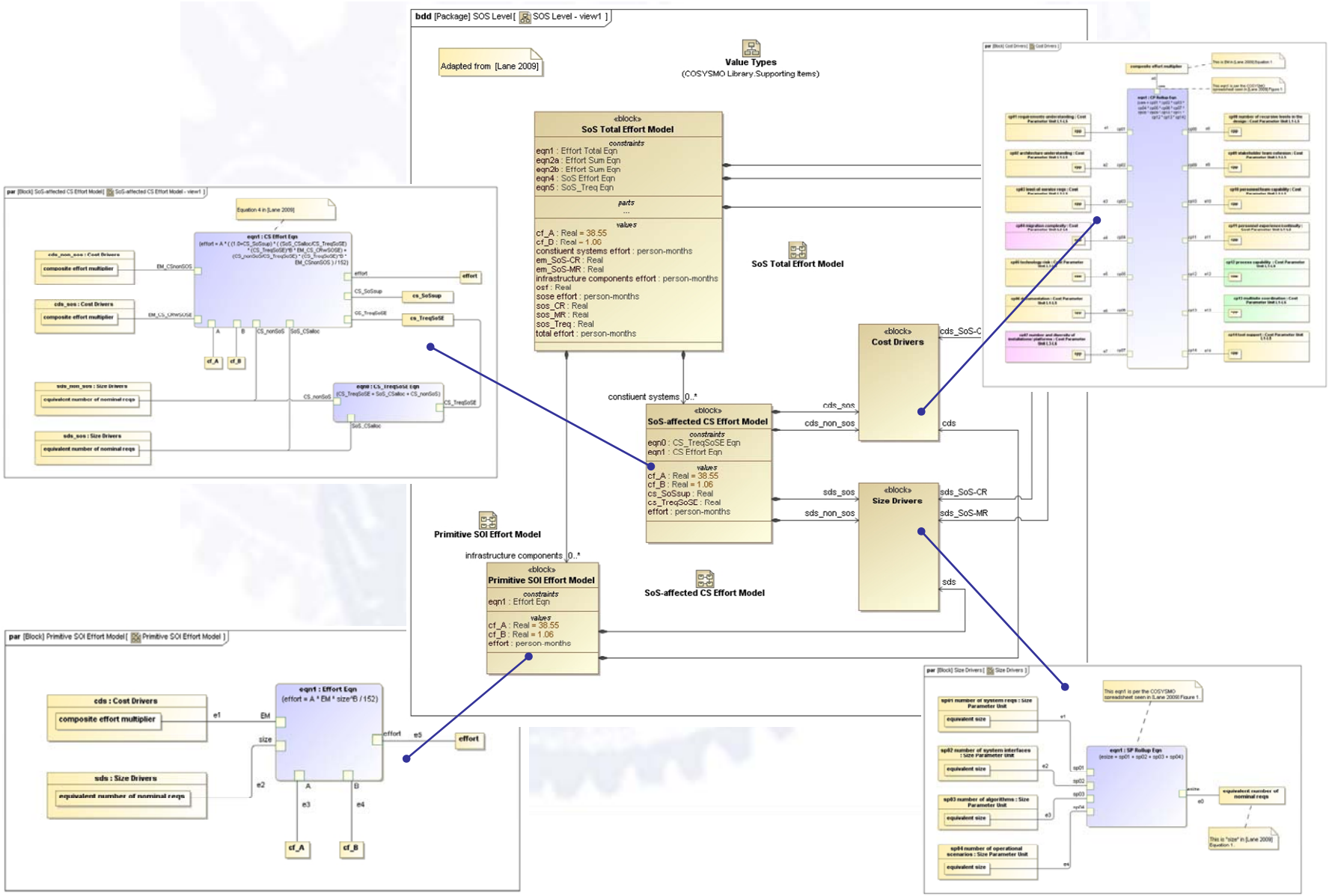


Recursive application of COSYSMO concepts for each constituent system in SoS, plus considerations specific to SoS top-level.

Healthcare SoS Case Study [Lane 2009] Implemented Using SysML Building Blocks: *Selected SysML Diagrams*



Implementation Results

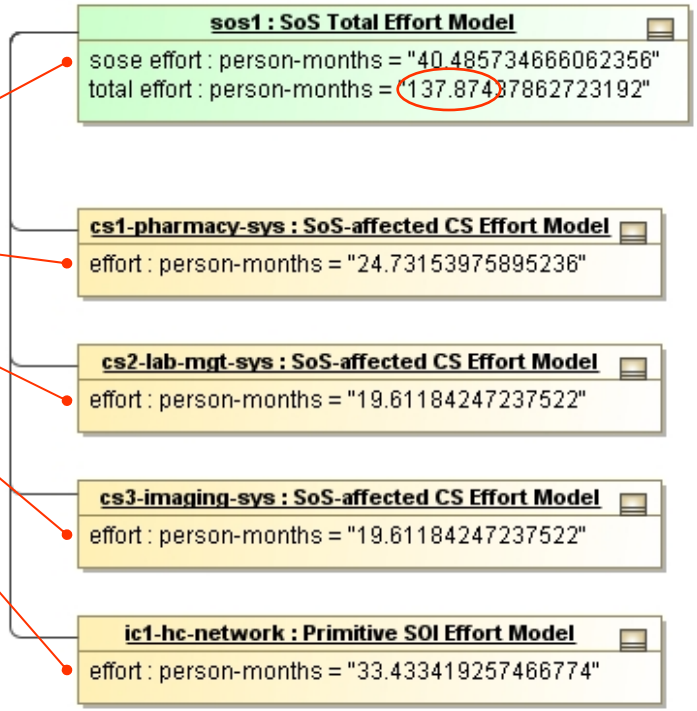
Good verification compared to original results

Original Results Summary [Lane 2009]

(subject to known corrections & round-off)

Aspect	Formula	Calculated Effort
SoSE effort (Equation 5)	Effort = $38.55*[((SoS_{CR} / SoS_{Treq})* (SoS_{Treq})^{1.06} * EM_{SOS\text{-}CR}) + ((SoS_{MR} / SoS_{Treq})* (SoS_{Treq})^{1.06} * EM_{SOS\text{-}MR}*OSF)] /152$ $= 38.55*[((50 / 52) * (52)^{1.06} * 2.50) + (20/52)*(52)^{1.06}* 0.47 * 10\%)] / 152$	40.41
Pharmacy System effort (Equation 4)	Effort = $38.55*[(1.0+CS_{SoSsup}) * ((SoS_{CSalloc}/CS_{TreqSoSE})* (CS_{TreqSoSE})^{1.06}* EM_{CS\text{-}CRwSOSE}) + (CS_{nonSoS}/CS_{TreqSoSE}) * (CS_{TreqSoSE})^{1.06} * EM_{CSnonSOS}] /152$ $= 38.55 *[(1.15) * ((50/70)*(70)^{1.06} * 1.06 + (20/70) * (70)^{1.06}*0.72] / 152$	24.65
Laboratory System effort (Equation 4)	Effort = $38.55*[(1.0+CS_{SoSsup}) * ((SoS_{CSalloc}/CS_{TreqSoSE})* (CS_{TreqSoSE})^{1.06}* EM_{CS\text{-}CRwSOSE}) + (CS_{nonSoS}/CS_{TreqSoSE}) * (CS_{TreqSoSE})^{1.06} * EM_{CSnonSOS}] /152$ $= 38.55 *[(1.15) * ((50/50)*(50)^{1.06} * 1.06 + 0] / 152$	19.55
Imaging System effort (Equation 4)	Effort = $38.55*[(1.0+CS_{SoSsup}) * ((SoS_{CSalloc}/CS_{TreqSoSE})* (CS_{TreqSoSE})^{1.06}* EM_{CS\text{-}CRwSOSE}) + (CS_{nonSoS}/CS_{TreqSoSE}) * (CS_{TreqSoSE})^{1.06} * EM_{CSnonSOS}] /152$ $= 38.55 *[(1.15) * ((50/50)*(50)^{1.06} * 1.06 + 0] / 152$	19.55
New infrastructure component effort (Equation 1)	Effort = $38.55*EM*(size)^{1.06}/152$ $= 38.55 * 1.0 * (100)^{1.06} / 152$	33.43
	Total Effort:	137.59

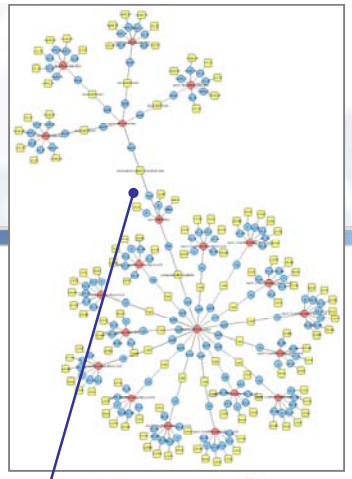
SysML-Based Results Summary



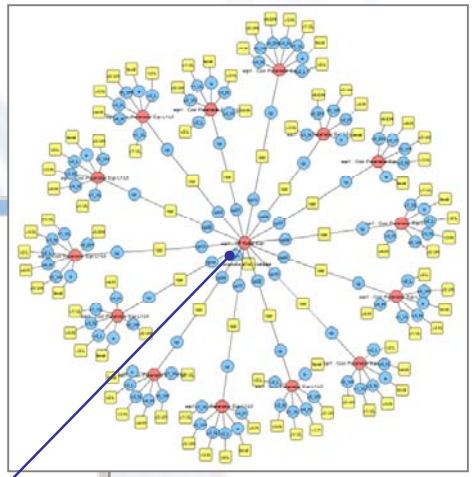
See also live demo.

Healthcare SoS Case Study [Lane 2009] Implemented Using SysML Building Blocks: DNA Signature View

Healthcare IT Network
Effort Model
(an infrastructure component; a primitive system;)

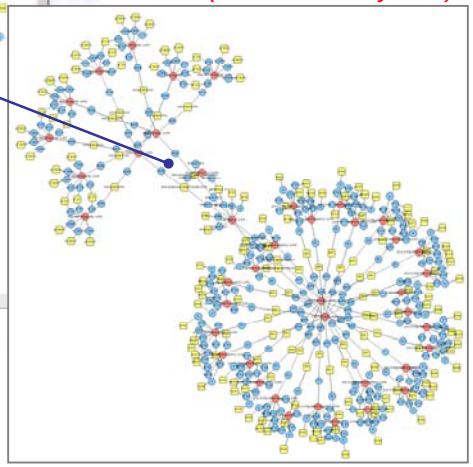


Healthcare SoS Effort Model *(a top-level SoS)*



Cost Drivers of
SoS Capability Reqs

Pharmacy System
Effort Model
(a constituent system)

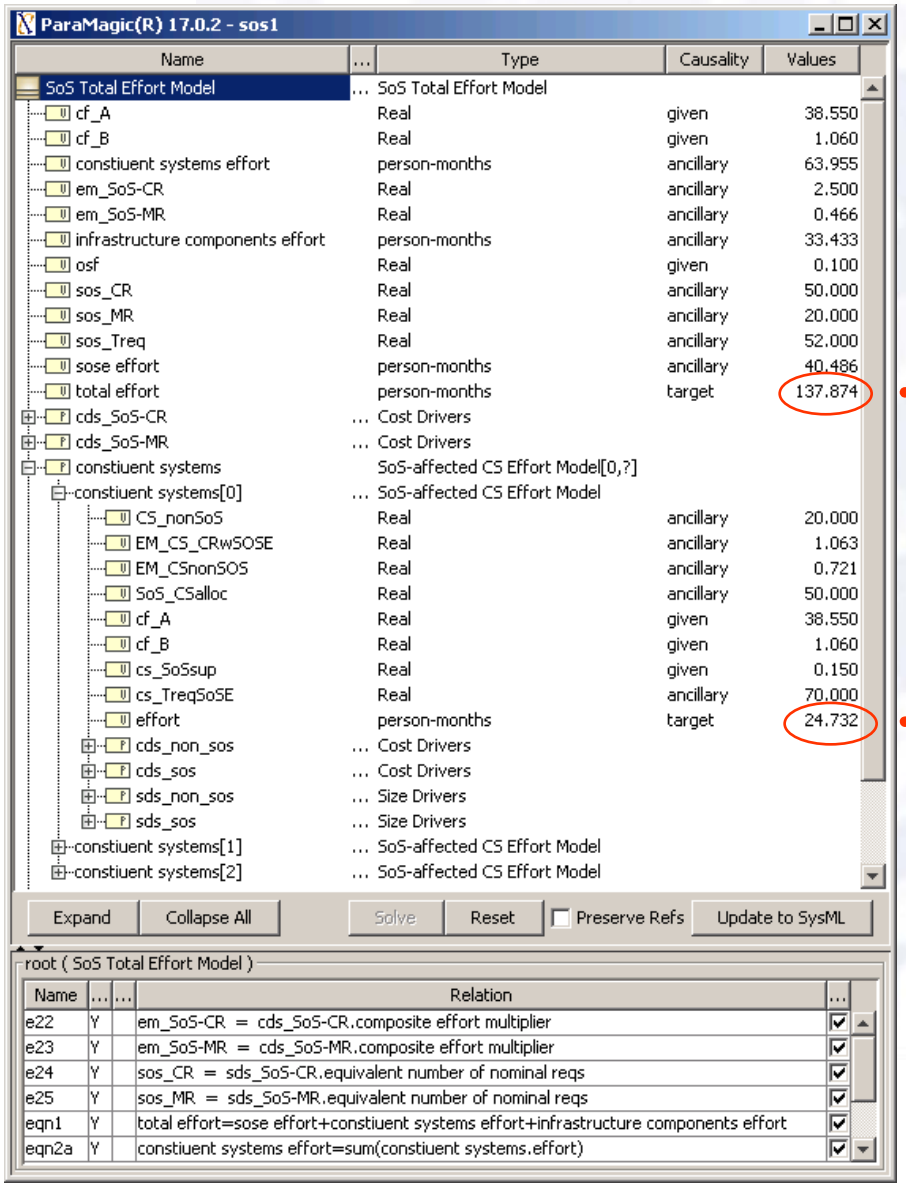


Size Drivers of
SoS Capability Reqs

Model Execution

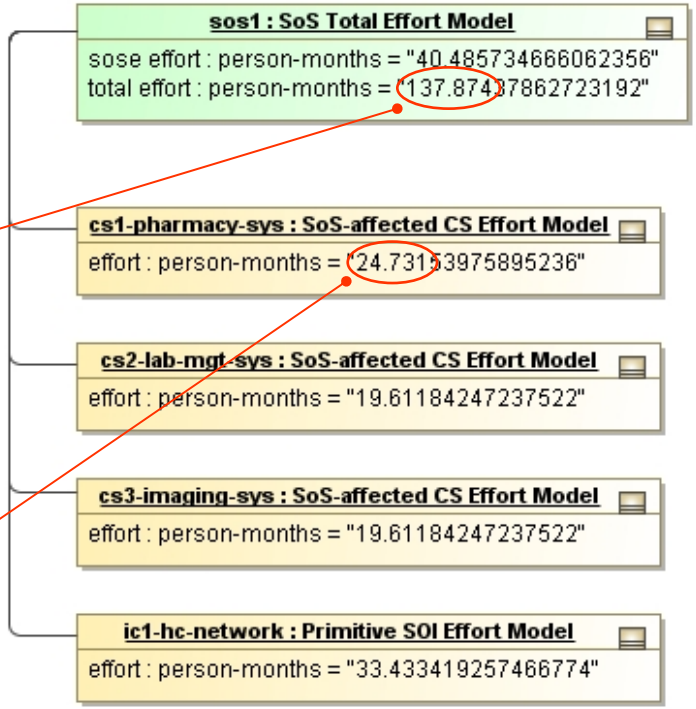
Tool for Solving SysML Instance Structures

(object-oriented spreadsheet-like tool)



Top-Level SysML Instances

(bdd view - after solving in ParaMagic)



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- ITAP/RT46 project context & summary
- Leveraged bodies of work (BW_i)
  - BW2: Patterns for model interoperability (MIM)
  - BW1: Trade study capabilities (FACT)
  - BW3: Cost modeling capabilities (COSYSMO ...)
  - BW4: Implementation enablers (MBSE/SysML ...)
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  - Building blocks and case study implementation
- Summary & observations
- Proposed future work
- Selected bibliography

Summary & Observations

- Created cost modeling building blocks in SysML
- Applied to healthcare SoS case study [Lane 2009]
- Challenges
  - Creating reusable building blocks takes time (like s/w libs)
  - SysML tools need better interactions with tabular data
- Benefits
  - Enables better knowledge capture
    - More modular, reusable, precise, maintainable, complete (e.g., units), ...
    - Acausal; better verification & validation vs. spreadsheets; ...
  - Enables swapping in/out alternative subsystem designs
  - Provides patterns that are easy-to-apply in other cases
- *Provides key step towards affordability trade studies involving diverse "-ilities"*

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Proposed Future Work

- Demonstrate building block usage in other more complex case studies
- Interface cost modeling with system design models (via MIM patterns)
- Include cost modeling in diverse "-ilities" trade space contexts
- Demonstrate in sponsor case studies and enable production deployment

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