

# **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)*

**Russell Peak – Georgia Tech  
Jo Ann Lane – USC**



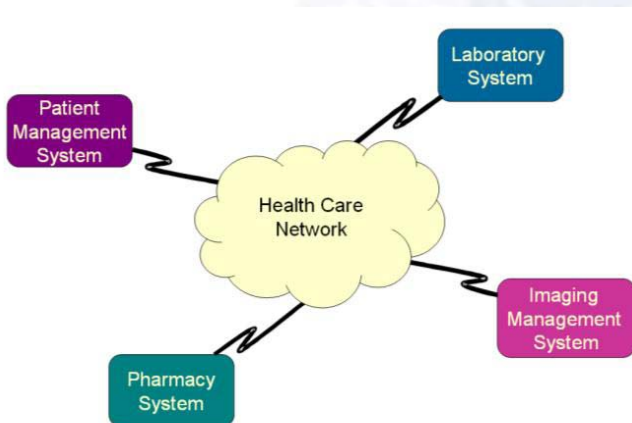
# Contents

- ➔ • 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)



**CO SYS MO 1.0**  
CONSTRUCTIVE SYSTEMS ENGINEERING COST MODEL  
© Ricardo Valerdi, University of Southern California

ENTER SIZE PARAMETERS FOR SYSTEM OF INTEREST

	Easy	Nominal	Difficult
# of System Requirements			
# of System Interfaces			
# of Algorithms			
# of Operational Scenarios			

SELECT COST PARAMETERS FOR SYSTEM OF INTEREST

	L	N	H
Requirements Understanding	N	1.00	1.00
Architecture Understanding	N	1.00	1.00
Level of Service Requirements	N	1.00	1.00
Migration Complexity	N	1.00	1.00
Technology Risk	N	1.00	1.00
Documentation	N	1.00	1.00
# and diversity of installations/platforms	N	1.00	1.00
# of recursion levels in the design	N	1.00	1.00
Stakeholder team cohesion	N	1.00	1.00
Personnel/team capability	N	1.00	1.00
Personnel experience/continuity	N	1.00	1.00
Process capability	N	1.00	1.00
Multiple coordination	L	1.00	1.00
Tool support	N	1.00	1.00

composite effort multiplier

Aspect	Formula	Calculated Effort
SoSE effort (Equation 5)	$\text{Effort} = 38.55 \cdot [((\text{SoS}_{\text{CR}} / \text{SoS}_{\text{TMS}}) \cdot (\text{SoS}_{\text{TMS}})^{1.06} \cdot \text{EM}_{\text{SoS-CR}}) + ((\text{SoS}_{\text{SM}} / \text{SoS}_{\text{TMS}}) \cdot (\text{SoS}_{\text{TMS}})^{1.06} \cdot \text{EM}_{\text{SoS-SM}} \cdot \text{OSF})] / 152$ $= 38.55 \cdot [((50 / 52) \cdot (52)^{1.06} \cdot 2.50) + (20/52) \cdot (52)^{1.06} \cdot 0.47 \cdot 10\%] / 152$	40.41
Pharmacy System effort (Equation 4)	$\text{Effort} = 38.55 \cdot [1.0 \cdot \text{CS}_{\text{req}}] \cdot ((\text{SoS}_{\text{System}} / \text{CS}_{\text{req}})^{1.06} \cdot \text{EM}_{\text{CS-COSYS}}) + (\text{CS}_{\text{total}} / \text{CS}_{\text{req}})^{1.06} \cdot \text{EM}_{\text{CS-COSYS}}] / 152$ $= 38.55 \cdot [(1.15) \cdot ((50/70) \cdot (70)^{1.06} \cdot 1.06 + (20/70) \cdot (70)^{1.06} \cdot 0.72)] / 152$	22.02
Laboratory System effort (Equation 4)	$\text{Effort} = 38.55 \cdot [1.0 \cdot \text{CS}_{\text{req}}] \cdot ((\text{SoS}_{\text{System}} / \text{CS}_{\text{req}})^{1.06} \cdot \text{EM}_{\text{CS-COSYS}}) + (\text{CS}_{\text{total}} / \text{CS}_{\text{req}})^{1.06} \cdot \text{EM}_{\text{CS-COSYS}}] / 152$ $= 38.55 \cdot [(1.15) \cdot ((50/50) \cdot (50)^{1.06} \cdot 1.06 + 0)] / 152$	19.55
Imaging System effort (Equation 4)	$\text{Effort} = 38.55 \cdot [1.0 \cdot \text{CS}_{\text{req}}] \cdot ((\text{SoS}_{\text{System}} / \text{CS}_{\text{req}})^{1.06} \cdot \text{EM}_{\text{CS-COSYS}}) + (\text{CS}_{\text{total}} / \text{CS}_{\text{req}})^{1.06} \cdot \text{EM}_{\text{CS-COSYS}}] / 152$ $= 38.55 \cdot [(1.15) \cdot ((50/50) \cdot (50)^{1.06} \cdot 1.06 + 0)] / 152$	19.55
New infrastructure component effort (Equation 1)	$\text{Effort} = 38.55 \cdot \text{EM}^{(size)^{1.06}} / 152$ $= 38.55 \cdot 1.0 \cdot (100)^{1.06} / 152$	33.43
<b>Total Effort:</b>		<b>134.96</b>

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# MIM Panorama for Naval/Marine Vessels

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

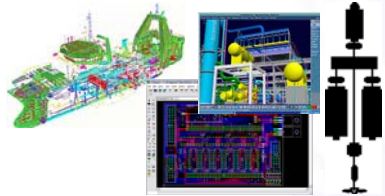
MIM = Modeling Interoperability Method  
[Peak et al. 2010]

Based on HMX 0.1  
2008-02-20

## a0. Descriptive Resources

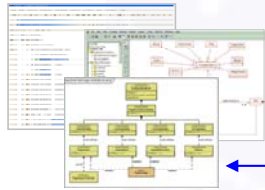
### ECAD & MCAD Tools

Tribon, CATIA, NX, Cadence, ...



### Systems & Software Tools

DOORS, E+  
MagicDraw,  
Studio,  
Eclipse, ...



### Operation Mgt. Systems

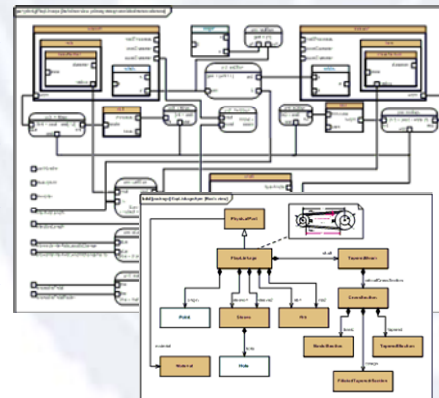
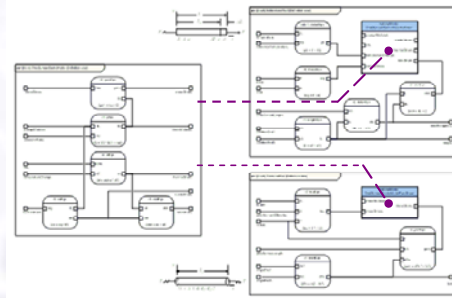


### Libraries & Databases

Classification Codes, Materials,  
Personnel, Procedures, ...

## c2. Optimization Templates

## d0. Simulation Building Blocks

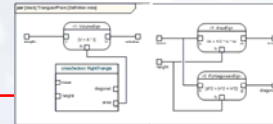


## b0. Federated Descriptive Models

## c0. Context-Specific Models

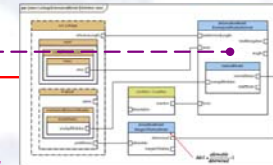
## c1. Simulation Templates (of diverse behavior & fidelity)

Evacuation  
Mgt.

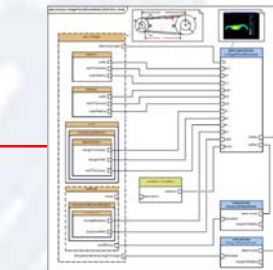


Propeller  
Hydro-  
dynamics

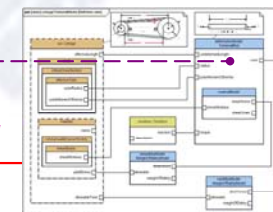
2D



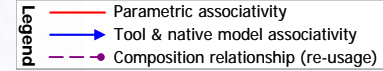
3D



Damaged  
Stability



Navigation  
Accuracy



## e0. Solver Resources

### Evacuation Codes

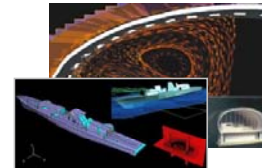
Egress, Exodus, ...

### General Math

Mathematica,  
Maple, Matlab, ...

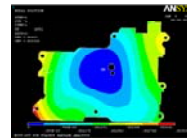
### CFD

Flotherm, Fluent, ...



### FEA

Abaqus, Ansys,  
Patran, Nastran, ...



### Discrete Event

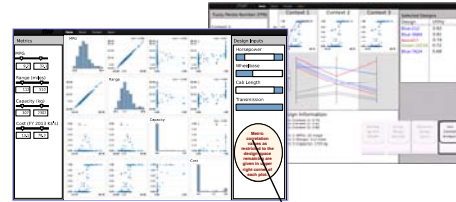
Arena, Quest, ...

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

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

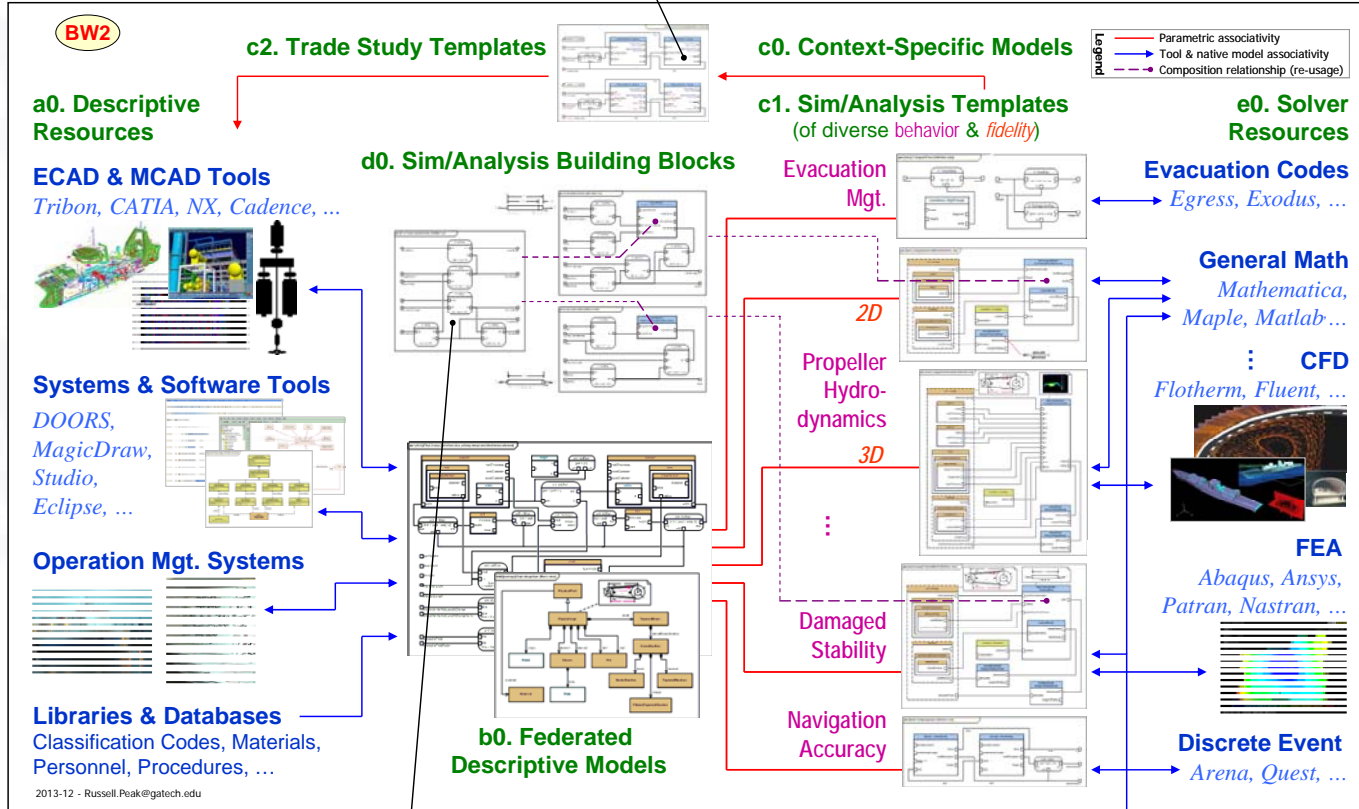
**ITAP Future Work**

Tradespace Exploration (c2)  
**BW1** FACT



Core Implementation Enabler:  
**BW4** SysML/MBSE/MBE

MIM Patterns (a0-e0)



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



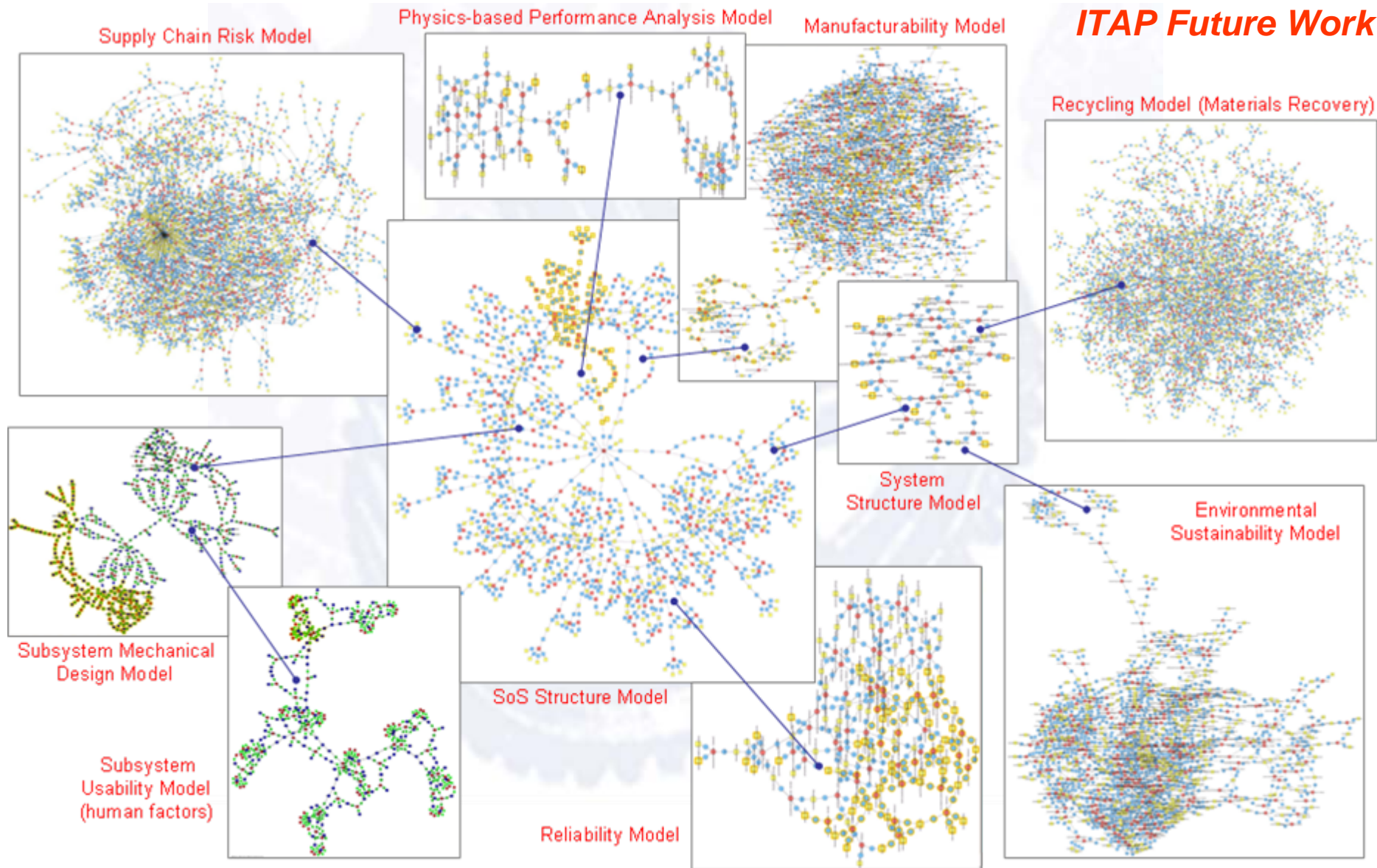
Software Engr Cost Models

Systems Engr Cost Models

**BW<sub>j</sub>** = body of work j brought together in ITAP project

# Trade Studies with Diverse “-ilities” [DNA Signature View]

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



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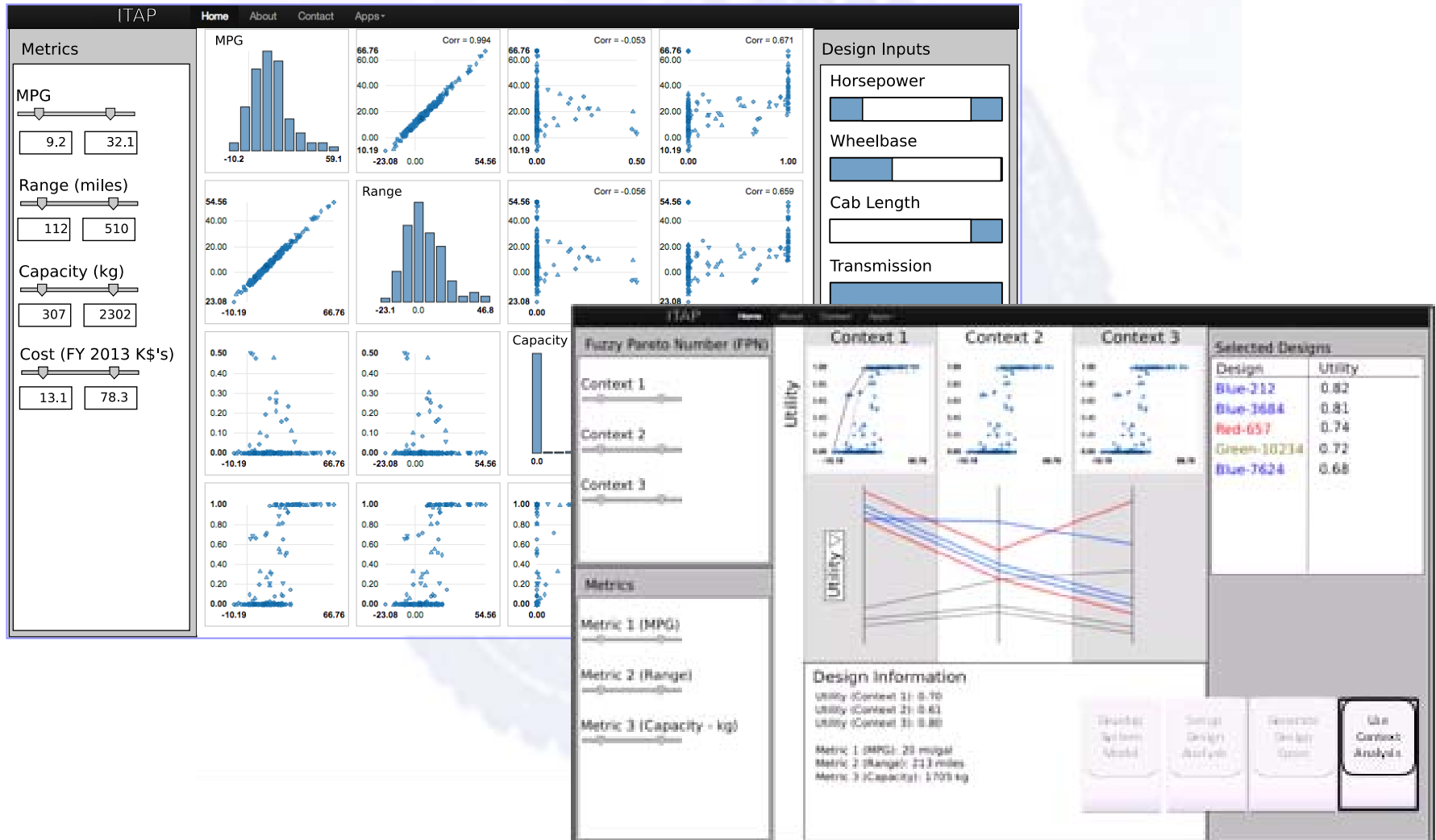


# FACT Highlights

Contact: Tommer Ender et al. @ GTRI

*ITAP Future Work  
(integrating cost modeling w/ FACT)*

## SysML-Based Environment for Advanced Trade Studies

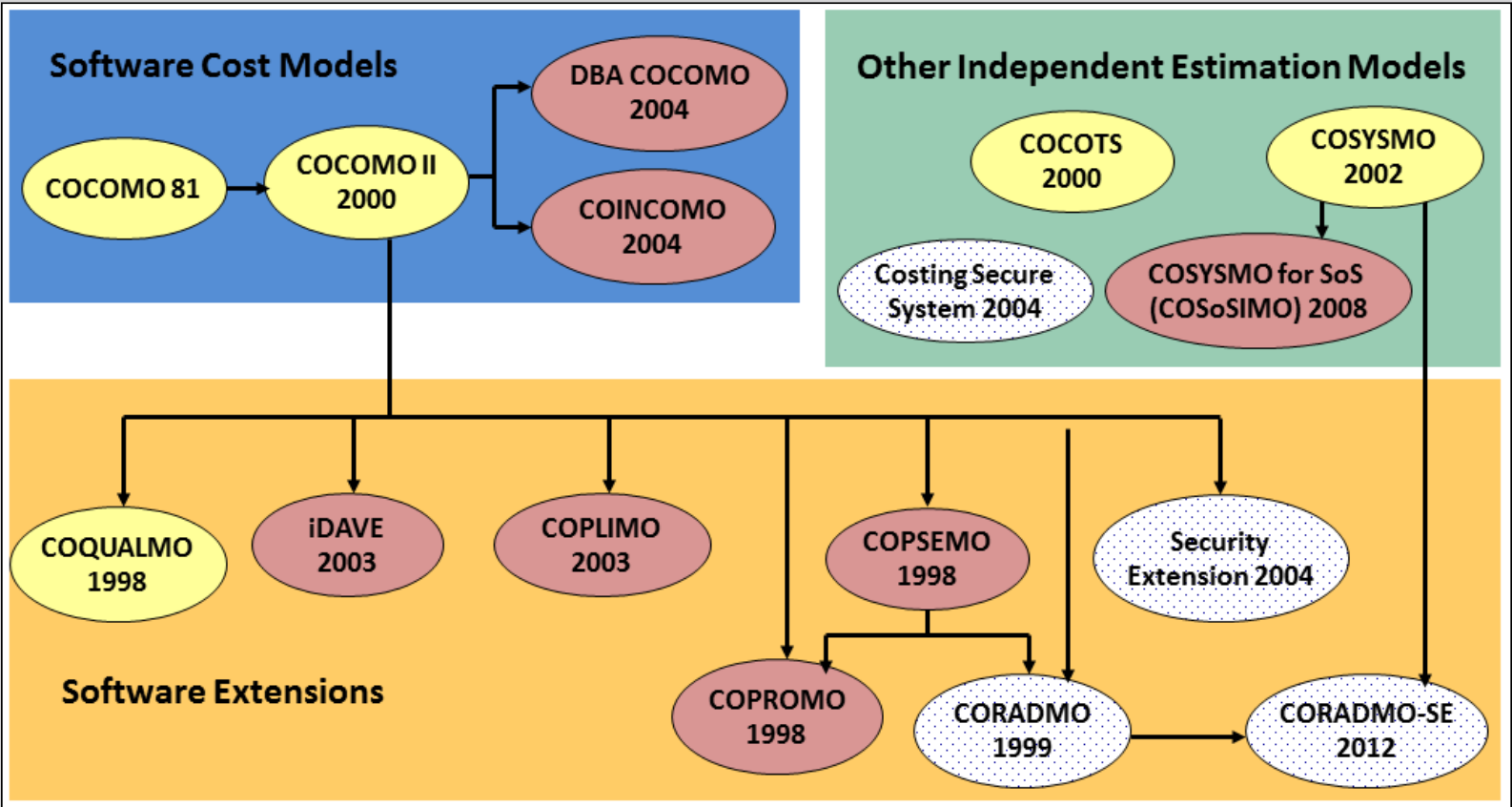


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# Cost/Effort Modeling Background

## COCOMO Models to Support Systems and Software Engineering Effort Estimation



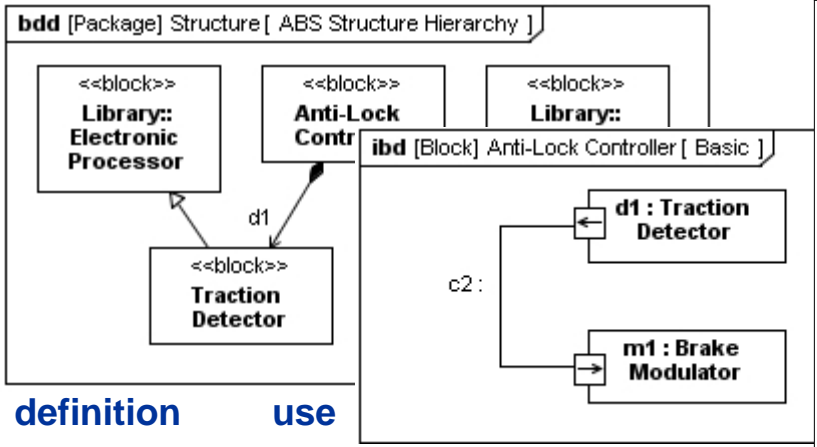
# Cost/Effort Modeling: Further Applications

- 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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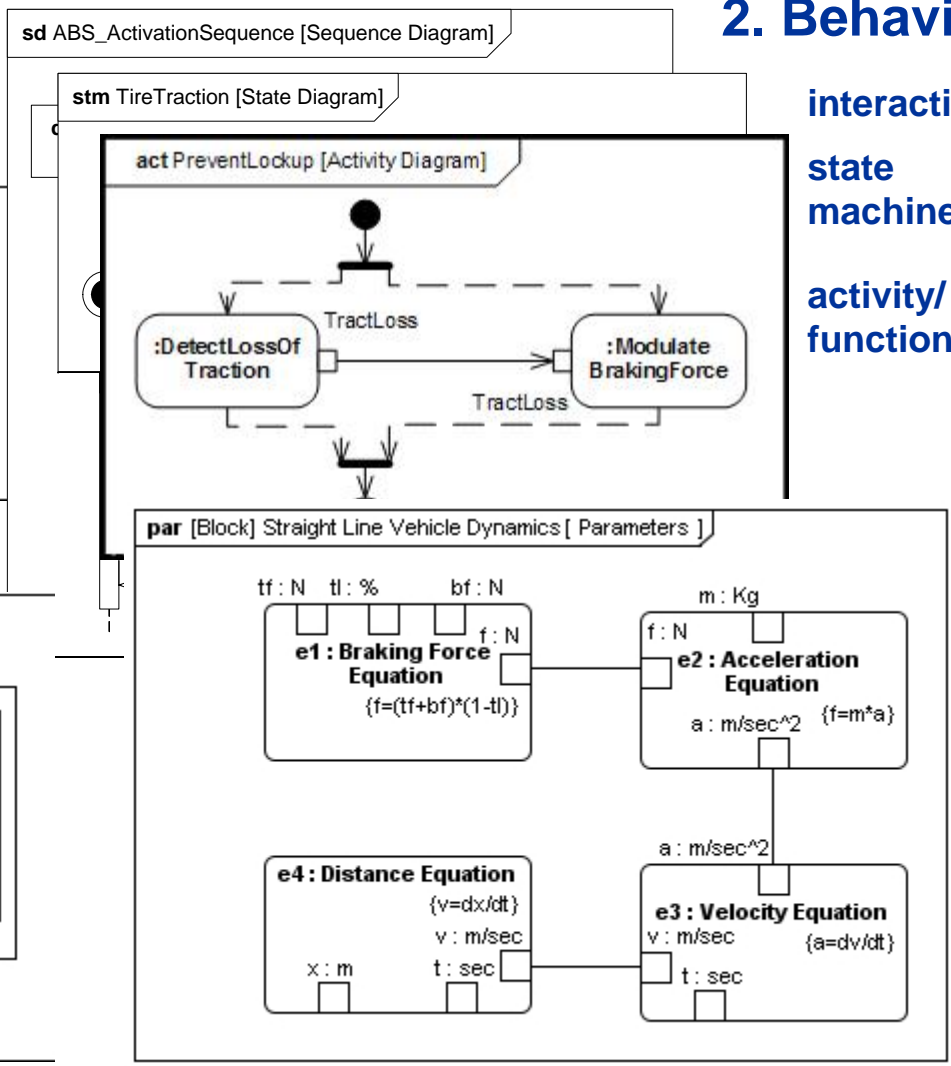
## 1. Structure



definition

use

## 2. Behavior

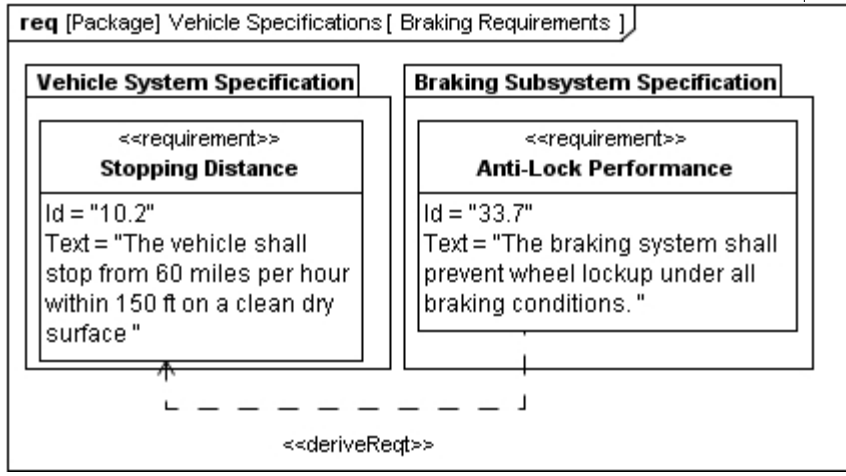


interaction

state machine

activity/function

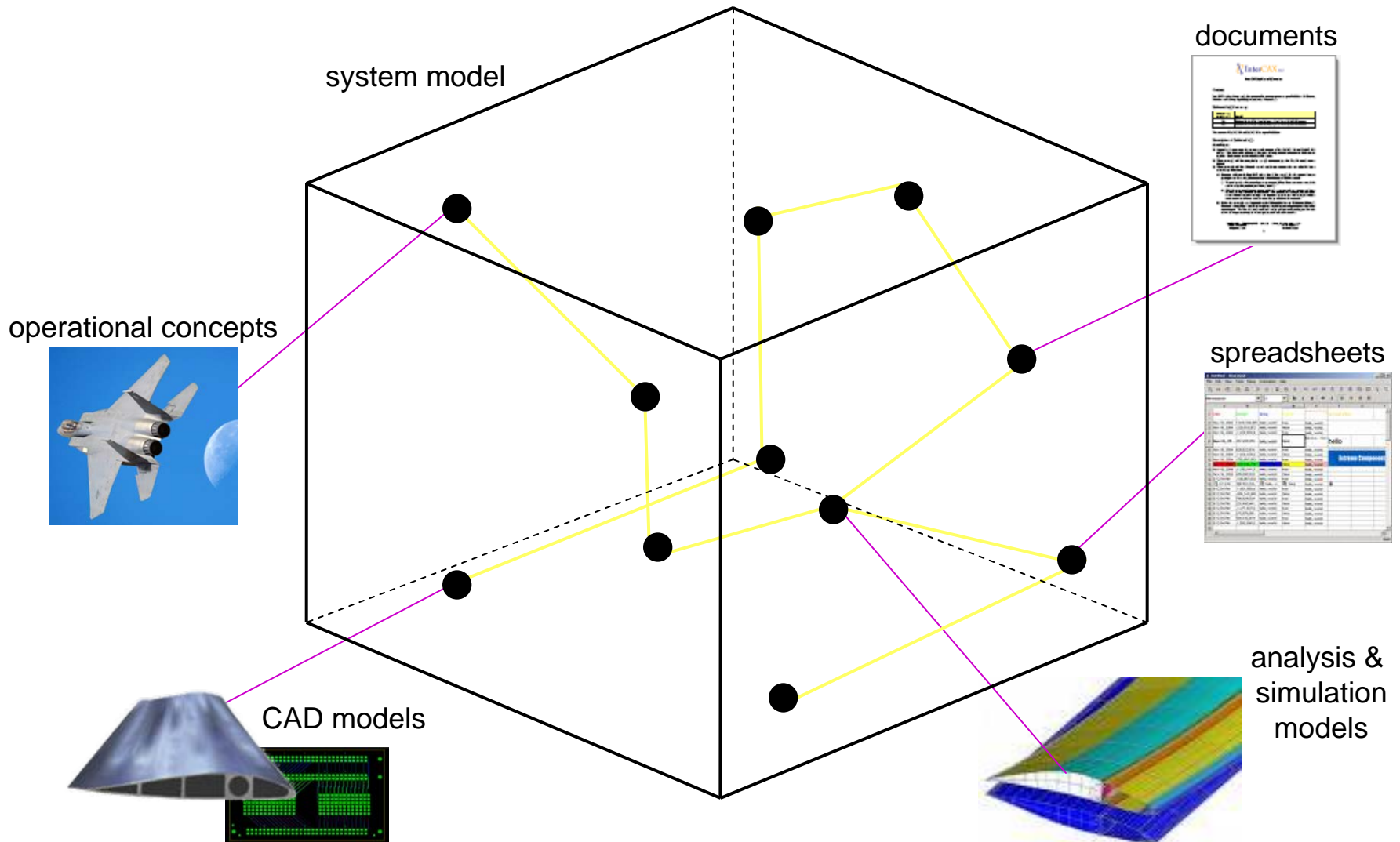
## 3. Requirements



## 4. Parametrics

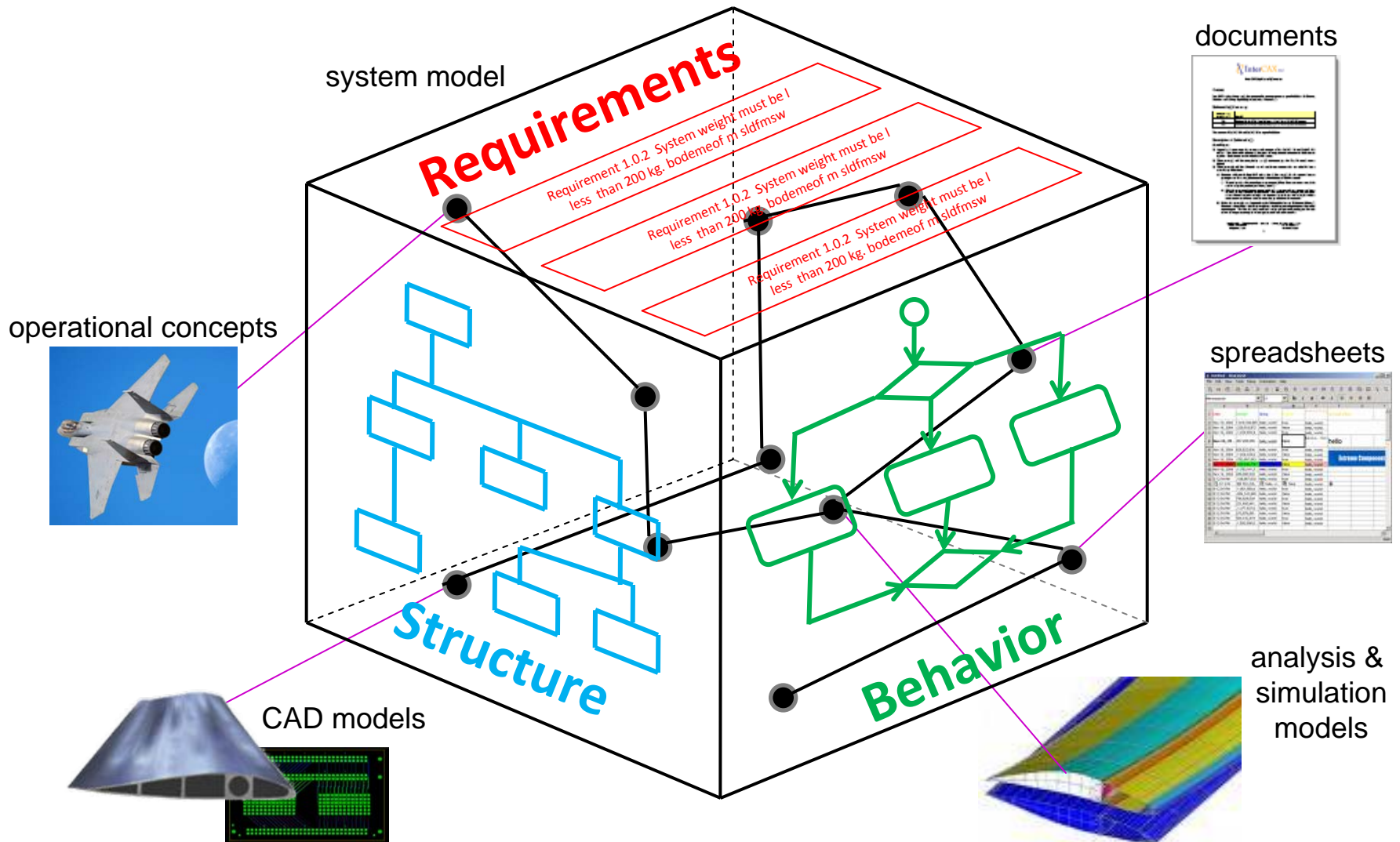
# Developing Systems

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



# Developing Systems

*With SysML: Unified, Connected, Consistent, Explicit*

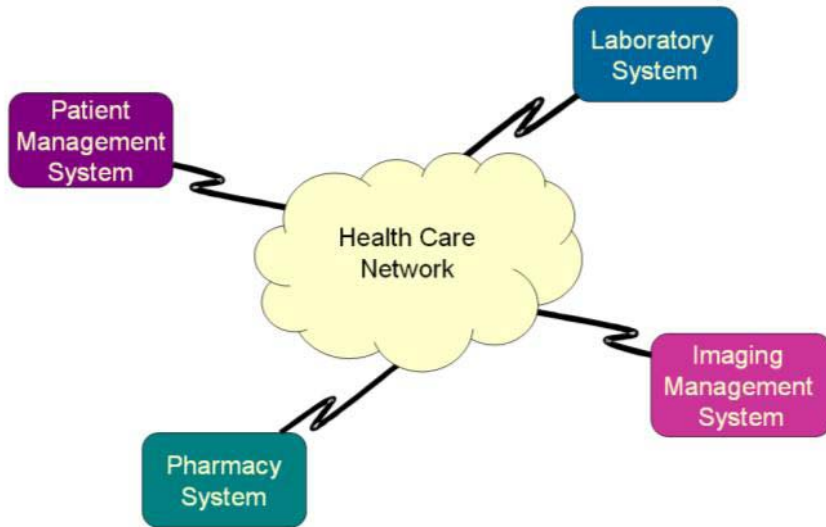




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# Healthcare SoS Case Study [Lane 2009]



Aspect	Formula	Calculated Effort
SoSE effort (Equation 5)	$\text{Effort} = 38.55 * [((\text{SoS}_{CR} / \text{SoS}_{Treq}) * (\text{SoS}_{Treq})^{1.06} * \text{EM}_{\text{SoS-CR}}) + ((\text{SoS}_{MR} / \text{SoS}_{Treq}) * (\text{SoS}_{Treq})^{1.06} * \text{EM}_{\text{SoS-MR}} * \text{OSF})] / 152$ $= 38.55 * [((50 / 52) * (52)^{1.06} * 2.50) + (20/52) * (52)^{1.06} * 0.47 * 10\%] / 152$	40.41
Pharmacy System effort (Equation 4)	$\text{Effort} = 38.55 * [(1.0 + \text{CS}_{\text{SoSsup}}) * ((\text{SoS}_{\text{Csalloc}} / \text{CS}_{\text{TreqSoSE}}) * (\text{CS}_{\text{TreqSoSE}})^{1.06} * \text{EM}_{\text{CS-CRwSoSE}}) + (\text{CS}_{\text{nonSoS}} / \text{CS}_{\text{TreqSoSE}}) * (\text{CS}_{\text{TreqSoSE}})^{1.06} * \text{EM}_{\text{CSnonSoS}}] / 152$ $= 38.55 * [(1.15) * ((50/70) * (70)^{1.06} * 1.06 + (20/70) * (70)^{1.06} * 0.72)] / 152$	22.02
Laboratory System effort (Equation 4)	$\text{Effort} = 38.55 * [(1.0 + \text{CS}_{\text{SoSsup}}) * ((\text{SoS}_{\text{Csalloc}} / \text{CS}_{\text{TreqSoSE}}) * (\text{CS}_{\text{TreqSoSE}})^{1.06} * \text{EM}_{\text{CS-CRwSoSE}}) + (\text{CS}_{\text{nonSoS}} / \text{CS}_{\text{TreqSoSE}}) * (\text{CS}_{\text{TreqSoSE}})^{1.06} * \text{EM}_{\text{CSnonSoS}}] / 152$ $= 38.55 * [(1.15) * ((50/50) * (50)^{1.06} * 1.06 + 0)] / 152$	19.55
Imaging System effort (Equation 4)	$\text{Effort} = 38.55 * [(1.0 + \text{CS}_{\text{SoSsup}}) * ((\text{SoS}_{\text{Csalloc}} / \text{CS}_{\text{TreqSoSE}}) * (\text{CS}_{\text{TreqSoSE}})^{1.06} * \text{EM}_{\text{CS-CRwSoSE}}) + (\text{CS}_{\text{nonSoS}} / \text{CS}_{\text{TreqSoSE}}) * (\text{CS}_{\text{TreqSoSE}})^{1.06} * \text{EM}_{\text{CSnonSoS}}] / 152$ $= 38.55 * [(1.15) * ((50/50) * (50)^{1.06} * 1.06 + 0)] / 152$	19.55
New infrastructure component effort (Equation 1)	$\text{Effort} = 38.55 * \text{EM} * (\text{size})^{1.06} / 152$ $= 38.55 * 1.0 * (100)^{1.06} / 152$	33.43
<b>Total Effort:</b>		134.96

**COSYSMO 1.0**  
 CONSTRUCTIVE SYSTEMS ENGINEERING COST MODEL  
 © Ricardo Valeri, University of Southern California

**ENTER SIZE PARAMETERS FOR SYSTEM OF INTEREST**

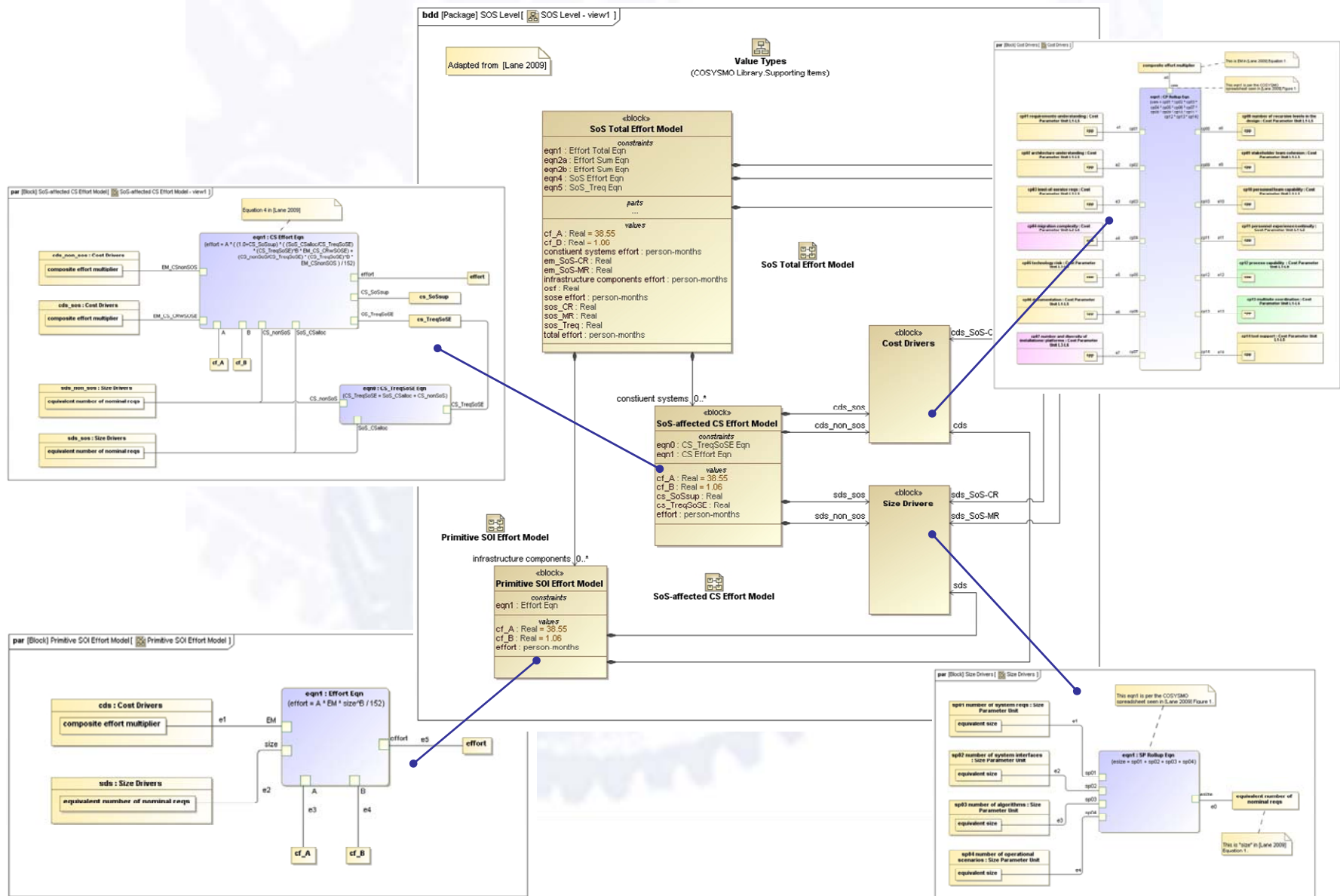
	Easy	Nominal	Difficult
# of System Requirements			
# of System Interfaces			
# of Algorithms			
# of Operational Scenarios			

**SELECT COST PARAMETERS FOR SYSTEM OF INTEREST**

Requirements Understanding	L	1.36
Architecture Understanding	N	1.00
Level of Service Requirements	H	1.32
Migration Complexity	N	1.00
Technology Risk	N	1.00
Documentation	N	1.00
# and diversity of installations/platforms	N	1.00
# of recursive levels in the design	H	1.21
Stakeholder team cohesion	N	1.00
Personnel/team capability	N	1.00
Personnel experience/continuity	N	1.00
Process capability	N	1.00
Multisite coordination	L	1.15
Tool support	N	1.00
		<b>2.50</b> composite effort multiplier

*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)

## SysML-Based Results Summary

Aspect	Formula	Calculated Effort
SoSE effort (Equation 5)	$\text{Effort} = 38.55 * [((\text{SoS}_{\text{CR}} / \text{SoS}_{\text{Treq}}) * (\text{SoS}_{\text{Treq}})^{1.06} * \text{EM}_{\text{SoS-CR}}) + ((\text{SoS}_{\text{MR}} / \text{SoS}_{\text{Treq}}) * (\text{SoS}_{\text{Treq}})^{1.06} * \text{EM}_{\text{SoS-MR}} * \text{OSF})] / 152$ $= 38.55 * [((50 / 52) * (52)^{1.06} * 2.50) + (20/52) * (52)^{1.06} * 0.47 * 10\%] / 152$	40.41
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Laboratory System effort (Equation 4)	$\text{Effort} = 38.55 * [(1.0 + \text{CS}_{\text{SoSsup}}) * ((\text{SoS}_{\text{Csallocc}} / \text{CS}_{\text{TreqSoSE}}) * (\text{CS}_{\text{TreqSoSE}})^{1.06} * \text{EM}_{\text{CS-CRwSoSE}}) + (\text{CS}_{\text{nonSoS}} / \text{CS}_{\text{TreqSoSE}}) * (\text{CS}_{\text{TreqSoSE}})^{1.06} * \text{EM}_{\text{CSnonSoS}}] / 152$ $= 38.55 * [(1.15) * ((50/50) * (50)^{1.06} * 1.06 + 0)] / 152$	19.55
Imaging System effort (Equation 4)	$\text{Effort} = 38.55 * [(1.0 + \text{CS}_{\text{SoSsup}}) * ((\text{SoS}_{\text{Csallocc}} / \text{CS}_{\text{TreqSoSE}}) * (\text{CS}_{\text{TreqSoSE}})^{1.06} * \text{EM}_{\text{CS-CRwSoSE}}) + (\text{CS}_{\text{nonSoS}} / \text{CS}_{\text{TreqSoSE}}) * (\text{CS}_{\text{TreqSoSE}})^{1.06} * \text{EM}_{\text{CSnonSoS}}] / 152$ $= 38.55 * [(1.15) * ((50/50) * (50)^{1.06} * 1.06 + 0)] / 152$	19.55
New infrastructure component effort (Equation 1)	$\text{Effort} = 38.55 * \text{EM} * (\text{size})^{1.06} / 152$ $= 38.55 * 1.0 * (100)^{1.06} / 152$	33.43
<b>Total Effort:</b>		<b>137.59</b>

**sos1 : SoS Total Effort Model**

sosese effort : person-months = "40.485734666062356"  
 total effort : person-months = "137.87437862723192"

**cs1-pharmacy-sys : SoS-affected CS Effort Model**

effort : person-months = "24.73153975895236"

**cs2-lab-mgt-sys : SoS-affected CS Effort Model**

effort : person-months = "19.61184247237522"

**cs3-imaging-sys : SoS-affected CS Effort Model**

effort : person-months = "19.61184247237522"

**ic1-hc-network : Primitive SOfI Effort Model**

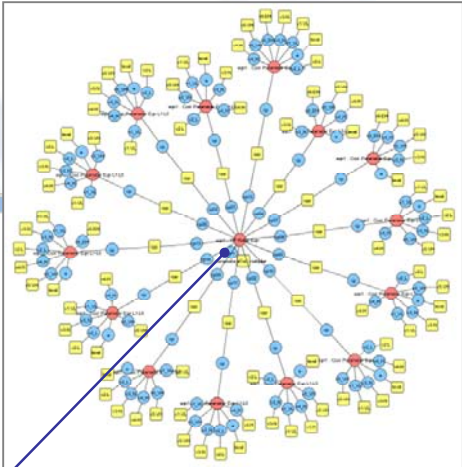
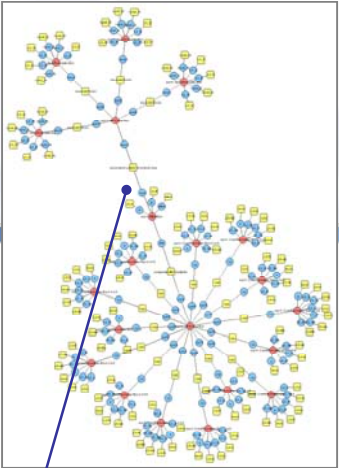
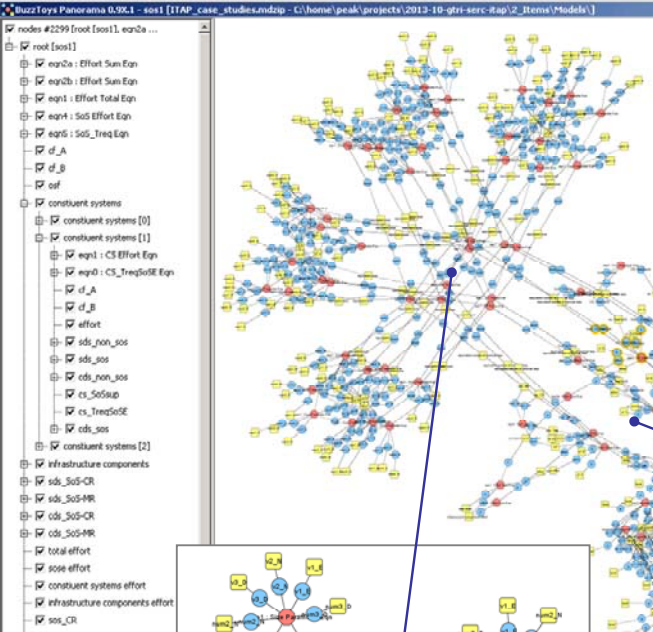
effort : person-months = "33.433419257466774"

*See also live demo.*

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

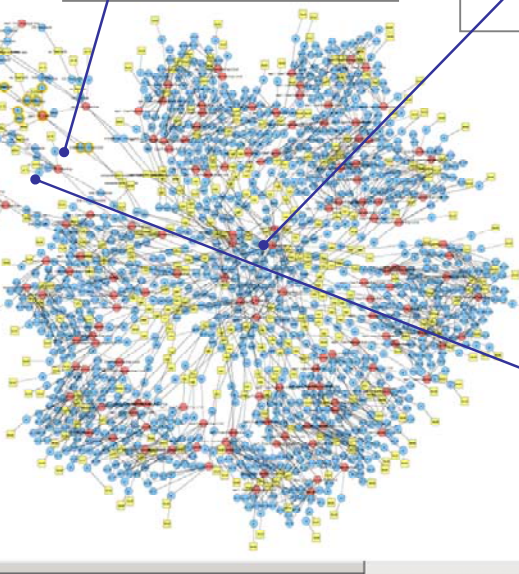
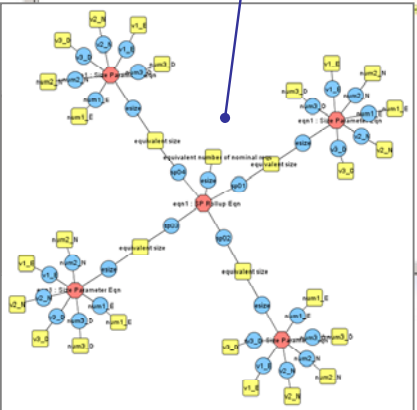
Healthcare IT Network Effort Model  
(an infrastructure component; a primitive system;)

Healthcare SoS Effort Model (a top-level SoS)

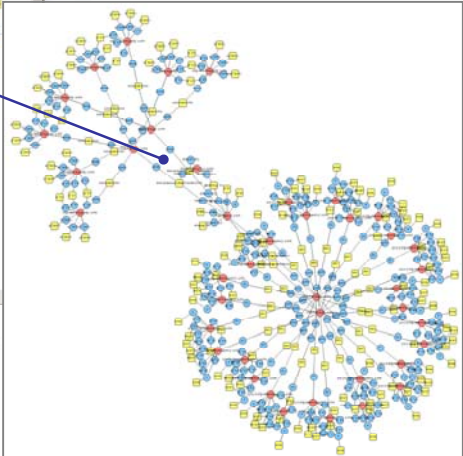


Cost Drivers of SoS Capability Reqs

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)

The screenshot shows the ParaMagic(R) 17.0.2 - sos1 interface. The main window displays a tree view of the SysML model structure. The 'SoS Total Effort Model' is expanded, showing various components and their values. The 'total effort' value is highlighted with a red circle and is 137.874. The 'effort' value for the 'constituent systems' is also highlighted with a red circle and is 24.732.

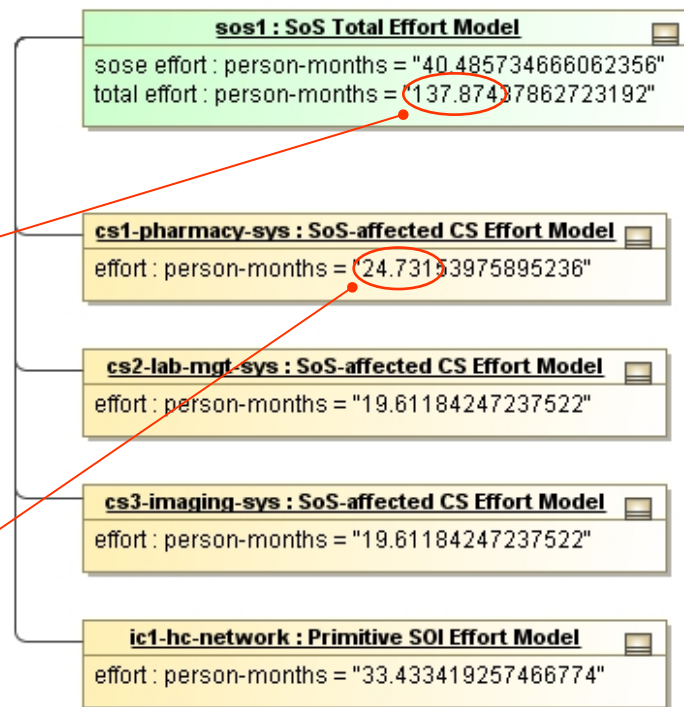
Name	Type	Causality	Values
SoS Total Effort Model	SoS Total Effort Model		
cf_A	Real	given	38.550
cf_B	Real	given	1.060
constituent systems effort	person-months	ancillary	63.955
em_SoS-CR	Real	ancillary	2.500
em_SoS-MR	Real	ancillary	0.466
infrastructure components effort	person-months	ancillary	33.433
osf	Real	given	0.100
sos_CR	Real	ancillary	50.000
sos_MR	Real	ancillary	20.000
sos_Treq	Real	ancillary	52.000
sose effort	person-months	ancillary	40.486
total effort	person-months	target	137.874
cds_SoS-CR	Cost Drivers		
cds_SoS-MR	Cost Drivers		
constituent systems	SoS-affected CS Effort Model[0,?]		
constituent systems[0]	SoS-affected CS Effort Model		
CS_nonSoS	Real	ancillary	20.000
EM_CS_CRwSOSE	Real	ancillary	1.063
EM_CSnonSOS	Real	ancillary	0.721
SoS_CSalloc	Real	ancillary	50.000
cf_A	Real	given	38.550
cf_B	Real	given	1.060
cs_SoSsup	Real	given	0.150
cs_TreqSoSE	Real	ancillary	70.000
effort	person-months	target	24.732
cds_non_sos	Cost Drivers		
cds_sos	Cost Drivers		
sds_non_sos	Size Drivers		
sds_sos	Size Drivers		
constituent systems[1]	SoS-affected CS Effort Model		
constituent systems[2]	SoS-affected CS Effort Model		

Buttons: Expand, Collapse All, Solve, Reset, Preserve Refs, Update to SysML

root ( SoS Total Effort Model )

Name	Relation
e22	em_SoS-CR = cds_SoS-CR.composite effort multiplier
e23	em_SoS-MR = cds_SoS-MR.composite effort multiplier
e24	sos_CR = sds_SoS-CR.equivalent number of nominal reqs
e25	sos_MR = sds_SoS-MR.equivalent number of nominal reqs
eqn1	total effort=sose effort+constituent systems effort+infrastructure components effort
eqn2a	constituent systems effort=sum(constituent systems.effort)

Top-Level SysML Instances  
(bdd view - after solving in ParaMagic)



# Contents

- ITAP/RT46 project context & summary
- Leveraged bodies of work (BW<sub>i</sub>)
  - 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

# 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

# Selected Bibliography

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