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Integration of Parametric Cost Estimation with System Architecture

… It's a dirty job but someone has to do it

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Hey! You've got your cost model on my architecture model!!

No! You've got your architecture model on my cost model!!

OMG SYSTEMS MODELING LANGUAGE SYSML ™

CO SYS MO
CONSTRUCTIVE SYSTEMS ENGINEERING COST MODEL

Hey! Your cost estimate is way out of whack!!

No! Your architecture has to be realistic and affordable!!

OMG SYSTEMS MODELING LANGUAGE SYSML™

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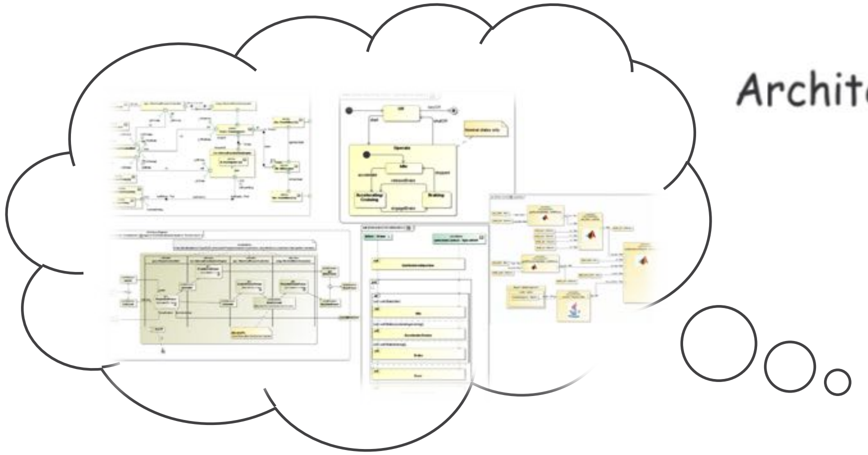
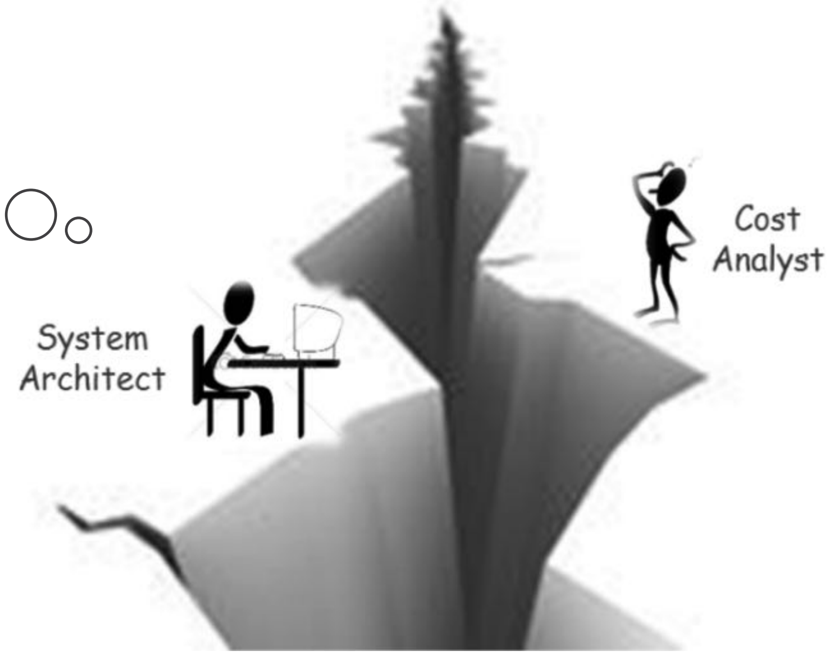
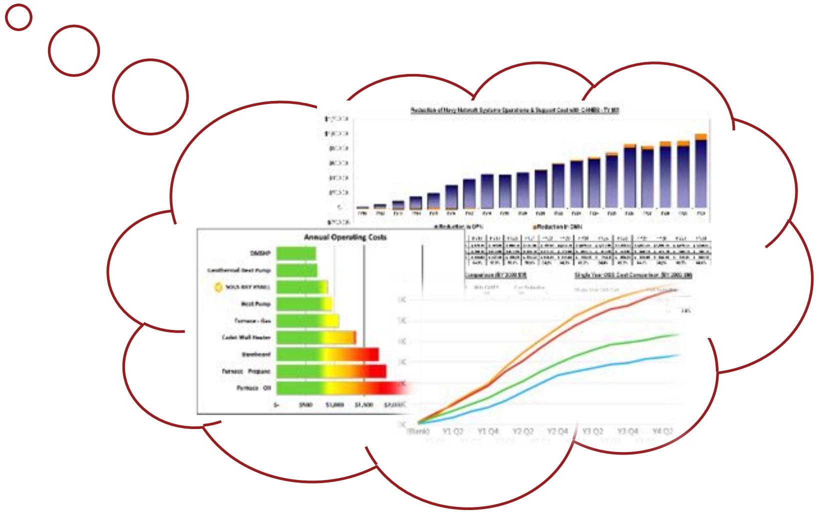
“Chasm” Between the Two Worlds



Architecture Development vs. Cost Estimation

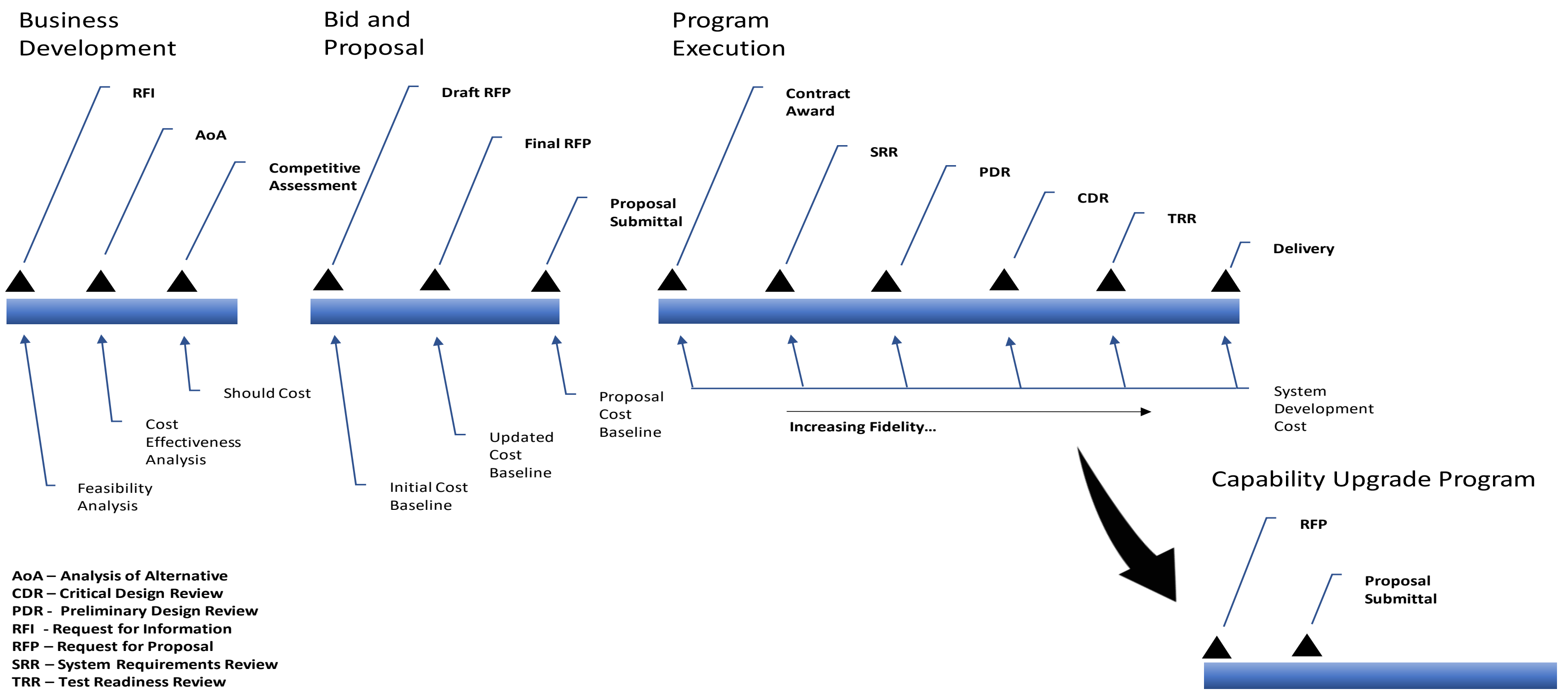




Separated by the Same Data!

When Do Systems Engineers Care About Cost Estimating?

Concept Exploration	•Multiple concepts •Investment decisions
Competitive Assessment	•Time critical •Cost criteria affects design decisions
Proposal Gates	•Limited time and resources •Early estimates based on high level concepts
Cost Volume Final Pricing	•Bottoms-up methods historically underestimate •Time and labor intensive.
Engineering Change Proposals	•Design details often not available •Limited time and resources

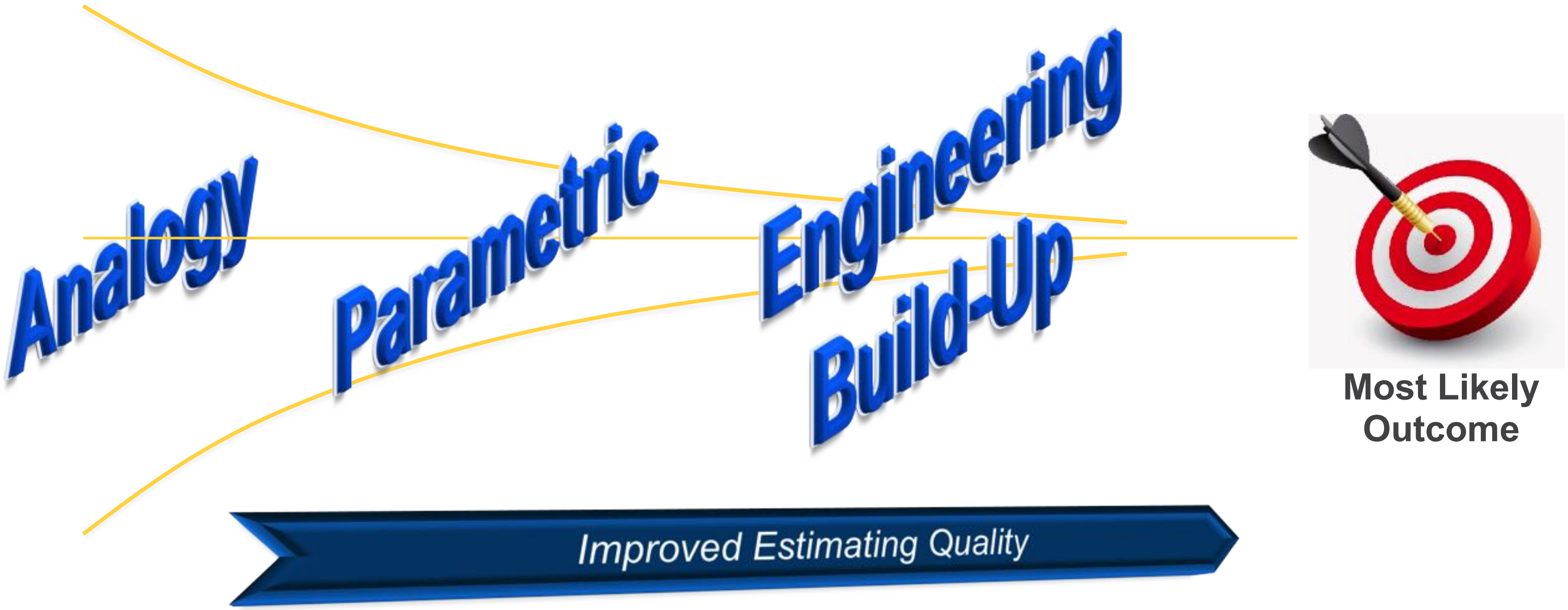


AoA – Analysis of Alternative
CDR – Critical Design Review
PDR - Preliminary Design Review
RFI - Request for Information
RFP – Request for Proposal
SRR – System Requirements Review
TRR – Test Readiness Review

Cost baseline is part of the technical baseline throughout the project lifecycle!

The Big Three: Leading Estimating Methodologies

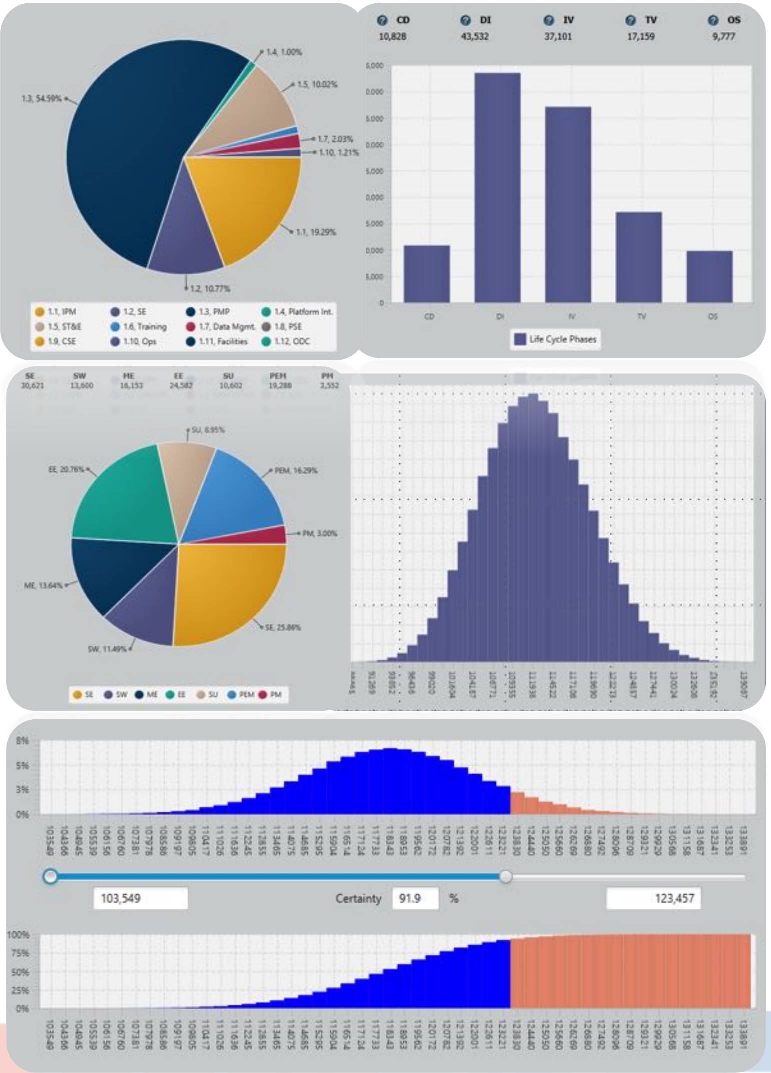
- When all else is equal…



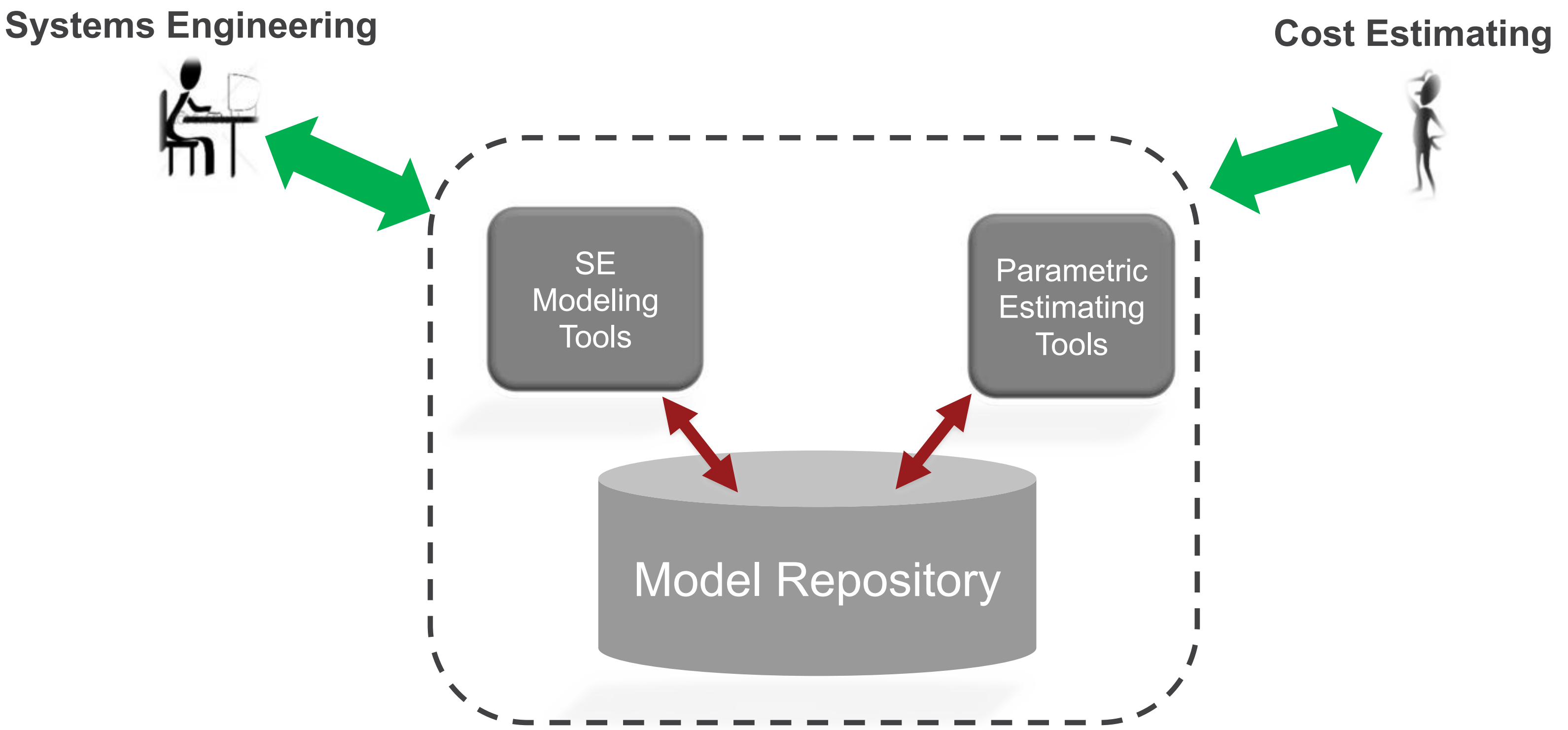
- …however, **Paramedic** method is typically **preferred**

Why Parametric Cost Estimation?

- An established, often preferred estimating methodology
  - Traceability to design and historical data
  - Objective measures of validity
- Ideal for early lifecycle before detailed design date exists
  - Simple, quick, low cost
  - Easily adjusted for changes
  - Statistical measures of risk
- Effective for what-ifs, trade studies
  - Exploration of architecture options (trades)
  - “What-if” sensitivity analyses
- Validation for more detailed, labor intensive methods (e.g. bottoms-up.)



The Goal: Integrated System Design and Cost Estimation



"**Single Source of Truth**" – Extending the digital thread into the cost domain!

COSYSMO: Parametric Model for Systems

- **COSYSMO** – COnstructive SYStems Engineering Cost MOdel
  - Based on COCOMO II Software Cost Estimation Model
  - V1.0 developed by Dr. Ricardo Valerdi (MIT/LAI), Dr. Barry Boehm (USC)
  - Supported by an industry/academia collaboration: USC CSSE, INCOSE, ISPA, PSM…
- Parametric Estimation of The Systems Engineering Effort
  - Covers full systems engineering lifecycle
  - Supports EIA/ANSI 632 and ISO/IEC 15288
- Further **extended** by industry partner to cover **total engineering effort** in system development – V3.0 work in progress
  - All of Engineering functional disciplines
  - WBS, lifecycle phases
  - "Generalized Reuse Framework:" investment vs. leverage

COSYSMO CONOPS

4 Size Drivers and 14 Cost Drivers….

Size Drivers

- # System Requirements
- # System Interfaces
- # Operational Scenarios
- # Critical Algorithms

Effort Multipliers

- Application factors
  - -8 factors
- Team factors
  - -6 factors

CO SYS MO 3.0

CONSTRUCTIVE SYSTEMS ENGINEERING COST MODEL

$$PH_{Total} = A_{DWR} \cdot SS_{DWR}^{E_{DWR}} \cdot CEM_{DWR} + A_{DFR} \cdot SS_{DFR}^{E_{DFR}} \cdot CEM_{DFR}$$

$$SS_{DWR} = \sum_k \left(\sum_r w_r \left(w_{e,k}\Phi_{e,k} + w_{n,k}\Phi_{n,k} + w_{d,k}\Phi_{d,k} \right) \right)$$

$$SS_{DFR} = \sum_k \left(\sum_q w_q \left(w_{e,k}\Psi_{e,k} + w_{n,k}\Psi_{n,k} + w_{d,k}\Psi_{d,k} \right) \right)$$

Effort

Calibration (Historical Data)

Mapping of COSYSMO Size Drivers to SysML Model Elements

REQ
- Number of System Requirements

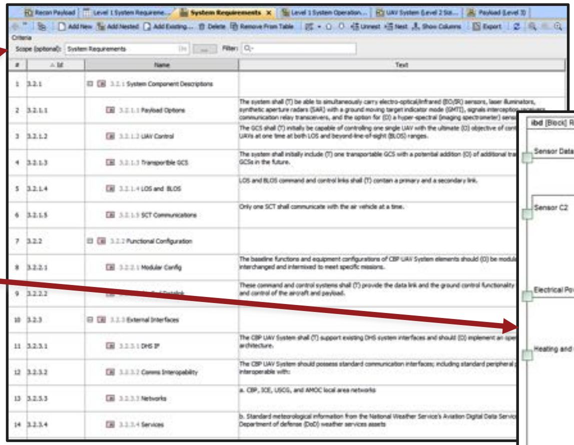
IF
- Number of System Interfaces

ALG
- Number of Critical Algorithms

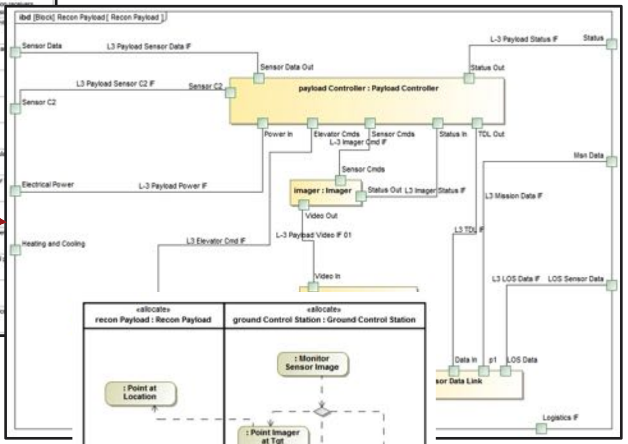
SCN
- Number of Operational Scenarios

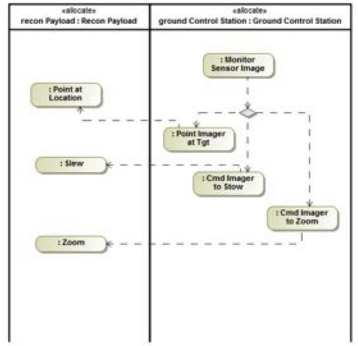
Each weighted by:
1) Levels of complexity
2) Categories of reuse

Requirements

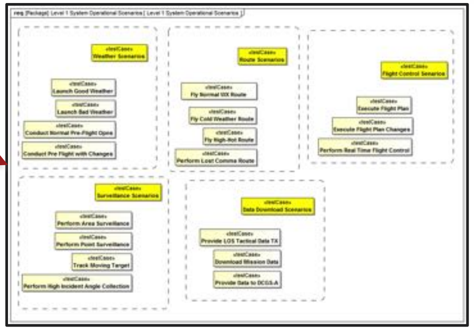


Ports and Connectors





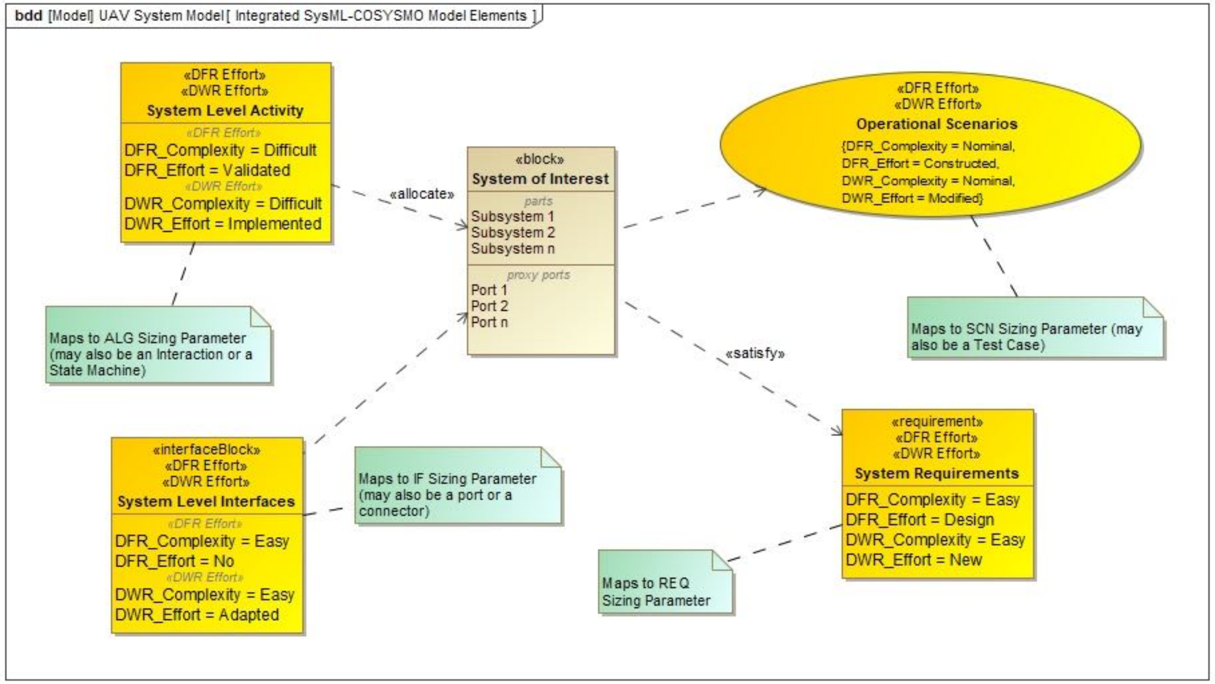
Activities, Interactions and State Machines



Use Cases & Behaviors

Connecting the Dots… System Models Provide Direct Estimating Inputs

- COSYSMO size drivers embedded in SysML model elements
- Effort and Complexity attributes applied as analysis properties of the design components
- MBSE tool features automate assignment and collection of sizing parameters
- Sizing data becomes a property of the architecture

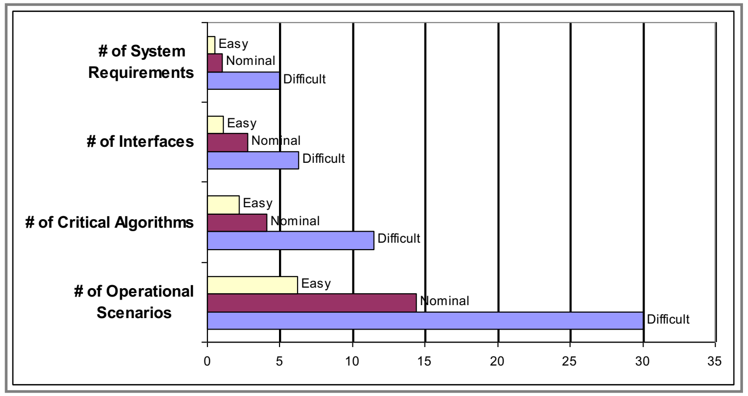


Reference: "Enabling Repeatable SE Cost Estimation with COSYSMO and MBSE"; Volume27, Issue1, July 2017, Pages 1699-1713

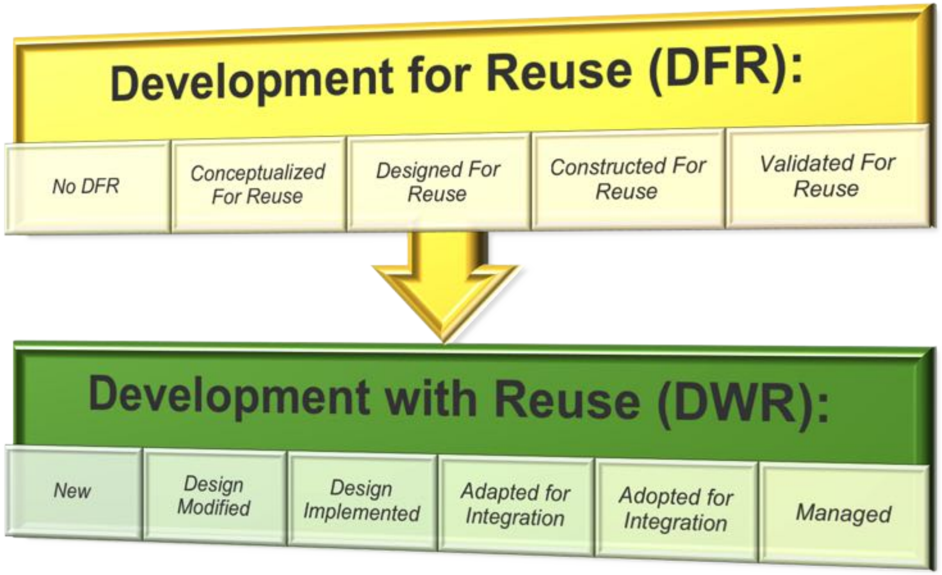
The integrated SysML-COSYSMO modeling environment seamlessly incorporates estimating activity into the system design/modeling workflow

Driver Counting/Classification Rules Built Into the Modeling Environment

- **Levels of Complexity**
  - "Easy"
  - "Nominal"
  - "Difficult"

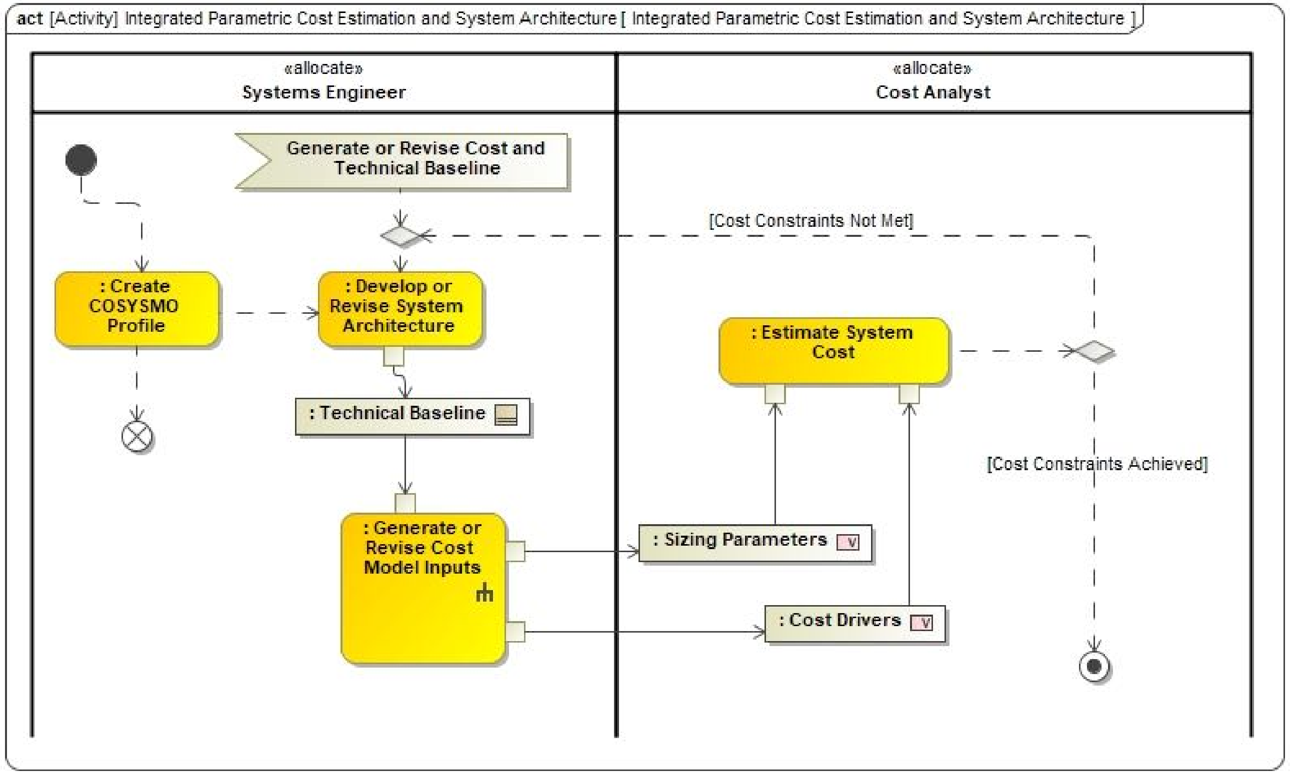


- **Degrees of Reuse**
  - "Generalized Reuse Framework"



Build-in Rules Provide Estimating Guidance to System Modelers and Architects

A New CONOPS: Estimating as an Integral Part of System Modeling



Four (4) Fundamental Activities:

I. Create COSYSMO Profile (one-time configuration)

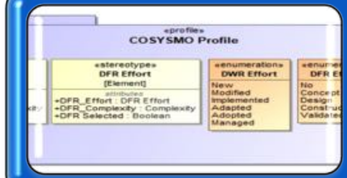
II. Develop System Models

III. Identify Cost Model Inputs – Sizing Parameters

IV. Generate Cost Estimate

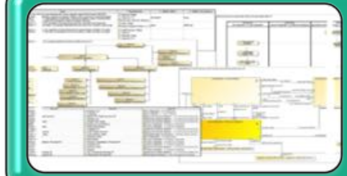
The integrated SysML-COSYSMO modeling environment seamlessly incorporates estimating activity into the system design/modeling workflow

Model Integration: Four Basic Activities



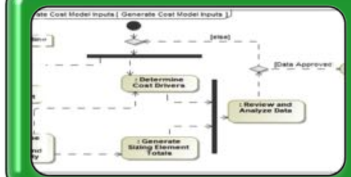
Activity 1 – Create COSYSMO Profile (one-time configuration)

- SysML Profile Package
- DWR, DFR and Complexity Stereotypes and Counting Metrics
- Create once and reuse in any project



Activity 2 – Develop System Architecture

- Unchanged from current practice
- Application of modeling guidelines ensure consistent definition across projects.

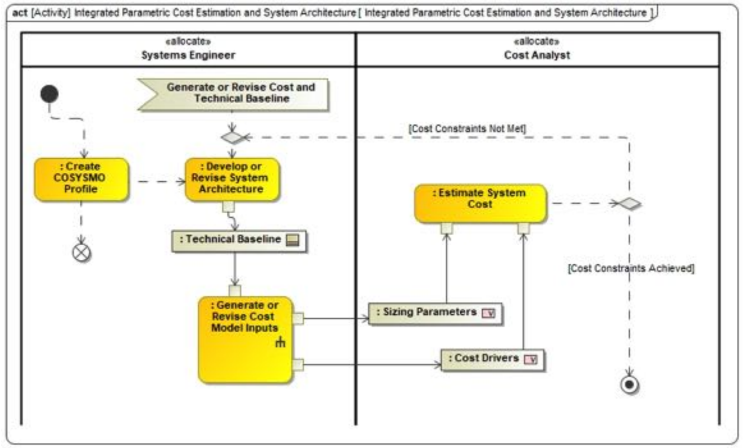


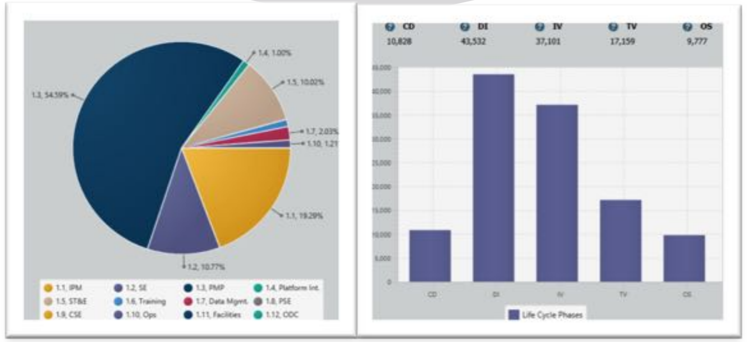
Activity 3 – Identify Cost Model Inputs

- Enabled by tool automation and SysML constructs
- Assigns Reuse Category and Complexity

Activity 4 – Generate Estimate

- Execution of the cost model is unchanged
- Cost model inputs are now part of the system architecture definition





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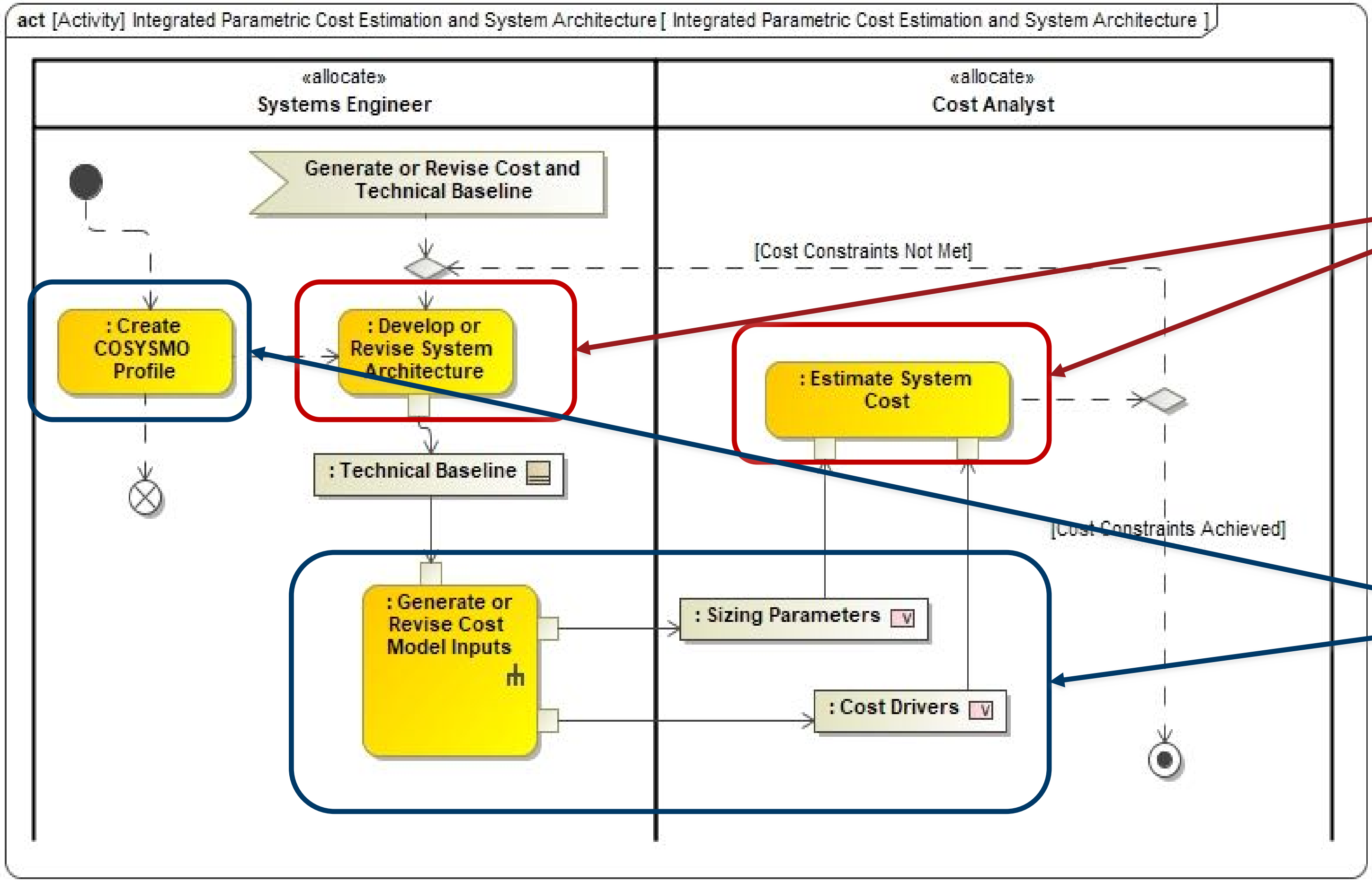
The Activities Are Performed as Part of an Augmented System Modeling Process



Activities 2 & 3: We do this already!

Activities 1 & 4: This is what's new!

Connecting the digital thread into the cost estimation domain!

Activity 3: Identify Cost Model Inputs

Identify Sizing Elements	Determine Reuse Category and Complexity	Count Sizing Elements	Generate Cost Drivers	Review for Consistency
Count at the SOI Black Box Level Requires System and Domain Experience *>Requirements* *>Interfaces* *>Algorithms* *>Operational Scenarios*	DWR and DFR Easy, Nominal, Complex Requires System and Domain Experience Effort is trivial made by SysML language properties and tool automation	MBSE Tool features automate counting and collection of sizing data A potential of 132 individual pieces of sizing data: 5 DFR Reuse Categories 6 DWR Reuse Categories 3 Levels of Complexity 4 Sizing Elements Types (REQ, ALG, SCN and IF)	14 Cost Drivers Qualitative characteristics of both the system and the systems engineering environment 10 of the 14 derived directly from the characteristics of the SOI	The key to accurate and repeatable parametric cost estimation Tool features enable detailed review and analysis of sizing data

The Linchpin is identifying cost model inputs directly from the SysML attributes, as models are developed

Review Data for Consistency

Advanced query features enable comprehensive analysis of sizing inputs.

Criteria

Element Type: Activity ... Scope (optional): L2 System Functions ... Filter:

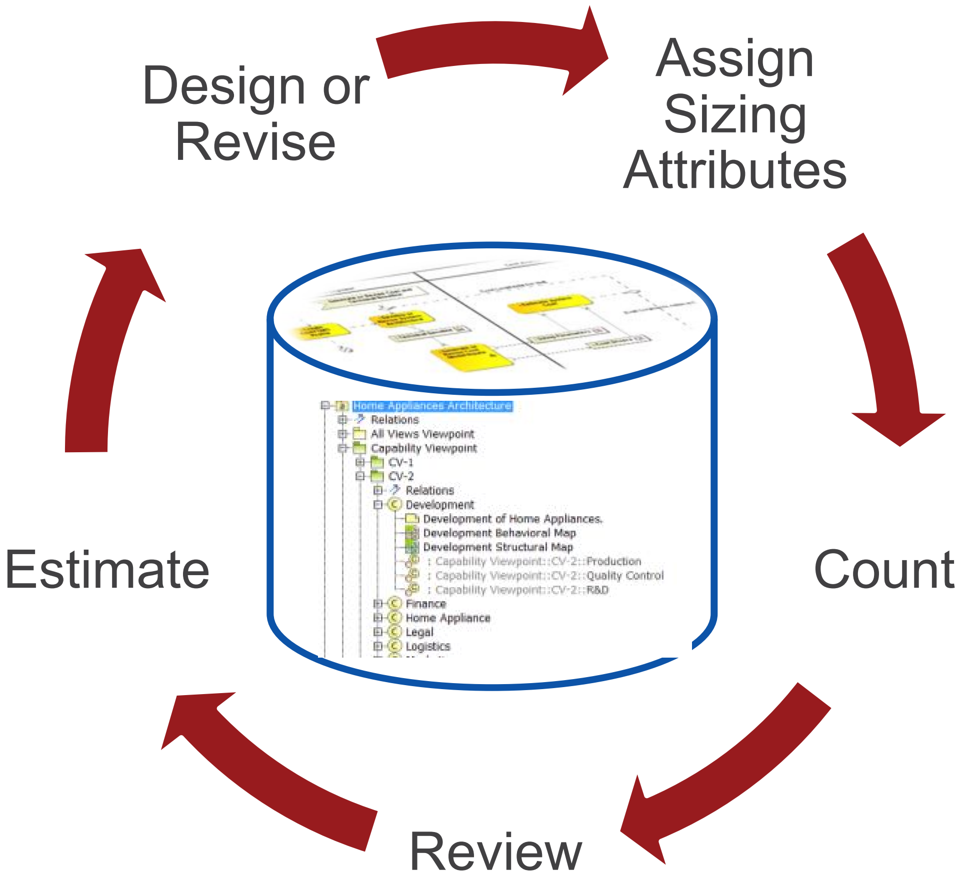
#	Name	Allocated To	DWR_Effort	DWR_Complexity	Satisfies	Rqmt DWR Effort	Rqmt DWR Complexity
1	Point at Location	1.2 Recon Payload	Adapted	Nominal	3.2.5.1.5.4 Simul	Implemente	Nominal
2	record streaming image	1.2 Recon Payload	Adopted	Easy	3.2.5.1.5.4 Simul	Implemente	Nominal
3	Report Sensor Status	1.2 Recon Payload	Adapted	Nominal	3.2.5.1.5.4 Simul	Implemente	Nominal
4	Store Search Plan	1.2 Recon Payload	Adapted	Difficult	3.2.5.1.4 Pre-Flig	New	Difficult
5	Monitor Sensor Status	1.2 Recon Payload	Adapted	Nominal	3.2.1 Payload Op 3.2.5.1.5.4 Simul	Modified Implemente	Easy Nominal

Example:

- The requirement that drove a specific critical algorithm should have similar DWR/DFR and complexity values as the SysML Activity that satisfies it.

Cross-cutting views and other analysis features of the MBSE toolset enable detailed review and analysis of sizing & cost driving parameters

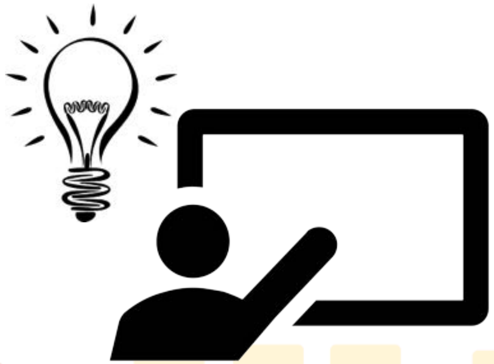
Integrated Modeling-Estimating Environment Enables Rapid Design Iteration and Optimization



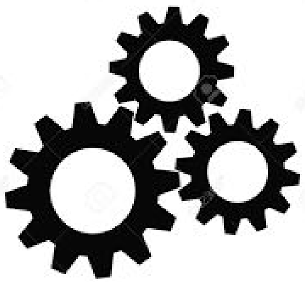
- Sizing Data is a property of the architecture and maintained with the system model
- Alternatives can be quickly evaluated to achieve optimized design that meets:
  - Functional and Performance Requirements
  - Cost Targets
- Cost impacts can now be integrated into the systems engineering decision process

MBSE Allows Systems Engineers to Focus on the Important Things

- **Tasks for the Systems Engineer**
  - Design the System
  - Determine Sizing Elements
  - Determine Reuse Category and Complexity
  - Analyze Results



- **Tasks for MSBE Toolset**
  - Maintain Sizing Data as part of the System Architecture
  - Provide efficient User Interface to apply Sizing Parameters
  - Automate Counting
  - Provide Cross Cutting Views for Analysis



Benefits of the Integrated MBSE-Cost Estimating Environment

- Provides complete **traceability** between the system architecture and the cost estimate
- Enables **repeatable** cost estimation with analysis features increasing levels of **confidence** by maintaining traceability throughout the development life cycle
- Provides data integrity and "**single source of truth**" not available with document based methods
- Model integration and automation provided by the MBSE toolset significantly reduces estimating and review time, **effort** and **cost**
- Reduces the **cycle time** from design to cost, enabling to **earlier decision** making and faster time to market, applying parametric estimation and cost-based architecture trades

Conclusion

- The integration of the COSYSMO parametric cost model with SysML is a natural extension of the MBSE environment.
- The data elements defined within the cost model map directly to the SysML model elements used to define the system architecture.
- Features of the language (profiles and stereotypes) allow these cost elements to be defined once and reused for each estimation effort.
- The MBSE environment provides the same benefits to parametric cost estimation as it does to the systems engineering process.
- The integrated system modelling and cost estimating extends the “digital thread” and enables early system understanding, design trades, time-to-market, and ultimately improves the ability of decision makers for better systems.

Future Work

- Application of the process for development of cost model calibration data from legacy projects
- Evaluation of tool-tool data exchange formats and protocols between SysML modelling tools and COSYSMO cost estimation tools
- Description of lifecycle management of cost estimation data within the MBSE repository as a corporate asset
- Conduct of one or more pilot case study projects

About the Authors

Barry Papke is the Director of Professional Services for No Magic Inc. He has thirty-two years of systems engineering and operations analysis experience in the aerospace and defense industry across the entire systems engineering lifecycle from concept development through integration, test and post-delivery support.

Gan Wang, Ph.D., is a Global Engineering Fellow at BAE Systems and the Chief Engineer for its Integrated Defense Solutions businesses. He has been actively engaged in systems engineering processes, cost estimating and analysis, modeling & simulation, multi-criteria decision making methods, and system-of-systems engineering methodologies.