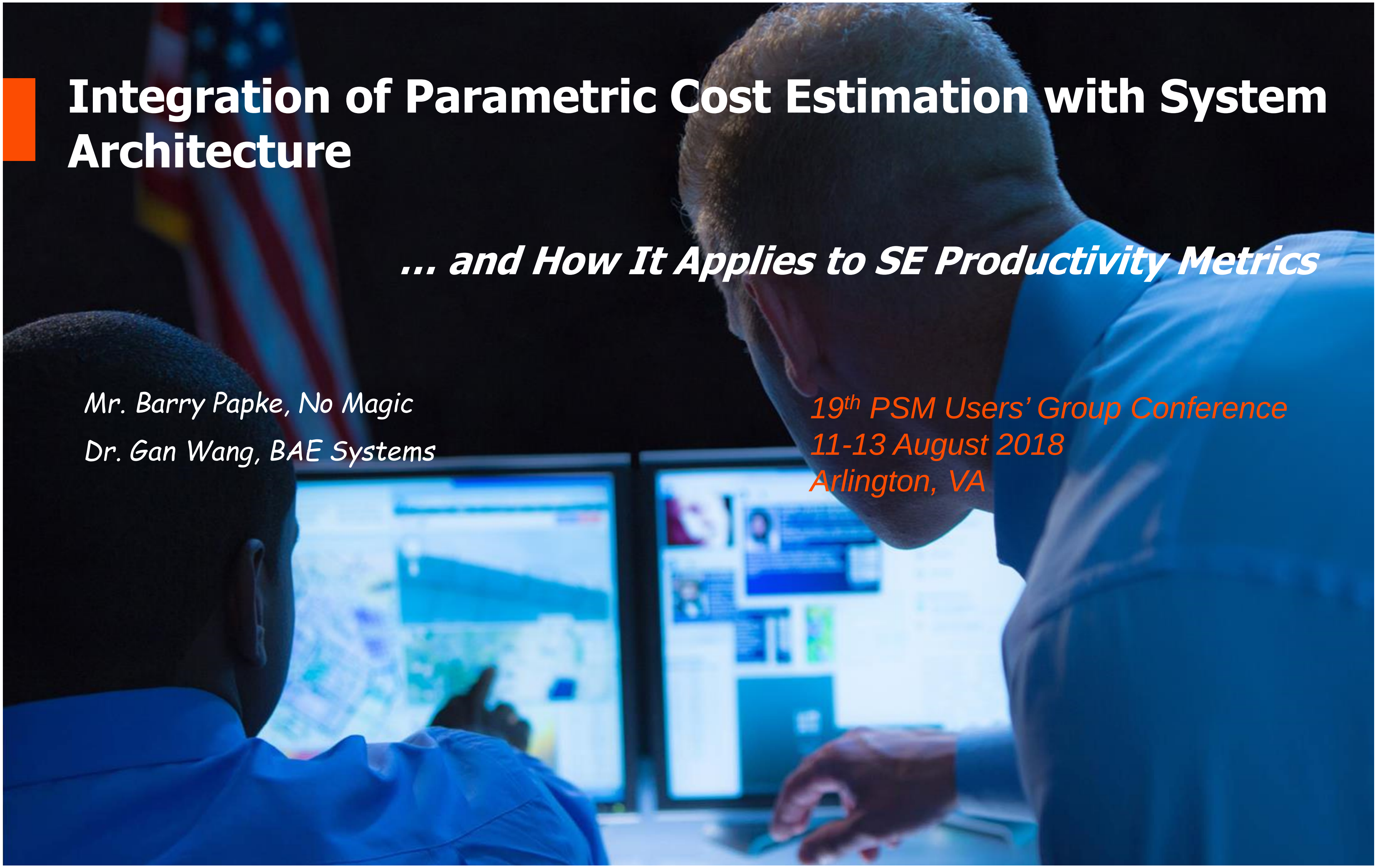

Integration of Parametric Cost Estimation with System Architecture

… and How It Applies to SE Productivity Metrics

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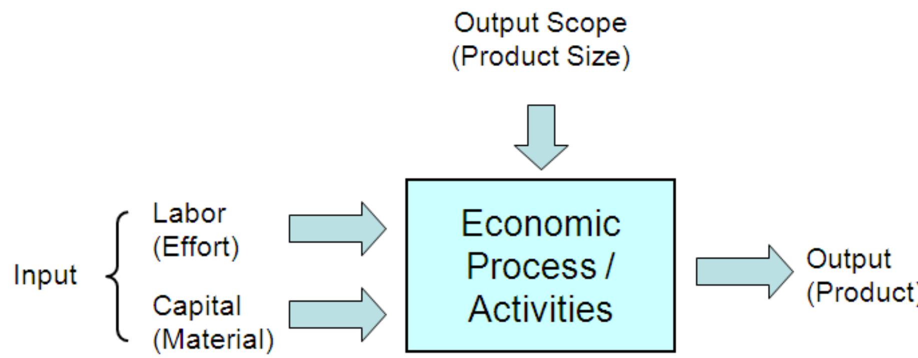
Measuring Productivity: Terminology

- A General **Production Model**:

$$Q = f(K, L)$$

where,

Q = output; K = capital; L = Labor



- **Productivity**, in general economic terms:

$$Productivity = \frac{Output\ Created}{Input\ Used}$$

- **Labor productivity** (LP) is typically measured as output per worker or *output per labor-hour*:

$$LP = \frac{\partial Q(K, L)}{\partial L}$$

Systems Engineering Productivity

- We have established:
  - Wang, et al, “Measuring Systems Engineering Productivity,” *Proceedings of the 20th INCOSE International Symposium*, Chicago, IL. July 2010

- ***SE Productivity***: Productivity for systems engineering is defined as the amount of the system (measured in *eReq*) produced or realized per unit of labor (measured in eng. hour)

$$SE\ \ Productivity = \frac{System\,Size}{Total\ SE\ Hours} \qquad (eReqs/SE\ Hours)$$

- ***SE Efficiency***: Efficiency for systems engineering is defined as the number work hours or effort (measured in eng. hours) required to produce a given unit of system (measured in *eReq*)

$$SE\ \ Efficiency = \frac{Total\ SE\ Hours}{System\,Size} \qquad (SE\ Hours/eReq)$$

SE Productivity Measure Is Based on COSYSMO CER

4 Size Drivers and 14 Cost Drivers….

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

Size Drivers

Effort Multipliers

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

COSYSMO 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)

Normalized Systems Engineering Productivity

- ***Normalized SE Productivity***: amount of the system produced or realized per unit of labor, under the *nominal* system complexity and project environment
  - Mathematically

$$SE\ \ Productivity_{Norm} = SE\ \ Productivity \cdot CEM$$
$$= \left(\frac{System\,Size}{Total\ SE\ Hours} \right) \cdot CEM$$

1. What to measure?
2. How to measure?

Where,

CEM = the *composite effort multiplier* defined from 14 cost drivers

$$CEM = \left(\prod_{i=1}^{8} AF_i \right)^{1/8} \cdot \left(\prod_{j=1}^{6} TF_j \right)^{1/6}$$

(COSYSMO 3.0 CER)

- "*Normalize*" different projects to the same level of complexity – or, take the complexity/environment "out of the equation"

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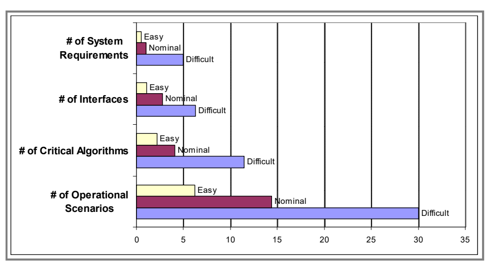
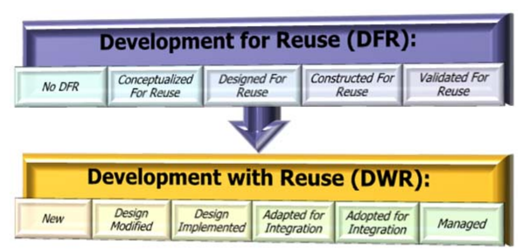
Question 1/2: What to Measure?

- We have also established:
  - Wang, G., Roedler, G. J., Pena, M., & Valerdi, R. "A Generalized Systems Engineering Reuse Framework and Its Cost Estimating Relationship," *Proceedings of the 24th INCOSE International Symposium*, 274-297. 2014
  - Wang, G., "The Generalized Reuse Framework - Strategies and the Decision Process for Planned Reuse." *Proceedings of the 26th INCOSE International Symposium,* Volume 26, Issue 1, July 2016: 175-189. Wiley and Sons

- **COSYSMO 3.0**:
  - **Size Drivers = {REQ, IF, ALG, SCN}**
  - **Levels of Complexity**
    - *"Easy"*
    - *"Nominal"*
    - *"Difficult"*
  - **Degrees of Reuse**
    - *"Generalized Reuse Framework"*





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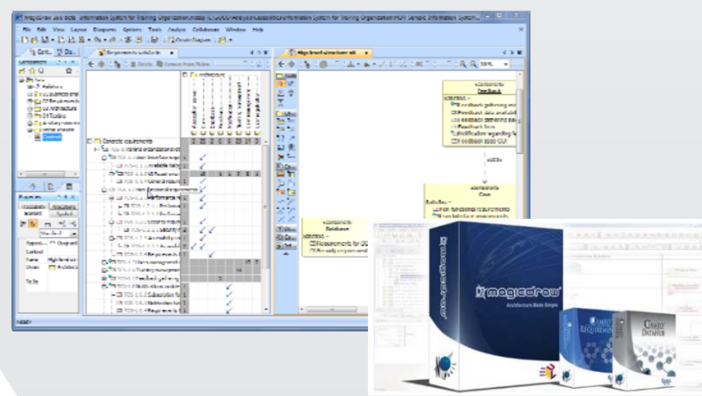
Question 2/2: How to Measure?

- We have further established: the linkage between COSYSMO size drivers and SysML based architecture attributes
  - Papke, B., Wang, G., & Pavalkis, S., "Enabling Repeatable SE Cost Estimation with COSYSMO and MBSE," Pro*ceedings of the 27th INCOSE International Symposium*, 2017: 1699-1713, John Wiley and Sons
  - Papke, B., Wang, G., "Integration of Parametric Cost Estimation with System Architecture – It's a dirty job but someone has to do it!" *Proceedings of the 28th INCOSE International Symposium*, 2018, John Wiley and Sons

Parametric Cost Model

CO SYS MO
CONSTRUCTIVE SYSTEMS ENGINEERING COST MODEL
3.0

SysML Modeling Environment



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Note: the principle applies to all modeling tools

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What Has Have Established…

… System Models Provide Direct Estimating Size Driver Inputs

REQ • Number of System Requirements

IF • Number of System Interfaces

ALG • Number of Critical Algorithms

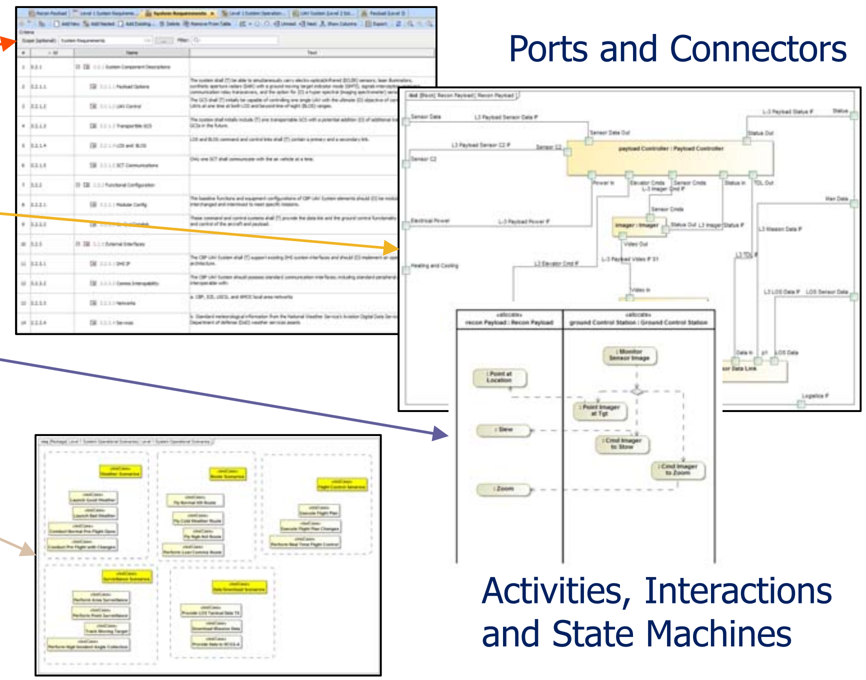
SCN • Number of Operational Scenarios

Each weighted by:

1) **Levels of complexity**
2) **Categories of reuse**

Requirements

Ports and Connectors



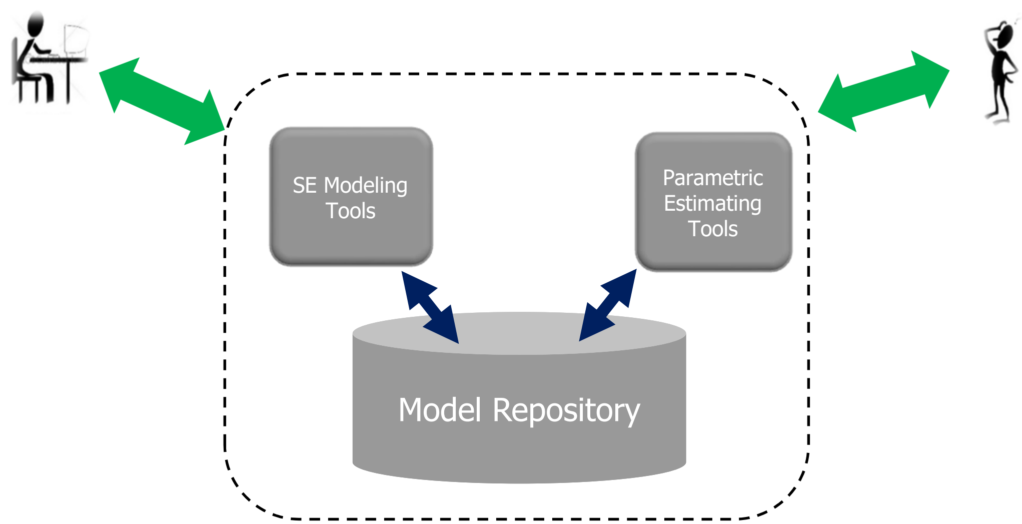
Activities, Interactions and State Machines

Use Cases & Behaviors

***Reference**: "Enabling Repeatable SE Cost Estimation with COSYSMO and MBSE" Volume 27, Issue1, July 2017, Pages 1699-1713*

Our Motivation: Integrated System Design and Cost Estimation

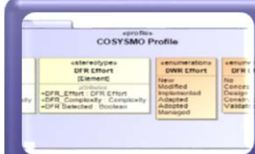
Systems Engineering **Cost Estimating**



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

A New SE CONOPS – Estimating as an Integral Part of System Architecture Modeling

Four (4) Integrated Modeling Activities:

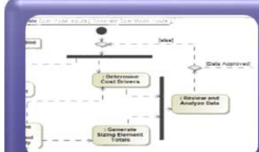


Activity 1 – Create COSYSMO Profile (one-time configuration)

- 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

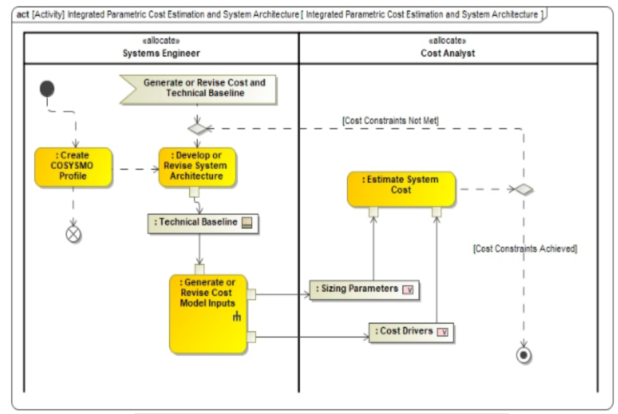


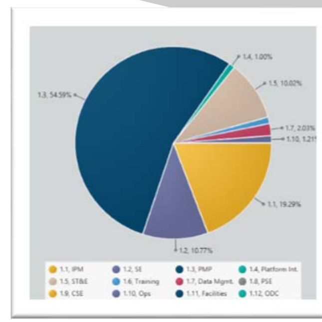
Activity 3 – Identify Cost Model Inputs

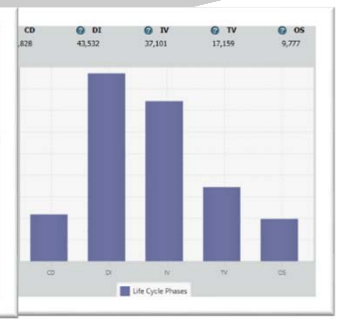
- Enabled by tool automation and SysML constructs
- Assigns Reuse Category and Complexity

Activity 4 – Generate Estimate

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

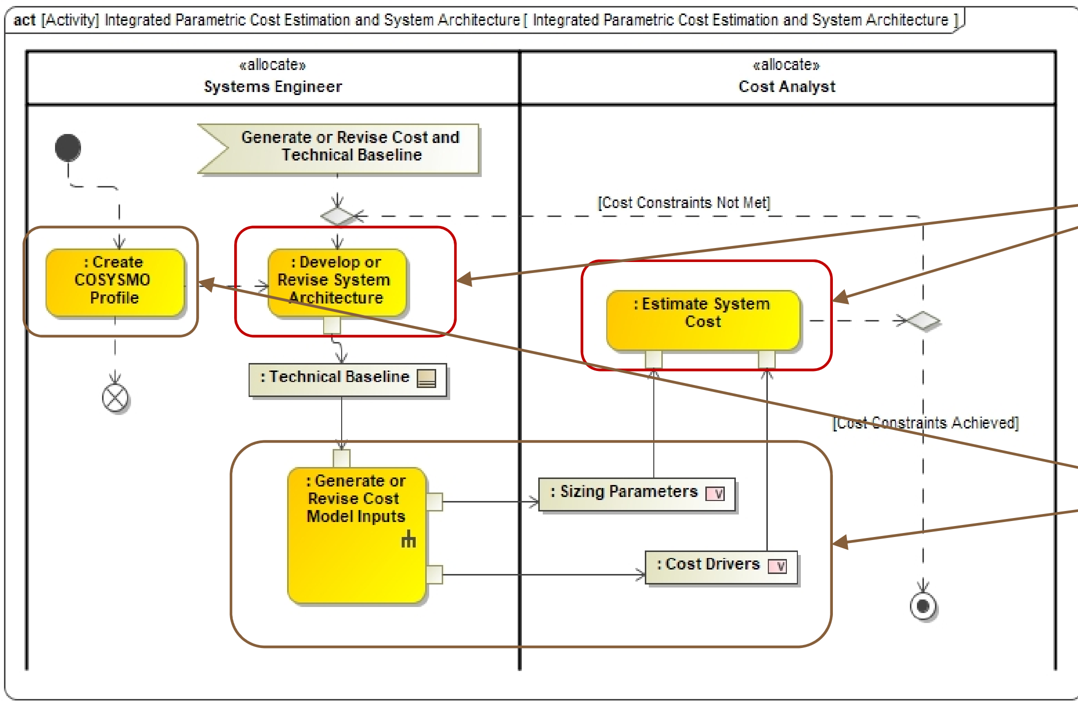






***Reference**: "Enabling Repeatable SE Cost Estimation with COSYSMO and MBSE" Volume 27, Issue1, July 2017, Pages 1699-1713*

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

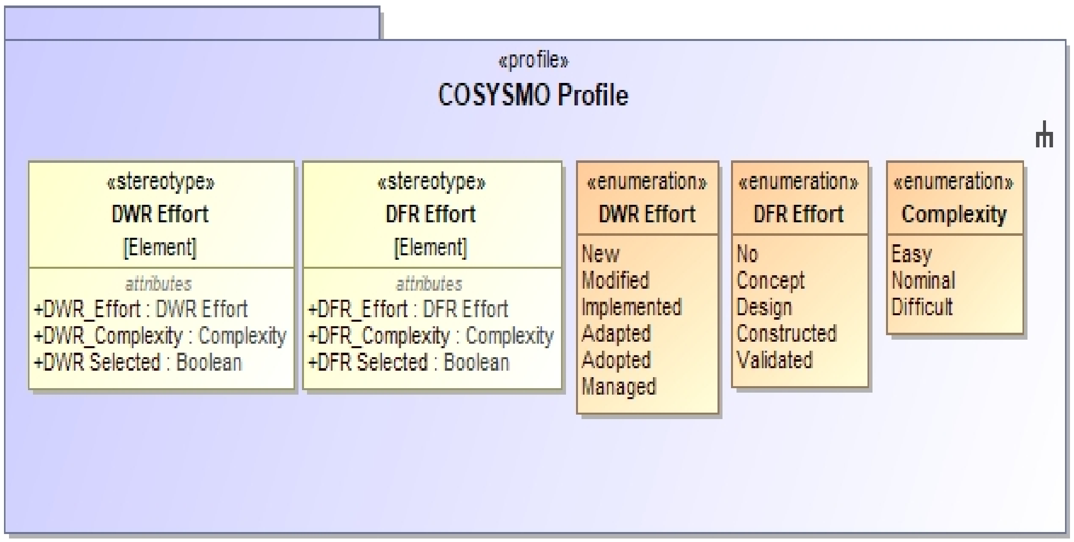


Activities 2 & 3: we do this already, sort of…

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

Connecting the digital thread into the cost estimation domain!

Activity 1: Create COSYSMO Profile (one-time event)



- **SysML Profile** package enables creation of stereotypes for
  - Reuse categories: DWR and DFR
  - Level of complexity: easy, nominal, difficult
- Once created, it can be reused in any new model

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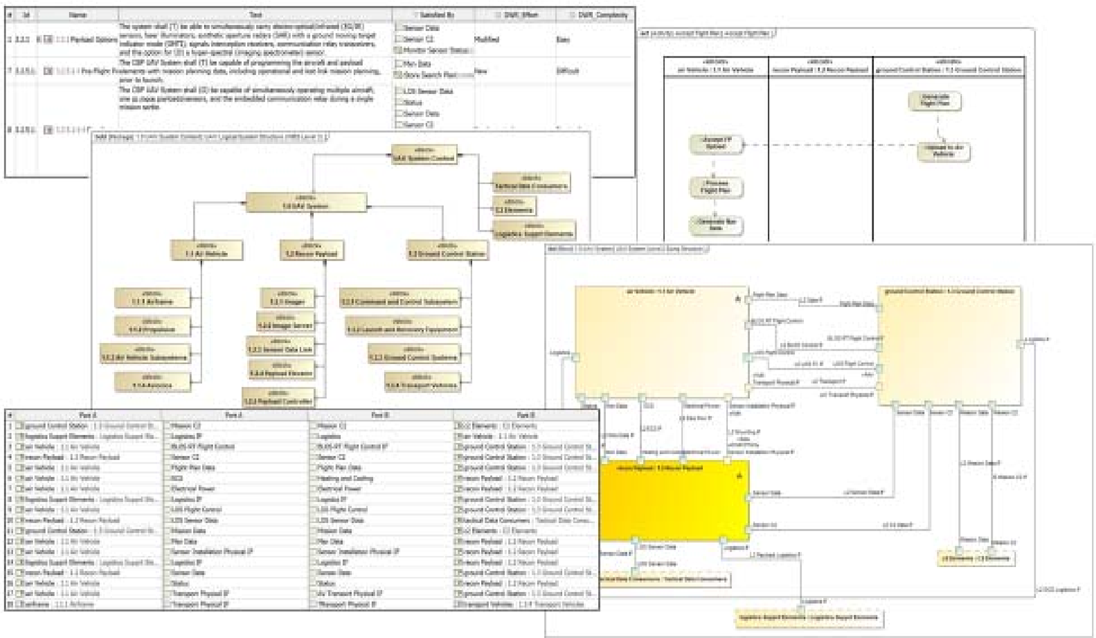
Activity 2: Develop System Architecture



Development of the SysML architecture model is unchanged*

* Projects must adopt consistent modeling standards to ensure repeatable sizing estimates that are consistent with calibration data.

Activity 3: Identify Cost Model Inputs

Iteratively with Step 2…

Identify Sizing Elements	Determine Reuse Category and Complexity	Count Sizing Elements (Automatic)	Generate Cost Drivers	Review for Consistency
System of Interest (Count at the SOI Black Box Level): •Requirements •Interfaces •Algorithms •Operational Scenarios	DFR DWR Level of Complexity	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 System characteristics Assessed based on Behavior and Parametric Model Elements	The key to accurate and repeatable parametric cost estimation Tool features enable detailed review and analysis of sizing data

Requires System Domain Experience

Rely on tool automation

Rely on SysML language properties

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

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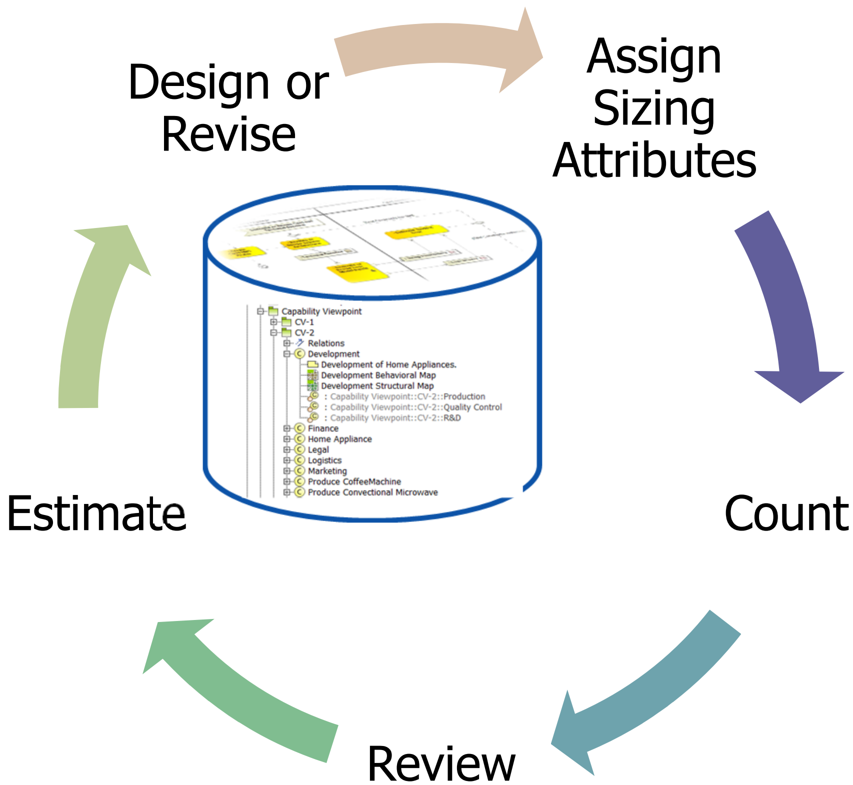
Integrated Modeling-Estimating Environment Enables Rapid Design Iteration and Optimization



- 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

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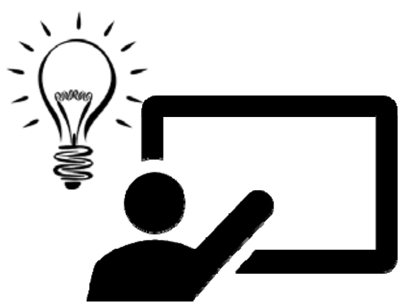
MBSE Allows Systems Engineers to Focus on the Important Things…

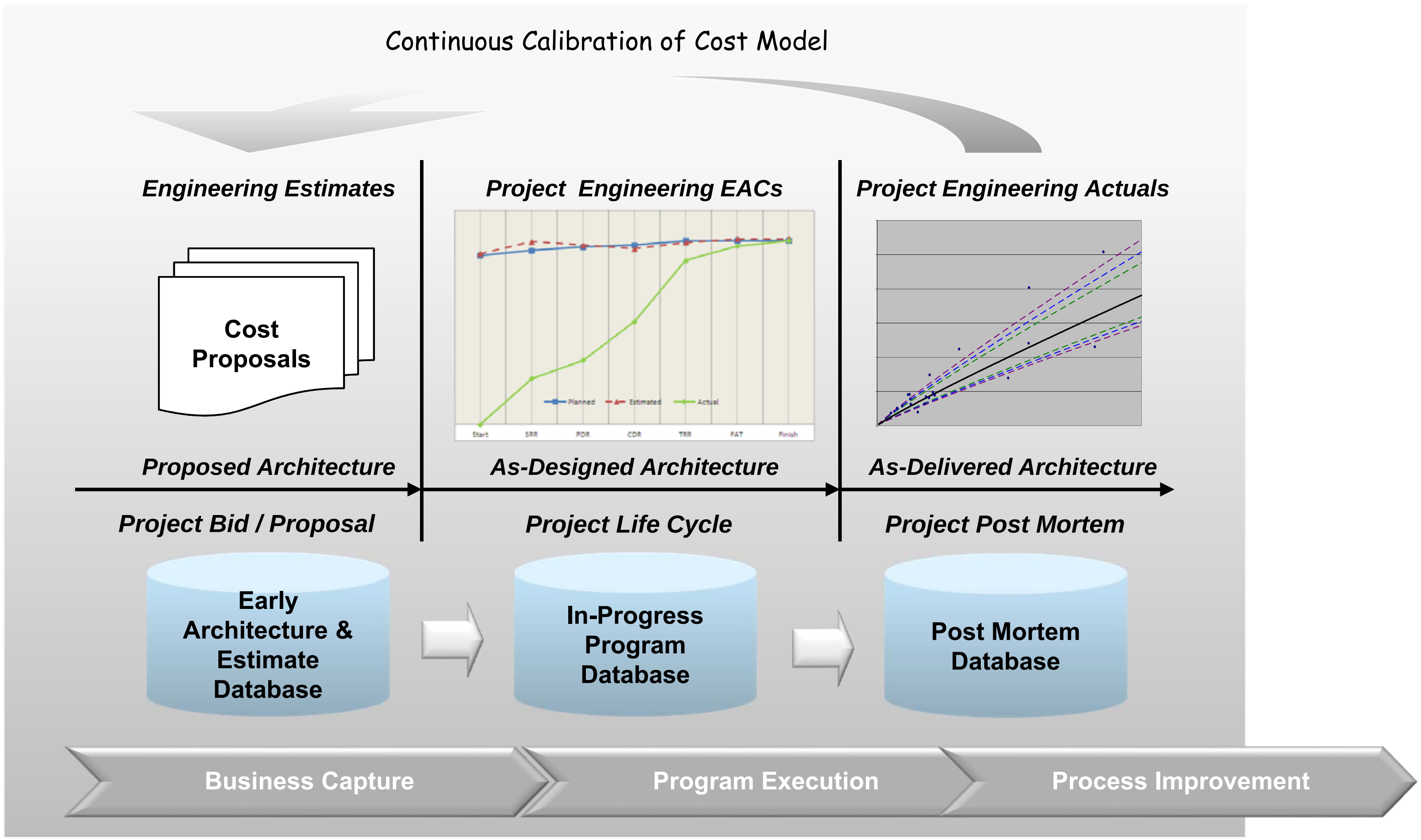
- **Tasks for MBSE Toolset**
  - Maintain Sizing Data as part of the System Architecture
  - Provide efficient User Interface to apply Sizing Parameters
  - Automate Counting
  - Provide Cross Cutting Views for Analysis

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



Managing SE Productivity Metrics for Enterprise

- Combined model library with productivity metrics database
- Lifecycle metrics across product lines and organizations



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Reference: Wang, et al, "The Architecture and Design of a Corporate Engineering Data Repository," Proceedings of the 22nd INCOSE International Symposium, Rome, Italy, July 2012

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The Prospect…

- As an attribute, SE productivity metric is embedded in system architecture models
  - Enabling systematic reuse and early design decisions
  - Enabling estimating capabilities: *analogy*, *parametric*
  - Connecting system (functions and performance) to economics

Conclusion with Perceived Benefits

- Integration of cost estimation with system modeling further extends the “digital thread”
  - Complete traceability from design to cost
  - **Repeatable** estimating with direct analysis/trade features
- Formalized development, integration, curation, and use of models for life cycle
  - **Early** system understanding
  - Reduced **cycle time** from design to cost, enabling to **earlier decision** making and **faster** time to market
- Enduring and authoritative “**Single source of truth**”
  - Reliable, trustworthy, and authoritative
  - Ultimately, better systems

Future Work

- Evaluation of tool-tool data exchange formats and protocols between SysML modelling and COSYSMO estimating tools
  - Potential MagicDraw add-on/extension
- Lifecycle management of cost estimation data within the MBSE repository as a corporate asset
- Conduct of one or more pilot case study projects

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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.

Thank You

Dr. Gan Wang, BAE Systems

Mr. Barry Papke, No Magic