Practical Software and Systems Measurement

A foundation for objective project management

COSYSMO 2.0 Reuse
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COSYSMO 2.0 Reuse

- Constructive Systems Engineering Cost Model (COSYSMO) continues to be successful and accepted by the community
  - Developed over four years, published in 2005
  - Commercial and non-commercial implementations, taught in several university graduate engineering courses
- Development continues as areas of improvement identified
  - Practitioners realized COSYSMO estimate errors a result of significant amounts of reuse
  - Accounting for reuse identified as the most critical area of improvement for model
- 2nd version of model (COSYSMO 2.0) will account for reuse
  - Development of a reuse extension for the size drivers

Objectives of the Workshop

1. Review COSYSMO 2.0 development
2. Determine weights of reuse categories for use in COSYSMO 2.0 model
3. Identify a set of common systems engineering artifacts that are reusable
4. Develop a framework for how organizations (should) handle systems engineering reuse
5. Enable participants to exchange reuse experiences and learn from others

Workshop Format

Background	**1:30-1:45**
- COSYSMO Overview and Guiding Principles	
- Reuse Introduction	
- Systems Engineering Reuse Overview	
- COSYSMO 2.0 Highlights	
Exercises	
- Reuse Category Delphi	1:45-3:15
Break	3:15-3:30
- Reuse Artifact Identification	3:30-4:00
- Reuse Framework/Process Discussion	4:00-4:45
Conclusion	**4:45-5:00**

Workshop Background

- Past COSYSMO workshops at PSM (2002-2007)
  - Established model development path
  - Performed Delphi rounds 1-3
  - Presented calibration results
  - Reviewed experiences from model deployment
  - Identified model improvements

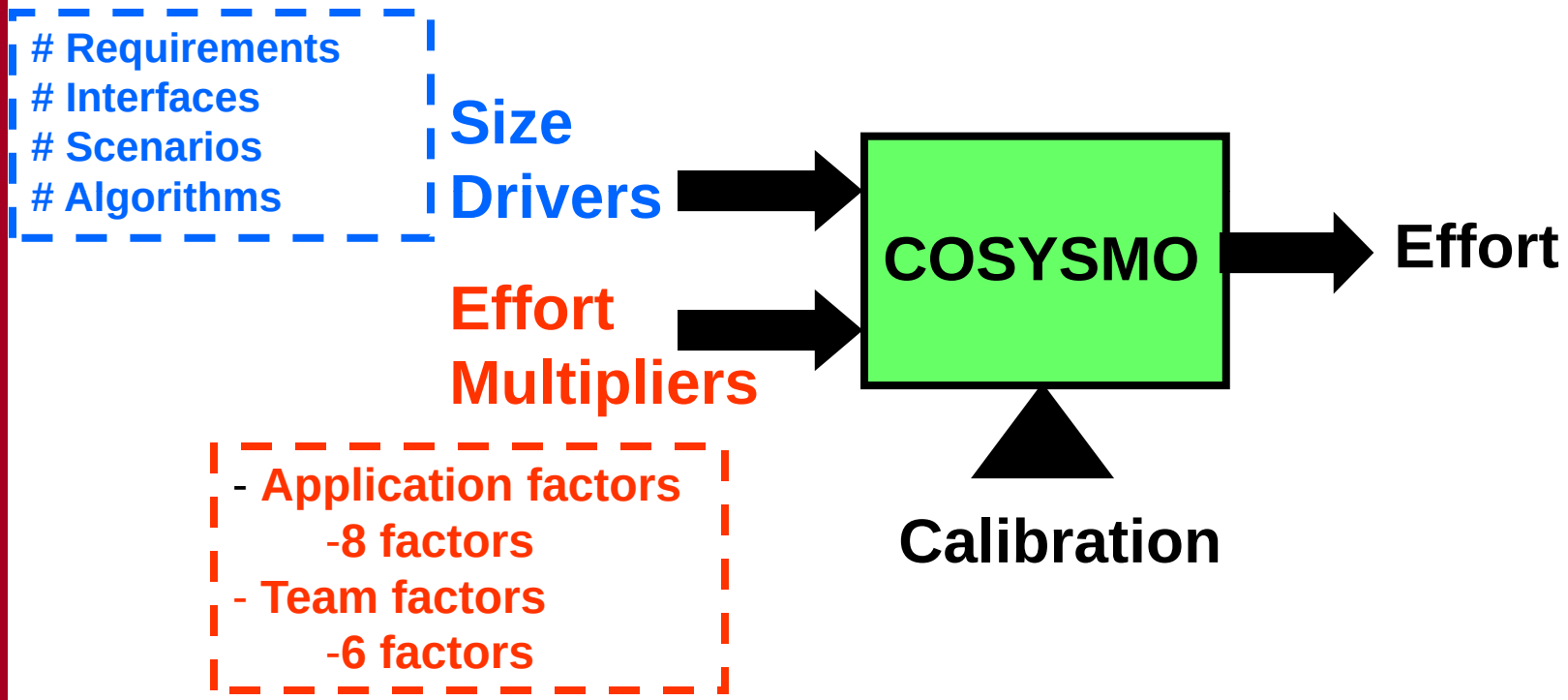
- Identification of need to address reuse in COSYSMO was first presented at PSM (2007)
  - Development of reuse extension continues

Intended Output

- Concurrence on reuse categories
- Validation of reuse category weights
- Identification of common reuse framework

COSYSMO 2.0 Background

COSYSMO Operational Concept



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ENTER SIZE PARAMETERS FOR SYSTEM OF INTEREST

	Easy	Nominal	Difficult	
# of System Requirements				0
# of System Interfaces				0
# of Algorithms				0
# of Operational Scenarios				0
				0 equivalent size

SELECT COST PARAMETERS FOR SYSTEM OF INTEREST

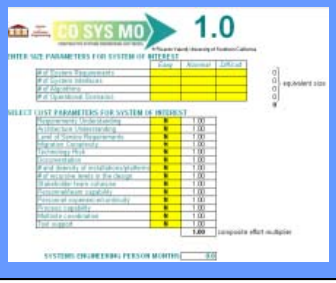
Requirements Understanding	N	1.00
Architecture Understanding	N	1.00
Level of Service Requirements	N	1.00
Migration Complexity	N	1.00
Technology Risk	N	1.00
Documentation	N	1.00
# and diversity of installations/platforms	N	1.00
# of recursive levels in the design	N	1.00
Stakeholder team cohesion	N	1.00
Personnel/team capability	N	1.00
Personnel experience/continuity	N	1.00
Process capability	N	1.00
Multisite coordination	N	1.00
Tool support	N	1.00
		1.00 composite effort multiplier

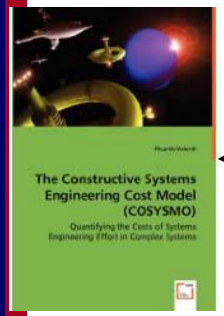
SYSTEMS ENGINEERING PERSON MONTHS **0.0**

Impact

COSYSMO Model

$$PM_{NS} = A \cdot \left(\sum_{k} (w_{e,k}\Phi_{e,k} + w_{n,k}\Phi_{n,k} + w_{d,k}\Phi_{d,k}) \right)^{E} \cdot \prod_{j=1}^{14} EM_j$$





10 theses

Academic Curricula

SMU

MIT

GEORGE MASON UNIVERSITY

NPS NAVAL POSTGRADUATE SCHOOL

UCSanDiego

University of Southern California

Commercial Implementations

SystemStar™
SystemStar 1.02
Build 1.0.2.683
Copyright © 1986 - 2006 Softstar Systems

SEER®

PRICE

Policy & Contracts

NASA

U.S. AIR FORCE

DEPARTMENT OF DEFENSE

U.S.ARMY

Proprietary Implementations

BAE SYSTEMS

LOCKHEED MARTIN

Raytheon

BOEING

SEEMaP

COSYSMO-R

SECOST

Sys Engr Cost Tool

COSYSMO Development Principles

- Bring a quantifiable and justifiable approach to estimating the cost of systems engineering
  - Leverage expertise of hundreds of systems engineers to identify drivers of project size and cost
- Establish a tool with both broad usability and direct applicability
  - Create common-denominator drivers/definitions to enable organization to use as appropriate to fit their operational needs
- Follow a proven parametric model development methodology and estimation structure
  - Establish a minimum set of drivers to adequately account for the size and cost of the systems engineering elements of a project

COSYSMO Discussion Principles

- *COSYSMO is an open model, developed by the community and for the community*
  - *Users are free to change and/or extend the model to fit the needs and characteristics of their organization*
- *Common definitions and parameters benefit the entire community*
  - *Facilitates the communication of bases of estimates*

What is Systems Engineering Reuse?

- *Systems engineering activities are support-focused*
  - *Do not produce physical products (HW, SW, etc.)*
  - *Produce architectures, requirements, test plans, and other technical documents*
- *Systems engineering products can be viewed as "artifacts"*
  - *Encapsulation of systems engineering knowledge in a document or process*
  - *Representative of systems engineering effort*
- *Reuse of an artifact should reduce the expected systems engineering effort for the development of a new system*

  …but how do you account for the effect?

State of the Art (1)

How does the systems engineering literature handle reuse?

				Discuss Reuse?	*Artifact Reuse?*	*Systems Engineering Reuse?*
Systems Engineering	Texts	**Maier and Rechtin**	The Art of Systems Architecting (2002)	✓		
		Blanchard and Fabrycky	Systems Engineering and Analysis (1998)			
	Handbooks	**INCOSE**	Systems Engineering Handbook (v 3.1)	✓	✓	✓ (1 instance)
		NASA	Systems Engineering Handbook (2004)	✓		
	Standards and Procedures	**NASA 7123.1A**	NASA Procedural Requirement--Systems Engineering Processes and Requirements (2007)	✓		
		IEEE 1220-2005	Systems Engineering--Application and Management of the Systems Engineering Process	✓		
		ANSI/EIA 632	Processes for Engineering a System (2003)	✓		
Software Engineering		**IEEE 1517-1999**	Software Life Cycle Processes--Reuse Processes	✓	✓	

State of the Art (2)

*How does the **software** engineering literature handle reuse?*

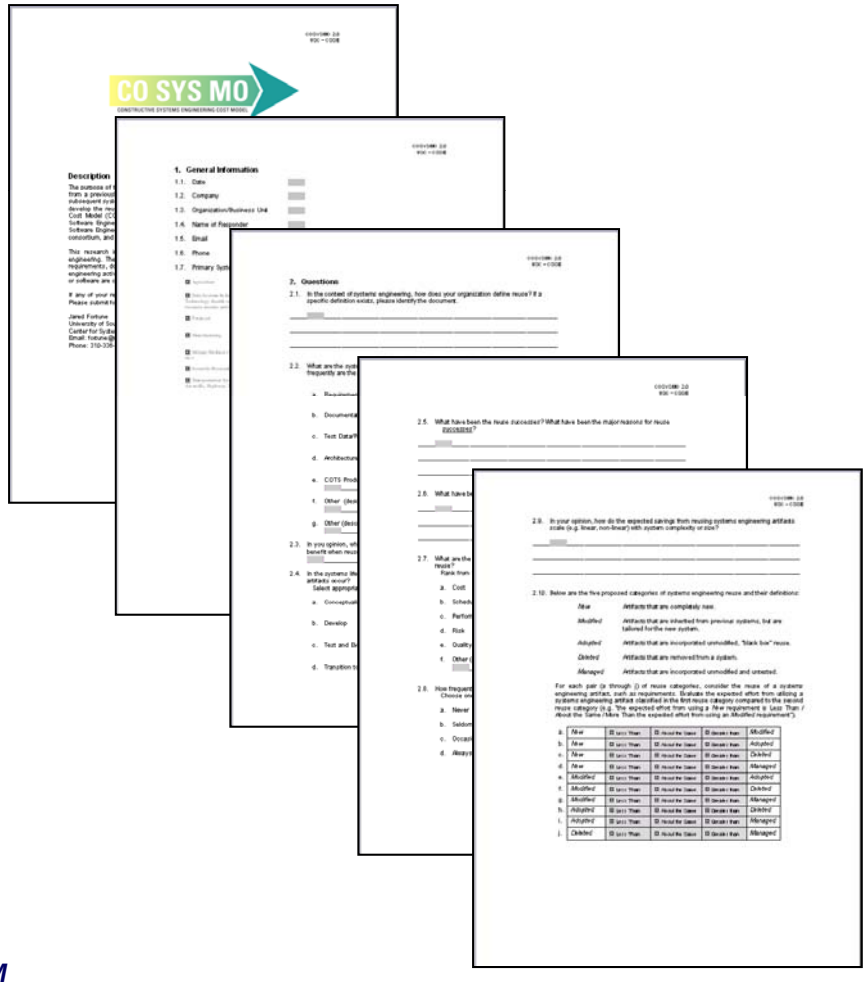
Fortune, J., Valerdi, R. Considerations for Successful Reuse in Systems Engineering. AIAA Space 2008. September 2008. San Diego, CA.

Observations

1. ***Reuse is done for the purpose of economic benefit, intending to shorten schedule, reduce cost, and/or increase performance.***
2. ***Reuse is not free, upfront investment is required to understand the technical opportunities and limitations.***
3. ***Products, processes, and knowledge are all reusable artifacts.***
4. ***Reuse needs to be planned from the conceptualization phase of programs.***
5. ***Reuse is as much of an organizational issue as it is a technical one.***
6. ***Reuse is knowledge that must be deliberately captured in order to be beneficial.***
7. ***The benefits of reuse are limited to closely related domains.***
8. ***The benefits of reuse do not scale linearly***

State of the Practice (1)

How does industry handle reuse?



Reuse Survey Responders
BAE Systems
General Dynamics
Lockheed Martin
Orbital Sciences
Raytheon
Reynolds, Smith, and Hills

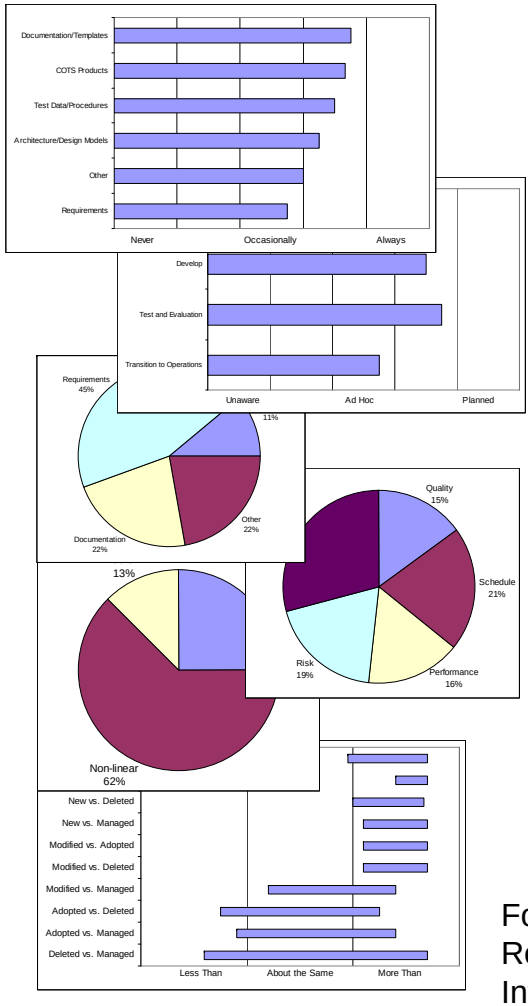
COSYSMO 2.0 Reuse Survey

State of the Practice (2)

Key Survey Questions

1. *How do systems engineering organizations define reuse?*
2. *What systems engineering artifacts are typically reused?*
3. *When in the system life cycle does reuse occur?*
4. *What contributes to successful or unsuccessful reuse?*

State of the Practice (3)



Results

1. ***Requirements reuse is only performed occasionally, but has the largest benefit associated with it.***
2. ***Reuse occurs more frequently early in the life cycle than later.***
3. ***Cost savings is the most promoted benefit for reuse, but benefits also exist in risk, schedule, and performance.***
4. ***The proposed five categories of reuse are reasonable in characterizing systems engineering reuse.***
5. ***Experienced personnel is a key factor for successful reuse.***

Fortune, J., Valerdi, R., Wang, G. Systems Engineering Reuse: A Report on the State of the Practice. 23rd International Forum on COCOMO and Systems/Software Cost Modeling. October 2008. Los Angeles, CA.

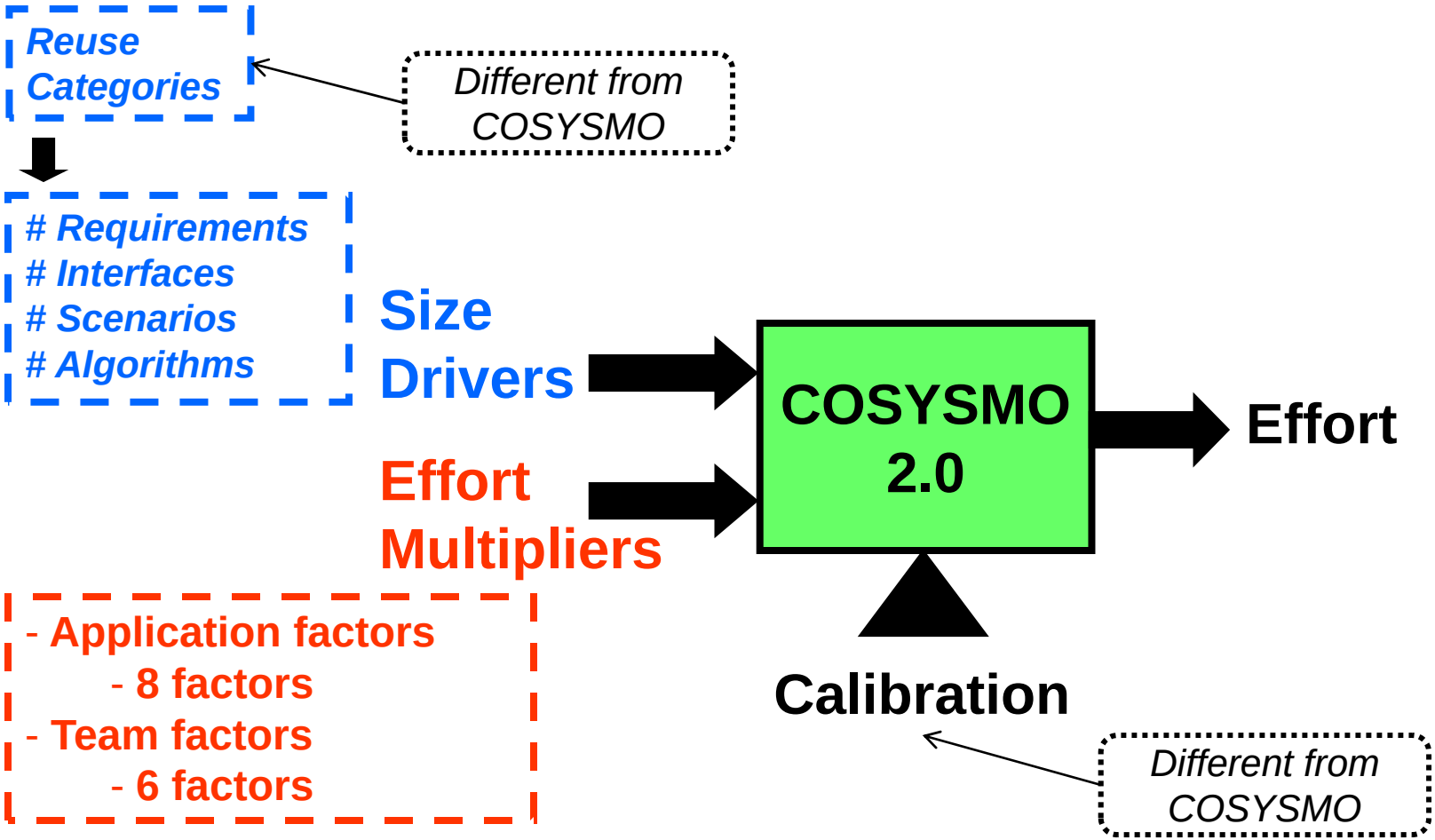
COSYSMO Reuse Data Analysis (1)

- Initial COSYSMO calibration data set (2005) included some reuse data
  - "Reuse" was not consistently defined
  - 54% of projects reported some amount of reuse
  - 13% of projects reported reuse in all four size drivers
- Reuse data reported as percent of size driver that was reused
  - Ex: 50 nominal requirements and 5 of those nominal requirements were reused
- Exercise examined ability to account for reuse with a single reuse category
  - Results demonstrated the need for multiple reuse categories

COSYSMO Reuse Data Analysis (2)

- *Analysis proved one reuse category (no reuse vs. "reuse") is inadequate*
  - *A single reuse category inconsistently accounted for the benefit of reuse*
  - *Across various reuse weights, estimation power of model (e.g. PRED(30) < 50%) was significantly worse*
- *Results supported the need to look at multiple categories of reuse to improve model estimation power*

Preliminary COSYSMO 2.0 Operational Concept



Recommended COSYSMO Reuse Categories

1) New: artifacts that are completely new

   i) Design for Reuse: artifacts that require an additional upfront investment to improve the potential reusability

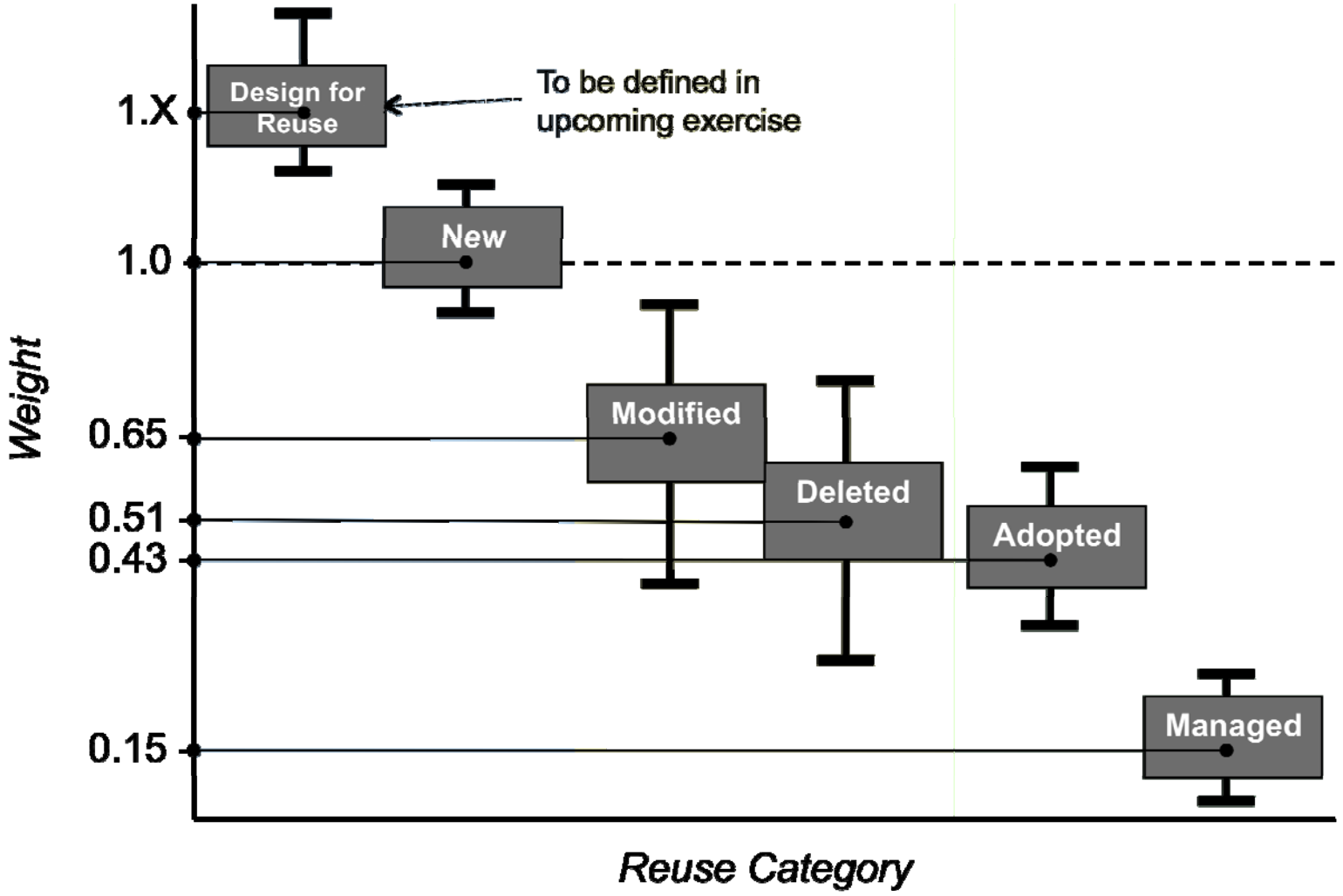
2) Modified: artifacts that are inherited, but are tailored

   ii) Deleted: artifacts that are removed from the system

3) Adopted: artifacts that are incorporated unmodified (also known as "black box reuse")

   iii) Managed: artifacts that are incorporated unmodified and with minimal testing

Reuse Category Continuum



Preliminary COSYSMO 2.0 Model Form

$$PM_{NS} = A \cdot \left[\sum_{k} \left(\sum_{r} w_r \left(w_{e,k} \Phi_{e,k} + w_{n,k} \Phi_{n,k} + w_{d,k} \Phi_{d,k} \right) \right) \right]^{E} \cdot \prod_{j=1}^{14} EM_j$$

Where:

PM_{NS} = effort in Person Months (Nominal Schedule)

A = calibration constant derived from historical project data

k = {REQ, IF, ALG, SCN}

r = {New, Design for Reuse, Modified, Deleted, Adopted, Managed}

w_r = weight for defined degrees of reuse

w_x = weight for "easy", "nominal", or "difficult" size driver

Φ_x = quantity of "k" size driver

E = represents diseconomy of scale

EM = effort multiplier for the j_{th} cost driver. The geometric product results in an overall effort adjustment factor to the nominal effort.

Preliminary Size Driver Extensions

COSYSMO
Size Drivers

	Easy	Nominal	Difficult
Number of System Requirements			
Number of Major Interfaces			
Number of Critical Algorithms			
Number of Operational Scenarios			

COSYSMO 2.0
Size Drivers & Extensions

	Easy						Nominal						Difficult					
	Design for	*New*	*Modified*	*Deleted*	*Adopted*	*Managed*	*Design for*	*New*	*Modified*	*Deleted*	*Adopted*	*Managed*	*Design for*	*New*	*Modified*	*Deleted*	*Adopted*	*Managed*
Number of System Requirements																		
Number of Major Interfaces																		
Number of Critical Algorithms																		
Number of Operational Scenarios																		

Application of reuse categories to size drivers

"New" + 5 reuse categories = 6 total

- ***3 major reuse categories, 3 sub-reuse categories***

COSYSMO 2.0 Reuse Workshop Exercises

Exercises

1) Reuse Category Delphi

2) Reuse Artifact Identification

3) Reuse Framework / Process Discussion

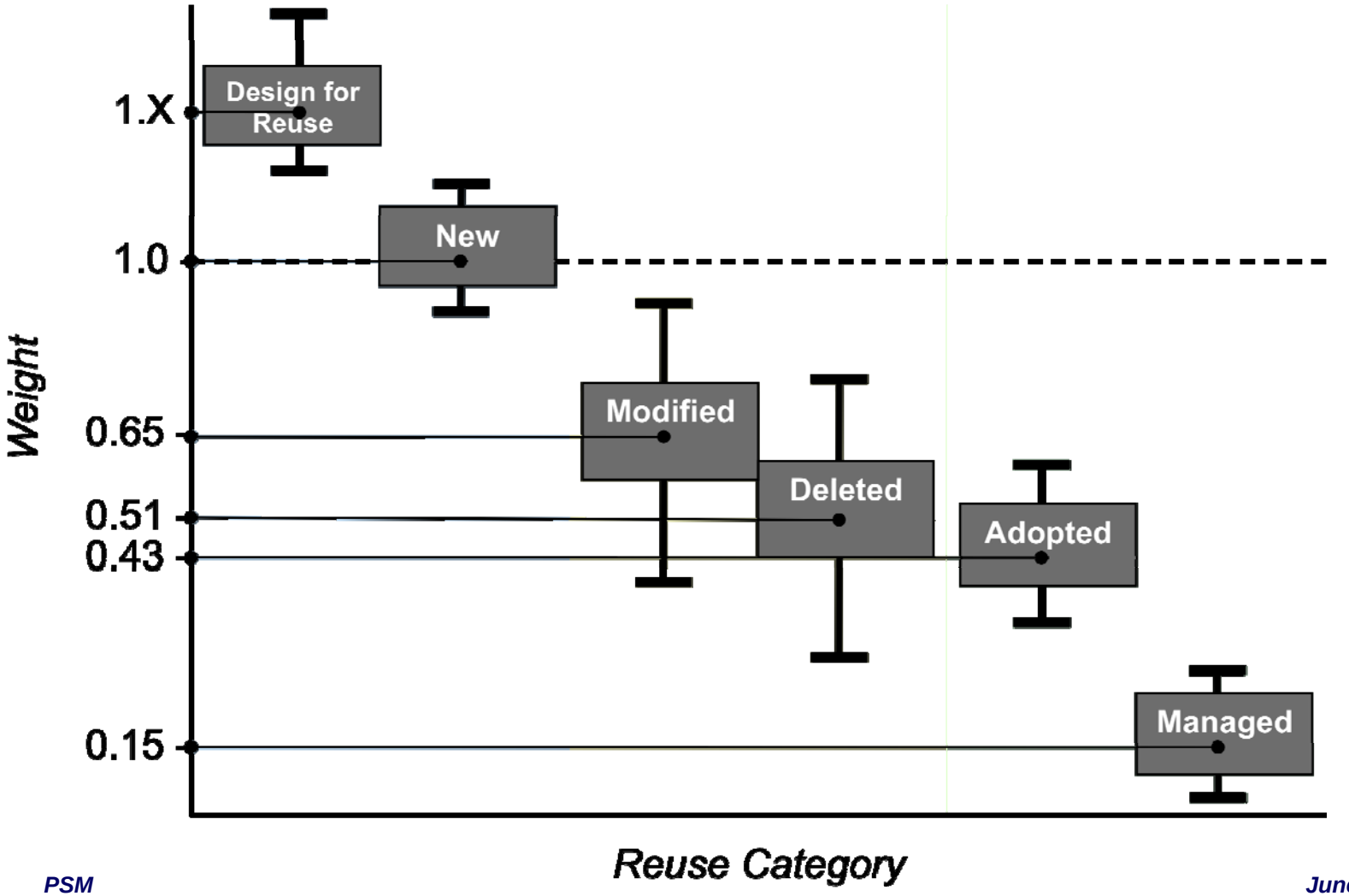
1) Reuse Category Delphi

Exercise

- ***Previous exercises have identified weights for 5 of 6 categories***
  - ***Need to identify weight for 6th ("Design for Reuse") category***

- ***Is "Design for Reuse" more/same/less than other categories?***
  - ***What and how much effort is created in this category vs. others?***
  - ***What and how much effort is saved in this category vs. others when reused? When reused multiple times?***

1) Reuse Category Delphi



2) Reuse Artifact Identification

Exercise

- ***What are systems engineering artifacts that are reusable?***
  - ***Ex: Requirements, Test Procedures/Data, etc.***
- ***What are artifacts that can be designed for reuse?***
- ***How have systems engineering artifacts been reused in your organization?***

3) Reuse Framework Discussion

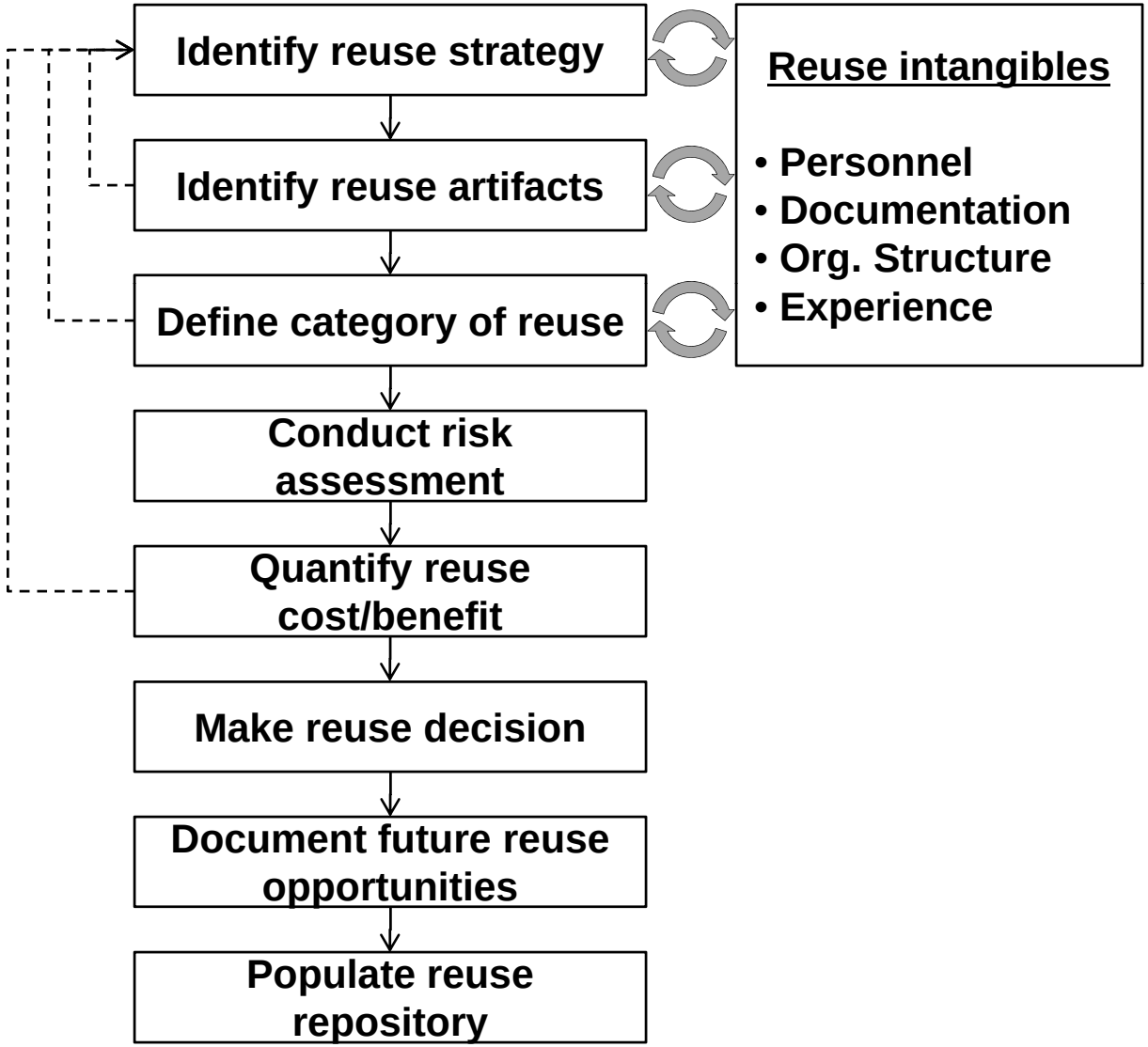
- *During development of COSYSMO 2.0, several issues emerged*
  - *Most systems engineers know they reuse artifacts, but don't have a formal process for how much effort it takes for reuse*
  - *Most systems engineers don't understand how reuse fits into the "big picture"*
  - *It is difficult to quantify the benefits of reuse*
- *Reuse framework under development to put reuse in perspective*
  - *Formal process for thinking about reuse*
  - *Explain aspects of reuse a cost model alone could not explain*
  - *Justify the business case for reuse*
- *Facilitate the connection between what should be reused (artifacts) and what is the benefit (COSYSMO 2.0)*

3) Reuse Framework Discussion

Exercise

- ***What is the process of thinking about/addressing reuse in an organization?***
  - ***How is the process affected by "intangibles"?***
  - ***What is the effect of artifacts designed vs. not designed for reuse?***
  - ***What are the risks to reuse? Is there any prescriptive guidance?***
  - ***Would a reuse repository increase reuse frequency?***
- ***Example framework/process in your organization?***

3) Reuse Framework Discussion



Conclusion

- Provided an introduction to COSYSMO 2.0
  - Motivation for development
  - Preliminary model
- Completed three exercises on SE reuse
  - Reuse of SE artifacts
  - Reuse framework
  - Delphi on reuse categories in COSYSMO 2.0 size drivers
- Results will be incorporated into COSYSMO 2.0

Call for Participation

Background

The USC Center for Systems and Software Engineering (CSSE) and Lean Advancement Initiative (LAI) at MIT in collaboration with the INCOSE Measurement Working Group have initiated the next phase of development of a Systems Engineering Cost Model called COSYSMO. Since the first version of the model was completed in 2005, COSYSMO has been widely accepted and adopted by over a dozen industrial and government organizations. To continually address the needs of the user community, an incremental update to the model is currently underway. This update, called COSYSMO 2.0, will improve the estimation power of the model by accounting for systems engineering reuse. To perform an industry calibration, we are seeking industry data in the form of labor actuals on various types of systems engineering projects that involved a significant amount of reuse.

Benefits

By providing data for this model your organization will:

- ensure that your particular application domain is addressed by COSYSMO 2.0
- learn to tailor and calibrate the **updated model** for their specific application domain
- enable the **quantification of varying degrees of systems engineering reuse** on project estimates
- be able to claim in **CMMI reviews** that your systems engineering cost estimates are based on calibrated industry models

Proven Methodology

COSYSMO (Constructive Systems Engineering Cost Model) employs a proven methodology developed for the COCOMO (Constructive Cost Model), the most widely used software cost model in the world.

Proven Process

USC-CSSE and LAI at MIT have proven processes in place to ensure the confidentiality of the data with its Corporate Affiliates and Consortium Members. Successful data protection has enabled it to attract the participation of several organizations in this effort including Boeing, Raytheon, Northrop Grumman, Lockheed Martin, General Dynamics, SAIC, L-3 Communications, BAE Systems, and the US Air Force Space & Missile Systems Center.

Contact

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Ricardo Valerdi [rvalerdi@mit.edu]

Backup

COSYSMO Model Form

$$PM_{NS} = A \cdot \left(\sum_{k} (w_{e,k} \Phi_{e,k} + w_{n,k} \Phi_{n,k} + w_{d,k} \Phi_{d,k}) \right)^{E} \cdot \prod_{j=1}^{14} EM_{j}$$

Where:

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A = calibration constant derived from historical project data

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Φ_x = quantity of "k" size driver

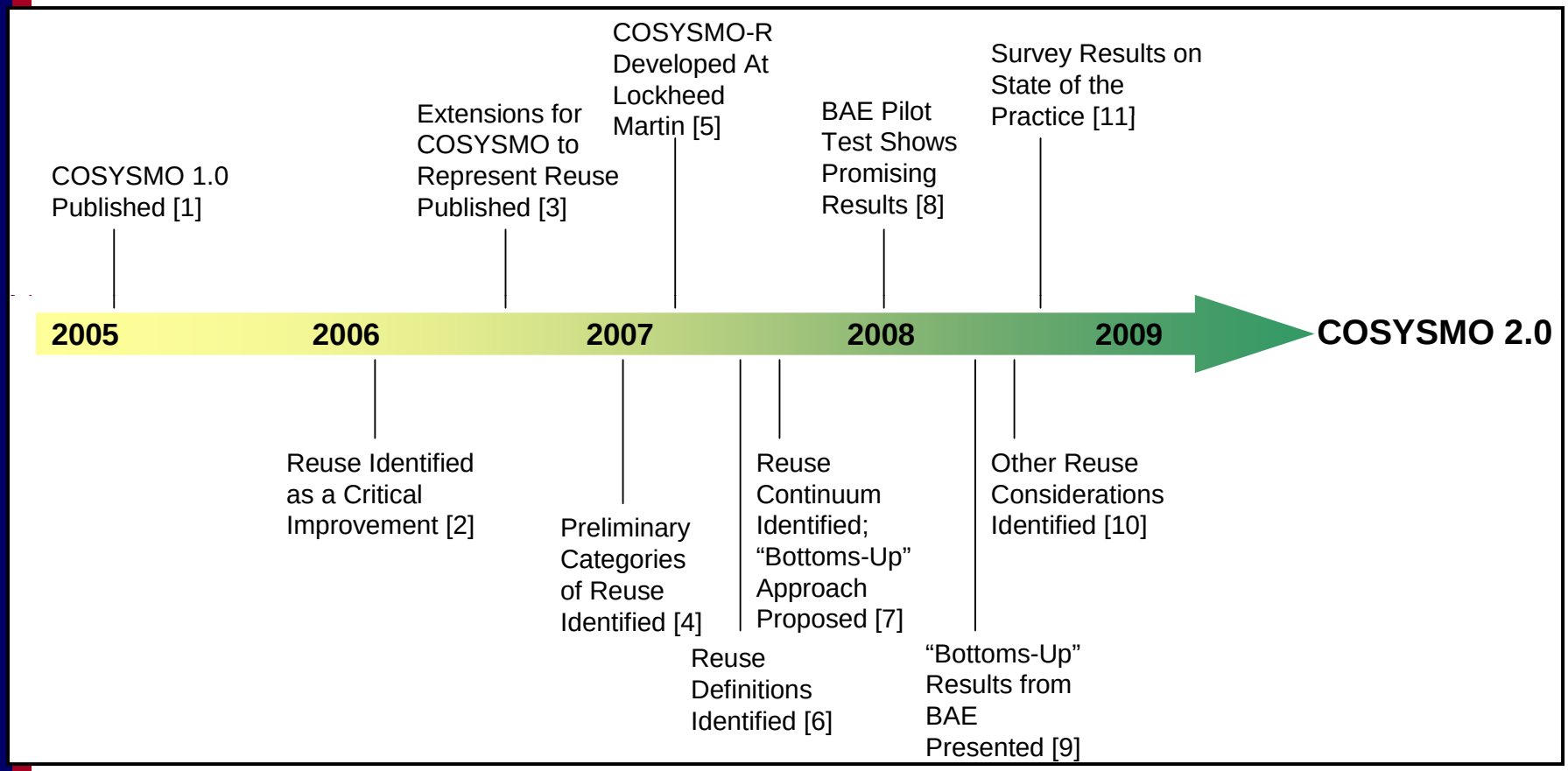
E = represents diseconomy of scale

EM = effort multiplier for the j_{th} cost driver. The geometric product results in an overall effort adjustment factor to the nominal effort.

COSYSMO Data Sources

Boeing	*Integrated Defense Systems (Seal Beach, CA)*
Raytheon	*Intelligence & Information Systems (Garland, TX)*
Northrop Grumman	*Mission Systems (Redondo Beach, CA)*
Lockheed Martin	*Transportation & Security Solutions (Rockville, MD)* *Integrated Systems & Solutions (Valley Forge, PA)* *Systems Integration (Owego, NY)* *Aeronautics (Marietta, GA)* *Maritime Systems & Sensors (Manassas, VA; Baltimore, MD; Syracuse, NY)*
General Dynamics	*Maritime Digital Systems/AIS (Pittsfield, MA)* *Surveillance & Reconnaissance Systems/AIS (Bloomington, MN)*
BAE Systems	*National Security Solutions/ISS (San Diego, CA)* *Information & Electronic Warfare Systems (Nashua, NH)*
SAIC	*Army Transformation (Orlando, FL)* *Integrated Data Solutions & Analysis (McLean, VA)*
L-3 Communications	*Greenville, TX*

COSYSMO 2.0 Development Timeline



[1] Valerdi. *COSYSMO*. Ph.D. Dissertation,2005.
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[4] Valerdi. *COSYSMO Working Group.* PSM Workshop 2006.
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[7] Valerdi, Wang, Roedler, Rieff, Fortune. *COSYSMO Reuse Extension.* COCOMO Forum, 2007.
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[11] Fortune, Valerdi, Wang. *State of the Practice.* COCOMO Forum, 2008