COSYSMO 3.0: Cost Estimation of Systems Engineering in a Context of Rapid Changes

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COSYSMO 3.0 Objectives

- **Context:**
  - Current and future trends create challenges for full-system cost estimation of satellite systems
    - Emergent requirements, rapid change, net-centric systems of systems, COTS, clouds, apps, widgets, high assurance with agility, multi-mission systems
  - Current development practices can minimize cost of one phase, such as development, while raising ground station cost
- **COSYSMO 3.0 is being developed to mitigate this situation by supporting accurate estimates of systems engineering costs, with benefits including:**
  - Allowing thoughtful system-level systems engineering during development, which can result in, for example, choosing new technologies that reduce ground station cost
  - Allowing thoughtful systems engineering of ground stations to support life-cycle flexibility

Acknowledgements

1. The development of COSYSMO 3.0 has benefited greatly from GSAW Working Groups held in 2014 & 2015
2. This presentation was adapted from one with these authors:

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Dr Barry W Boehm	
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Dr Gan Wang	BAE Systems
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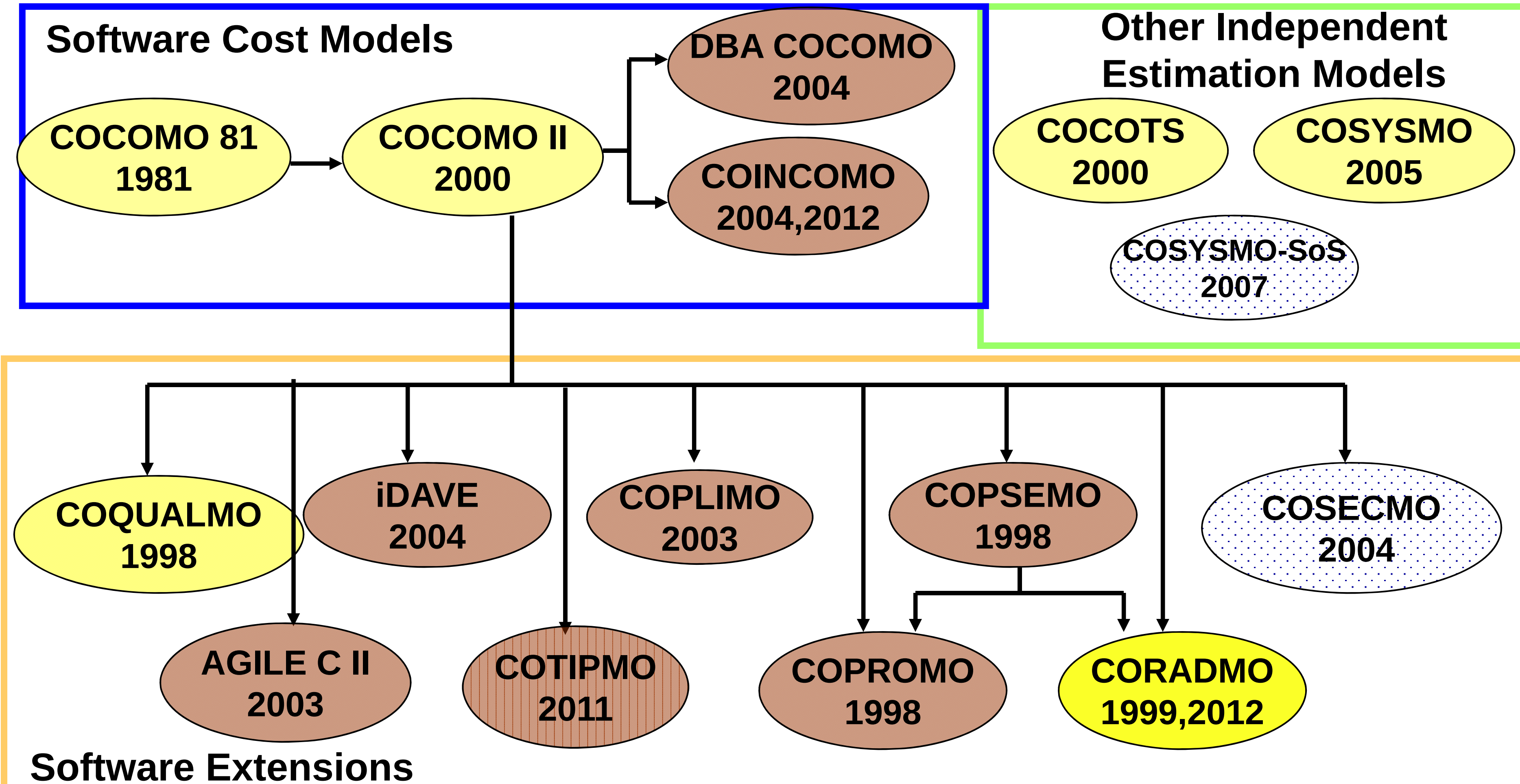
Agenda

Agenda:

- **The motivation for COSYSMO 3.0**
- **History of COSYSMO 3.0**
- **Overview of the content of the COSYSMO 3.0 estimating model**
- **System-of-systems estimating: interoperability in COSYSMO 3.0**
- **Summary**

COCOMO Family of Cost Models



Legend:
Model has been calibrated with historical project data and expert (Delphi) data
Model is derived from COCOMO II
Model has been calibrated with expert (Delphi) data

Dates indicate the time that the first paper was published for the model

History of COSYSMO Models

COSYSMO 1.0
Valerdi, 2005

- Identifies form of model
- Identifies basic cost drivers
- Identifies Size measure

With Reuse
Wang et al, 2008

- Adds weights to Size elements, reducing net Size in the presence of reuse

Req'ts Volatile
Pena, 2012

- Adds scale factor based on requirements volatility

For Reuse
Wang et al, 2014

- Adds weights to Size elements, reducing net Size when artifacts are only partially completed

Sys of Sys
Lane et al, 2011

- Adds effort multiplier when in the presence of system-of-systems

COSYSMO 3.0
Alstad, 2016?

- Integrates features of previous models

COSYSMO 3.0 Directions

Incorporate and harmonize existing COSYSMO model research and experience for estimating systems engineering effort:

- **Several factors affecting the COSYSMO cost model have been shown to be valuable in increasing estimation accuracy (terminology from [1]):**
  - **Reuse (partial model—Development With Reuse) [3]**
  - **Reuse (with Development For Reuse) [1]**
  - **Requirements volatility (RV) [4]**

  The rating scales for these could be integrated into a comprehensive COSYSMO model.

Enhancement planned for inclusion:

- **System-of-system considerations are hypothesized to affect system engineering costs:**
  - **Interoperability considerations [6]**

COSYSMO 3.0 Directions Part 2

Enhancements under discussion:

- **Explore a model for total development cost based primarily on the COSYSMO parameters (following work led by Reggie Cole of Lockheed Martin [17, 7])**

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COSYSMO 3.0 Top-Level Model

$$PH = A \cdot (AdjSize)^{E} \cdot \prod_{j=1}^{15} EM_j$$

Elements of the COSYSMO 3.0 model:

- **Calibration parameter A**
- **Adjusted Size model**
  - **eReq submodel, where 4 products contribute to size**
  - **Reuse submodel**
- **Exponent (E) model**
  - **Accounts for diseconomy of scale**
  - **Constant and 3 scale factors**
- **Effort multipliers EM**
  - **15 cost drivers**

Harmonized COSYSMO 3.0 Size Model

$$AdjSize_{C3} = \sum_{SizeDrivers} eReq(Type(SD), Difficulty(SD)) \times PartialDevFactor(AL_{Start}(SD), AL_{End}(SD), RType(SD))$$

- ***SizeDriver*** **is one of the system engineering products that determines size in the COSYSMO family (per [2]). Any product of these types is included:**
  - **System requirement**
  - **System interface**
  - **System algorithm**
  - **Operational scenario**
- **There are two submodels:**
  - **Equivalent nominal requirements ("eReq")**
    - **Raw size**
  - **Partial development**
    - **Adjusts size for reuse**

Size Model – eReq Submodel

- The eReq submodel is unchanged from [2].
- The submodel computes the size of a *SizeDriver*, in units of eReq ("equivalent nominal requirements")
- Each *SizeDriver* is evaluated as being easy, nominal, or difficult.
- The following table contains conversion factors for the conversion of a *SizeDriver* to a number of eReq:

Size Driver Type	Easy	Nominal	Difficult
System Requirement	0.5	1.0	4.5
System Interface	1.9	3.9	9.0
System Algorithm	2.0	3.9	10.0
Operational Scenario	6.4	13.8	26.1

How Reuse Is Addressed

Reuse has two aspects [1]:

- **Development with reuse (DWR): previously developed artifacts are reused on the current project**
  - **Addressed completely by the DWR partial development model**
- **Development for reuse (DFR): the current project is creating artifacts to be reused on other projects**
  - **One aspect of DFR development is that DFR costs more than ordinary development**
    - **Addressed by the DFR cost driver (below)**
  - **Another aspect of DFR is that the artifacts may be only partially completed, as during an IR&D project**
    - **Addressed by the DFR partial development model**

Size Model – Partial Development Submodel

- **(Concepts here are simplified a little)**
- **The basic DWR concept:**
  - **If a reused *SizeDriver* is being brought in, that saves effort, and so we adjust the size by multiplying the raw size by a *PartialDevFactor* less than 1.**
  - **The value of *PartialDevFactor* is based on the maturity of the reused *SizeDriver*, and is looked up in a table [24].**
    - **How fully developed was the *SizeDriver*?**
  - **If there is no reuse for this *SizeDriver*, then *PartialDevFactor* = 1 (no adjustment).**

DWR Activity Level:	New	Design Modified	Design Im-plemented	Adapted for Integration	Adopted for Integration	Managed
DWR % of full-project cost:	100.00%	85.59%	71.18%	58.80%	39.75%	22.52%

- **The basic development-for-reuse (DFR) concept is analogous:**
  - **A product to be reused may be not be taken through the full development cycle (e.g., an IR&D project)**

DFR Activity Level:	Conceptualized for Reuse	N/A	Designed for Reuse	Constructed for Reuse	N/A	Validated for Reuse
DFR % of full-project cost	32.92%		54.91%	81.27%		96.79%

COSYSMO 3.0 Exponent Model

- **Exponent model is expanded from Peña [4, 9]**

$$E = E_{COSYSMO1} + SF_{ROR} + SF_{PC} + SF_{RV}$$

Where:

- $E_{COSYSMO1}$ **= 1.06 [2]**
- **SF = scale factor**
- ***ROR* = Risk/Opportunity Resolution**
- ***PC* = Process Capability**
- ***RV* = Requirements Volatility**

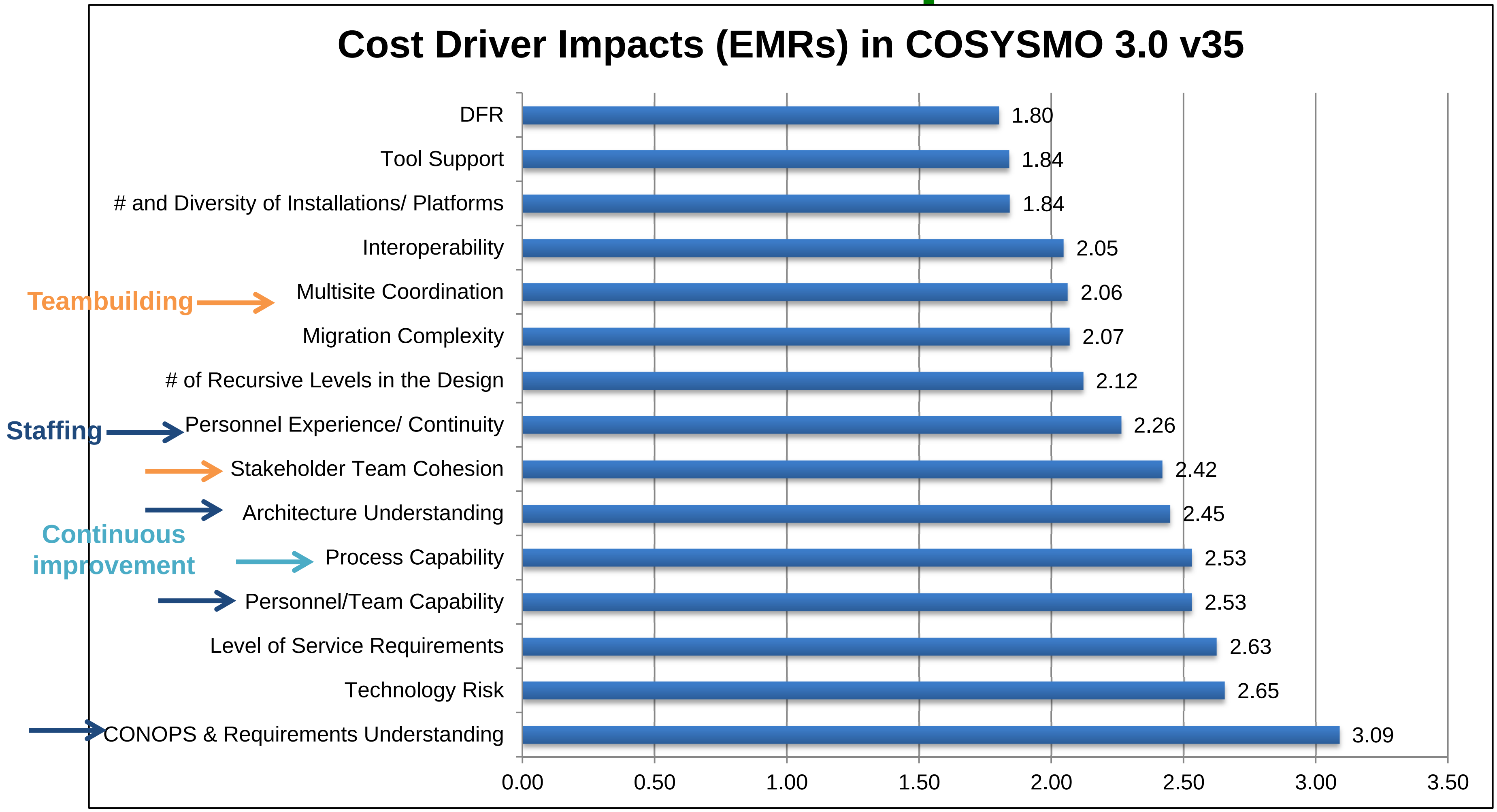
The effect of a large exponent is more pronounced on bigger projects

Harmonized COSYSMO 3.0 Cost Driver Model

- **Here are the 15 cost drivers:**

Driver Name	**Data Item**
CONOPS & requirements understanding	Subjective assessment of the CONOPS & the system requirements
Architecture understanding	Subjective assessment of the system architecture
Stakeholder team cohesion	Subjective assessment of all stakeholders
Level of service requirements	Subjective difficulty of satisfying the key performance parameters
Technology risk	Maturity, readiness, and obsolescence of technology
# of Recursive levels in the design	Number of applicable levels of the Work Breakdown Structure
Development for reuse	Is this project developing artifacts for later reuse?
# and Diversity of installations/platforms	Sites, installations, operating environment, and diverse platforms
Migration complexity	Influence of legacy system (if applicable)
Interoperability	Degree to which this system has to interoperate with others
Personnel/team capability	Subjective assessment of the team's intellectual capability
Process capability	CMMI level or equivalent rating
Personnel experience/continuity	Subjective assessment of staff consistency
Multisite coordination	Location of stakeholders and coordination barriers
Tool support	Subjective assessment of SE tools

Harmonized COSYSMO 3.0 Cost Driver Impacts



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System-of-Systems and Interoperability

- **Suppose that SE work is being done on a system that is a constituent system in a system-of-systems. How is that context manifested in the SE project?**
  - **Answer: As interoperability requirements**
  - **Interoperability: The ability of a system to work with another system or group of systems.**
- **COSYSMO 3.0 includes interoperability as an influence on cost**

COSYSMO 3.0 Interoperability Model

- Lane & Valerdi [6] propose that interoperability be considered a cost influence in the COSYSMO family
- Propose this influence could be manifested in two ways:
  - Method 1: Add a new cost driver (covered there)
  - Method 2: Adjust the easy/medium/difficult rating scale for system interfaces (part of the Size model)
- The working COSYSMO 3.0 includes both methods; only one would be retained in final COSYSMO 3.0.

Size Model – Adjustment for Interoperability

Adjustment for interoperability (Method 2):

- [6] proposes (in its Table 3) that the table that defines the easy/medium/hard rating scale for a system interface (from [2]) be adjusted by adding a new row (the last row in this table):

Easy	Medium	Difficult
Simple messages and protocols	Moderate communication complexity	Complex protocol(s)
Uncoupled	Loosely coupled	Tightly coupled
Strong consensus among stakeholders	Moderate consensus among stakeholders	Low consensus among stakeholders
Well behaved	Predictable behavior	Emergent behavior
Domain or enterprise standards employed	**Functional standards employed**	**Isolated or connected systems with few or no standards**

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Summary

- **COSYSMO 3.0 will provide independent estimates of the cost of thorough systems engineering required based on project parameters**
  - **Thereby assisting in facing the challenge of the rapid rate of change**

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