COSYSMO 3.0: Updating Cost Estimation of Systems Engineering To Support Affordability

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PSM Users' Group Meeting

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Agenda

Agenda:

- **Affordability issues can be caused by inaccurate estimates of systems engineering cost**
- **Introduction to COSYSMO**
- **Overview of the content of the COSYSMO 3.0 estimating model**
- **System-of-systems estimating: interoperability in COSYSMO 3.0**
- **Trying the Analytic Hierarchy Process**
- **Summary**

Poor SE Cost Estimation Threatens Affordability

Poor estimates of systems engineering cost can lead to suboptimal systems engineering, resulting in missed engineering opportunities. Here are some example outcomes:

- **Rushed or reduced scope of systems engineering, resulting in increased development costs for other engineering disciplines or missed life cycle considerations**
- **Inadequate time to consider new technologies that could result in major cost reductions**
- **Technical debt (such as defects and unresolved issues) surfacing during operations & sustainment**

Each of these is an affordability problem:

- **Systems engineering cost is reduced, but total life cycle cost is increased**

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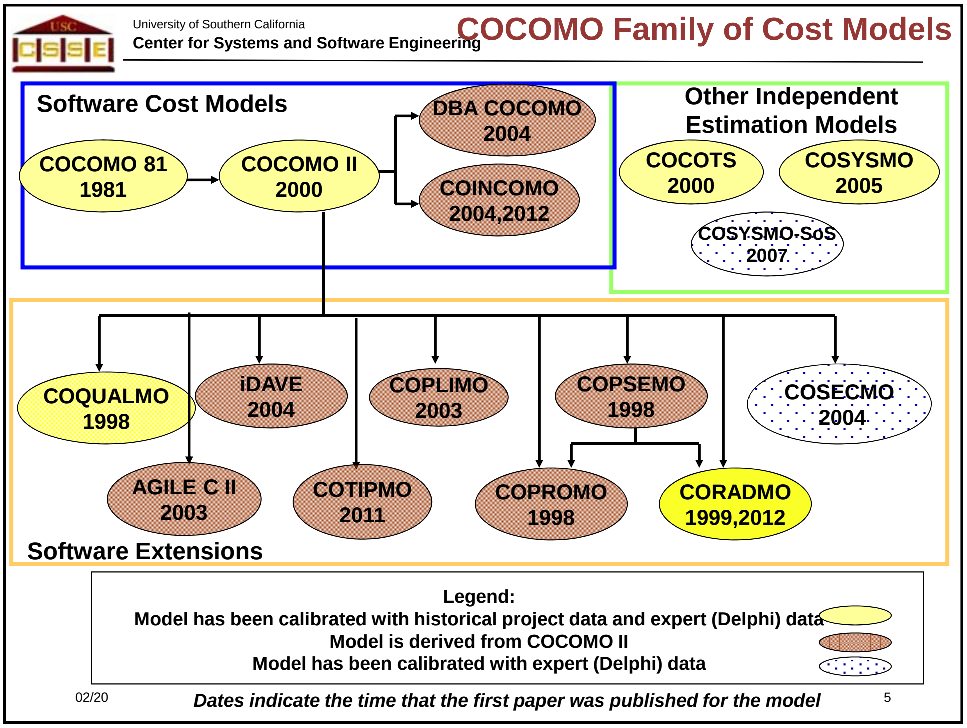
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COCOMO Family of Cost Models
Software Cost Models
COCOMO 81 1981
COCOMO II 2000
DBA COCOMO 2004
COINCOMO 2004,2012
Other Independent Estimation Models
COCOTS 2000
COSYSMO 2005
COSYSMO-SoS 2007
COQUALMO 1998
iDAVE 2004
COPLIMO 2003
COPSEMO 1998
COSECMO 2004
AGILE C II 2003
COTIPMO 2011
COPROMO 1998
CORADMO 1999,2012
Software Extensions
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
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Dates indicate the time that the first paper was published for the model
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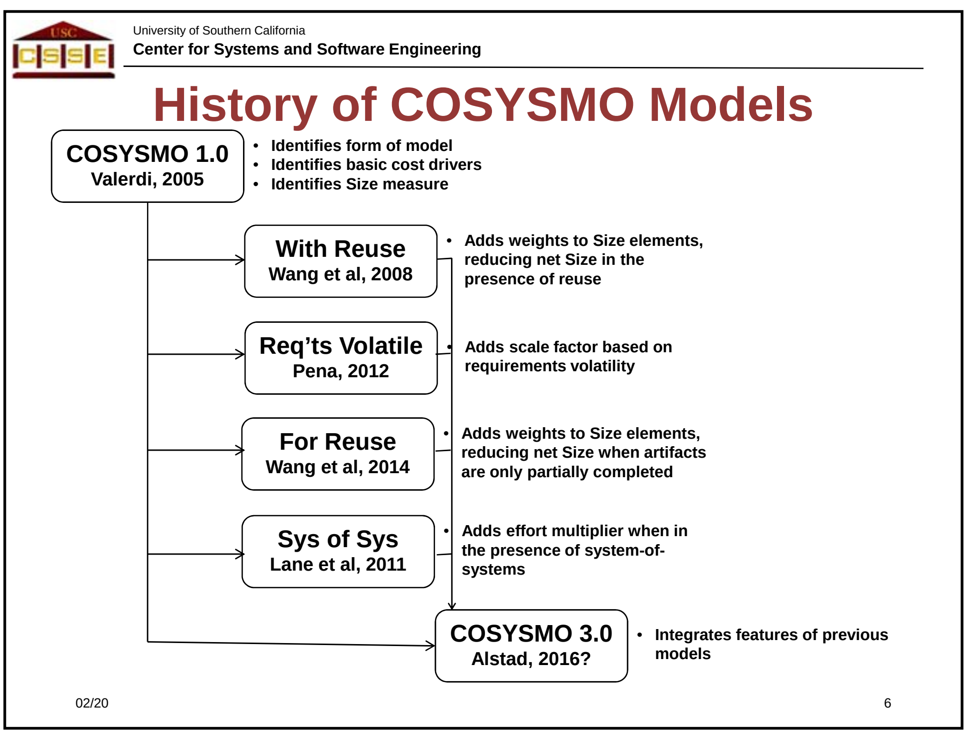
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History of COSYSMO Models
COSYSMO 1.0 Valerdi, 2005
• Identifies form of model
• Identifies basic cost drivers
• Identifies Size measure
With Reuse Wang et al, 2008
• Adds weights to Size elements, reducing net Size in the presence of reuse
Req'ts 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
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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 [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

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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**

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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

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Size Model – Partial Development Submodel

- (Concepts here are simplified a little)
- The basic development-with-reuse (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

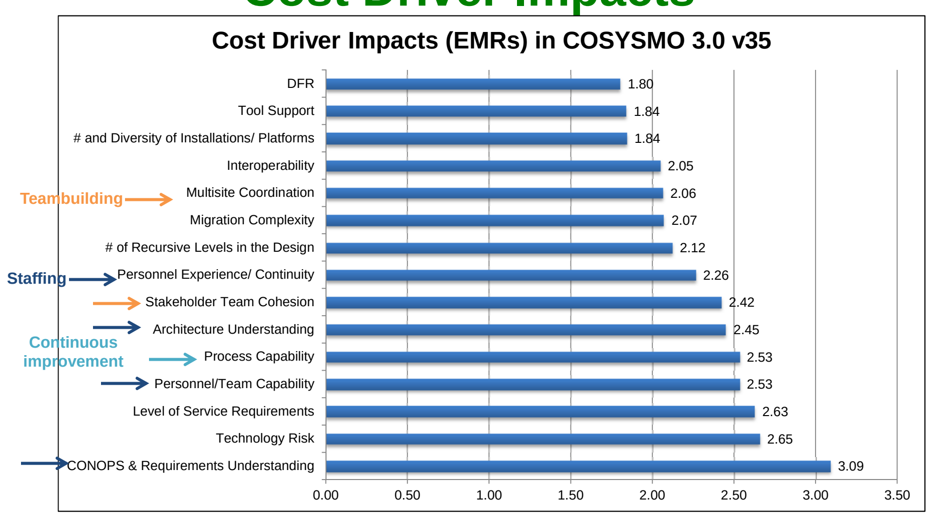
The effect of a large exponent is more pronounced on bigger projects

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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AHP Trial (1/4)

Background:
- The Analytic Hierarchy Process (AHP) is a mathematical technique for weighting preferences among a group of choices
  - Result is a set of weights that sums to 1.0
- The AHP algorithm determines the preferences based on a set of pairwise importance ratings
  - Each importance rating is on a 9-level scale from Extreme Unimportance to Equal Importance to Extreme Importance
  - Numeric equivalents: 1/9 to 1 to 9
- In a group context, AHP assumes group consensus on the importance ratings

Motivation:
- Some members of the COSYSMO 3.0 Working Group suggested trying AHP to gather expert input on COSYSMO cost driver impacts

AHP Trial (2/4)

Motivation (con't):

- To see if results were better than using the traditional COCOMO/COSYSMO technique: Direct expert input on EMRs, via a series of Wideband Delphi group meetings
  - "EMR" = Effort Multiplier ratio = ratio of maximum cost driver value to minimum

Approach:

- Develop spreadsheet questionnaire comparing cost driver impacts
  - Derived from work of Kevin Woodward of Lockheed Martin
- Compare within cost driver groups, and between groups
  - Reduces number of comparisons from 105 to 26.

AHP Trial (3/4)

Got a (very) small number of responses from Working Group members

- Therefore conclusions are (very) tentative

Numeric results:

- AHP requires some type of "anchor" value to go from the set of weights to EMR values
  - Got results for both "product of EMRs equal to previous" and "one previous EMR is correct"
- For definiteness, asked separately about maximum values and minimum values
- Results:
  - Maximum, minimum, and EMR values were overall similar to previous
  - One exception: the "one previous EMR is correct" product of maximum values was about 1/3 of the previous product
    - But product of minimum values was close to previous
    - Suggests weakness in "one previous EMR is correct" approach

AHP Trial (4/4)

Other results:

- Gave respondents a chance to express opinions about questionnaire
- There were two types of respondents:
  A. Those with more AHP experience than Delphi + EMR
  B. Those with more Delphi + EMR experience than AHP
- Some key responses differed by type:
  – Type A found making pairwise comparisons and the AHP ballot overall easier
  – Type B found direct estimation of EMRs and a typical Delphi exercise easier
- Conclusion: perhaps comfort and efficiency with different approaches depends on respondent's background

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Summary

- COSYSMO 3.0 will provide independent estimates of the cost of thorough systems engineering required based on the project parameters
  - Thereby avoiding inadequate systems engineering efforts that tend to lead to affordability problems

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