COSYSMO 3.0: Looking Ahead to Data Analysis

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  Dr Barry W Boehm  USC Center for Systems and Software Engineering
  Dr Jo Ann Lane
  Mr Garry Roedler  Lockheed Martin
  Dr Gan Wang  BAE Systems
  Ms Marilee Wheaton  The Aerospace Corporation
COSYSMO 3.0 Objectives

• Context:
  – Current and future trends create challenges for full-system cost estimation
    • 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 full-system 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 total system cost
  – Allowing thoughtful engineering of systems to support life-cycle flexibility
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
• Model status & plans
• Numerical values of COSYSMO 3.0 parameters
• A solicitation
• Issues in evaluating actual project data
Software Cost Models

COCOMO 81 1981

COCOMO II 2000

COQUALMO 1998

iDAVE 2004

COPLIMO 2003

COTIPMO 2011

COPromo 1998

COPSEMO 1998

CORADMO 1999,2012

COCOMO II

COQUALMO 1998

iDAVE 2004

COPLIMO 2003

COTIPMO 2011

COPSEMO 1998

CORADMO 1999,2012

Other Independent Estimation Models

COCOTS 2000

COSYSMO 2005

COSYSMO-SoS 2007

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

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, 2018
- 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 [24]):
  – Reuse (partial model—Development With Reuse) [3, 24]
  – Reuse (with Development For Reuse) [24]
  – Requirements volatility (RV) [4]

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

Enhancement included:

• 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

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

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
Expert-Based COSYSMO 3.0
Size Model

\[ AdjSize_{C3} = \sum_{SizeDrivers} eReq(\text{Type}(SD), \text{Difficulty}(SD)) \times \]

\[ \text{PartialDevFactor}(AL_{\text{start}}(SD), AL_{\text{end}}(SD), RType(SD)) \]

- **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:

<table>
<thead>
<tr>
<th>Size Driver Type</th>
<th>Easy</th>
<th>Nominal</th>
<th>Difficult</th>
</tr>
</thead>
<tbody>
<tr>
<td>System Requirement</td>
<td>0.5</td>
<td>1.0</td>
<td>4.5</td>
</tr>
<tr>
<td>System Interface</td>
<td>1.9</td>
<td>4.0</td>
<td>9.0</td>
</tr>
<tr>
<td>System Algorithm</td>
<td>1.9</td>
<td>3.8</td>
<td>9.8</td>
</tr>
<tr>
<td>Operational Scenario</td>
<td>6.4</td>
<td>13.6</td>
<td>26.3</td>
</tr>
</tbody>
</table>
How Reuse Is Addressed

Reuse operates in two directions [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 (covered there)
  - 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).

<table>
<thead>
<tr>
<th>DWR Activity Level:</th>
<th>New</th>
<th>Design Modified</th>
<th>Design Implemented</th>
<th>Adapted for Integration</th>
<th>Adapted for Integration</th>
<th>Managed</th>
</tr>
</thead>
<tbody>
<tr>
<td>DWR % for this AL through end</td>
<td>100.00%</td>
<td>83.00%</td>
<td>70.13%</td>
<td>56.88%</td>
<td>37.82%</td>
<td>17.50%</td>
</tr>
</tbody>
</table>

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)
COSYSMO 3.0
Exponent Model

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

\[ E = E_{Base} + SF_{ROR} + SF_{PC} + SF_{RV} \]

Where:
- \( E_{Base} = \) A minimum exponent for diseconomy of scale
- 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
# Expert-Based COSYSMO 3.0 Cost Driver Model

- Here are the 15 cost drivers:

<table>
<thead>
<tr>
<th>Driver Name</th>
<th>Data Item</th>
</tr>
</thead>
<tbody>
<tr>
<td>CONOPS &amp; requirements understanding</td>
<td>Subjective assessment of the CONOPS &amp; the system requirements</td>
</tr>
<tr>
<td>Architecture understanding</td>
<td>Subjective assessment of the system architecture</td>
</tr>
<tr>
<td>Stakeholder team cohesion</td>
<td>Subjective assessment of all stakeholders</td>
</tr>
<tr>
<td>Level of service requirements</td>
<td>Subjective difficulty of satisfying the key performance parameters</td>
</tr>
<tr>
<td>Technology risk</td>
<td>Maturity, readiness, and obsolescence of technology</td>
</tr>
<tr>
<td># of Recursive levels in the design</td>
<td>Number of applicable levels of the Work Breakdown Structure</td>
</tr>
<tr>
<td>Development for reuse</td>
<td>Is this project developing artifacts for later reuse?</td>
</tr>
<tr>
<td># and Diversity of installations/platforms</td>
<td>Sites, installations, operating environment, and diverse platforms</td>
</tr>
<tr>
<td>Migration complexity</td>
<td>Influence of legacy system (if applicable)</td>
</tr>
<tr>
<td>Interoperability</td>
<td>Degree to which this system has to interoperate with others</td>
</tr>
<tr>
<td>Personnel/team capability</td>
<td>Subjective assessment of the team’s intellectual capability</td>
</tr>
<tr>
<td>Process capability</td>
<td>CMMI level or equivalent rating</td>
</tr>
<tr>
<td>Personnel experience/continuity</td>
<td>Subjective assessment of staff consistency</td>
</tr>
<tr>
<td>Multisite coordination</td>
<td>Location of stakeholders and coordination barriers</td>
</tr>
<tr>
<td>Tool support</td>
<td>Subjective assessment of SE tools</td>
</tr>
</tbody>
</table>
Expert-Based COSYSMO 3.0
Cost Driver Impacts

Teambuilding
Continuous improvement
Staffing

Cost Driver Impacts (EMRs) in Expert-Based COSYSMO 3.0

- DFR
- Multisite Coordination
- Tool Support
- # and Diversity of Installations/Platforms
- # of Recursive Levels in the Design
- Migration Complexity
- Interoperability
- Process Capability
- Personnel Experience/Continuity
- Architecture Understanding
- Stakeholder Team Cohesion
- Technology Risk
- Level of Service Requirements
- Personnel/Team Capability
- CONOPS & Requirements Understanding

03/12
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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
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)

Expert-Based COSYSMO 3.0 includes both methods; only one will be retained in final COSYSMO 3.0.
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):

<table>
<thead>
<tr>
<th>Easy</th>
<th>Medium</th>
<th>Difficult</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simple messages and protocols</td>
<td>Moderate communication complexity</td>
<td>Complex protocol(s)</td>
</tr>
<tr>
<td>Uncoupled</td>
<td>Loosely coupled</td>
<td>Tightly coupled</td>
</tr>
<tr>
<td>Strong consensus among stakeholders</td>
<td>Moderate consensus among stakeholders</td>
<td>Low consensus among stakeholders</td>
</tr>
<tr>
<td>Well behaved</td>
<td>Predictable behavior</td>
<td>Emergent behavior</td>
</tr>
<tr>
<td>Domain or enterprise standards</td>
<td>Functional standards employed</td>
<td>Isolated or connected systems with few or no</td>
</tr>
<tr>
<td>employed</td>
<td></td>
<td>standards</td>
</tr>
</tbody>
</table>
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USC-CSSE Modeling Methodology

Figure 4.1 from [22]

- **Determine Model Needs**
- **Step 1:** Analyze existing literature
- **Step 2:** Perform Behavioral analyses
- **Step 3:** Define relative significance, data, ratings
- **Step 4:** Perform expert-judgment Delphi assessment, formulate a priori model
- **Step 5:** Gather project data
- **Step 6:** Determine Bayesian A-Posteriori model
- **Step 7:** Gather more data; refine model
- **Step 8:**

This step complete (= Expert-Based Model)

Have started this step
Model Status & Plans

• The expert-based version of the COSYSMO 3.0 model has been under development for over a year, with critical input from:
  – The COSYSMO 3.0 Working Group
  – Attendees at conferences like this one

• The Expert-Based Model was completed last year
  – Along with a “Rosetta Stone”, for rerating old projects under COSYSMO 3.0

• A Data Collection Spreadsheet is available
  – A supplementary document, “Data Management and Security Procedures”, has been revised

• Next work items:
  – See how model works on existing calibration data
    • In progress
  – Gather new calibration data: completed projects
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• Numerical values of COSYSMO 3.0 parameters
  – Cost Drivers and Scale Factors
  – (Reuse and Size parameters shown above)
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## Cost Driver Detailed Parameters (1/2)

<table>
<thead>
<tr>
<th>EMR</th>
<th>Cost Driver</th>
<th>Ratings</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CONOPS and Requirements Understanding</td>
<td>VL  L   N</td>
</tr>
<tr>
<td>3.093</td>
<td></td>
<td>1.76 1.33 1.00</td>
</tr>
<tr>
<td>2.423</td>
<td>Architecture Understanding</td>
<td>VL  L   N</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.56 1.25 1.00</td>
</tr>
<tr>
<td>2.467</td>
<td>Stakeholder Team Cohesion</td>
<td>VL  L   N</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.57 1.25 1.00</td>
</tr>
<tr>
<td>2.682</td>
<td>Level of Service Requirements</td>
<td>VL  L   N</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.64 1.28 1.00</td>
</tr>
<tr>
<td>2.581</td>
<td>Technology Risk</td>
<td>VL  L   N</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.62 0.79 1.00</td>
</tr>
<tr>
<td>1.932</td>
<td># of Recursive Levels in the Design</td>
<td>VL  L   N</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.72 0.85 1.00</td>
</tr>
<tr>
<td>1.932</td>
<td># and Diversity of Installations/Platforms</td>
<td>N   H   VH</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.00 1.25 1.55</td>
</tr>
<tr>
<td>1.996</td>
<td>Migration Complexity</td>
<td>N   H   VH</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.00 1.26 1.59</td>
</tr>
<tr>
<td>2.118</td>
<td>Interoperability</td>
<td>VL  L   N</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.46 1.21 1.00</td>
</tr>
<tr>
<td>EMR</td>
<td>Cost Driver</td>
<td>Ratings</td>
</tr>
<tr>
<td>----------</td>
<td>------------------------------</td>
<td>---------</td>
</tr>
<tr>
<td></td>
<td>Personnel/Team Capability</td>
<td>VL  L   N   H   VH</td>
</tr>
<tr>
<td>2.690</td>
<td></td>
<td>1.64   1.28 1.00 0.78 0.61</td>
</tr>
<tr>
<td></td>
<td>Process Capability</td>
<td>VL  L   N   H   VH   EH</td>
</tr>
<tr>
<td>2.158</td>
<td></td>
<td>1.36   1.17 1.00 0.86 0.74 0.63</td>
</tr>
<tr>
<td></td>
<td>Personnel</td>
<td>VL  L   N   H   VH</td>
</tr>
<tr>
<td>2.315</td>
<td>Experience/Continuity</td>
<td>VL  L   N   H   VH   EH</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.52   1.23 1.00 0.81 0.66</td>
</tr>
<tr>
<td></td>
<td>Multisite Coordination</td>
<td>VL  L   N   H   VH   EH</td>
</tr>
<tr>
<td>1.787</td>
<td></td>
<td>1.26   1.12 1.00 0.89 0.79 0.71</td>
</tr>
<tr>
<td></td>
<td>Tool Support</td>
<td>VL  L   N   H   VH</td>
</tr>
<tr>
<td>1.843</td>
<td></td>
<td>1.36   1.17 1.00 0.86 0.74</td>
</tr>
<tr>
<td></td>
<td>DFR (Development for Reuse)</td>
<td>L     N   H   VH   EH</td>
</tr>
<tr>
<td>1.638</td>
<td></td>
<td>0.88   1.00 1.13 1.28 1.45</td>
</tr>
</tbody>
</table>
## Scale Factor Detailed Parameters

<table>
<thead>
<tr>
<th>Maximum</th>
<th>Scale Factor</th>
<th>Ratings</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.06129</td>
<td>Risk/Opportunity</td>
<td>VL</td>
</tr>
<tr>
<td></td>
<td>Resolution</td>
<td>L</td>
</tr>
<tr>
<td></td>
<td></td>
<td>N</td>
</tr>
<tr>
<td></td>
<td></td>
<td>H</td>
</tr>
<tr>
<td></td>
<td></td>
<td>VH</td>
</tr>
<tr>
<td></td>
<td></td>
<td>EH</td>
</tr>
<tr>
<td>0.0613</td>
<td>0.0490</td>
<td>0.0368</td>
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<tr>
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<td>0.0123</td>
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<td></td>
<td>0.0000</td>
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<tr>
<td>0.05422</td>
<td>Process Capability</td>
<td>VL</td>
</tr>
<tr>
<td></td>
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<td>L</td>
</tr>
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<td></td>
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<td>N</td>
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<td>H</td>
</tr>
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<td></td>
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<td>VH</td>
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<td></td>
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<td>EH</td>
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<td>0.0542</td>
<td>0.0434</td>
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<td>0.0217</td>
<td>0.0108</td>
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<td></td>
<td>0.0000</td>
<td></td>
</tr>
<tr>
<td>0.03788</td>
<td>Requirements Volatility</td>
<td>VL</td>
</tr>
<tr>
<td></td>
<td></td>
<td>L</td>
</tr>
<tr>
<td></td>
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<td>M</td>
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<tr>
<td></td>
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<td>H</td>
</tr>
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<td>VH</td>
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<tr>
<td></td>
<td>0.0284</td>
<td>0.0379</td>
</tr>
<tr>
<td>EBase</td>
<td>1.0279</td>
<td></td>
</tr>
</tbody>
</table>
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Will
Write Thesis
for
Data
Data Gathering

• Please contact Jim if your organization may be able to provide data
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**Issue 1: Background**

- COSYSMO (1.0 and 3.0) use this set of System Engineering activities, which (in COSYSMO 3.0) is based on ISO/IEC TS 24748 [25]:

<table>
<thead>
<tr>
<th>COSYSMO Stage</th>
<th>Corresponding 24748 Stage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conceptualize</td>
<td>Concept</td>
</tr>
<tr>
<td>Develop</td>
<td>Development, except as covered in the stage below</td>
</tr>
<tr>
<td>Operational Test and Evaluation</td>
<td>These Development activities: verifying and validating the system, performing appropriate inspections</td>
</tr>
<tr>
<td>Transition to Operation</td>
<td>Utilization activities directed at the transition from development</td>
</tr>
</tbody>
</table>
Issue 1

• Issue 1: How to account for the fact that different data points (projects) have different degrees of effort in the various stages?

• COSYSMO 1.0 solution to Issue 1:
  – Gather data on which COSYSMO stages the project performed work
  – Adjust (increase) reported project hours to account for the missing stages
Issue 1.A

- Issue 1.A: How exactly to make this adjustment?
- COSYSMO 1.0 solution to Issue 1.A:
  - Determine a nominal distribution of effort across the COSYSMO stages for a full project (survey of industry experts):

<table>
<thead>
<tr>
<th>COSYSMO Stage</th>
<th>% of Effort during a Complete Project</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conceptualize</td>
<td>23%</td>
</tr>
<tr>
<td>Develop</td>
<td>35%</td>
</tr>
<tr>
<td>Operational Test and Evaluation</td>
<td>28%</td>
</tr>
<tr>
<td>Transition to Operation</td>
<td>14%</td>
</tr>
</tbody>
</table>

- For projects that only cover the Develop stage, multiply by the appropriate ratio to cover the missing stages
  - Ratio = 100% / 35%.

- COSYSMO 3.0: Is this approach OK?
Issue 2

• Issue 2: Which data points are considered to be outliers?
• COSYSMO 1.0 solution to Issue 2 uses two criteria:
  – Projects (6) that had significantly higher productivity than the bulk of the projects
  – Projects (2) that had much higher adjusted systems engineering hours
• COSYSMO 3.0: Are these criteria OK?
  – Assuming the answer is, “These should be considered and used if appropriate”, what other criteria should be considered?


Bibliography (3/5)


