# The COSYSMO 3.0 Final Model
## *Including Outbrief*

Dr. Jim Alstad USC Center for Systems and Software Engineering

**PSM Users' Group 2018 – Workshop #9**

**Lockheed Martin Global Vision Center**

**Arlington VA**

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# Acknowledgements

- **This presentation was adapted from one with these authors:**



| | |
|---|---|
| Dr Jim Alstad<br>Dr Barry W Boehm<br>Dr Jo Ann Lane | USC Center for Systems and Software Engineering |
| 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

# Workshop Preview

- **Agenda:**
  - Go over this presentation, capturing feedback
    - The COSYSMO 3.0 Final Model
    - Suggestions for further COSYSMO development
- **Intended output:**
  - This presentation
  - With feedback captured

# Agenda

**Agenda:**

- The motivation for COSYSMO 3.0
- History of COSYSMO 3.0
- Overview of the content of the COSYSMO 3.0 estimating model
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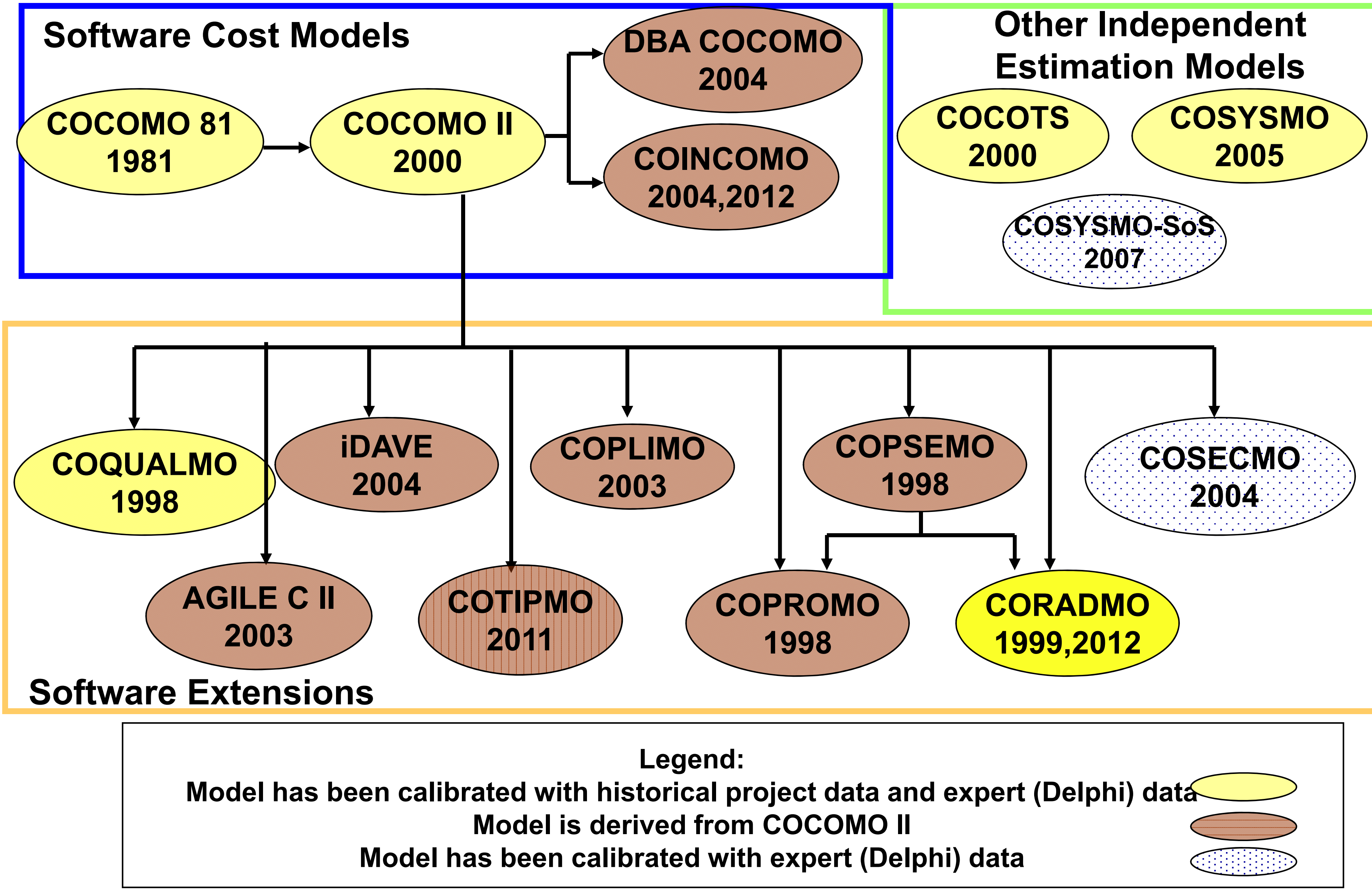
# COCOMO Family of Cost Models




*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

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

**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

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

- *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 | 5.0 |
| System Interface | 1.1 | 2.8 | 6.3 |
| System Algorithm | 2.2 | 4.1 | 11.5 |
| Operational Scenario | 6.2 | 14.4 | 30.0 |

# 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).**

| DWR Activity Level: | New | Design Modified | Design Im-plemented | Adapted for Integration | Adopted for Integration | Managed |
|---|---|---|---|---|---|---|
| DWR % for this AL through end | 100.00% | 83.00% | 70.13% | 56.88% | 37.82% | 17.50% |

- **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 % from start through this AL | 31.96% | | 54.60% | 78.06% | | 90.69% |

# 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**

# COSYSMO 3.0 Cost Driver Model

- **Here are the 13 cost drivers:**

| | Driver Name | **Data Item** |
|---|---|---|
| UNDR | 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 |
| CMPX | 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? |
| OPRN | # and Diversity of installations/platforms | Sites, installations, operating environment, and diverse platforms |
| | Migration complexity | Influence of legacy system (if applicable) |
| PERS | Personnel/team capability | Subjective assessment of the team's intellectual capability |
| | Personnel experience/continuity | Subjective assessment of staff consistency |
| ENVR | Multisite coordination | Location of stakeholders and coordination barriers |
| | Tool support | Subjective assessment of SE tools |

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- **A solicitation**
- **Some points for model developers**
- **Suggestions for further COSYSMO development**

# System-of-Systems: Multiple Subprojects

- **Lane [10] developed a model for allocating systems engineering effort across a system-of-systems and its constituent systems.**
  - **This applied the COCOMO II multiple-subproject model to this systems engineering situation.**
  - **Her model is part of the COSYSMO 3.0 Final Model**

$$PM_{C3M} = A_{C3} \cdot (TotalSize_{C3})^{E_{C3}} \cdot \sum_{s \in Subprojects} \left( \frac{Subproject_s Size_{C3}}{TotalSize_{C3}} \cdot \prod_{j=1}^{15} EM_{C3:s,j} \right)$$

# COSYSMO 3.0 Interoperability Model

- After groundwork for including interoperability had been laid, no interoperability data could be found
- So interoperability was dropped form the Final Model

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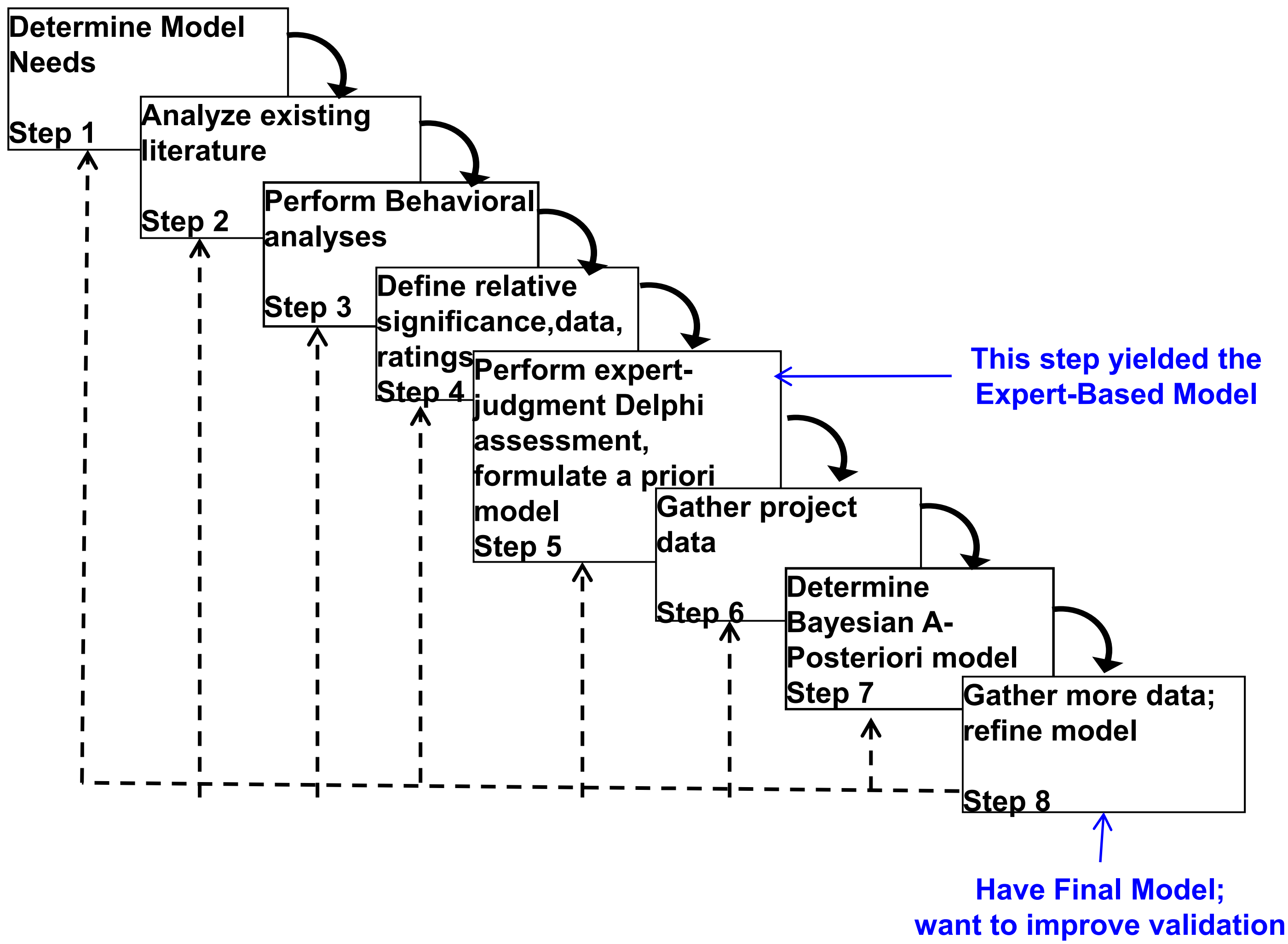
# USC-CSSE Modeling Methodology

## Figure 4.1 from [22]



# Model Status & Plans

- The expert-based version of the COSYSMO 3.0 model was 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
- I obtained a suitable (though imperfect) data set
  - By calibrating to that data set, I generated the COSYSMO 3.0 Final Model, which is what is presented here.

# Core Members of the Working Group

| Member | Present Affiliation |
|---|---|
| Barry Boehm | USC |
| Brad Clark | Software Metrics |
| Bob Epps | Retired |
| Bill Golaz | Lockheed Martin |
| Gary Hafen | Retired |
| Jo Ann Lane | San Diego State University |
| Dan Ligett | Softstar Systems |
| Garry Roedler | Lockheed Martin |
| John Sautter | Northrup-Grumman |
| Gan Wang | BAE Systems |
| Marilee Wheaton | The Aerospace Corporation |

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- Attributes of the Final Model
  - Numeric values of parameters
    - Reuse and size parameters shown above
  - Other properties of the Final Model
- A solicitation
- Some points for model developers
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# Cost Driver & Scale Factor Values

| | Text Rating: | Very Low | Low | Nominal | High | Very High | Extra High |
|---|---|---|---|---|---|---|---|
| | Numeric Rating: | -2 | -1 | 0 | 1 | 2 | 3 |
| **Cost Driver** | **Step Size** | **Effort Multipliers** | | | | | |
| CONOPS & Requirements Understanding | 0.765 | 1.71 | 1.31 | 1.00 | 0.76 | 0.59 | (Invalid) |
| Architecture Understanding | 0.805 | 1.54 | 1.24 | 1.00 | 0.81 | 0.65 | (Invalid) |
| Stakeholder Team Cohesion | 0.802 | 1.55 | 1.25 | 1.00 | 0.8 | 0.64 | (Invalid) |
| Level of Service Requirements | 1.277 | 0.61 | 0.78 | 1.00 | 1.28 | 1.63 | (Invalid) |
| Technology Risk | 1.262 | 0.63 | 0.79 | 1.00 | 1.26 | 1.59 | (Invalid) |
| # of Recursive Levels in the Design | 1.179 | 0.72 | 0.85 | 1.00 | 1.18 | 1.39 | (Invalid) |
| # and Diversity of Installations/ Platforms | 1.238 | (Invalid) | (Invalid) | 1.00 | 1.24 | 1.53 | 1.90 |
| Migration Complexity | 1.252 | (Invalid) | (Invalid) | 1.00 | 1.25 | 1.57 | 1.96 |
| Personnel/Team Capability | 0.831 | 1.45 | 1.2 | 1.00 | 0.83 | 0.69 | (Invalid) |
| Personnel Experience/ Continuity | 0.858 | 1.36 | 1.17 | 1.00 | 0.86 | 0.74 | (Invalid) |
| Multisite Coordination | 0.812 | 1.52 | 1.23 | 1.00 | 0.81 | 0.66 | 0.54 |
| Tool Support | 0.892 | 1.26 | 1.12 | 1.00 | 0.89 | 0.8 | (Invalid) |
| **Scale Factor** | **Step Size** | **Scale Factor Values** | | | | | |
| Risk & Opportunity Management | -0.012 | 0.0602 | 0.0482 | 0.0361 | 0.0241 | 0.012 | 0.0000 |
| Process Capability | -0.0107 | 0.0536 | 0.0429 | 0.0322 | 0.0214 | 0.0107 | 0.0000 |
| Requirements Volatility | 0.0095 | 0.0000 | 0.0095 | 0.0189 | 0.0284 | 0.0379 | (Invalid) |

# Model Constants

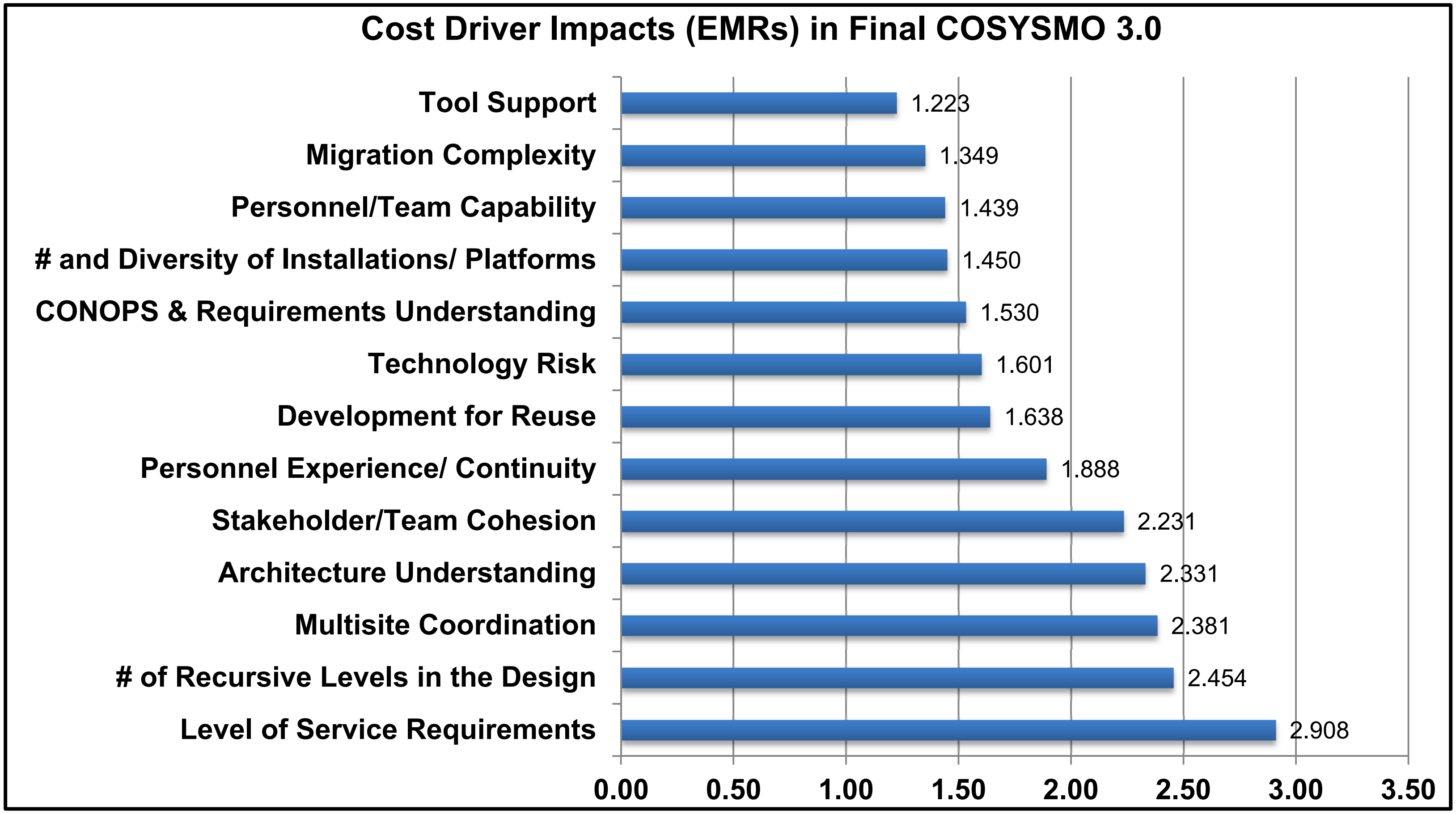
| | | |
|---|---|---|
| A | Productivity Factor | 26.33 |
| EBase | Exponent Base | 1.0332 |

# Summary of Sources of the Model

| Element of the Model | Source(s) |
|---|---|
| Basic structure (size, exponent, cost drivers, equation) | C1, RV thesis |
| Reuse submodel | PE, Delphi |
| New drivers (requirements volatility, risk/opportunity management, development for reuse) | PE, WG |
| Parameters values for size multipliers, reuse level factors, requirements volatility, development for reuse | Delphi |
| Interoperability | (Dropped) |
| Other parameter values | Fits |
| Placement of process capability | Calibration |

**Key:**
- **C1 = COSYSMO 1.0**
- **RV = Requirements Volatility**
- **PE = Published enhancements to C1**
- **WG = COSYSMO 3.0 Working Group**

# Cost Driver Impacts




**The EMR (Effort Multiplier Ratio) of a cost driver is its maximum possible value divided by its minimum possible value; this is the impact of the cost driver.**

# COSYSMO 3.0 Features versus Previous Models

| Feature | COSYSMO 1.0 | COSYSMO 2.0 | COSYSMO RV | GRF | Sys-of-Sys | COSYSMO 3.0 |
|---|---|---|---|---|---|---|
| Use of a specific size measure | X | X | X | X | X | X |
| Cost drivers | X | X | X | X | X | X |
| Use of exponent on size | X | X | X | X | X | X |
| Addresses reuse | | X | | X | | X |
| Tailoring via calibration parameter | X | X | X | X | X | X |
| Sophisticated reuse model | | | | X | | X |
| Use of rated exponents | | | X | | | X |
| Account for increased cost when developing for reuse | | | | | | X |
| Subproject model | | | | | X | X |
| Size includes multiple artifacts | X | X | X | X | X | X |
| Address interoperability | | | | | X | |

# Numerical Properties of COSYSMO 3.0 versus Previous Models

| Parameter | COSYSMO 1.0 | Previous Proposals (Together) | Expert-Based C3 | Final (v4) COSYSMO 3.0 | PL4O.nlm |
|---|---|---|---|---|---|
| # Cost Drivers | 14 | - | 14 | 13 | 13 |
| # Scale Factors | 0 | 2 | 3 | 3 | 3 |
| Total EMR | 44,095 | - | 145,745 | 23,001 | 2,198 |
| A (Productivity factor) | 38.55 | - | 38.55 | 26.33 | 29.09 |
| Nominal Exponent | 1.060 | 1.060 | 1.116 | 1.120 | 1.162 |
| Multiplier, on 25,000 eReq project | 1.84 | 1.84 | 3.24 | 3.39 | 5.14 |
| Max - Min Exponent | 0.000 | 0.038 | 0.153 | 0.151 | 0.152 |
| Multiplier, on 25,000 eReq project | 1.00 | 1.47 | 4.73 | 4.63 | 4.66 |

# Coordination with COCOMO III (1/2)

The Final Model has been coordinated with Brad Clark's in-progress COCOMO III definition effort, with these results:

- Essentially identical definitions of Risk/Opportunity Management scale factor.
- Essentially identical definitions of Multi-Site Development cost driver.
- COSYSMO 3.0 Development for Reuse cost driver taken from COCOMO II.
- COSYSMO 3.0 Personnel/Team Capability cost driver definition modified to agree with COCOMO II's.

# Coordination with COCOMO III (2/2)

- **A 2012 paper* was published distinguishing the scopes of COCOMO and COSYSMO in a project; Brad and the COSYSMO 3.0 Working Group coordinated on an (unpublished) update ("COCOMO – COSYSMO Estimation Boundaries")**

***Wang, G., Valerdi, R., Roedler, G., Ankrum, A., Gaffney, J. E., "Harmonizing Systems and Software Cost Estimation," International Journal of Computer Integrated Manufacturing, Volume 25, 2012 - Issue 4-5: Special Issue: Through Life Cost Estimating.**

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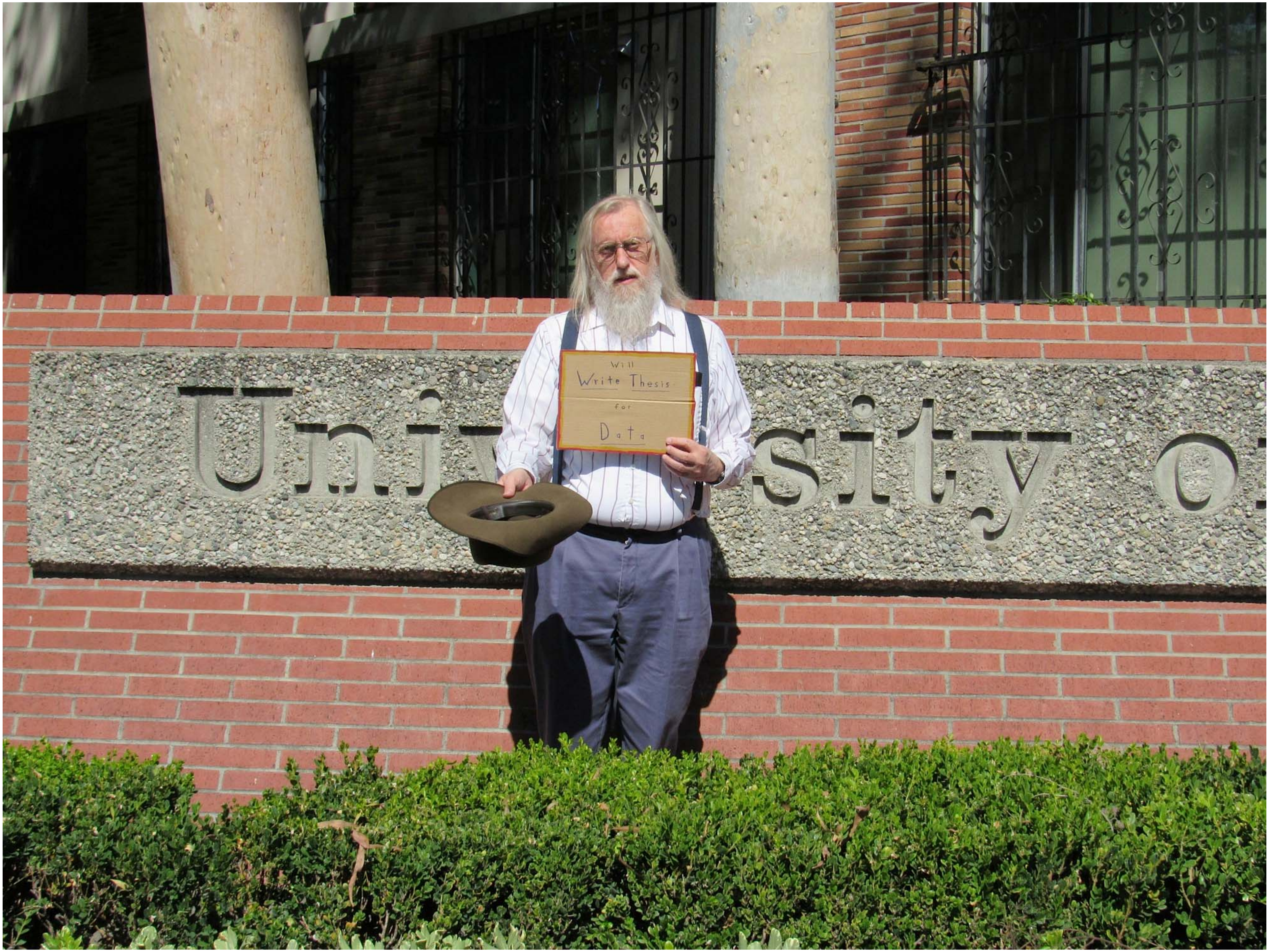
of Southern
Data


Will
Write Thesis
for
Data
Univ sity o


Will improve
model
for data

# Data Gathering

- **Please contact Jim if your organization may be able to provide data**

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  - Fitting without using linear regression
  - Enhancing Bayesian analysis
- Suggestions for further COSYSMO development

# Fitting a Model Can Be a Difficult Problem – Part 1

- **Part of my thesis work was demonstrating that the Final Model could be calibrated to a particular dataset, PL4O, with PRED(.30) <= 50%.**
- **Model PL4O was the result of a linear regression fit to the PL4O data set. The result:**
  - **F statistic (CD) = 1668; PRED(.30) = 66.7%; few coefficients fit significantly; some coefficients have non-credible values.**
- **Then, model PL4O.Bayes was the result of a Bayes computation, using:**
  - **PL4O data**
  - **The Delphi result and CEM CD values as priors**

  **The result:**
  - **F statistic (CD) = 103.1; PRED(.30) = 28.2%; all but three coefficients fit at p<.05 or better; all coefficient values are credible.**

# Fitting a Model Can Be a Difficult Problem – Part 2

- **Per previous slide, there are tensions between data-only fits and Bayesian fits:**

| Tensions between Types of Fits | |
|---|---|
| **Data-Only Fits** | **Bayesian Fits** |
| Data tends to be close to fit | Data may be dispersed from fit |
| May have non-credible coefficient values | Coefficients tend to have credible values |

- **Also between another dimension of fits:**

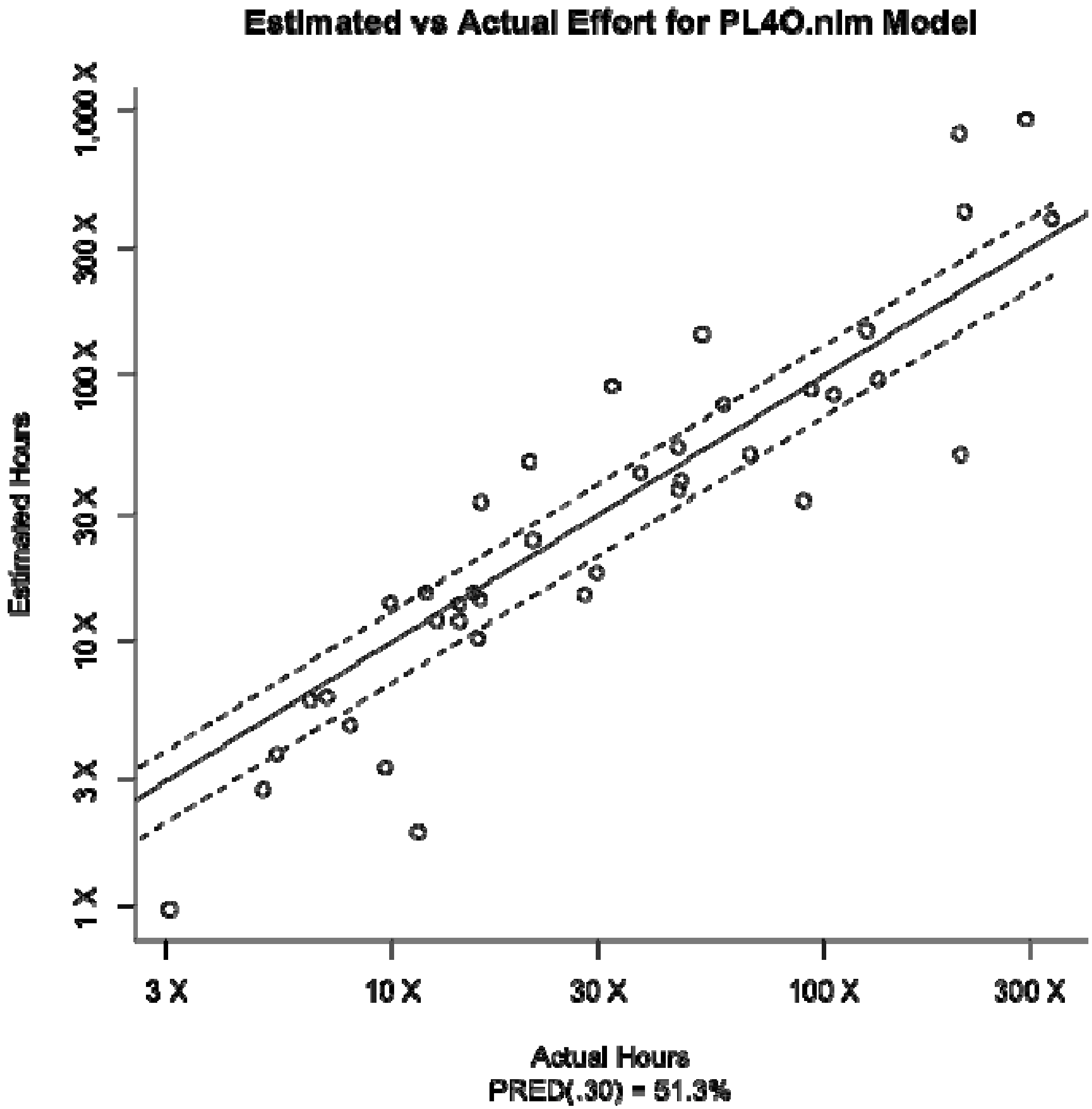
| Another Tension between Types of Fits | |
|---|---|
| **Least-squares Fits** | **Absolute-Deviation Fits** |
| Example fitting techniques: linear regression, F statistic | Example fitting techniques: MMRE, PRED |
| Data far from the middle have more influence on the fit | All data have equal influence on the fit |
| Must work on log(data) | Can work directly on the data |

# Fitting a Model to this Dataset with PRED(.30) >= 50%

- We want a model fit to the PL4O data set that results in PRED(.30) >= 50%.
  - Need the Bayes to achieve credible coefficients
  - Want a technique that achieves the PRED(.30) on the actual data; don’t care about sum of squares measures
- An approach: hill-climbing
  - Take an error function on the current model’s parameters
  - Trying small variations in parameter values, see if any variation leads to an improvement
    - And, if so, which variation leads to the biggest improvement
    - If no improvement, stop with this local maximum
  - Modify the parameter values by taking a step in the direction of biggest improvement, and repeat
- The free statistics software package R includes a hill-climbing function called “nlm”.

# Results of Using nlm

- **Used nlm with these arguments:**
  - The PL4O.Bayes parameter values to start; and
  - An error function of PRED(.30) computed on the PL4O dataset ("Actuals") versus "Estimates", values computed using the current parameter values and PL4O ratings.
    - Note: some details of the error function are given in the Backup
- **nlm found a model PL4O.nlm with these properties:**
  - All parameter values are credible; and
  - PRED(.30) on the PL4O dataset = 51.3%.


Estimated vs Actual Effort for PL4O.nlm Model
Estimated Hours
1 X
3 X
10 X
30 X
100 X
300 X
1,000 X
3 X
10 X
30 X
100 X
300 X
Actual Hours
PRED(.30) = 51.3%

# New Practices in Model Calibration (Summary)

- Current two-step practice for Bayesian fit:
  - Use linear regression on data to find a fit (coefficients)
  - Then apply prior information to update coefficients and their variances
    - Uses a single-variable model to compute new coefficients and variances
- Expansion of Bayesian model generation:
  - Use of full covariance matrix, not just variances
    - More appropriate to the task at hand
  - Fine-grained control over application of priors
    - Can choose coefficients on which to apply prior information
    - Use of priors from multiple sources
  - Recasting Bayes data set to allow use of ordinary linear regression packages
    - Eliminates the need for two separate steps
    - Allows mixing of variance-only and covariance priors
  - (R software to support this)

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  - Also attendee list

# Ideas for Further Development of COSYSMO (1/3)

**Jim's suggestions:**

- Create a validated model for interoperability
  - Existing COSYSMO 3.0 work provides an excellent foundation
- Create tailored models for different types of project
  - "Tailored" = some driver values are pre-filled in
  - Defense, software-intensive, ...
- Estimating model for total development cost, based primarily on COSYSMO 3.0 drivers
  - Some work already done at Lockheed-Martin
- Better integrate activity levels between DWR and DFR

# Ideas for Further Development of COSYSMO (2/3)

**Workshop suggestions:**

- Explicitly address security
  - Could be cost driver
  - Could be a tailored model
  - Could be advice on "Using COSYSMO on Secure Systems"
  - Supports rugged DevOps
- Supports
- Refine/evolve cost driver def'ns to reflect latest research
- Interoperate with MBSE
  - Figure out how to derive parameter values from MBSE elements
  - In an automated fashion, if possible
- Estimate additional attributes of a project
  - Schedule, quality, …
- Support attribution of value to systems engineering elements
  - Where determining value may be an issue

# Ideas for Further Development of COSYSMO (3/3)

**Workshop suggestions:**

- **Include number of decision makers (perhaps in Stakeholder Team Cohesion)**

# Attendees at Workshop

| Name | Organization |
|---|---|
| Jim Alstad | USC CSSE |
| Allen Borechard | AFLCMC/HNJJ |
| Mike Konrad | SEI |
| Barry Boehm | USC-CSSE |
| Mark Cornwell | Decisive Analytics |
| Martin Masami Toyoshima | DENSO |
| Lyle Patashnick | NGA |

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1. “A Generalized Systems Engineering Reuse Framework and its Cost Estimating Relationship”, Gan Wang, Garry J Roedler, Mauricio Pena, and Ricardo Valerdi, INCOSE 2014.
2. “The Constructive Systems Engineering Cost Model (COSYSMO)”, Ricardo Valerdi (PhD Dissertation), 2005.
3. “Estimating Systems Engineering Reuse with the Constructive Systems Engineering Cost Model (COSYSMO 2.0)”, Jared Fortune (PhD Dissertation), 2009.
4. “Quantifying the Impact of Requirements Volatility on Systems Engineering Effort”, Mauricio Pena (PhD Dissertation), 2012.
5. “Life Cycle Cost Modeling and Risk Assessment for 21st Century Enterprises”, Barry Boehm, Jo Ann Lane, Supannika Koolmanojwong, Richard Turner (presentation), April 29, 2014.
6. "System Interoperability Influence on System of Systems Engineering Effort", Jo Ann Lane, Ricardo Valerdi, CSER 2011.
7. “COSYSMO Extension as a Proxy Systems Cost Estimation” (presentation), Reggie Cole, Garry Roedler, October 23, 2013.

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