Cost Estimation IV for Next-Generation Ground Systems

Focusing on

COSYSMO 3.0: The Expert-Based Model

Jim Alstad USC Center for Systems and Software Engineering

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"Looking Beyond the Horizon"

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

Estimating Costs: COSATMO and COSYSMO

"Cost Estimating for Next Generation Ground Systems" at previous GSAWs:

- **2014: workshop helped kick off the development of COSATMO, a total ownership cost model for satellite systems.**
- **2015: workshop presented and helped develop COSYSMO 3.0, a systems engineering cost model applicable to ground stations, including exercising a preliminary model**
- **2016 (Alstad, Boehm, Wheaton): interactive session improved data collection form**

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**

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- **History of COSYSMO 3.0**
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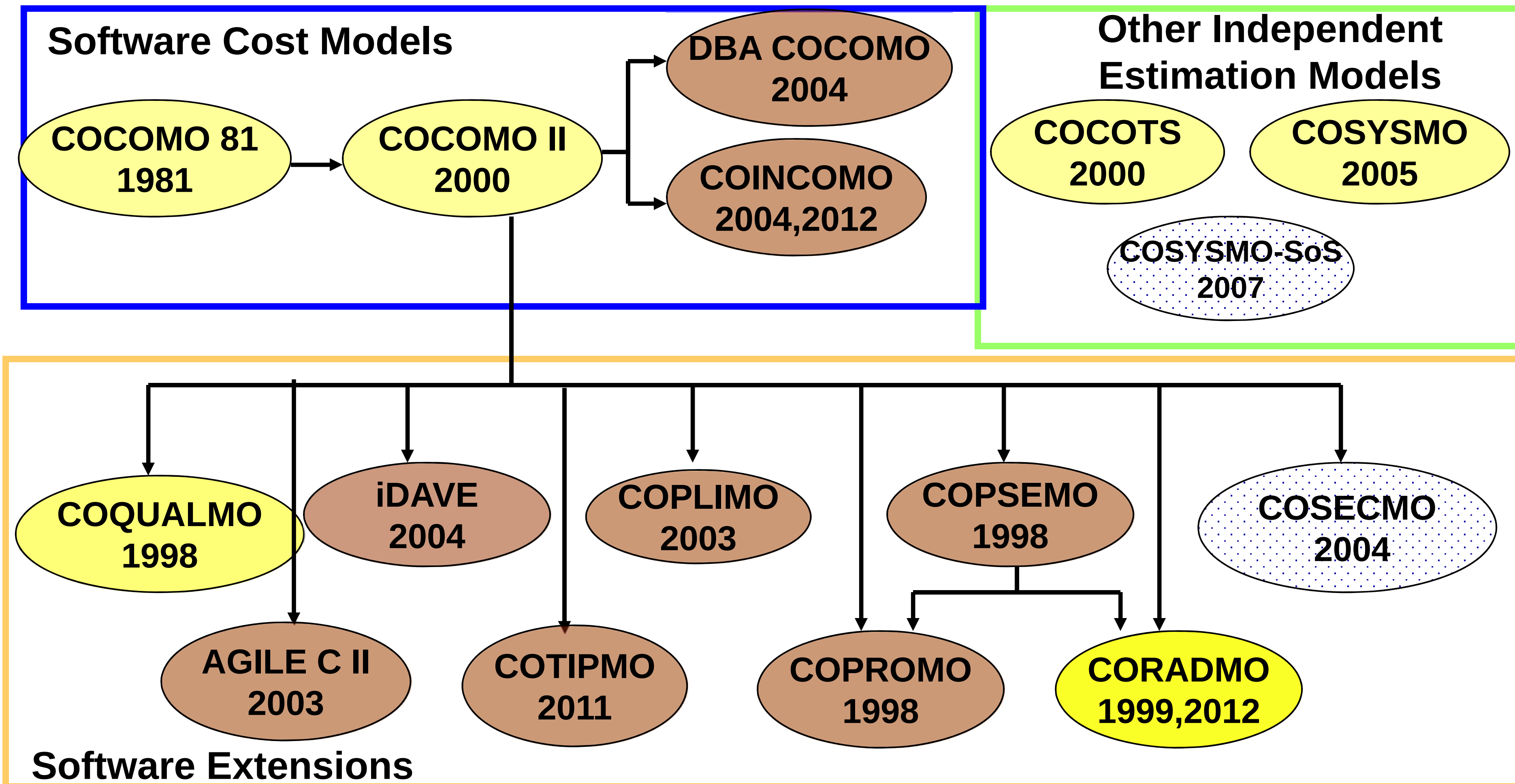
COCOMO Family of Cost Models



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, 2017?

- 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	4.5
System Interface	1.9	4.0	9.0
System Algorithm	1.9	3.8	9.8
Operational Scenario	6.4	13.6	26.3

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 % 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**

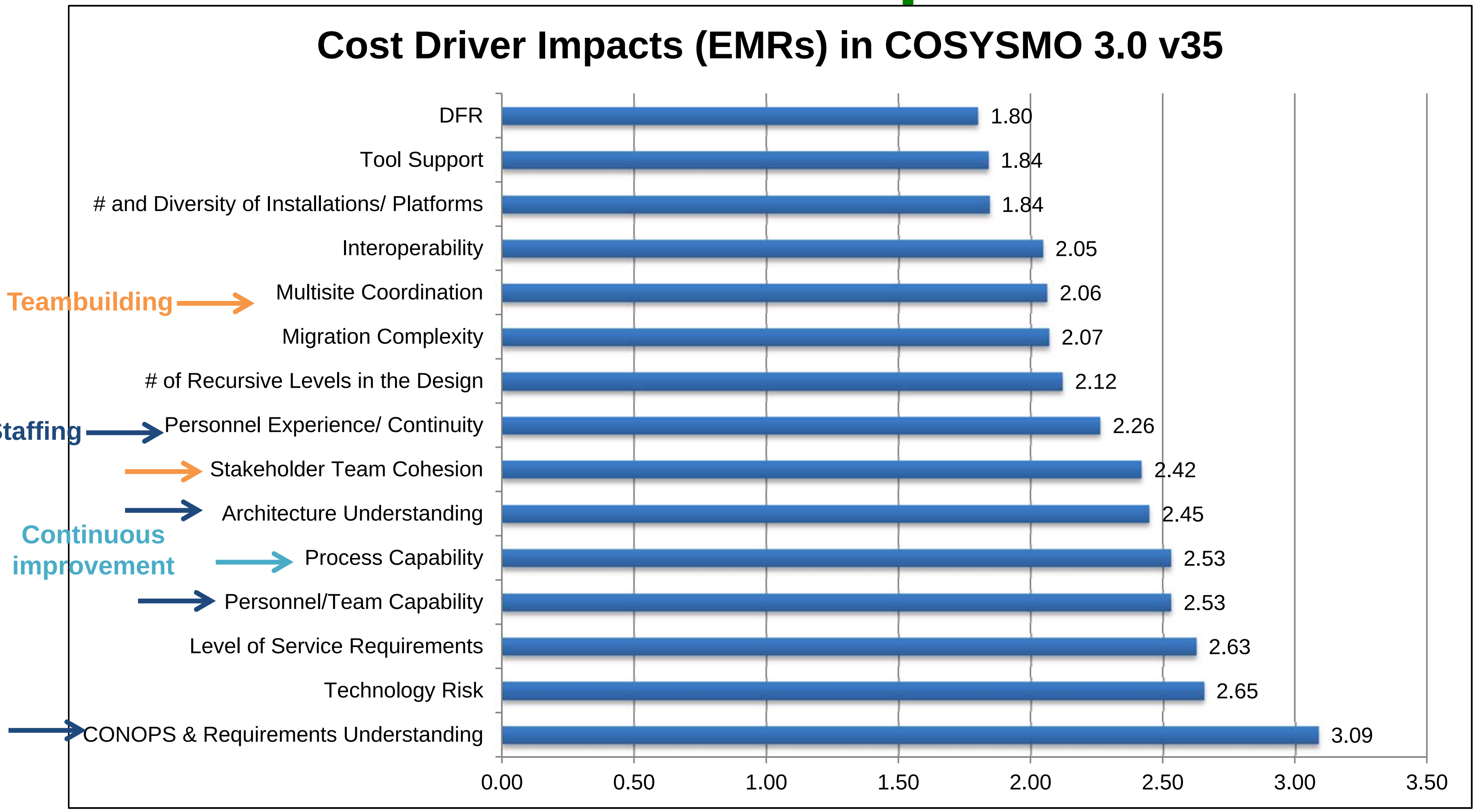
The effect of a large exponent is more pronounced on bigger projects

Expert-Based COSYSMO 3.0 Cost Driver Model

- **Here are the 15 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)
	Interoperability	Degree to which this system has to interoperate with others
PERS	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
ENVR	Multisite coordination	Location of stakeholders and coordination barriers
	Tool support	Subjective assessment of SE tools

Expert-Based 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)**
- **Expert-Based COSYSMO 3.0 includes both methods; only one will 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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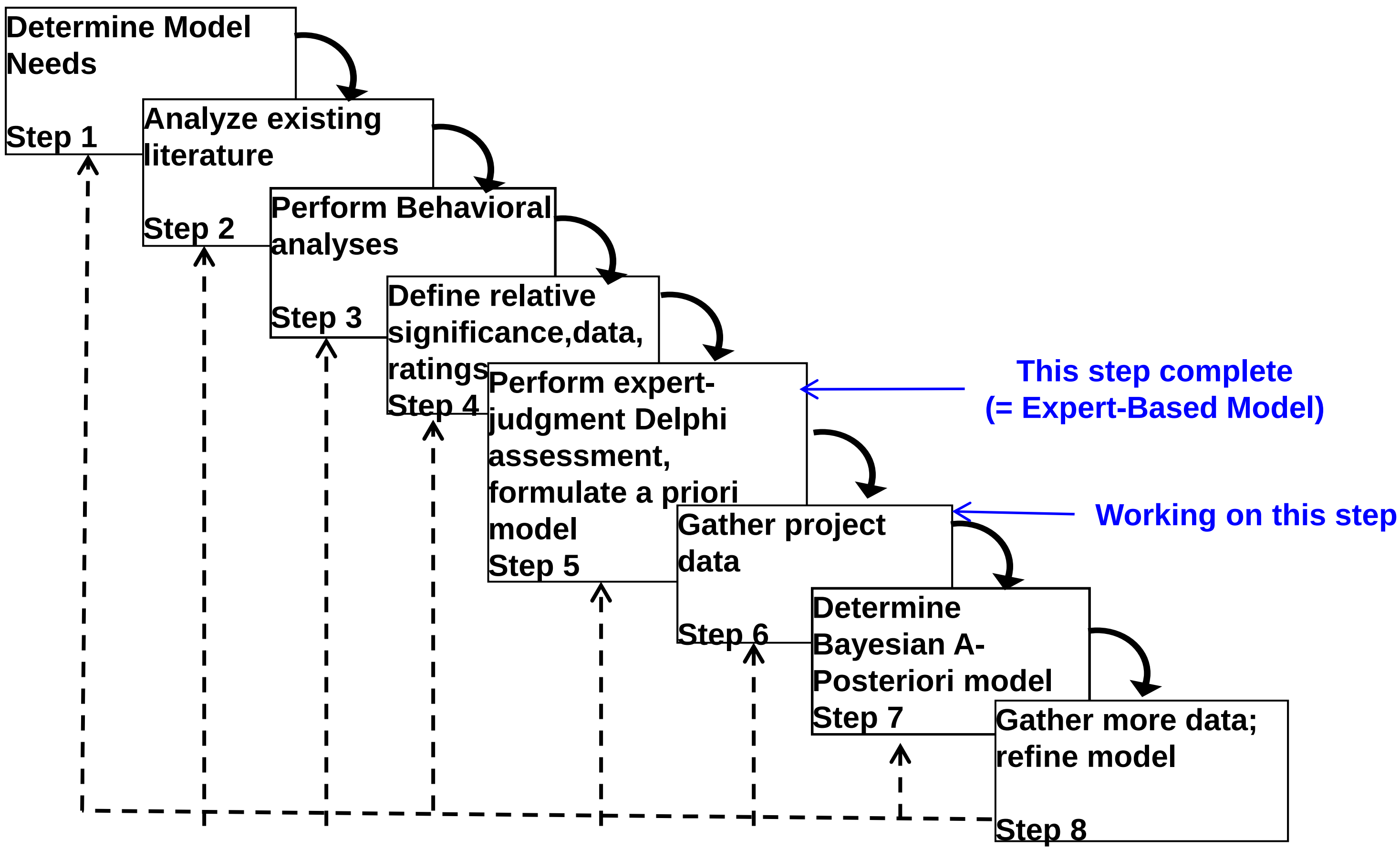
USC-CSSE Modeling Methodology

Figure 4.1 from [22]



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 Form is very close to completion
- Next work items:
  - Finish Data Collection Form
  - Gather new calibration data: completed projects
  - See how model works on existing calibration data

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  - Cost Drivers and Scale Factors
  - (Reuse and Size parameters shown above)
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Cost Driver Detailed Parameters (1/2)

EMR	Cost Driver	Ratings				
	CONOPS and Requirements Understanding	VL	L	N	H	VH
3.093		1.76	1.33	1.00	0.75	0.57
	Architecture Understanding	VL	L	N	H	VH
2.423		1.56	1.25	1.00	0.80	0.64
	Stakeholder Team Cohesion	VL	L	N	H	VH
2.467		1.57	1.25	1.00	0.80	0.64
	Level of Service Requirements	VL	L	N	H	VH
2.682		1.64	1.28	1.00	0.78	0.61
	Technology Risk	VL	L	N	H	VH
2.581		0.62	0.79	1.00	1.27	1.61
	# of Recursive Levels in the Design	VL	L	N	H	VH
1.932		0.72	0.85	1.00	1.18	1.39
	# and Diversity of Installations/Platforms	N	H	VH	EH	
1.932		1.00	1.25	1.55	1.93	
	Migration Complexity	N	H	VH	EH	
1.996		1.00	1.26	1.59	2.00	
	Interoperability	VL	L	N	H	VH
2.118		1.46	1.21	1.00	0.83	0.69

Cost Driver Detailed Parameters (2/2)

EMR	Cost Driver	Ratings					
	Personnel/Team Capability	VL	L	N	H	VH	
2.690		1.64	1.28	1.00	0.78	0.61	
	Process Capability	VL	L	N	H	VH	EH
2.158		1.36	1.17	1.00	0.86	0.74	0.63
	Personnel Experience/Continuity	VL	L	N	H	VH	
2.315		1.52	1.23	1.00	0.81	0.66	
	Multisite Coordination	VL	L	N	H	VH	EH
1.787		1.26	1.12	1.00	0.89	0.79	0.71
	Tool Support	VL	L	N	H	VH	
1.843		1.36	1.17	1.00	0.86	0.74	
	DFR (Development for Reuse)	L	N	H	VH	EH	
1.638		0.88	1.00	1.13	1.28	1.45	

Scale Factor Detailed Parameters

Maximum	Scale Factor	Ratings					
	Risk/Opportunity Resolution	VL	L	N	H	VH	EH
0.06129		0.0613	0.0490	0.0368	0.0245	0.0123	0.0000
	Process Capability	VL	L	N	H	VH	EH
0.05422		0.0542	0.0434	0.0325	0.0217	0.0108	0.0000
	Requirements Volatility	VL	L	M	H	VH	
0.03788		0.0000	0.0095	0.0189	0.0284	0.0379	
	EBase	1.0279					

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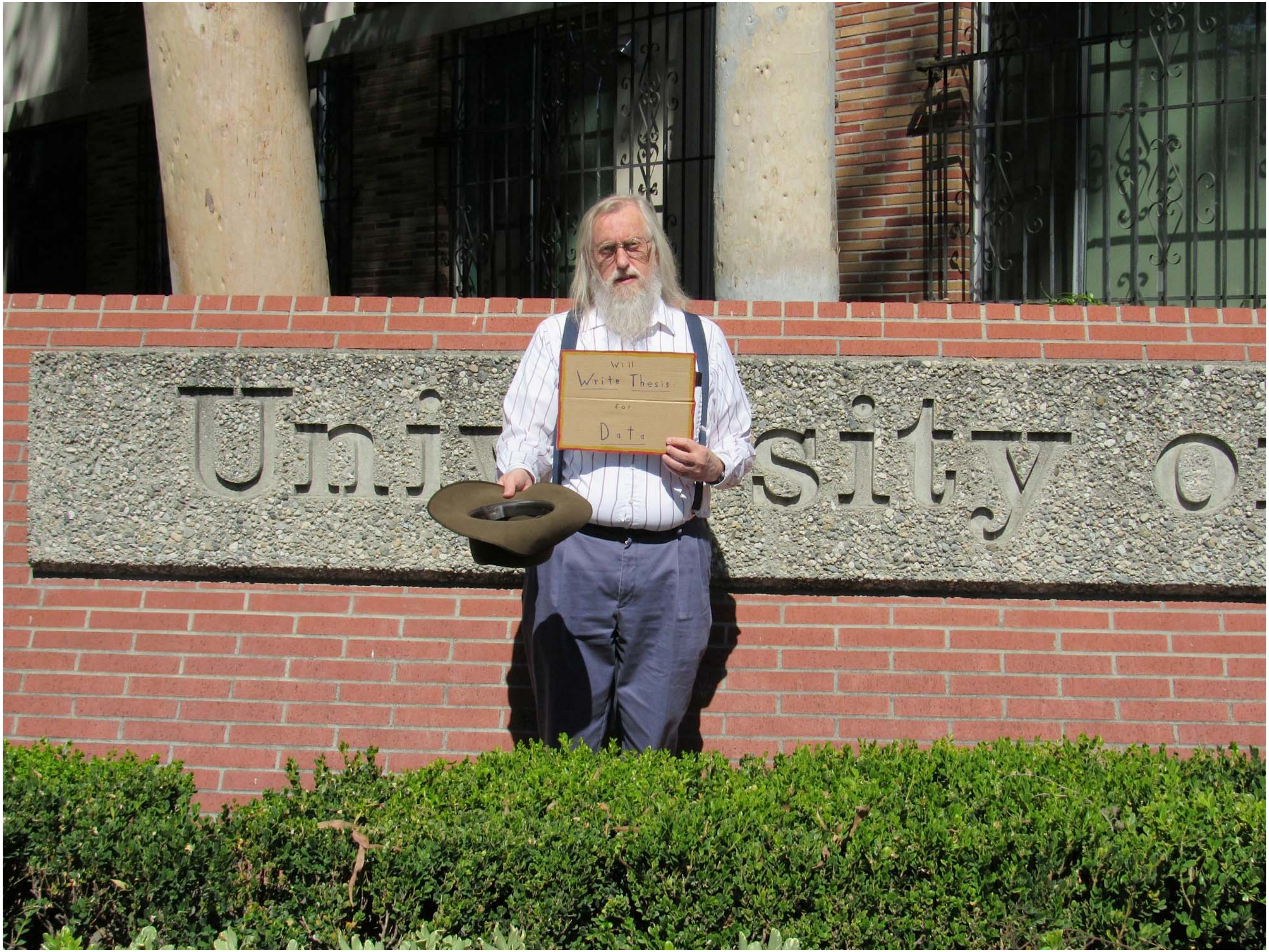
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Data Gathering

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

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