

The **CO**nstructive **SY**stems Engineering Cost **MO**del



Ricardo Valerdi

*University of Southern California
The Aerospace Corporation
Los Angeles Chapter of INCOSE
INCOSE Measurement Working Group*

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Outline

- **Background on CSE and COSYSMO**
- **COSYSMO Overview**
- **Expert Data Results**
- **Historical Project Results**
- **Future Work**
- **Demo**

USC Center for Software Engineering (CSE)

- **Researches, teaches, and practices CMMI-based Software engineering**
 - **Systems and software engineering fully integrated**
- **Focuses on better models to guide integrated systems and software engineering**
 - **Success models: stakeholder win-win, business cases**
 - **Product models: requirements, architectures, COTS**
 - **Process models: spiral extensions, value-based RUP extensions**
 - **Property models: cost, schedule, quality**

USC-CSE Cost, Schedule, and Quality Models

- **Build on experience with COCOMO 1981, COCOMO II**
 - **Developed with Affiliate funding, expertise, data support**
- **Collaborative efforts between Computer Science (CS) and Industrial Systems Engineering (ISE) Depts.**
- **COCOMO Suite of models**
 - **Cost, schedule: COCOMO II, CORADMO, COCOTS**
 - **Quality: COQUALMO**
 - **Systems Engineering: COSYSMO**
- **Uses mature 7-step model development methodology**

USC-CSE Affiliates (34)

- **Commercial Industry (15)**
 - Daimler Chrysler, Freshwater Partners, Galorath, Group Systems.Com, Hughes, IBM, Cost Xpert Group, Microsoft, Motorola, Price Systems, Rational, Reuters Consulting, Sun, Telcordia, Xerox
- **Aerospace Industry (7)**
 - BAE Systems, Boeing, General Dynamics, Lockheed Martin, Northrop Grumman, Raytheon, SAIC
- **Government (8)**
 - DARPA, DISA, FAA, NASA-Ames, NSF, OSD/ARA/SIS, US Army Research Labs, US Army TACOM
- **FFRDC's and Consortia (4)**
 - Aerospace, JPL, SEI, SPC

Need for Systems Engineering Measurement

- **Federal Government: spends \$18 billion annually on space systems**
 - **General Accounting Office Report (GAO-03-1073)**
 - **Problems during acquisition, increased costs, delayed schedules**
- **Department of Defense: Secretary of Defense's six transformational goals**
 - **Air Force SE Revitalization, Lt. Gen. Arnold (SMC)**
- **Commercial**
 - **Capability Maturity Model Integration v1.1**
 - **Can't do good software engineering without good Systems Engineering**

State of the Practice

- **Capability to measure systems engineering is unavailable in current cost models**
- **Possible approaches**
 - **Heuristics/rules of thumb (Honour)**
 - **Analogy**
 - **% of SW or HW effort (COCOMOII, PRICE-H)**
 - **% of total effort (Honour)**
 - **A function of complexity (Ernststoff)**
- **Systems Engineering is evolving**
 - **INCOSE (est. 1992)**
 - **Standards (EIA/ANSI632, EIA/ANSI731, ISO/IEC15288)**
 - **Academic degrees**
- **We start where COCOMO left off...**

COCOMO II

- **COCOMO is the most widely used, thoroughly documented and calibrated software cost model**
- **COCOMO - the “CO**nstructive **CO**st **MO**del”
 - **COCOMO II is the update to COCOMO 1981**
 - **ongoing research with annual calibrations made available**
- **Originally developed by Dr. Barry Boehm and published in 1981 book *Software Engineering Economics***
- **COCOMO II described in *Software Cost Estimation with COCOMO II* (2000)**

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Key Definitions & Concepts

Calibration: the tuning of parameters based on project data

CER: a model that represents the cost estimating relationships of factors

Cost Estimation: prediction of both the person-effort and elapsed time of a project

Driver: A factor that is highly correlated to the amount of Systems Engineering effort

Parametric: an equation or model that is approximated by a set of parameters

Rating Scale: a range of values and definitions for a particular driver

Understanding: an individual's subjective judgment of their level of comprehension

Model Differences

COCOMO II

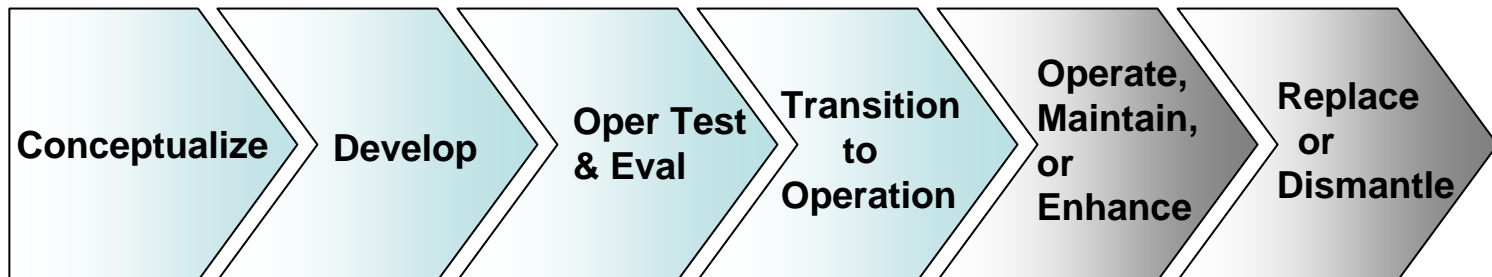
- **Software**
- **Development phases**
- **20+ years old**
- **200+ calibration points**
- **23 Drivers**
- **Variable granularity**
- **3 anchor points**
- **Size is driven by SLOC**

COSYSMO

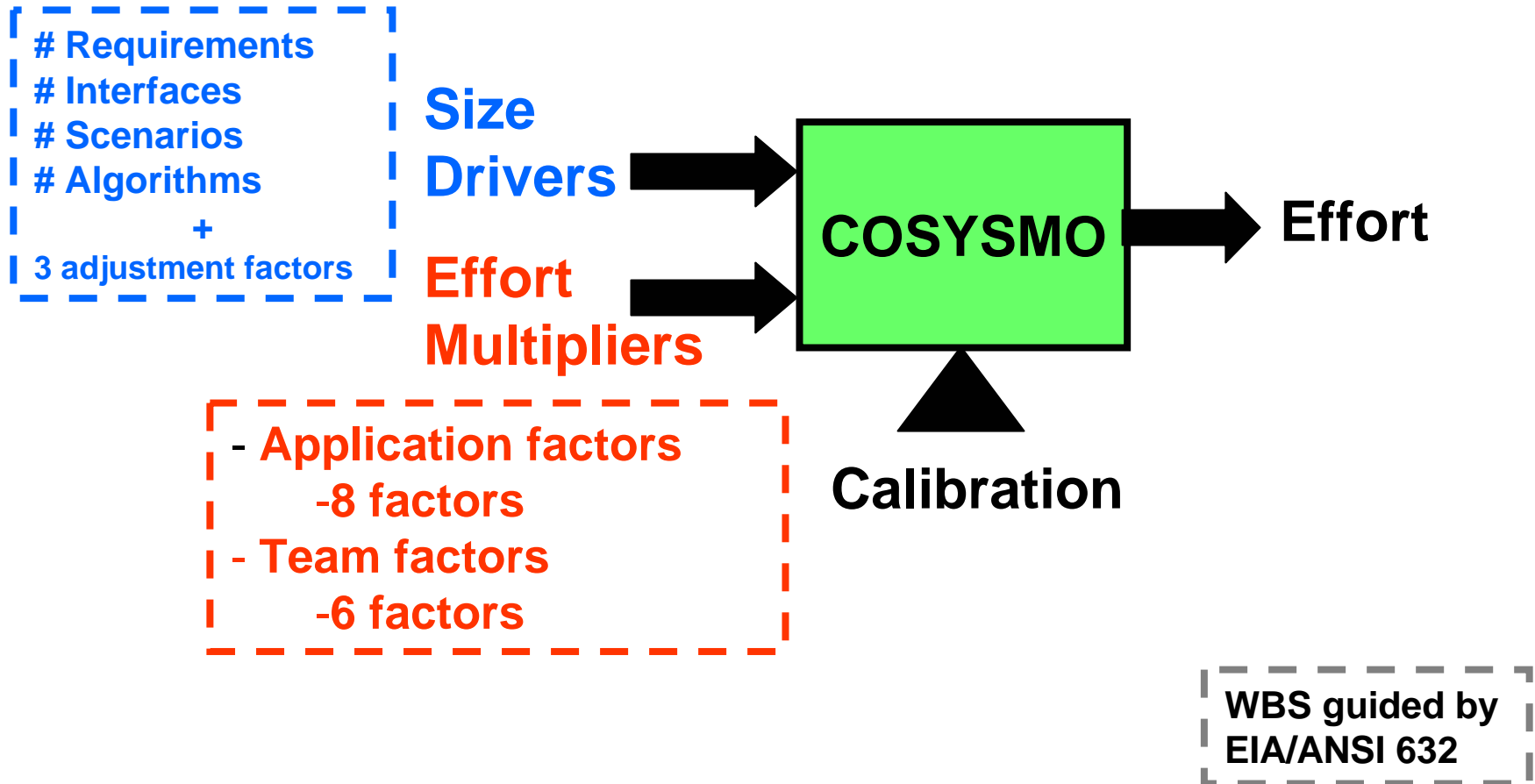
- **Systems Engineering**
- **4 of 6 Life Cycle phases**
- **4 years old**
- **35 calibration points**
- **18 drivers**
- **Fixed granularity**
- **No anchor points**
- **Size is driven by requirements, I/F, Algorithms, Op Scen**

COSYSMO Introduction

- Parametric model to estimate system engineering costs
- Includes 4 size & 14 cost drivers
- Covers 4 of the 6 life cycle phases



COSYSMO Operational Concept

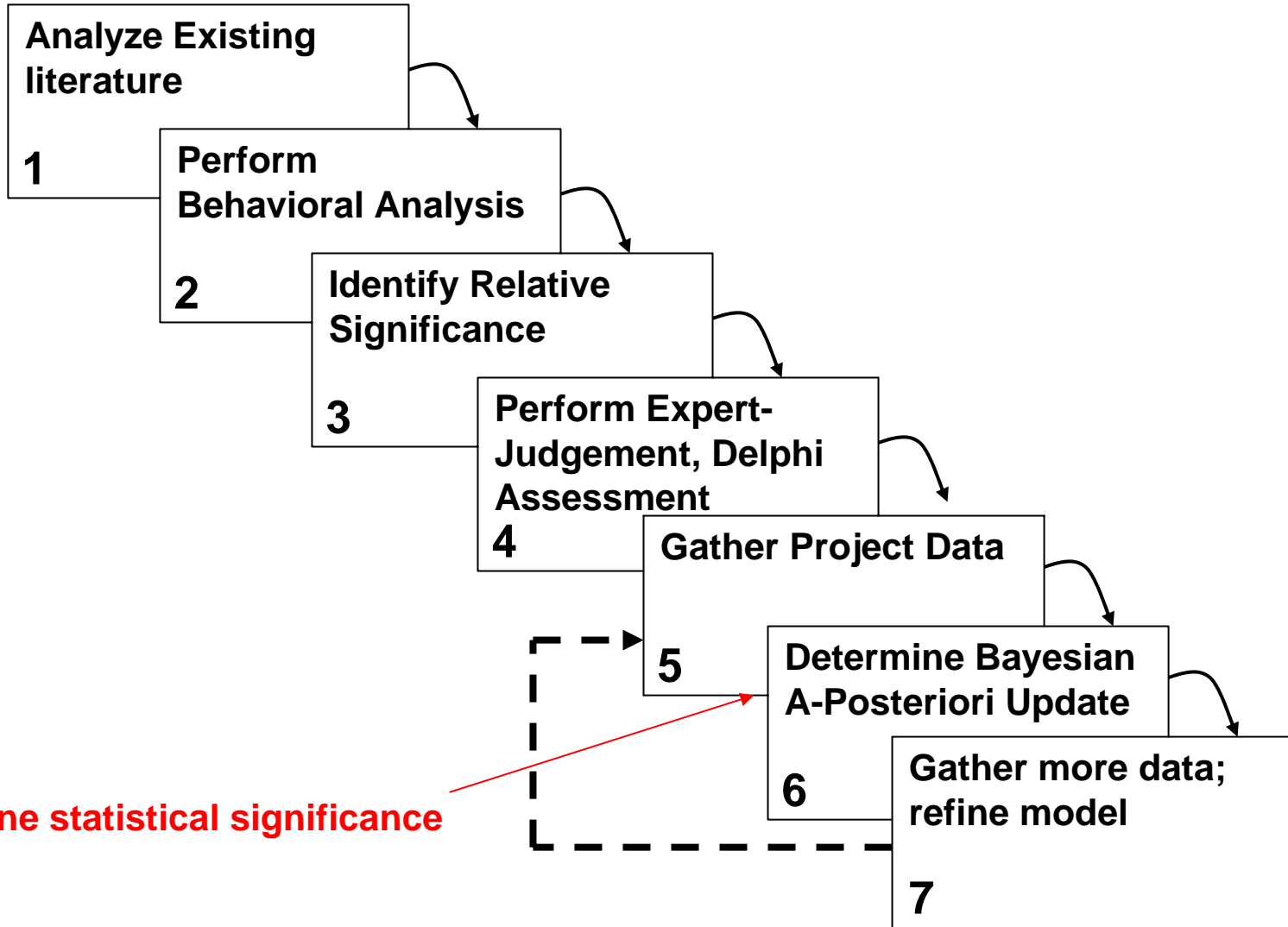


Systems Engineering Defined

What is included from EIA/ANSI 632 “Processes for Engineering a System”?

- **Acquisition and Supply**
 - Supply Process
 - Acquisition Process
- **Technical Management**
 - Planning Process
 - Assessment Process
 - Control Process
- **System Design**
 - Requirements Definition Process
 - Solution Definition Process
- **Product Realization**
 - Implementation Process
 - Transition to Use Process
- **Technical Evaluation**
 - Systems Analysis Process
 - Requirements Validation Process
 - System Verification Process
 - End Products Validation Process

7-step Modeling Methodology



Model Form

$$PM_{NS} = A \cdot \left(\sum_k (w_{e,k} \Phi_{e,k} + w_{n,k} \Phi_{n,k} + w_{d,k} \Phi_{d,k}) \right)^E \cdot \prod_{j=1}^{14} EM_j$$

Where:

PM_{NS} = effort in Person Months (Nominal Schedule)

A = calibration constant derived from historical project data

k = {REQ, IF, ALG, SCN}

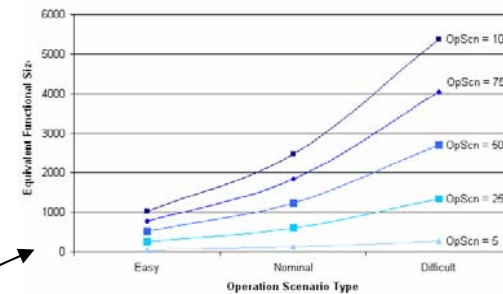
w_x = weight for “easy”, “nominal”, or “difficult” size driver

Φ_x = quantity of “k” size driver

E = represents diseconomy of scale (currently equals 1)

EM = effort multiplier for the j_{th} cost driver. The geometric product results in an overall effort adjustment factor to the nominal effort.

Relationship Between Operational Scenarios & Functional Size



4 Size Drivers

- 1. Number of System Requirements**
- 2. Number of System Interfaces**
- 3. Number of System Specific Algorithms**
- 4. Number of Operational Scenarios**

Weighted by complexity, volatility, and degree of reuse

Number of System Requirements

This driver represents the number of requirements for the system-of-interest at a specific level of design. The quantity of requirements includes those related to the effort involved in system engineering the system interfaces, system specific algorithms, and operational scenarios. Requirements may be functional, performance, feature, or service-oriented in nature depending on the methodology used for specification. They may also be defined by the customer or contractor. Each requirement may have effort associated with it such as V&V, functional decomposition, functional allocation, etc. System requirements can typically be quantified by counting the number of applicable shalls/wills/shoulds/mays in the system or marketing specification. Note: some work is involved in decomposing requirements so that they may be counted at the appropriate system-of-interest.

Easy	Nominal	Difficult
- Simple to implement	- Familiar	- Complex to implement or engineer
- Traceable to source	- Can be traced to source with some effort	- Hard to trace to source
- Little requirements overlap	- Some overlap	- High degree of requirements overlap

Number of System Interfaces

This driver represents the number of shared physical and logical boundaries between system components or functions (internal interfaces) and those external to the system (external interfaces). These interfaces typically can be quantified by counting the number of external and internal system interfaces among ISO/IEC 15288-defined system elements.

Easy	Nominal	Difficult
- Simple message	- Moderate complexity	- Complex protocol(s)
- Uncoupled	- Loosely coupled	- Highly coupled
- Strong consensus	- Moderate consensus	- Low consensus
- Well behaved	- Predictable behavior	- Poorly behaved

Number of System-Specific Algorithms

This driver represents the number of newly defined or significantly altered functions that require unique mathematical algorithms to be derived in order to achieve the system performance requirements. As an example, this could include a complex aircraft tracking algorithm like a Kalman Filter being derived using existing experience as the basis for the all aspect search function. Another example could be a brand new discrimination algorithm being derived to identify friend or foe function in space-based applications. The number can be quantified by counting the number of unique algorithms needed to realize the requirements specified in the system specification or mode description document.

Easy	Nominal	Difficult
-Algebraic	- Straight forward calculus	- Complex constrained optimization; pattern recognition
- Straightforward structure	- Nested structure with decision logic	- Recursive in structure with distributed control
- Simple data	- Relational data	- Noisy, ill-conditioned data
- Timing not an issue	- Timing a constraint	- Dynamic, with timing and uncertainty issues
- Adaptation of library-based solution	- Some modeling involved	- Simulation and modeling involved

Number of Operational Scenarios

This driver represents the number of operational scenarios that a system must satisfy. Such scenarios include both the nominal stimulus-response thread plus all of the off-nominal threads resulting from bad or missing data, unavailable processes, network connections, or other exception-handling cases. The number of scenarios can typically be quantified by counting the number of system test thread packages or unique end-to-end tests used to validate the system functionality and performance or by counting the number of use cases, including off-nominal extensions, developed as part of the operational architecture.

Easy	Nominal	Difficult
- Well defined	- Loosely defined	- Ill defined
- Loosely coupled	- Moderately coupled	- Tightly coupled or many dependencies/conflicting requirements
- Timelines not an issue	- Timelines a constraint	- Tight timelines through scenario network
- Few, simple off-nominal threads	- Moderate number or complexity of off-nominal threads	- Many or very complex off-nominal threads

14 Cost Drivers

Application Factors (8)

1. Requirements understanding
2. Architecture understanding
3. Level of service requirements
4. Migration complexity
5. Technology Risk
6. Documentation Match to Life Cycle Needs
7. # and Diversity of Installations/Platforms
8. # of Recursive Levels in the Design

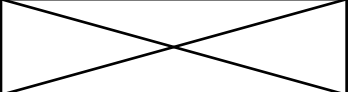
Requirements understanding

This cost driver rates the level of understanding of the system requirements by all stakeholders including the systems, software, hardware, customers, team members, users, etc. Primary sources of added systems engineering effort are unprecedented systems, unfamiliar domains, or systems whose requirements are emergent with use.

Very low	Low	Nominal	High	Very High
Poor: emergent requirements or unprecedented system	Minimal: many undefined areas	Reasonable: some undefined areas	Strong: few undefined areas	Full understanding of requirements, familiar system

Architecture understanding

This cost driver rates the relative difficulty of determining and managing the system architecture in terms of platforms, standards, components (COTS/GOTS/NDI/new), connectors (protocols), and constraints. This includes tasks like systems analysis, tradeoff analysis, modeling, simulation, case studies, etc.

Very low	Low	Nominal	High	Very High
Poor understanding of architecture and COTS, unprecedented system	Minimal understanding of architecture and COTS, many unfamiliar areas	Reasonable understanding of architecture and COTS, some unfamiliar areas	Strong understanding of architecture and COTS, few unfamiliar areas	Full understanding of architecture, familiar system and COTS
>6 level WBS	5-6 level WBS	3-4 level WBS	2 level WBS	

Level of service requirements

This cost driver rates the difficulty and criticality of satisfying the ensemble of level of service requirements, such as security, safety, response time, interoperability, maintainability, Key Performance Parameters (KPPs), the “ilities”, etc.

Viewpoint	Very low	Low	Nominal	High	Very High
<i>Difficulty</i>	Simple; single dominant KPP	Low, some coupling among KPPs	Moderately complex, coupled KPPs	Difficult, coupled KPPs	Very complex, tightly coupled KPPs
<i>Criticality</i>	Slight inconvenience	Easily recoverable losses	Some loss	High financial loss	Risk to human life

Migration complexity

This cost driver rates the extent to which the legacy system affects the migration complexity, if any. Legacy system components, databases, workflows, environments, etc., may affect the new system implementation due to new technology introductions, planned upgrades, increased performance, business process reengineering, etc.

Viewpoint	Nominal	High	Very High	Extra High
Legacy contractor	Self; legacy system is well documented. Original team largely available	Self; original development team not available; most documentation available	Different contractor; limited documentation	Original contractor out of business; no documentation available
Effect of legacy system on new system	Everything is new; legacy system is completely replaced or non-existent	Migration is restricted to integration only	Migration is related to integration and development	Migration is related to integration, development, architecture and design

Technology Risk

The maturity, readiness, and obsolescence of the technology being implemented. Immature or obsolescent technology will require more Systems Engineering effort.

Viewpoint	Very Low	Low	Nominal	High	Very High
<i>Lack of Maturity</i>	Technology proven and widely used throughout industry	Proven through actual use and ready for widespread adoption	Proven on pilot projects and ready to roll-out for production jobs	Ready for pilot use	Still in the laboratory
<i>Lack of Readiness</i>	Mission proven (TRL 9)	Concept qualified (TRL 8)	Concept has been demonstrated (TRL 7)	Proof of concept validated (TRL 5 & 6)	Concept defined (TRL 3 & 4)
<i>Obsolescence</i>	X	X	<ul style="list-style-type: none"> - Technology is the state-of-the-practice - Emerging technology could compete in future 	<ul style="list-style-type: none"> - Technology is stale - New and better technology is on the horizon in the near-term 	<ul style="list-style-type: none"> - Technology is outdated and use should be avoided in new systems - Spare parts supply is scarce

Documentation match to life cycle needs

The formality and detail of documentation required to be formally delivered based on the life cycle needs of the system.

Viewpoint	Very low	Low	Nominal	High	Very High
<i>Formality</i>	General goals, stories	Broad guidance, flexibility is allowed	Risk-driven degree of formality	Partially streamlined process, largely standards-driven	Rigorous, follows strict standards and requirements
<i>Detail</i>	Minimal or no specified documentation and review requirements relative to life cycle needs	Relaxed documentation and review requirements relative to life cycle needs	Risk-driven degree of formality, amount of documentation and reviews in sync and consistent with life cycle needs of the system	High amounts of documentation, more rigorous relative to life cycle needs, some revisions required	Extensive documentation and review requirements relative to life cycle needs, multiple revisions required

and diversity of installations/platforms

The number of different platforms that the system will be hosted and installed on. The complexity in the operating environment (space, sea, land, fixed, mobile, portable, information assurance/security). For example, in a wireless network it could be the number of unique installation sites and the number of and types of fixed clients, mobile clients, and servers. Number of platforms being implemented should be added to the number being phased out (dual count).

Viewpoint	Nominal	High	Very High	Extra High
Sites/ installations	Single installation site or configuration	2-3 sites or diverse installation configurations	4-5 sites or diverse installation configurations	>6 sites or diverse installation configurations
Operating environment	Existing facility meets all known environmental operating requirements	Moderate environmental constraints; controlled environment (i.e., A/C, electrical)	Ruggedized mobile land-based requirements; some information security requirements. Coordination between 1 or 2 regulatory or cross functional agencies required.	Harsh environment (space, sea airborne) sensitive information security requirements. Coordination between 3 or more regulatory or cross functional agencies required.
Platforms	<3 types of platforms being installed and/or being phased out/replaced	4-7 types of platforms being installed and/or being phased out/replaced	8-10 types of platforms being installed and/or being phased out/replaced	>10 types of platforms being installed and/or being phased out/replaced
	Homogeneous platforms	Compatible platforms	Heterogeneous, but compatible platforms	Heterogeneous, incompatible platforms
	Typically networked using a single industry standard protocol	Typically networked using a single industry standard protocol and multiple operating systems	Typically networked using a mix of industry standard protocols and proprietary protocols; single operating systems	Typically networked using a mix of industry standard protocols and proprietary protocols; multiple operating systems

of recursive levels in the design

The number of levels of design related to the system-of-interest (as defined by ISO/IEC 15288) and the amount of required SE effort for each level.

Viewpoint	Very Low	Low	Nominal	High	Very High
Number of levels	1	2	3-5	6-7	>7
Required SE effort	Focused on single product	Some vertical and horizontal coordination	More complex interdependencies coordination, and tradeoff analysis	Very complex interdependencies coordination, and tradeoff analysis	Extremely complex interdependencies coordination, and tradeoff analysis

14 Cost Drivers (cont.)

Team Factors (6)

1. Stakeholder team cohesion
2. Personnel/team capability
3. Personnel experience/continuity
4. Process capability
5. Multisite coordination
6. Tool support

Stakeholder team cohesion

Represents a multi-attribute parameter which includes leadership, shared vision, diversity of stakeholders, approval cycles, group dynamics, IPT framework, team dynamics, and amount of change in responsibilities. It further represents the heterogeneity in stakeholder community of the end users, customers, implementers, and development team.

Viewpoint	Very Low	Low	Nominal	High	Very High
Culture	<ul style="list-style-type: none"> ▪Stakeholders with diverse domain experience, task nature, language, culture, infrastructure ▪Highly heterogeneous stakeholder communities 	<ul style="list-style-type: none"> ▪Heterogeneous stakeholder community ▪Some similarities in language and culture 	<ul style="list-style-type: none"> ▪Shared project culture 	<ul style="list-style-type: none"> ▪Strong team cohesion and project culture ▪Multiple similarities in language and expertise 	<ul style="list-style-type: none"> ▪Virtually homogeneous stakeholder communities ▪<u>Institutionalized</u> project culture
Compatibility	<ul style="list-style-type: none"> ▪<u>Highly conflicting</u> organizational objectives 	<ul style="list-style-type: none"> ▪<u>Converging</u> organizational objectives 	<ul style="list-style-type: none"> ▪<u>Compatible</u> organizational objectives 	<ul style="list-style-type: none"> ▪Clear roles & responsibilities 	<ul style="list-style-type: none"> ▪<u>Strong mutual advantage to collaboration</u>
Familiarity	<ul style="list-style-type: none"> ▪Unfamiliar, never worked together 	<ul style="list-style-type: none"> ▪Willing to collaborate, little experience 	<ul style="list-style-type: none"> ▪Some familiarity 	<ul style="list-style-type: none"> ▪High level of familiarity 	<ul style="list-style-type: none"> ▪Extensive successful collaboration

Personnel/team capability

Basic intellectual capability of a Systems Engineer (compared to the national pool of SEs) to analyze complex problems and synthesize solutions.

Very Low	Low	Nominal	High	Very High
15 th percentile	35 th percentile	55 th percentile	75 th percentile	90 th percentile

Personnel experience/continuity

The applicability and consistency of the staff at the initial stage of the project with respect to the domain, customer, user, technology, tools, etc.

	Very low	Low	Nominal	High	Very High
Experience	Less than 2 months	1 year continuous experience, other technical experience in similar job	3 years of continuous experience	5 years of continuous experience	10 years of continuous experience
Annual Turnover	48%	24%	12%	6%	3%

Process capability

The consistency and effectiveness of the project team at performing SE processes. This may be based on assessment ratings from a published process model (e.g., CMMI, EIA-731, SE-CMM, ISO/IEC15504). It can also be based on project team behavioral characteristics, if no assessment has been performed.

	Very low	Low	Nominal	High	Very High	Extra High
Assessment Rating (Capability or Maturity)	Level 0 (if continuous model)	Level 1	Level 2	Level 3	Level 4	Level 5
Project Team Behavioral Characteristics	Ad Hoc approach to process performance	Performed SE process, activities driven only by immediate contractual or customer requirements, SE focus limited	Managed SE process, activities driven by customer and stakeholder needs in a suitable manner, SE focus is requirements through design, project-centric approach – not driven by organizational processes	Defined SE process, activities driven by benefit to project, SE focus is through operation, process approach driven by organizational processes tailored for the project	Quantitatively Managed SE process, activities driven by SE benefit, SE focus on all phases of the life cycle	Optimizing SE process, continuous improvement, activities driven by system engineering and organizational benefit, SE focus is product life cycle & strategic applications

Multisite coordination

Location of stakeholders, team members, resources, corporate collaboration barriers.

Viewpoint	Very low	Low	Nominal	High	Very High	Extra High
Collocation	International , severe time zone impact	Multi-city and multi-national, considerable time zone impact	Multi-city or multi-company, some time zone effects	Same city or metro area	Same building or complex, some co-located stakeholders or onsite representation	Fully co-located stakeholders
Communications	Some phone, mail	Individual phone, FAX	Narrowband e-mail	Wideband electronic communication	Wideband electronic communication, occasional video conference	Interactive multimedia
Corporate collaboration barriers	Severe export and security restrictions	Mild export and security restrictions	Some contractual & Intellectual property constraints	Some collaborative tools & processes in place to facilitate or overcome, mitigate barriers	Widely used and accepted collaborative tools & processes in place to facilitate or overcome, mitigate barriers	Virtual team environment fully supported by interactive, collaborative tools environment

Tool support

Coverage, integration, and maturity of the tools in the Systems Engineering environment.

Very low	Low	Nominal	High	Very High
No SE tools	Simple SE tools, little integration	Basic SE tools moderately integrated throughout the systems engineering process	Strong, mature SE tools, moderately integrated with other disciplines	Strong, mature proactive use of SE tools integrated with process, model-based SE and management systems

Additional Proposed Drivers

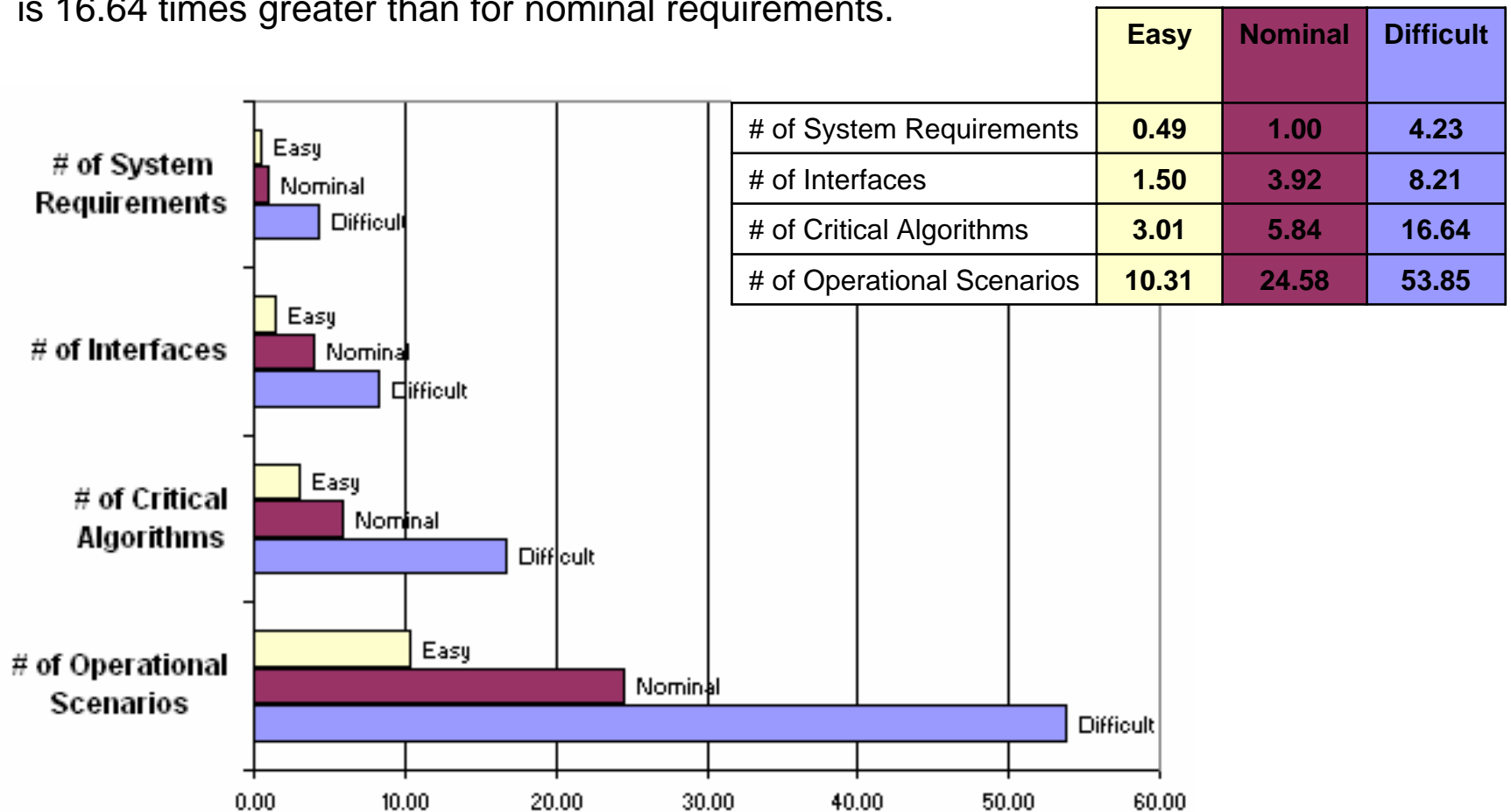
- **# and diversity of installations/platforms phased out**
- **# of years in operational life cycle**
- **Quality Attributes**
- **Manufacturability/Producibility**
- **Degree of Distribution**
- **Political climate**

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Size Driver Results

These four drivers help us determine how “big” a system is. The effort required for “nominal” # of system requirements serves as a basis for comparison to the other three size drivers. For example, the systems engineering effort required for difficult algorithms is 16.64 times greater than for nominal requirements.



Cost Driver Results

Note 1: The Effort Multiplier Ratio (EMR) is the ratio of the large value over the small one (i.e., Requirements Understanding EMR is $1.71/.65 = 2.63$)

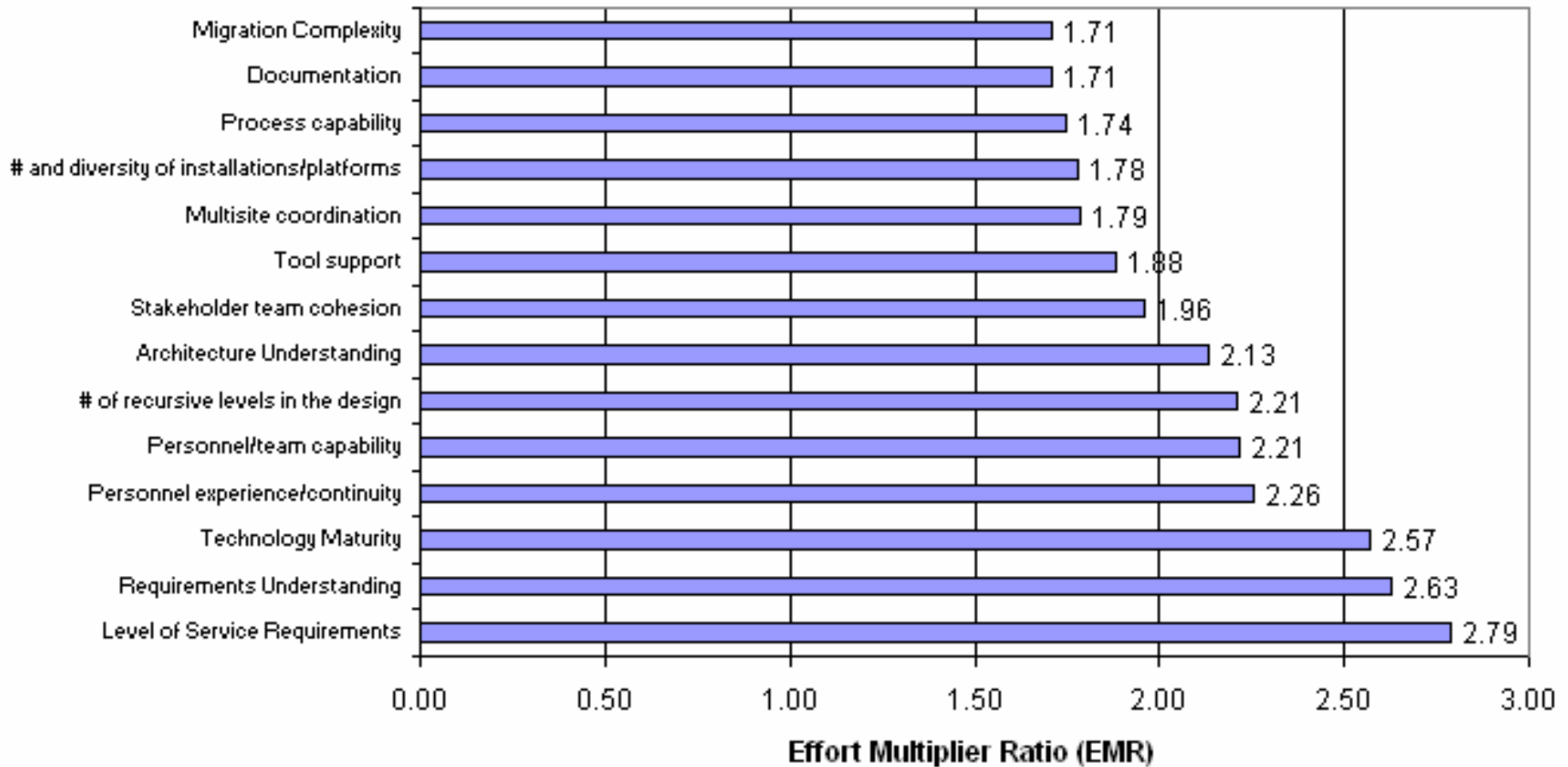
Note 2: Cost drivers are listed in order of appearance on the Delphi survey

Note 3: Intermediate values (Low, High, and Very High) were updated as geometric ratios rather than arithmetic differences. EMRs did not change.

	Very Low	Low	Nominal	High	Very High	Extra High	EMR
Requirements Understanding	1.71	1.31	1.00	0.81	0.65		2.63
Architecture Understanding	1.51	1.23	1.00	0.84	0.71		2.13
Level of Service Requirements	0.66	0.81	1.00	1.36	1.84		2.79
Migration Complexity			1.00	1.20	1.43	1.71	1.71
Technology Maturity	1.75	1.32	1.00	0.82	0.68		2.57
Documentation	0.77	0.88	1.00	1.15	1.32		1.71
# and diversity of installations/platforms			1.00	1.21	1.47	1.78	1.78
# of recursive levels in the design	0.67	0.82	1.00	1.22	1.48		2.21
Stakeholder team cohesion	1.45	1.20	1.00	0.86	0.74		1.96
Personnel/team capability	1.50	1.22	1.00	0.82	0.68		2.21
Personnel experience/continuity	1.54	1.24	1.00	0.82	0.68		2.26
Process capability	1.32	1.15	1.00	0.91	0.83	0.76	1.74
Multisite coordination	1.34	1.16	1.00	0.91	0.83	0.75	1.79
Tool support	1.39	1.18	1.00	0.86	0.74		1.88

Note: Cost drivers are listed in order of EMR value (or influence)

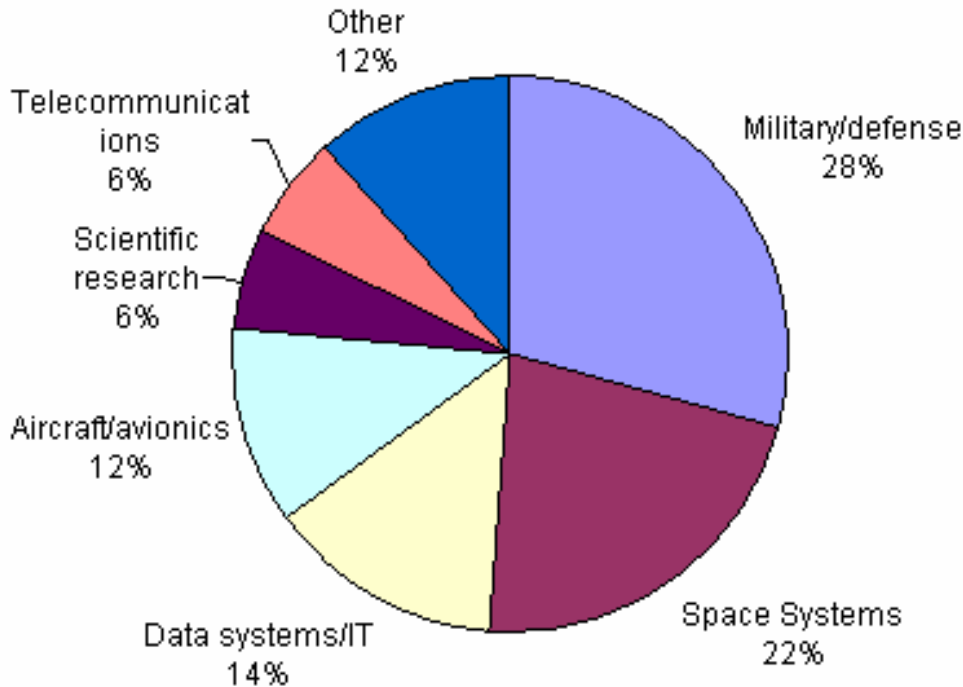
Cost Drivers



Profile of respondents (n=40)

- Average years of SW/SE experience: 18
- Average years of cost modeling experience: 6

Application domains (most respondents selected more than one category):



Other highlights:

- 22% of respondents also participated in Round 1 of the Delphi in January 2002
- 55% of the respondents were from Raytheon, Lockheed Martin, and Northrop Grumman

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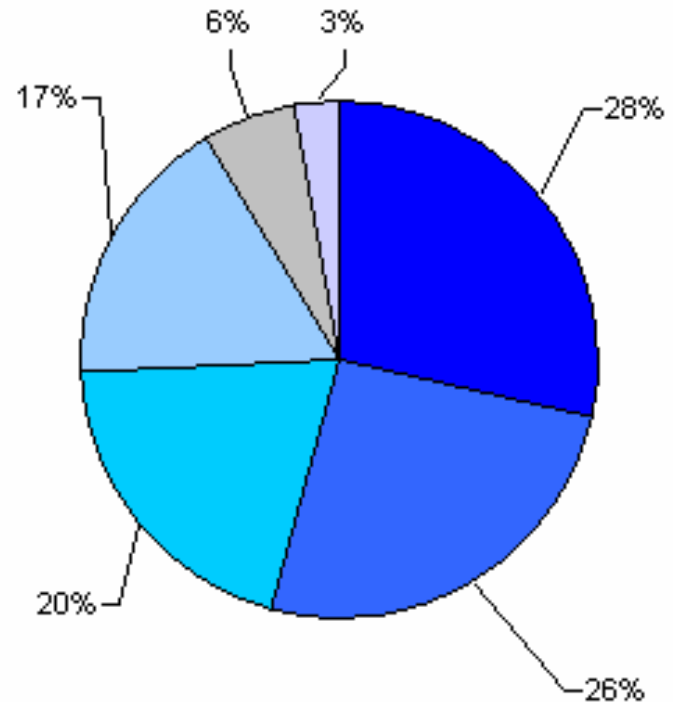
COSYSMO Data Sources

Raytheon	<i>Intelligence & Information Systems (Garland, TX)</i>
Northrop Grumman	<i>Mission Systems (Redondo Beach, CA)</i>
Lockheed Martin	<i>Transportation & Security Solutions (Rockville, MD)</i> <i>Integrated Systems & Solutions (Valley Forge, PA)</i> <i>Systems Integration (Owego, NY)</i> <i>Aeronautics (Marietta, GA)</i> <i>Maritime Systems & Sensors (Manassas, VA)</i>
General Dynamics	<i>Maritime Digital Systems/AIS (Pittsfield, MA)</i> <i>Surveillance & Reconnaissance Systems/AIS (Bloomington, MN)</i>
BAE Systems	<i>National Security Solutions/ISS (San Diego, CA)</i> <i>Information & Electronic Warfare Systems (Nashua, NH)</i>
SAIC	<i>Army Transformation (Orlando, FL)</i> <i>Integrated Data Solutions & Analysis (McLean, VA)</i>

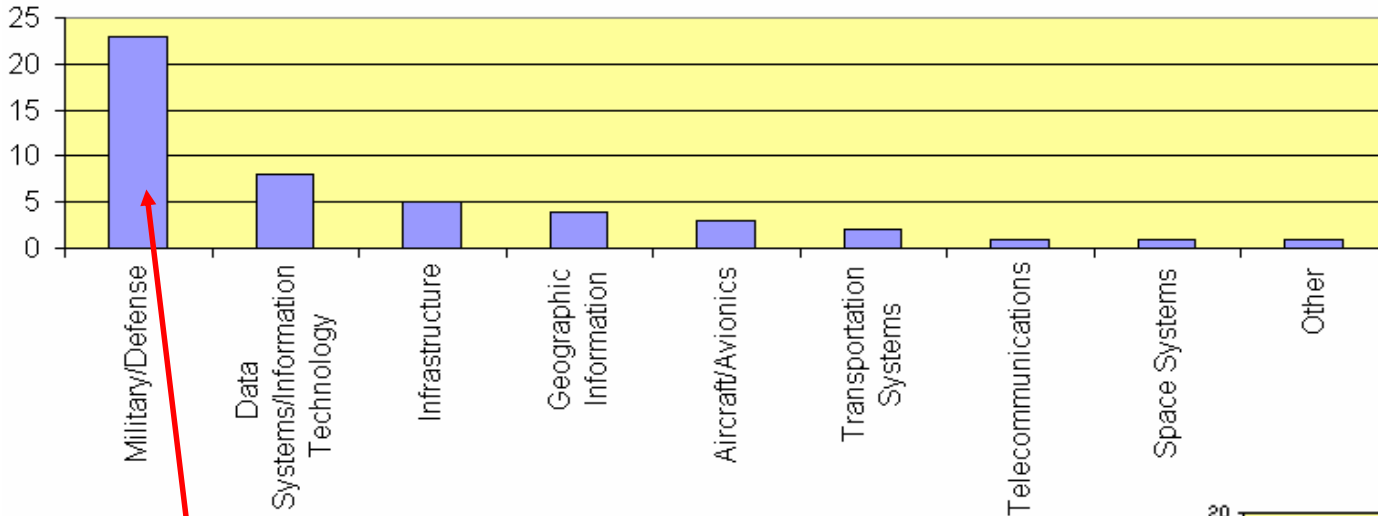
COSYSMO 1.0 Calibration Data Set

- Collected **35** data points
- From **6** companies;
13 business units
- No single company had **> 30%** influence

COSYSMO Data Set Distribution (6 companies)

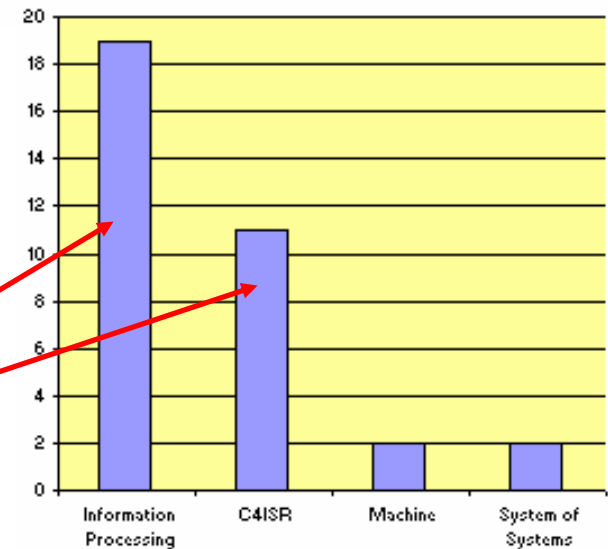


Meta Properties of Data Set

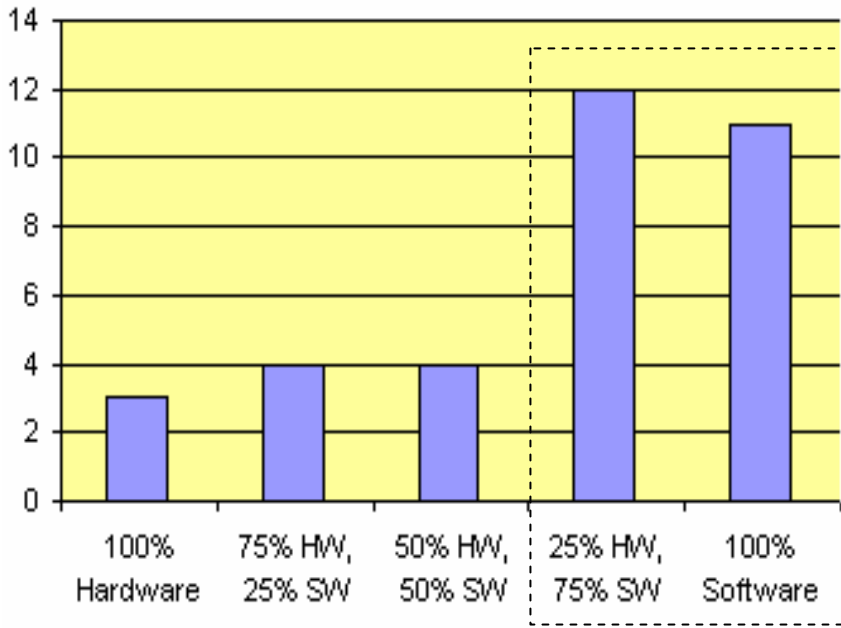


Almost half of the data received was from **Military/Defense** programs

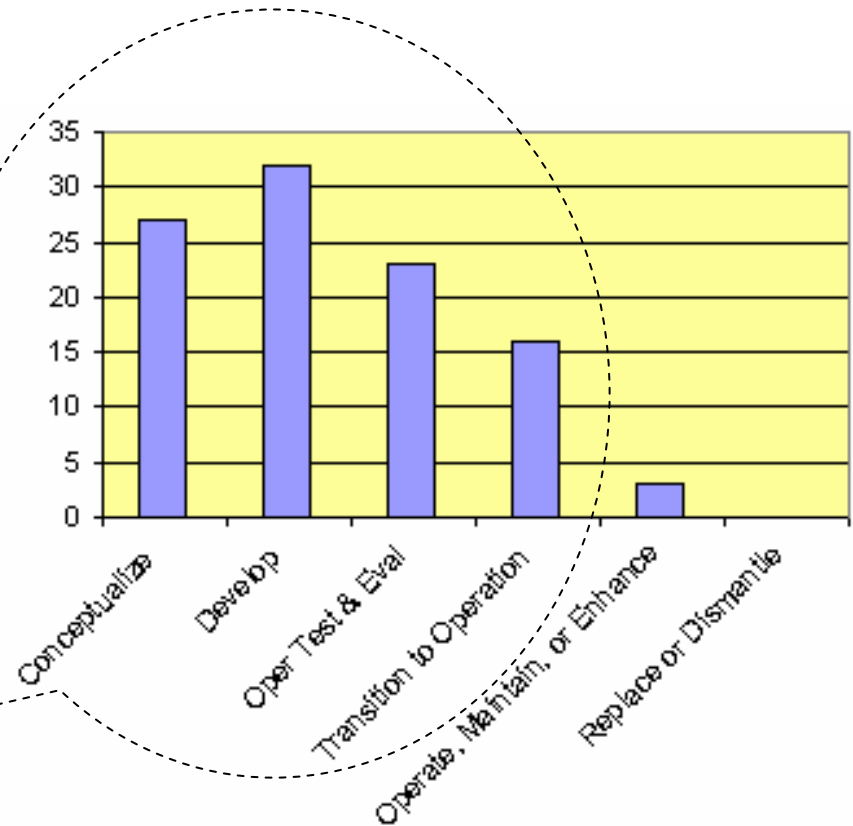
55% was from **Information Processing** systems and 32% was from **C4ISR**



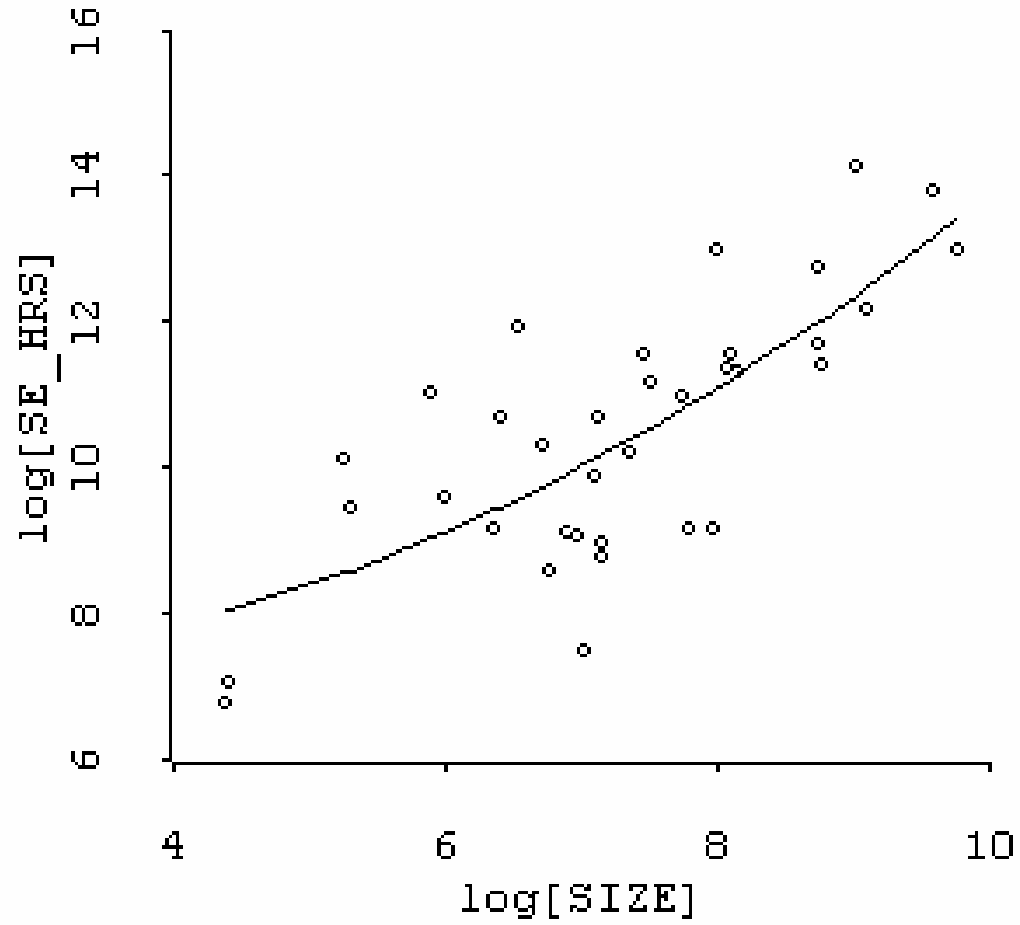
Meta Properties of Data Set



Two-thirds of the projects were **software-intensive**



First **4 phases** of the SE life cycle were adequately covered



Industry Calibration Factor

$$PM_{NS} = A \cdot \left(\sum_k (w_{e,k} \Phi_{e,k} + w_{n,k} \Phi_{n,k} + w_{d,k} \Phi_{d,k}) \right)^E \cdot \prod_{j=1}^{14} EM_j$$

Calculation is based on aforementioned data (n = 35)

$$\ln(SE_HRS) = 3.14 + 1.01 \cdot \ln(Size)$$

$$SE_HRS = 22.87 \cdot Size^{1.01}$$

This calibration factor must be adjusted for each organization

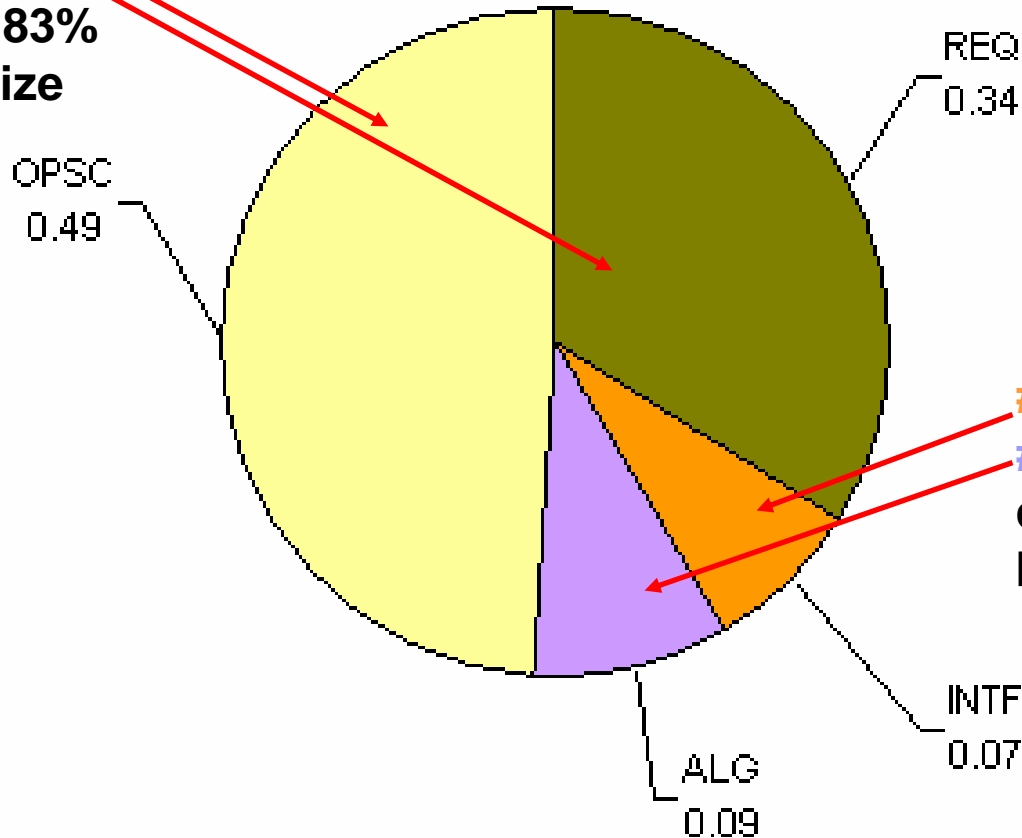
Evidence of diseconomies of scale
(partially captured in Size driver weights)

Size Driver Influence on Functional Size

N = 35

Functional Size Distribution

of scenarios and
of requirements
accounted for 83%
of functional size



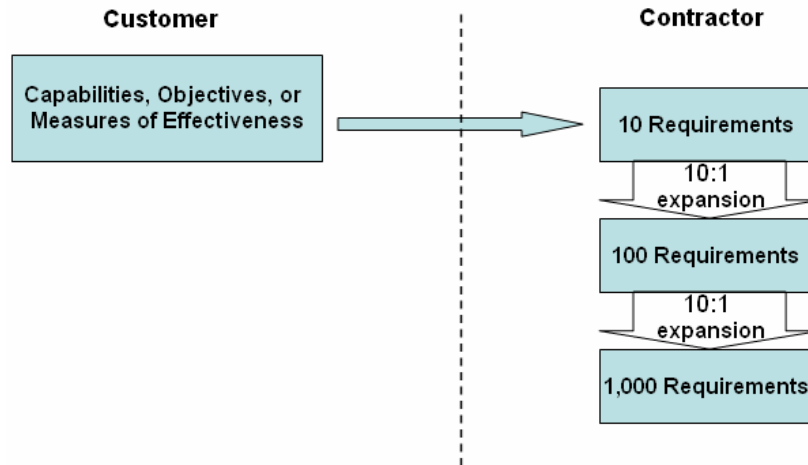
of Interfaces and
of Algorithms
drivers proved to
be less significant

A Day In the Life...

Common problems

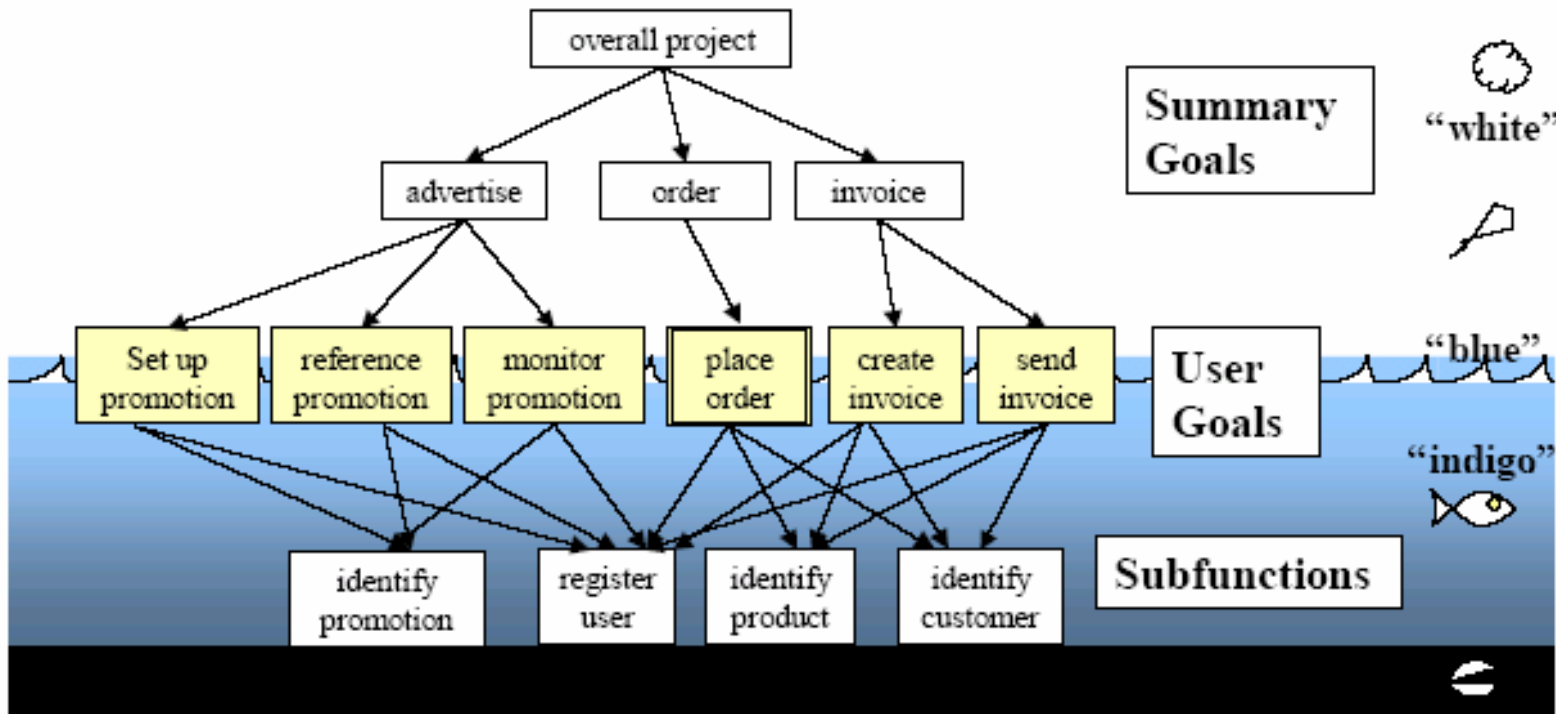
- **Requirements reported at “sky level” rather than “sea level”**
 - Test: if $REQS < OPSC$, then investigate
 - Often too high; requires some decomposition
- **Interfaces reported at “underwater level” rather than “sea level”**
 - Test: if INTF source = pin or wire level, then investigate
 - Often too low; requires investigation of physical or logical I/F

Requirements Evolution



- **Needs and capabilities become formal requirements**
- **Requirements growth can occur as a result of**
 - **Elaboration; clarification and development of needs**
 - **Expansion ratios; evolution between hierarchical levels**
 - **Decomposition; functional breakdown or separation**
 - **Derivation; implied requirements being born**

Cockburn's Use Case Framework



Source: Cockburn, A., *Writing Effective Use Cases*. Boston: Addison-Wesley 2001.

Counting Rules Example

Elaborate COSYSMO example for sky, kite, sea, and underwater levels where:



Sky level: Build an SE cost model



Kite level: Adopt EIA 632 as the WBS and ISO 15288 as the life cycle standard



Sea level: Utilize size and cost drivers, definitions, and counting rules

Underwater level: Perform statistical analysis of data with software tools and implement model in Excel

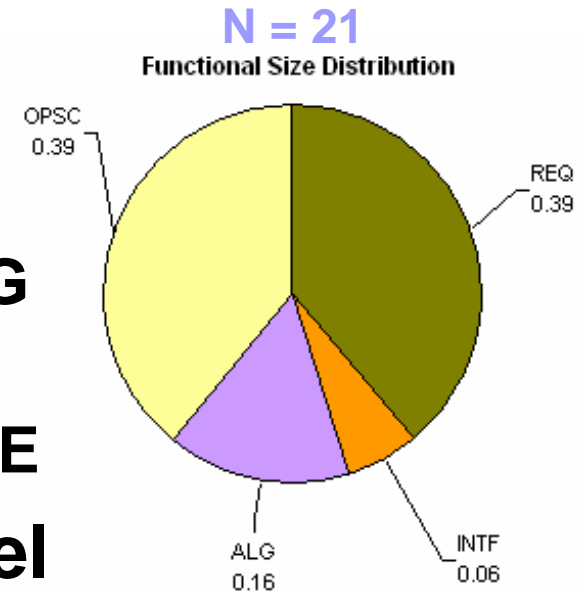
A Day In the Life... (part 2)

Common problems (cont.)

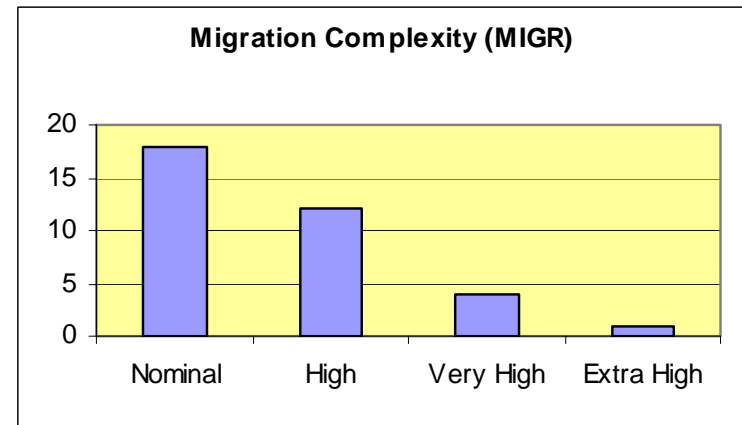
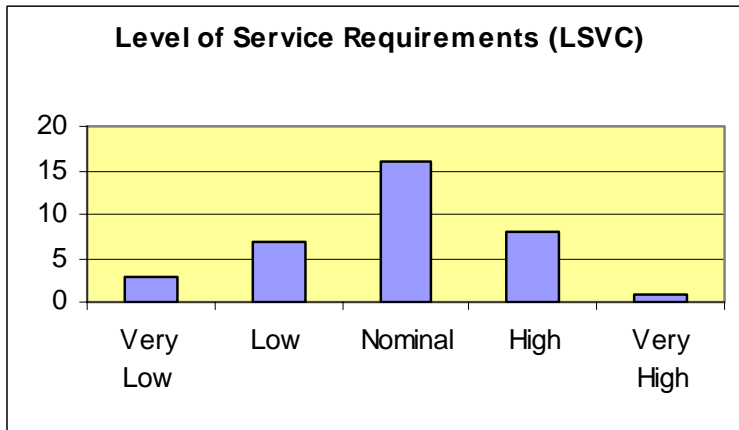
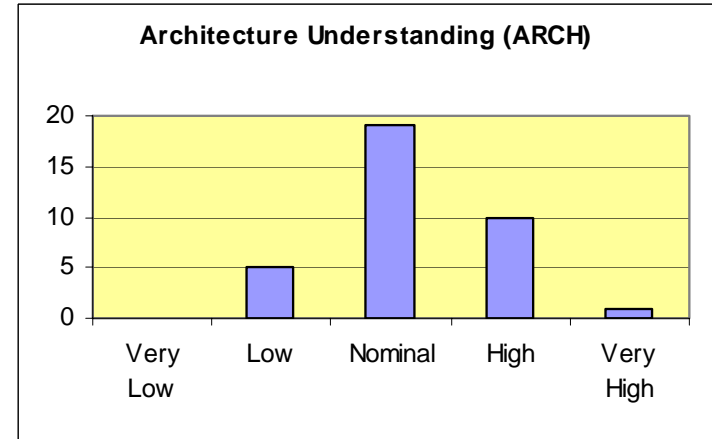
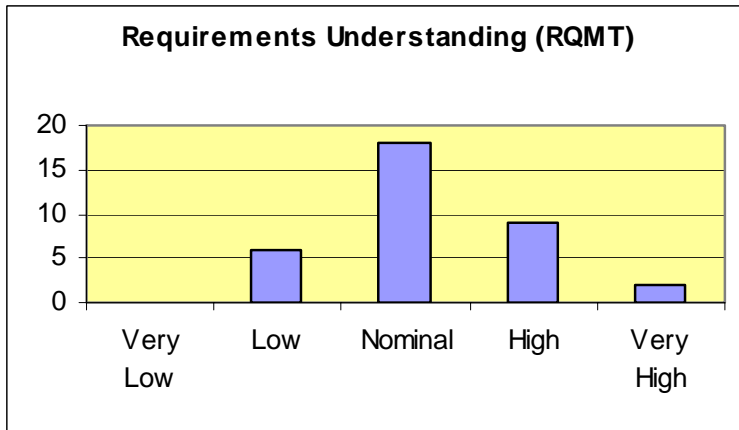
- **Algorithms not reported**
 - Only size driver omitted by 14 projects spanning 4 companies
 - Still a controversial driver; divergent support
- **Operational Scenarios not reported**
 - Only happened thrice (scope of effort reported was very small in all cases)
 - Fixable; involved going back to V&V documentation to extract at least one OPSC

The Case for *Algorithms*

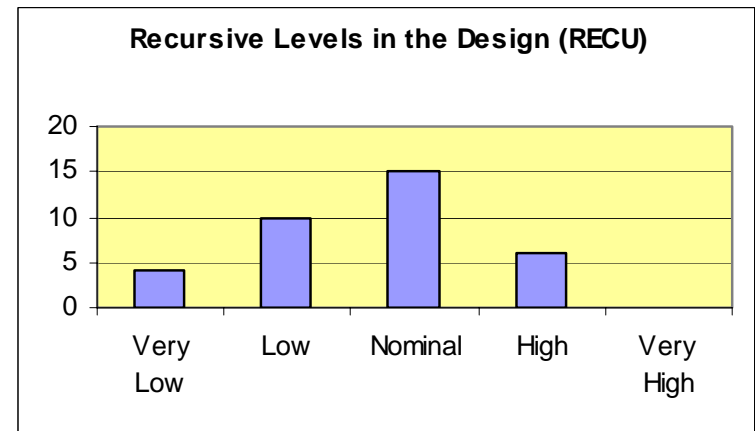
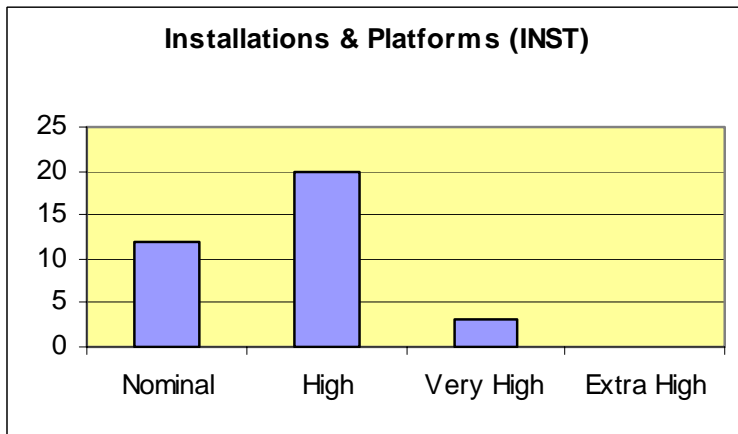
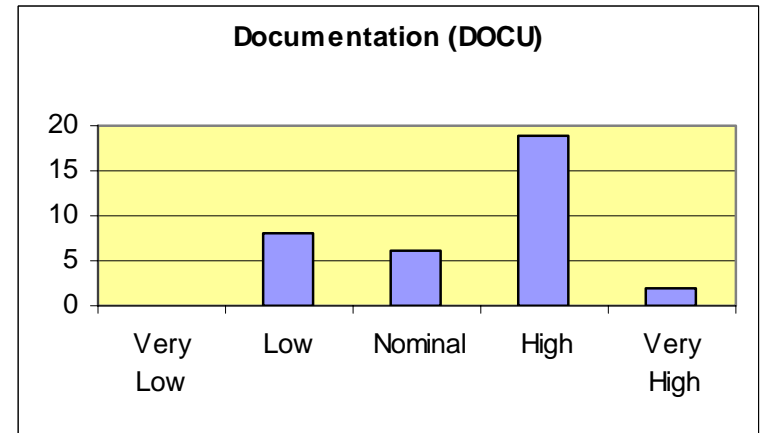
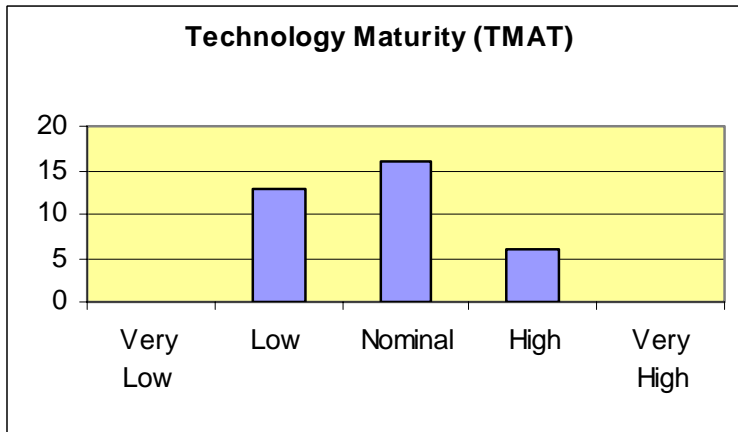
- **Reasons to keep ALG in model**
 - Accounts for 16% of the total size in the 21 projects that reported ALG
 - It is described in the INCOSE SE Handbook as a crucial part of SE
- **Reasons to drop ALG from model**
 - Accounts for 9% of total SIZE contribution
 - Omitted by 14 projects, 4 companies
 - Highly correlated with INTF (0.64)
 - Has a relatively small (0.53) correlation with Size (compared to REQ 0.91, INT 0.69, and OPSN 0.81)



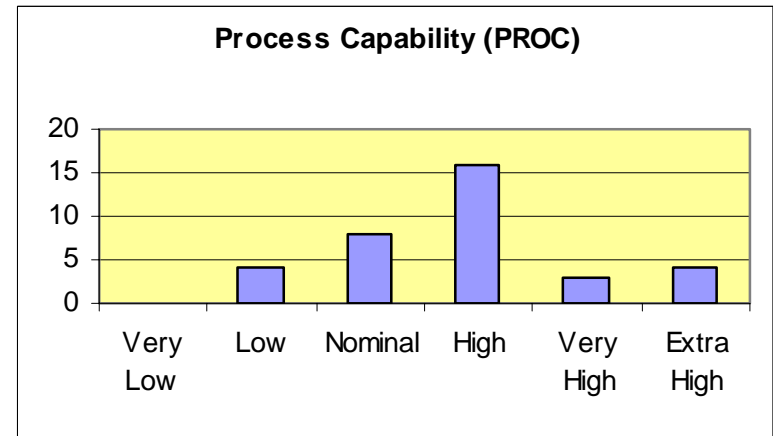
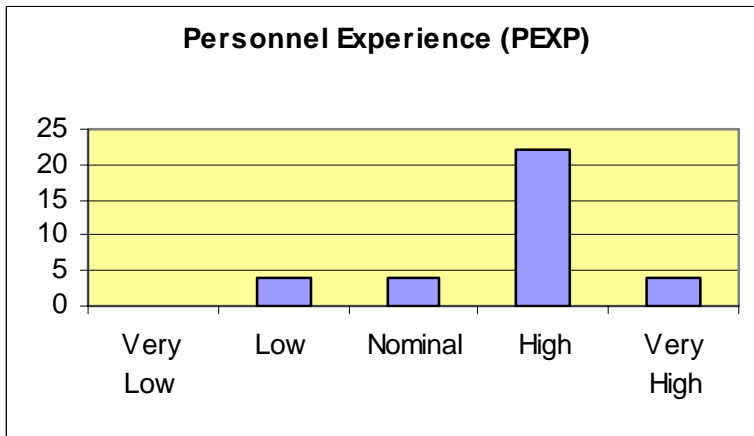
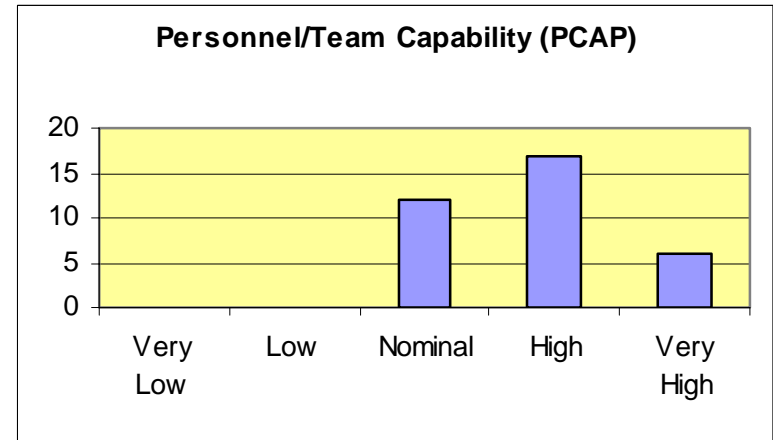
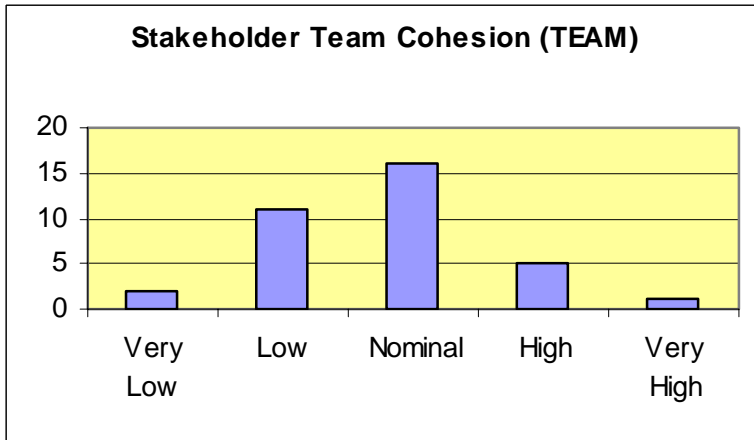
Cost Drivers: Application Factor Distribution (RQMT, ARCH, LSVC, MIGR)



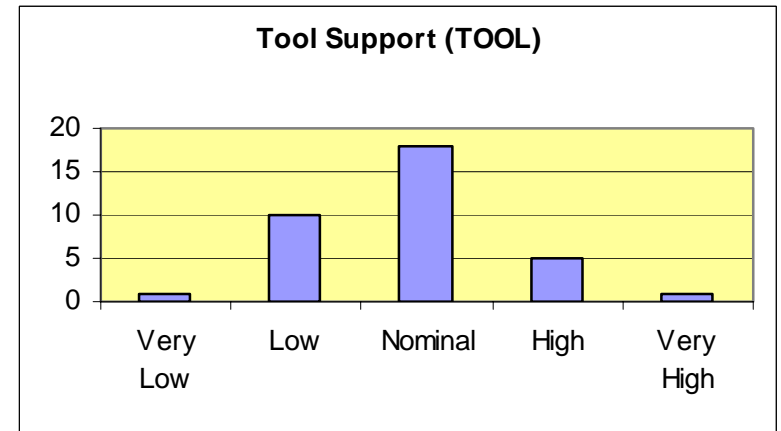
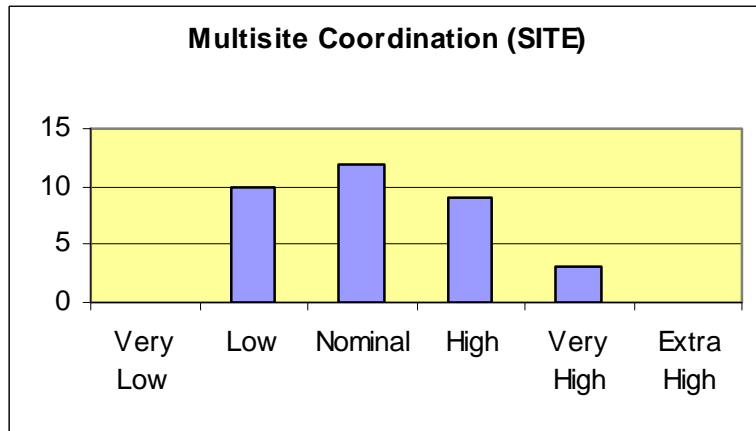
Cost Drivers: Application Factor Distribution (TMAT, DOCU, INST, RECU)



Cost Drivers: Team Factor Distribution (TEAM, PCAP, PEXP, PROC)



Cost Drivers: Team Factor Distribution (SITE, TOOL)



Top 10 Intra Driver Correlations

- **Size drivers correlated to cost drivers**
 - **0.39** Interfaces & # of Recursive Levels in the Design
 - **-0.40** Interfaces & Multi Site Coordination
 - **0.48** Operational Scenarios & # of Recursive Levels in Design
- **Cost drivers correlated to cost drivers**
 - **0.47** Requirements Und. & Architecture Und.
 - **-0.42** Requirements Und. & Documentation
 - **0.39** Requirements Und. & Stakeholder Team Cohesion
 - **0.43** Requirements Und. & Multi Site Coordination
 - **0.39** Level of Service Reqs. & Documentation
 - **0.50** Level of Service Reqs. & Personnel Capability
 - **0.49** Documentation & # of Recursive Levels in Design

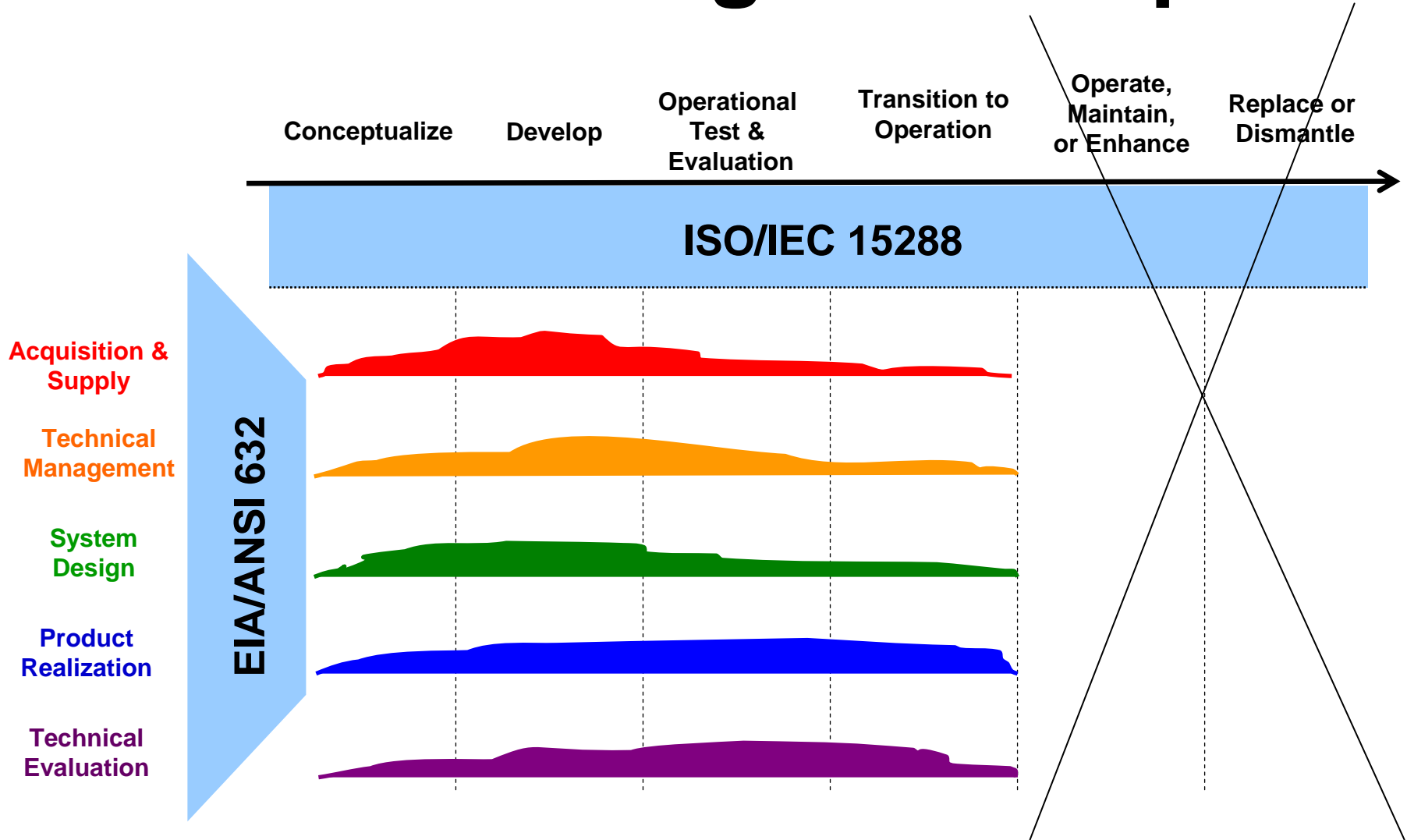
Effort Distribution Across EIA 632 Fundamental Processes

N = 18

EIA 632 Fundamental Process	Average	Standard Deviation
Acquisition & Supply	7%	3.5
Technical Management	17%	4.5
System Design	30%	6.1
Product Realization	15%	8.7
Technical Evaluation	31%	8.7

Total = 100%

Effort Profiling mini-Delphi



Effort Distribution of EIA 632 Fundamental Processes Across ISO 15288 Phases

N = 15

	Conceptualize	Develop	Operational Test & Eval.	Transition to Operation	Operate, Maintain, or Enhance	Replace or Dismantle	(check sum)
Acquisition and Supply	28 (12.3)	51 (18.6)	13 (11.3)	8 (5.0)			100
Technical Management	22 (10.0)	38 (9.9)	25 (7.4)	15 (6.4)			100
System Design	34 (12.4)	40 (19.4)	17 (9.6)	9 (6.2)			100
Product Realization	13 (14.1)	30 (24.3)	32 (16.0)	25 (20.4)			100
Technical Evaluation	18 (11.4)	27 (11.0)	40 (17.7)	15 (8.5)			100

In each cell: Average (Standard Deviation)

Outline

- **Background on CSE and COSYSMO**
- **COSYSMO Overview**
- **Expert Data Results**
- **Historical Project Results**
- **Future Work**
- **Demo**

Limitations of the model

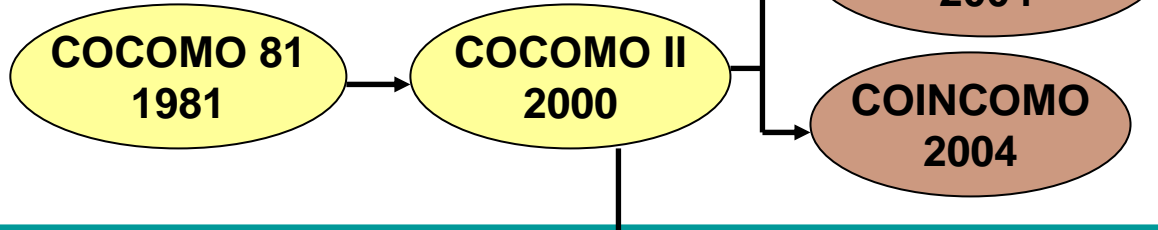
- 1. Mostly qualitative drivers**
- 2. Variance of Delphi responses**
- 3. Ratio of data to parameters is low**
- 4. Aerospace-heavy**
- 5. Good projects share data, bad ones don't**
- 6. Biased by mature organizations**

COSYSMO Invasion

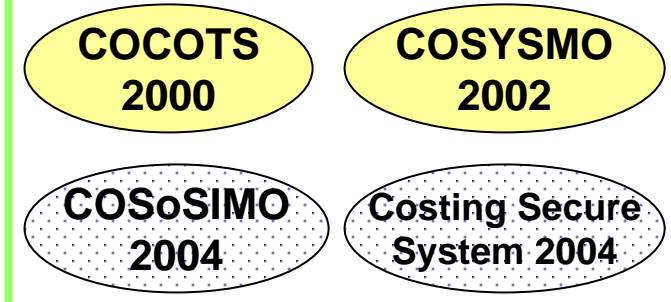
In chronological order:

Developer	Implementation	Availability
Gary Thomas (Raytheon)	<i>my</i> COSYSMO v1.22	Prototype at: www.valerdi.com/cosysmo
Ricardo Valerdi (USC)	<i>Academic</i> COSYSMO	August 2005
John Gaffney (Lockheed Martin)	Risk add-on	Prototype developed, not yet integrated
Dan Liggett (Costar)	<i>commercial</i> COSYSMO	TBD

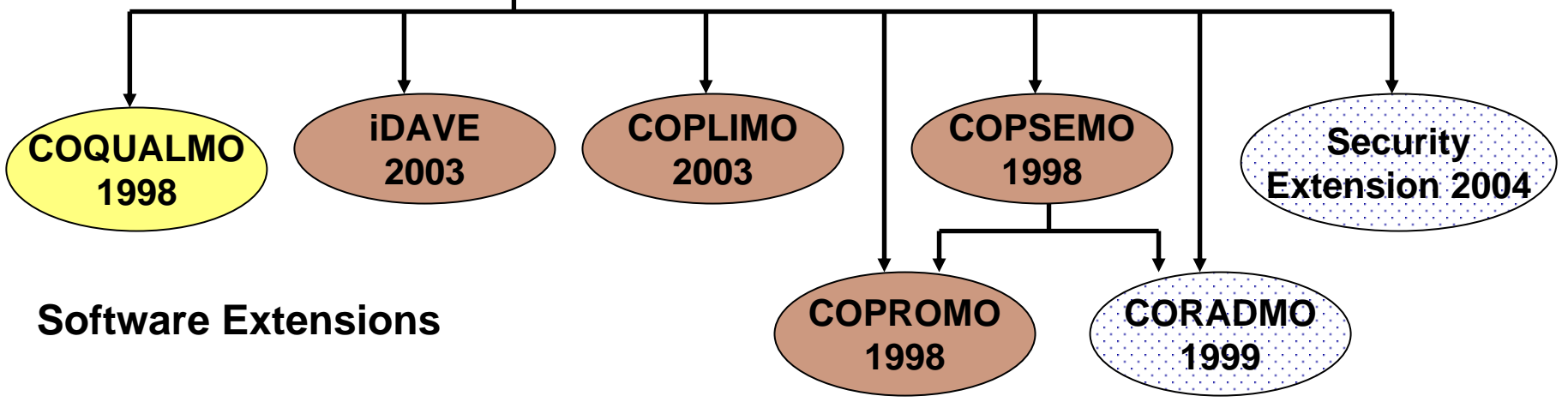
Software Cost Models



Other Independent Estimation Models



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

Contact Information

Ricardo Valerdi

[rvalerdi@sunset.usc.edu]

Websites

<http://www.valerdi.com/cosysmo>

<http://sunset.usc.edu>