COSYSMO

CONSTRUCTIVE SYSTEMS ENGINEERING COST MODEL

Project Status

PSM

Technical Working Group

(presented by Chris Miller)

Herndon, VA

March 26, 2003

Outline

- COSYSMO Overview
  - Operational concept and scope
  - Systems engineering coverage
- Model parameters
  - Size drivers
  - Cost drivers
- Project Information
  - Working sessions
  - Status
  - Key Participants

COSYSMO: Overview

- Parametric model to estimate system engineering costs
- Covers full system engineering lifecycle
- Focused on use for Investment Analysis, Concept Definition phases estimation and tradeoff analyses
  - Input parameters can be determined in early phases

Model Differences

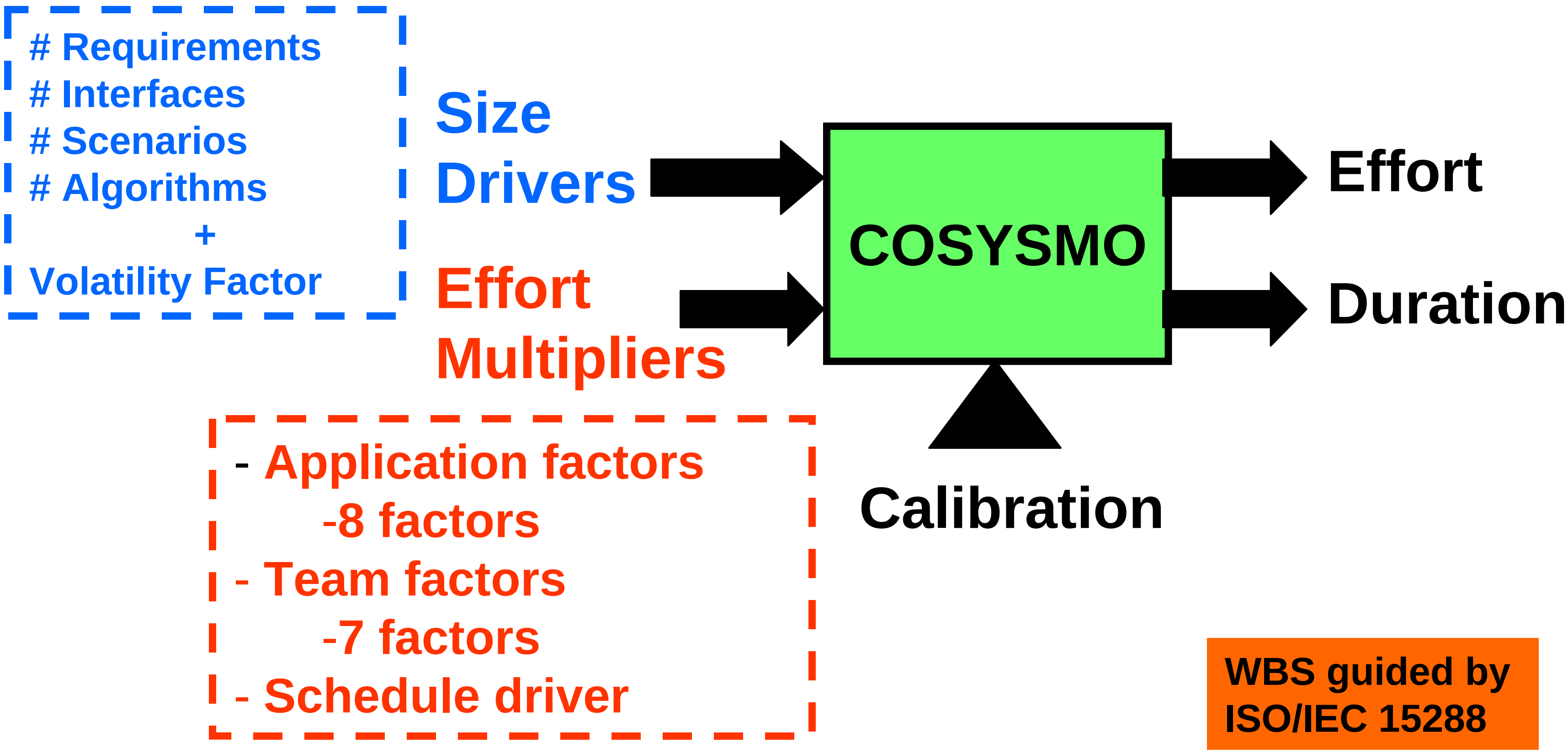
COCOMO II

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

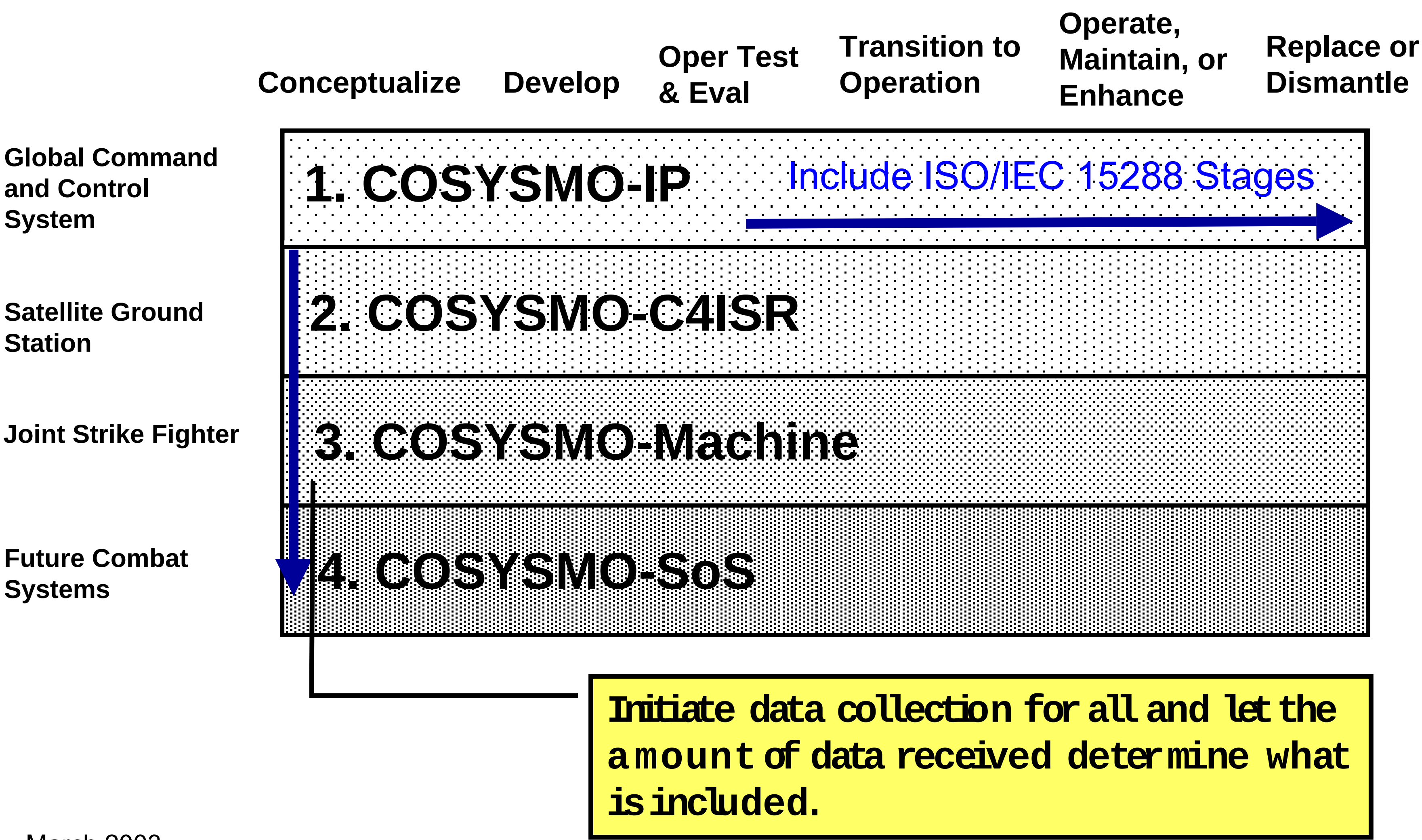
COSYSMO

- Systems Engineering
- Entire Life Cycle
- 2 years old
- 0 calibration points
- 20 drivers
- Fixed granularity
- No anchor points
- Size is driven by requirements, I/F, etc

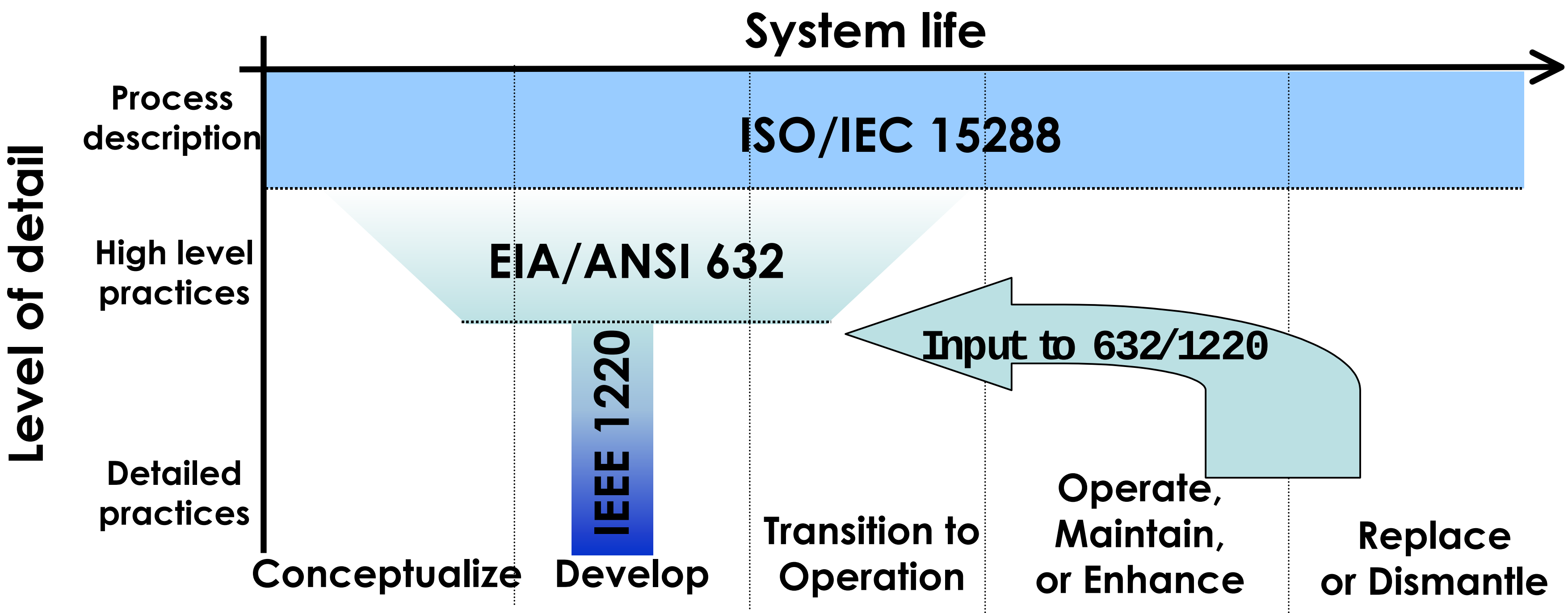
COSYSMO Operational Concept



COSYSMO Life Cycle Scope



Breadth and Depth of Key SE Standards



Purpose of the Standards:

ISO/IEC 15288 - *Establish a common framework for describing the life cycle of systems*

EIA/ANSI 632 - *Provide an integrated set of fundamental processes to aid a developer in the engineering or re-engineering of a system*

IEEE 1220 - *Provide a standard for managing systems engineering*

Source : Draft Report ISO Study Group May 2, 2000

4 Size Drivers

1. Number of System Requirements
2. Number of Major Interfaces
3. Number of Operational Scenarios
4. Number of Unique Algorithms

- Each weighted by complexity, volatility, and degree of reuse

15 Cost Drivers

Application Factors (8)

1. Requirements understanding
2. Architecture complexity
3. Level of service requirements
4. Migration complexity
5. Technology Risk
6. Technology Obsolescence
7. # and diversity of installations/platforms
8. # of recursive levels in the design

15 Cost Drivers (cont.)

Team Factors (7)

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

Working Sessions

- Barry Boehm introduced COSYSMO project to PSM at PSM Users group conference 2001 (Aspen, CO)
- Working sessions are held in conjunction with existing annual events:
  - INCOSE IW (February)
  - USC Annual Research Review (March) *(just held March 17,2003)*
  - PSM Users Group Conference (July)
  - USC COCOMO Conference (October)
- Next working session will be July, 2003 at the PSM Users Group Conference (Keystone, CO)

Status

- **Project website** (http://www.valerdi.com/cosysmo) **contains:**
  - Project Plan
  - Past briefings and presentations
  - Status reports
- **March Working Session focused on:**
  - Refining size and cost driver definitions
- **Next Steps include:**
  - Developing a data collection strategy
  - Generating a data collection form
  - Resolution of action items

March Workshop - Action Items

1. Include definition of SE role in data collection form
2. Develop candidate list of anchor points
3. Develop data collection instrument
4. Schedule follow-up teleconference
5. Reconcile model with Ernstoff's SE Products

March Workshop - Action Items(cont.)

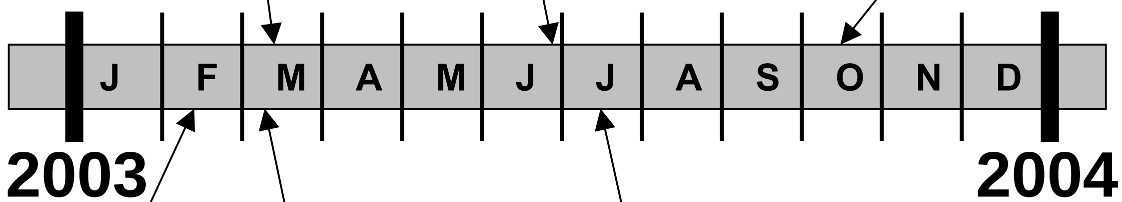
6. Update drivers
   – Migration complexity
   – Personnel capability
   – Process maturity
   – Collaboration barriers
   – # of recursive levels in the design
   – Formality of deliverables
7. Perform Delphi Round 2

Calendar of Activities: 2003

★ **USC CSE Annual Research Review**
(Los Angeles, CA)

INCOSE 2003
(Washington, DC)

★ **COCOMO Forum**
(Los Angeles, CA)



★ **INCOSE IW**
(Tampa, FL)

Conference on Systems Integration
(Hoboken, NJ)

★ **Practical Software & Systems Measurement Workshop**
(Keystone, CO)

★ **Working Group Meeting**

Key Members of the COSYSMO Working Group

Aerospace Corp.	Karen Owens, *Marilee Wheaton*
Galorath	Evin Stump
LMCO	*Garry Roedler*, Gary Hafen
Raytheon	*Gary Thomas*, *John Rieff*
SAIC	Tony Jordano, *Don Greenlee*
SPC	*Chris Miller*
US Army/PSM	Cheryl Jones
USC	*Barry Boehm*, *Elliot Axelband*, *Don Reifer*, *Ricardo Valerdi*

Italics = SE experience

Points of Contact

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Current Proposed set of Size and Cost Driver Definitions (as of 3/16/2003)

Note: The following description DO NOT reflect refinements made during the March 17th working session

COCOMO-based Parametric Cost Estimating Relationship

$$PM_{NS} = A \cdot (Size)^{E} \cdot \prod_{i=1}^{n} EM_{i}$$

Where:

PM$_{NS}$ = effort in Person Months (Nominal Schedule)

A = constant derived from historical project data

Size = determined by computing the weighted average of the size drivers

E = exponent for the diseconomy of scale dependent on size drivers (4)

n = number of cost drivers (16)

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

4 Size Drivers

1. Number of System Requirements
2. Number of Major Interfaces
3. Number of Operational Scenarios
4. Number of Unique Algorithms

- Each weighted by complexity, volatility, and degree of reuse

Number of System Requirements

This driver represents the number of requirements that are typically taken from the system or marketing specification. It may be functional, performance, feature, or service-oriented in nature depending on the methodology used for specification. System requirements can typically be quantified by counting the number of applicable "shall's" or "will's" in the system or marketing specification.

Easy	Nominal	Difficult
- Well specified	- Loosely specified	- Poorly specified
- Traceable to source	- Can be traced to source with some effort	- Hard to trace to source
- Simple to understand	- Takes some effort to understand	- Hard to understand
- Little requirements overlap	- Some overlap	- High degree of requirements overlap
- Familiar	- Generally familiar	- Unfamiliar
- Good understanding of what's needed to satisfy and verify requirements	- General understanding of what's needed to satisfy and verify requirements	- Poor understanding of what's needed to satisfy and verify requirements

Number of Major Interfaces

This driver represents the number of shared major 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 interfaces identified in either the system's context diagram and/or by counting the significant interfaces in all applicable Interface Control Documents.

Easy	Nominal	Difficult
- Well defined	- Loosely defined	- Ill defined
- Uncoupled	- Loosely coupled	- Highly coupled
- Cohesive	- Moderate cohesion	- Low cohesion
- Well behaved	- Predictable behavior	- Poorly behaved

Number of Operational Scenarios

This driver represents the number of operational scenarios that a system must satisfy. Such threads typically result in end-to-end test scenarios that are developed to validate the system satisfies all of its requirements. The number of scenarios can typically be quantified by counting the number of end-to-end tests used to validate the system functionality and performance. They can also be calculated by counting the number of high-level use cases developed as part of the operational architecture.

Easy	Nominal	Difficult
- Well defined	- Loosely defined	- Ill defined
- Few end-to-end scenarios (< 10)	- Modest no. of end-to-end scenarios ($10 < OS \leq 30$)	- Many end-to-end scenarios (> 30)
- Timelines not an issue	- Timelines a constraint	- Tight timelines through scenario network

Number of Unique 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 support each of the mathematical functions specified in the system specification or mode description document (for sensor-based systems).

Easy	Nominal	Difficult
- Existing algorithms	- Some new algorithms	- Many new algorithms
- Basic math	- Algebraic by nature	- Difficult math (calculus)
- Straightforward structure	- Nested structure with decision logic	- Recursive in structure with distributed control
- Simple data	- Relational data	- Persistent data
- Timing not an issue	- Timing a constraint	- Dynamic, with timing issues
- Library-based solution	- Some modeling involved	- Simulation and modeling involved

16 Cost Drivers

Application Factors (6)

1. Requirements understanding
2. Architecture complexity
3. Level of service requirements
4. Migration complexity
5. Technology Risk
6. Technology Obsolescence

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…

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

Architecture complexity

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 undefined areas	Reasonable understanding of architecture and COTS, some weak areas	Strong understanding of architecture and COTS, few undefined areas	Full understanding of architecture, familiar system and COTS
	2 level WBS	3-4 level WBS	5-6 level WBS	>6 level WBS

Level of service (KPP) requirements

This cost driver rates the difficulty and criticality of satisfying the ensemble of Key Performance Parameters (KPP), such as security, safety, response time, interoperability, maintainability, the "illities", etc…

	Very low	Low	Nominal	High	Very High
Difficulty	Simple	Low difficulty, coupling	Moderately complex, coupled	Difficult, coupled KPPs	Very complex, tightly coupled
Criticality	Slight inconvenience	Easily recoverable losses	Some loss	High financial loss	Risk to human life

Migration complexity

This cost driver rates the complexity of migrating the system from previous system components, databases, workflows, etc, due to new technology introductions, planned upgrades, increased performance, business process reengineering etc…

Very low	Low	Nominal	High	Very High
		Introduction of requirements is transparent	Difficult to upgrade	Very difficult to upgrade

Technology Maturity/Readiness

The maturity and readiness of the technology being implemented.

Viewpoint	Very Low	Low	Nominal	High	Very High
Technology Maturity	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
Technology Readiness Level	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)

Technology Obsolescence

Obsolescence characteristics of the technology which require added systems engineering effort.

Viewpoint	Very Low	Low	Nominal	High	Very High
Technology Obsolescence Level			- Technology is the state-of-the-practice - Emerging technology could compete in future	- Technology is stale - New and better technology is on the horizon in the near-term	- Technology is outdated and use should be avoided in new systems - Spare parts supply is scarce

16 Cost Drivers (cont.)

Team Factors (10)

1. Stakeholder team cohesion
2. Personnel capability
3. Personnel experience/continuity
4. Process maturity
5. Multisite coordination
6. Formality of deliverables
7. Tool support
8. # and diversity of installations/platforms
9. # of recursive levels in the design
10. # of years in operational life cycle

Stakeholder team cohesion

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

Very Low	Low	Nominal	High	Very High
▪Highly heterogeneous stakeholder communities with diverse objectives ▪Multiple stakeholders with diverse expertise, task nature, language, culture, infrastructure ▪System involving major changes in stakeholder roles & responsibilities	▪Heterogeneous stakeholder community with converging organizational objectives ▪System involves some changes in stakeholder roles & responsibilities	▪Common shared organizational objectives ▪Functional team	▪Strong team cohesion ▪High stakeholder trust level ▪Clear roles & responsibilities	▪Virtually homogeneous stakeholder communities ▪Institutionalized, shared project culture ▪Strong team dynamics

Personnel capability

Basic intellectual capability 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 over the life of the project with respect to the customer, user, technology, domain, 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	3%	6%	12%	24%	48%

Process maturity

Maturity per EIA/IS 731, SE CMM or CMMI.

	Very low	Low	Nominal	High	Very High	Extra High
CMMI	Level 1 (lower half)	Level 1 (upper half)	Level 2	Level 3	Level 4	Level 5
EIA731		Initial	Managed	Defined	Quantitatively Managed	Optimizing, continuous improvement

Multisite coordination

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

	Very low	Low	Nominal	High	Very High	Extra High
Collocation	International	Multi-city and multi-national	Multi-city or multi-company	Same city or metro area	Same building or complex, some co-located stakeholders or onsite represetation	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
Collaboration barriers	Multiple languages, severe time zone impact	Some language and export, security restrictions considerable time zone impact	Some contractual & Intellectual property constraints, some time zone effects	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

Formality of deliverables

The breadth and depth of documentation required to be formally delivered.

	Very low	Low	Nominal	High	Very High
Breadth	General goals	Broad guidance, flexibility is allowed	Streamlined processes, some relaxation	Partially streamlined process, some conformity with occasional relaxation	Rigorous, follows customer requirements
Depth	best effort for documentation and review requirments	Relaxed documentation and review requirements relative to life cycle needs	Amount of documentation and reviews in sync and consistent with life cycle needs of the program	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

Tool support

Experience and practice using the tools in the System 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 process	Strong, mature SE tools, moderately integrated with other disciplines	Strong, mature proactive SE tools integrated with process, model-based SE and management systems

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
Sites/installations	Few # of installations or many similar installations	Moderate # of installations or some amount of multiple types of installations	Numerous # of installations with many unique aspects
Operating environment	Not a driving factor	Moderate environmental constraints	Multiple complexities/constraints caused by operating environment
No. of Different Platforms	Few types of platforms (< 5) being installed and/or being phased out/replaced	Modest # and types of platforms (5 < P <10) being installed and/or being phased out/replaced	Many types of platforms (> 10) being installed and/or being phased out/replaced
	Homogeneous	Mixed	Heterogeneous
	Typically networked using a single protocol	Typically networked using several consistent protocols	Typically networked using different protocols

of recursive levels in the design

Viewpoint	Low	Nominal	High
	Maintaining system baseline with few planned upgrades	Sustaining SE for the product line, introducing some enhancements of product design features or optimizing performance and/or cost	Maintaining multiple configurations or enhancements with extensive pre-planned product improvements or new requirements, evolving
Percent	Delphi	Delphi	Delphi

of years in operational life cycle

Viewpoint	N	H	VH
Sites/installations	Few # of installations or many similar installations	Moderate # of installations or some amount of multiple types of installations	Numerous # of installations with many unique aspects
Operating environment	Not a driving factor	Moderate environmental constraints	Multiple complexities/constraint s caused by operating environment
# of Different Platforms	Few platforms (< 5)	Modest no. of platforms (5 < P <10)	Many platforms (> 10)
	Homogeneous	Mixed	Heterogeneous
	Typically networked using a single protocol	Typically networked using several consistent protocols	Typically networked using different protocols