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# Risk Expert Tool for Systems Engineering


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# Agenda

- COSYSMO Introduction
- Expert COSYSMO Overview
- Systems Engineering Effectiveness Measures (Barry Boehm)
- Expert COSYSMO Project Implementation
  - Process and Measurement Frameworks
- Group Case Studies
- Wrap-up and Next Steps

# Introduction

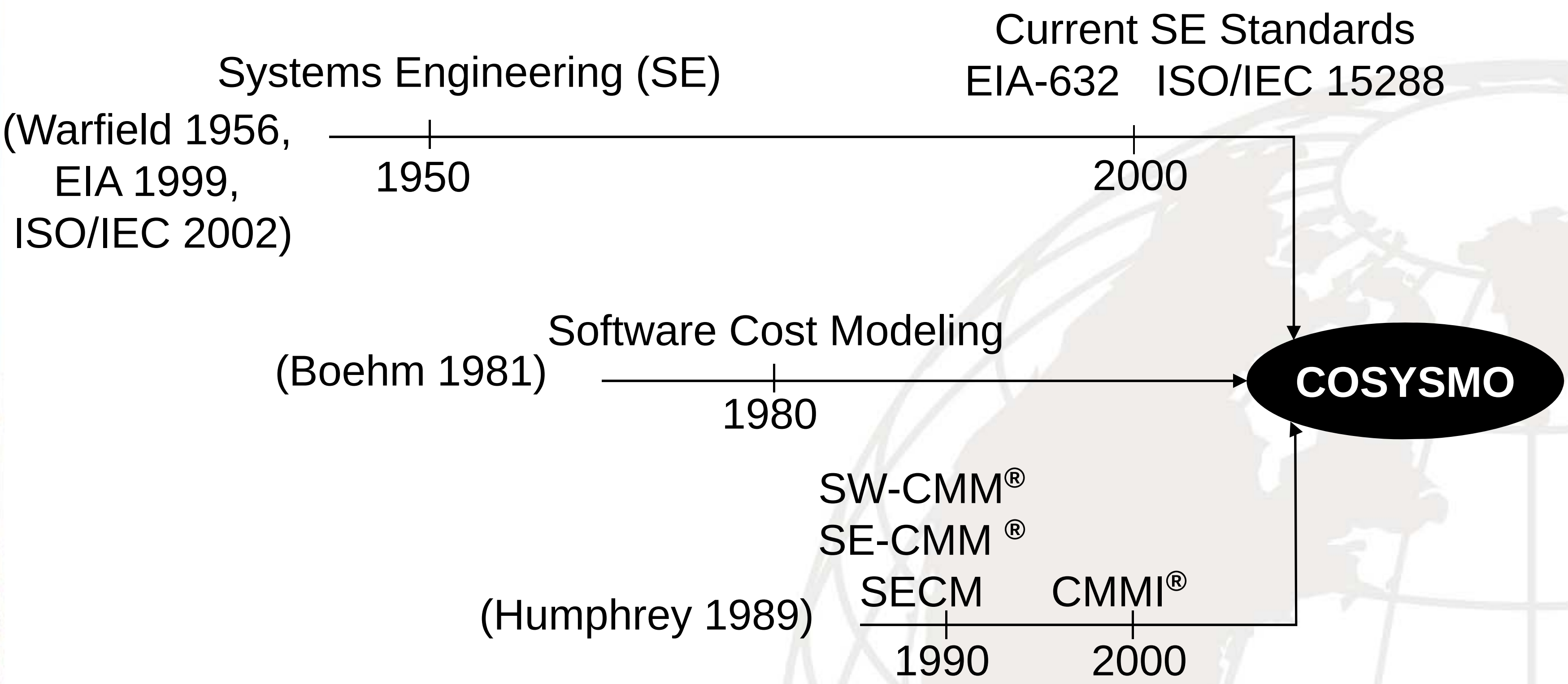
- The Constructive Systems Engineering Cost Model (COSYSMO) is a parametric cost estimation model for systems engineering effort [Valerdi 2005]
- <u>Constructive</u>: a user can tell why the model gives the estimate it does, and helps the systems engineer understand the job that needs to be done
- Expert COSYSMO leverages on the same cost factors to identify, quantify and mitigate risks
- The dual nature of Expert COSYSMO extends the constructiveness into risk management

# Systems Engineering Processes

- **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

EIA/ANSI 632, *Processes for Engineering a System*, 1999.
Note: The requirements of EIA/ANSI 632 are addressed in ISO/IEC 15288, which was also used as a Source for consistent definition in COSYSMO.

# COSYSMO Origins

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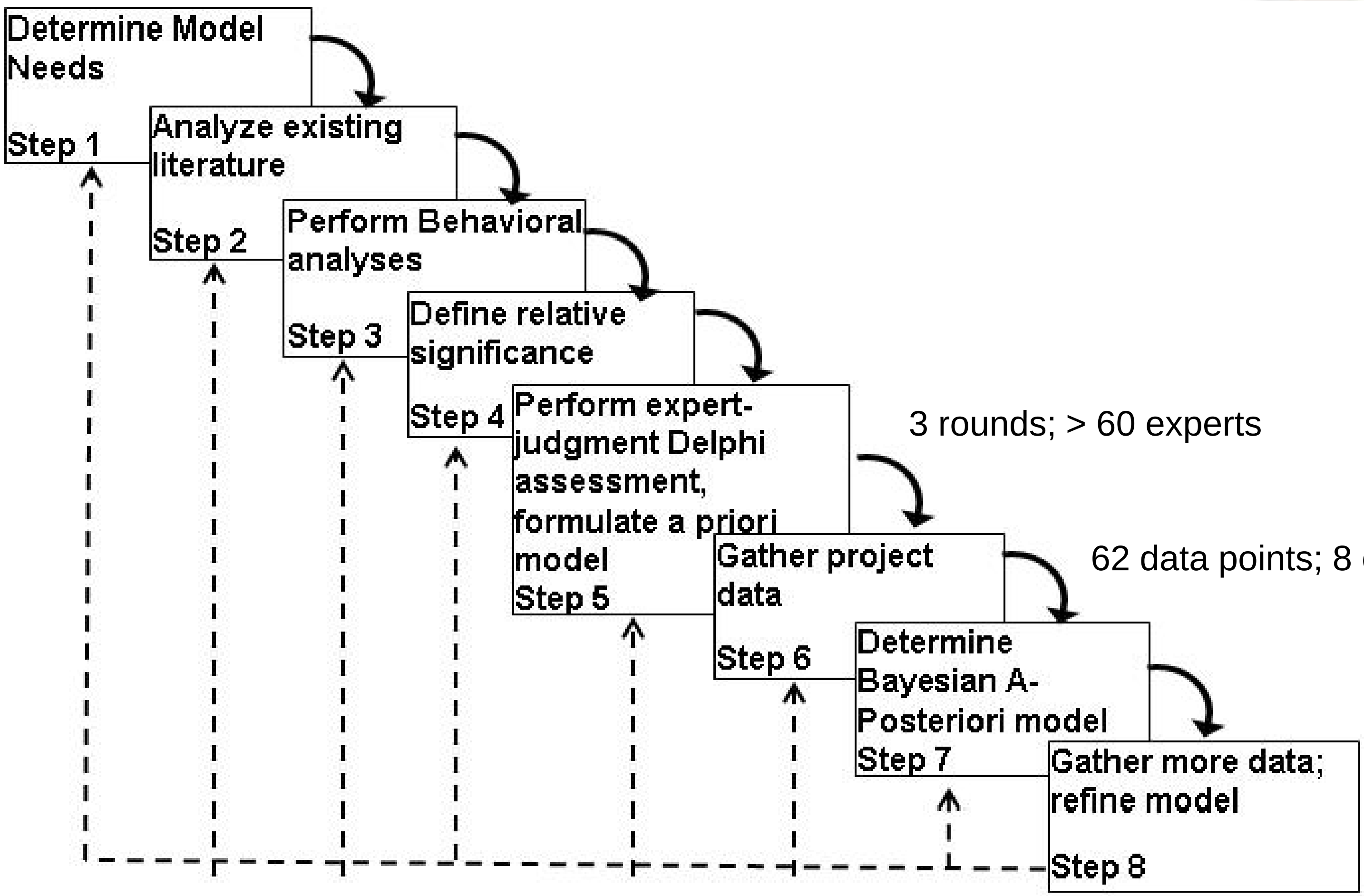
Warfield, J. N., *Systems Engineering*, United States Department of Commerce PB111801, 1956.
Boehm, B. W., *Software Engineering Economics*, Prentice Hall, 1981.
Humphrey, W. *Managing the Software Process*. Addison-Wesley, 1989.
EIA/ANSI 632, Processes for Engineering a System, 1999
ISO/IEC 15288, System Life Cycle Processes, 2002.

# COSYSMO Data Sources

| | |
|---|---|
| Boeing | *Integrated Defense Systems (Seal Beach, CA)* |
| Raytheon | *Intelligence & Information Systems (Garland, TX)* |
| Northrop Grumman | *Mission Systems (Redondo Beach, CA)* |
| Lockheed Martin | *Transportation & Security Solutions (Rockville, MD)*<br>*Integrated Systems & Solutions (Valley Forge, PA)*<br>*Systems Integration (Owego, NY)*<br>*Aeronautics (Marietta, GA)*<br>*Maritime Systems & Sensors (Manassas, VA; Baltimore, MD; Syracuse, NY)* |
| General Dynamics | *Maritime Digital Systems/AIS (Pittsfield, MA)*<br>*Surveillance & Reconnaissance Systems/AIS (Bloomington, MN)* |
| BAE Systems | *National Security Solutions/ISS (San Diego, CA)*<br>*Information & Electronic Warfare Systems (Nashua, NH)* |
| SAIC | *Army Transformation (Orlando, FL)*<br>*Integrated Data Solutions & Analysis (McLean, VA)* |
| L-3 Communications | *Greenville, TX* |

# Modeling Methodology

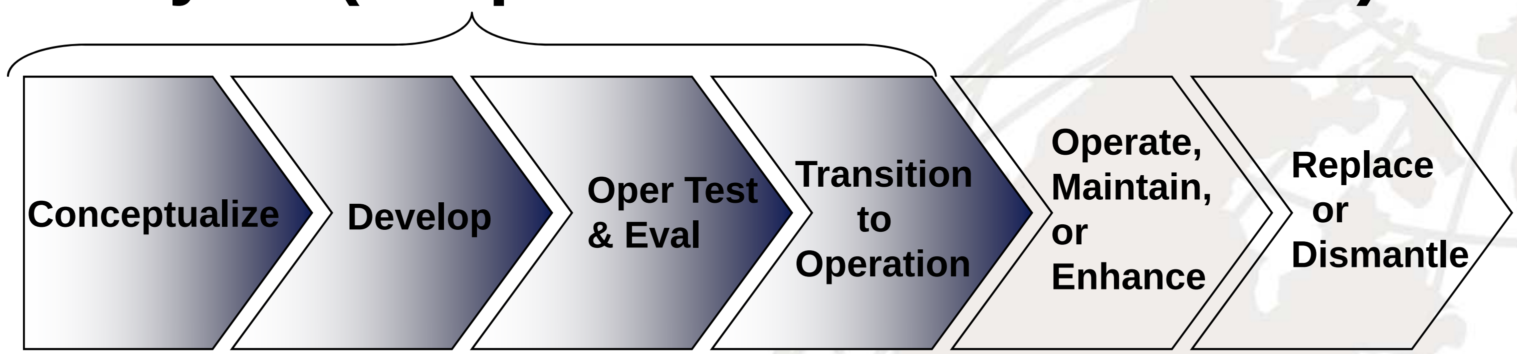



3 rounds; > 60 experts

62 data points; 8 organizations

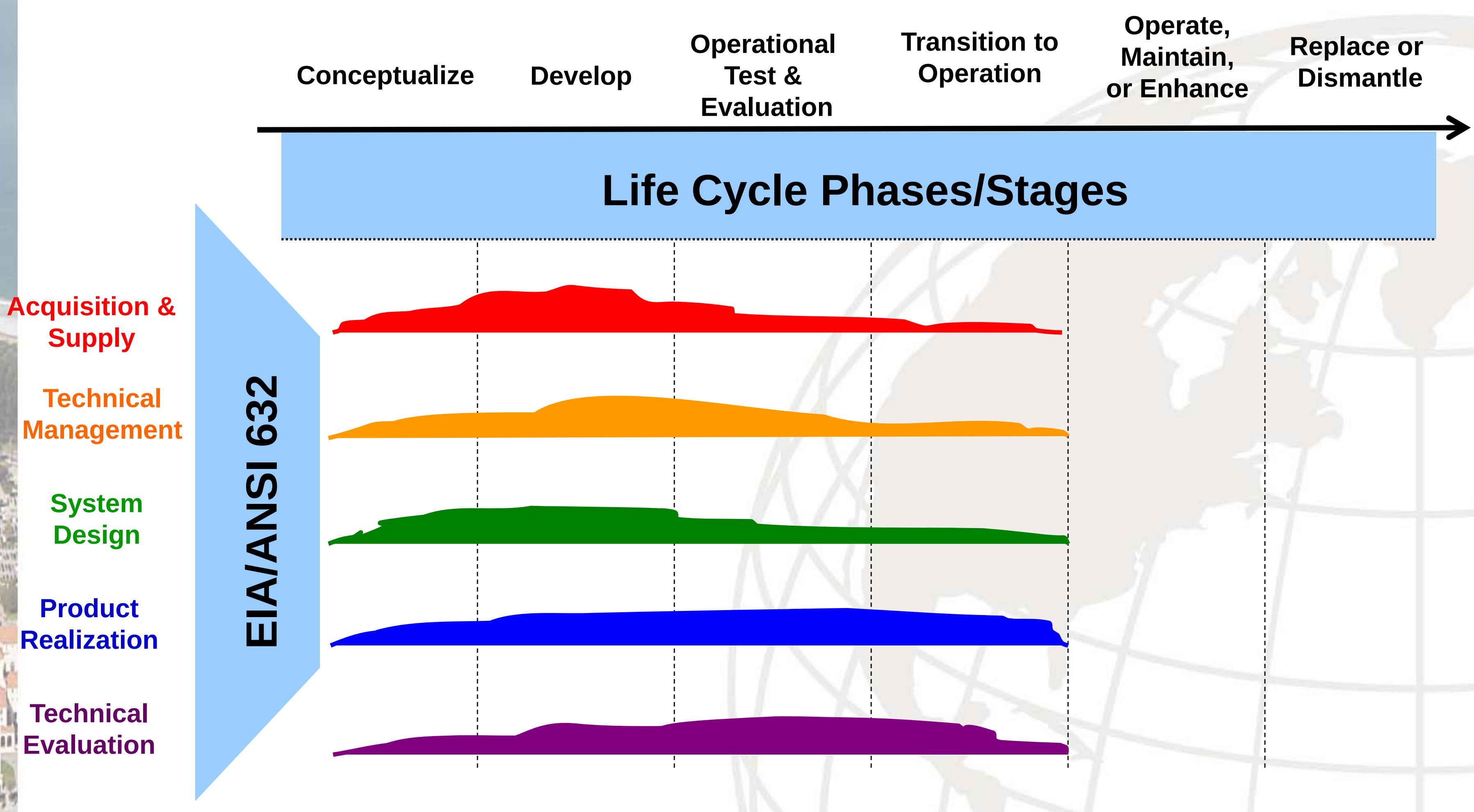
# COSYSMO Scope

- **Addresses <u>first four phases</u> of the system lifecycle (adapted from ISO/IEC 15288)**

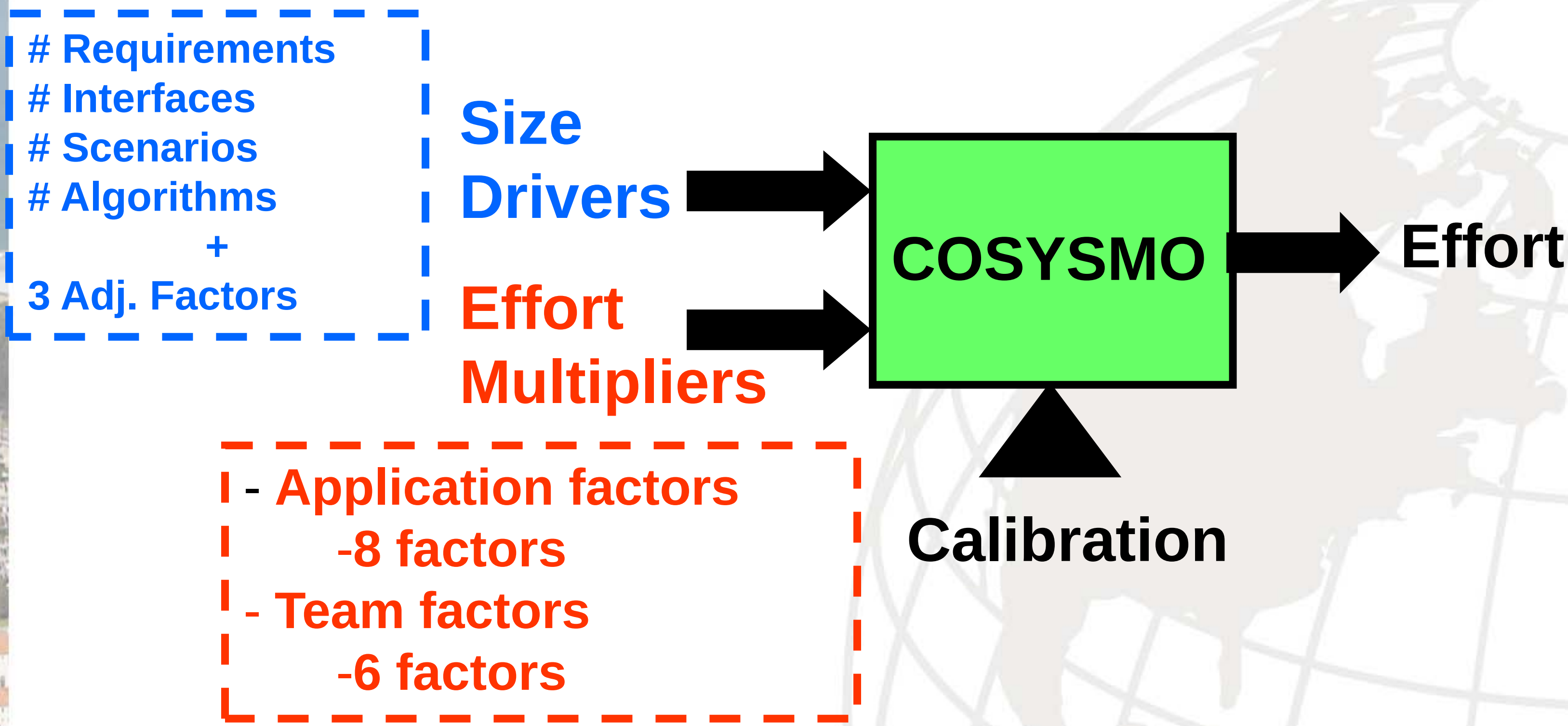



- **Considers standard Systems Engineering Work Breakdown Structure tasks (per EIA/ANSI 632)**

# Effort Profiling



# COSYSMO Operational Concept



# Size Drivers vs. Effort Multipliers

- Size Drivers: Additive, Incremental
  - Impact of adding a new item inversely proportional to current size
    - 10 -> 11 rqts = 10% increase
    - 100 -> 101 rqts = 1% increase
- Effort Multipliers: Multiplicative, system-wide
  - Impact of adding a new item independent of current size
    - 10 rqts + high security = 40% increase
    - 100 rqts + high security = 40% increase

# COSYSMO 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

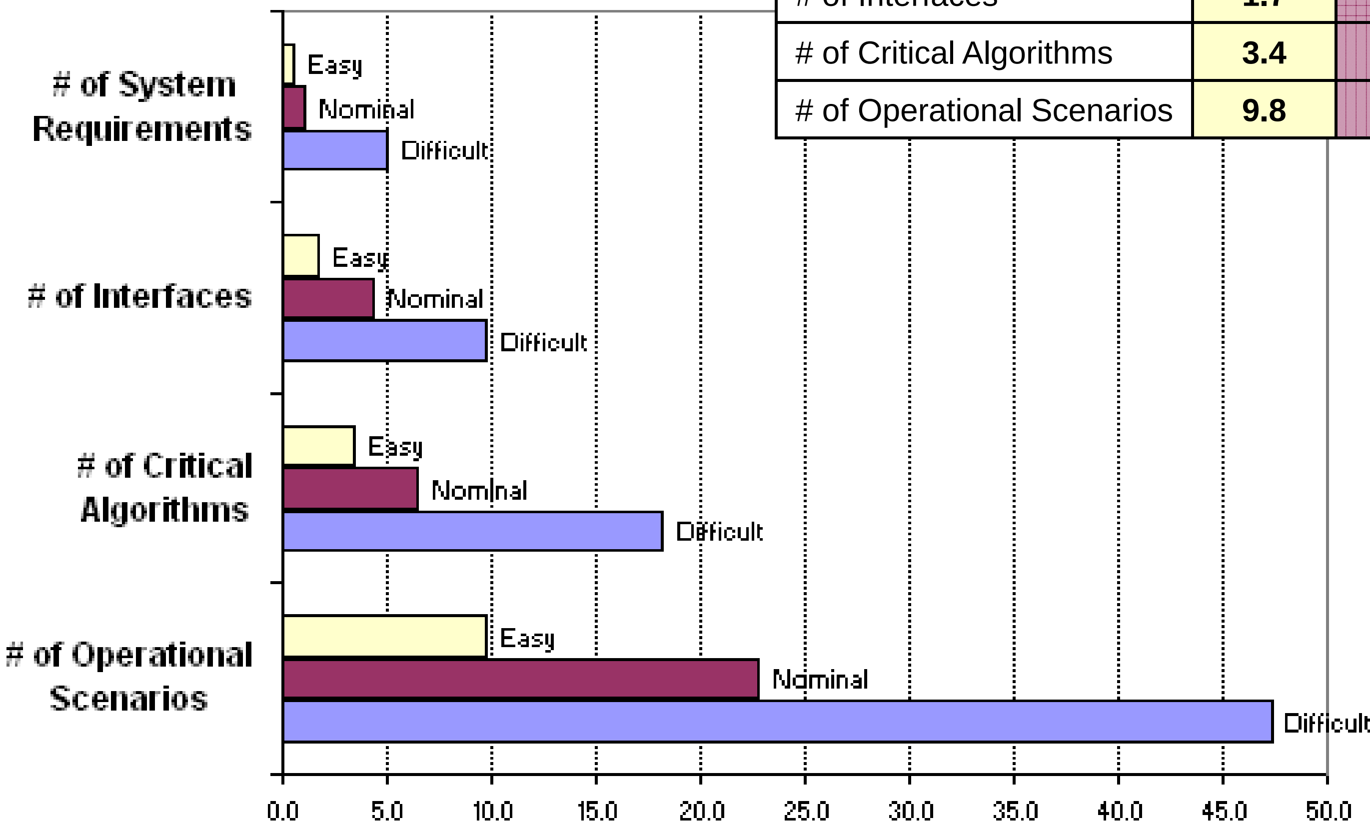
$\Phi_x$ = quantity of “k” size driver

**E** = represents diseconomies of scale

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

# Size Driver Weights

| | Easy | Nominal | Difficult |
|---|---|---|---|
| # of System Requirements | 0.5 | 1.00 | 5.0 |
| # of Interfaces | 1.7 | 4.3 | 9.8 |
| # of Critical Algorithms | 3.4 | 6.5 | 18.2 |
| # of Operational Scenarios | 9.8 | 22.8 | 47.4 |

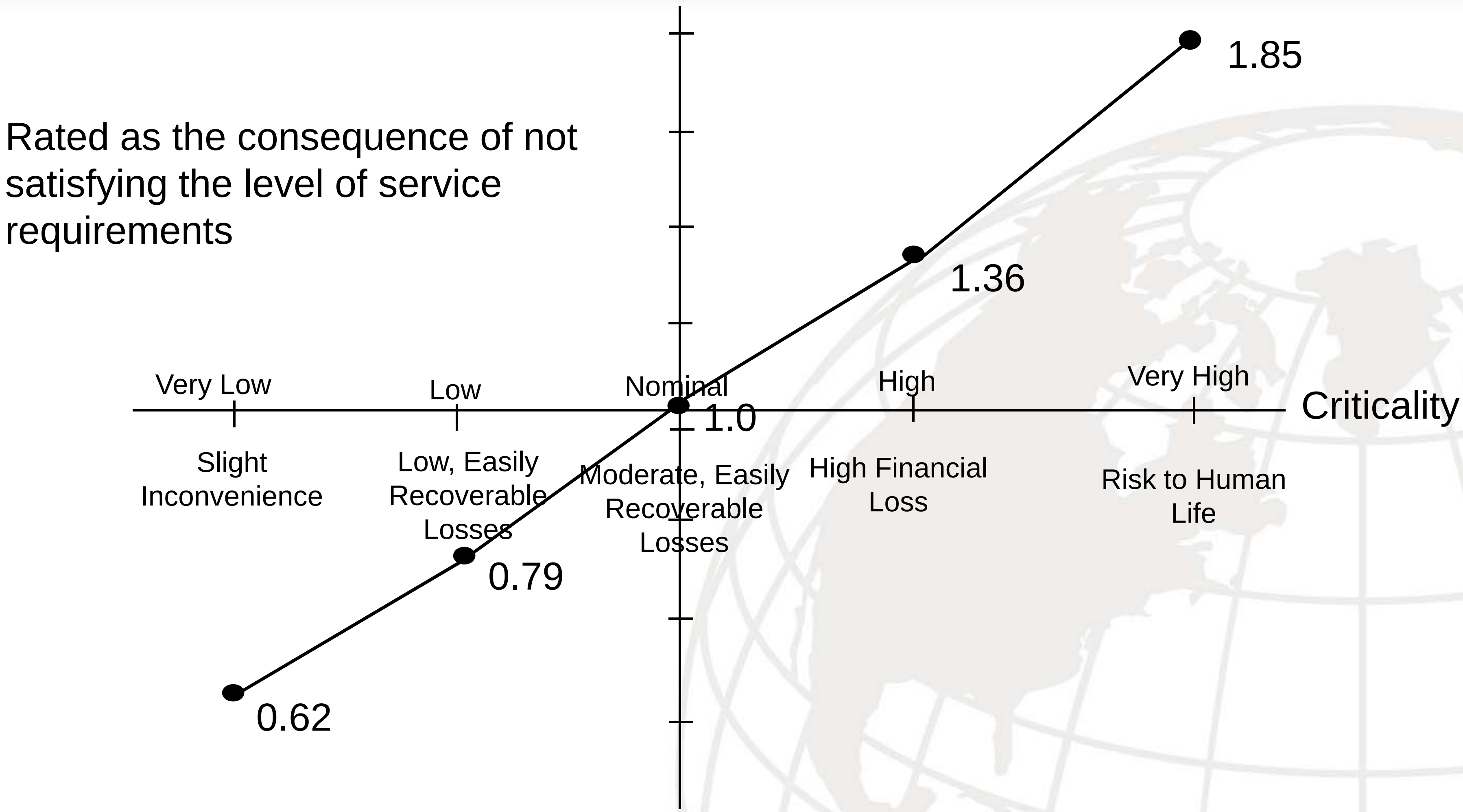


# Cost Driver Rating Scales and Effort Multipliers

| | Very Low | Low | Nominal | High | Very High | Extra High | EMR |
|---|---|---|---|---|---|---|---|
| Requirements Understanding | 1.87 | 1.37 | 1.00 | 0.77 | 0.60 | | 3.12 |
| Architecture Understanding | 1.64 | 1.28 | 1.00 | 0.81 | 0.65 | | 2.52 |
| Level of Service Requirements | 0.62 | 0.79 | 1.00 | 1.36 | 1.85 | | 2.98 |
| Migration Complexity | | | 1.00 | 1.25 | 1.55 | 1.93 | 1.93 |
| Technology Risk | 0.67 | 0.82 | 1.00 | 1.32 | 1.75 | | 2.61 |
| Documentation | 0.78 | 0.88 | 1.00 | 1.13 | 1.28 | | 1.64 |
| # and diversity of installations/platforms | | | 1.00 | 1.23 | 1.52 | 1.87 | 1.87 |
| # of recursive levels in the design | 0.76 | 0.87 | 1.00 | 1.21 | 1.47 | | 1.93 |
| Stakeholder team cohesion | 1.50 | 1.22 | 1.00 | 0.81 | 0.65 | | 2.31 |
| Personnel/team capability | 1.50 | 1.22 | 1.00 | 0.81 | 0.65 | | 2.31 |
| Personnel experience/continuity | 1.48 | 1.22 | 1.00 | 0.82 | 0.67 | | 2.21 |
| Process capability | 1.47 | 1.21 | 1.00 | 0.88 | 0.77 | 0.68 | 2.16 |
| Multisite coordination | 1.39 | 1.18 | 1.00 | 0.90 | 0.80 | 0.72 | 1.93 |
| Tool support | 1.39 | 1.18 | 1.00 | 0.85 | 0.72 | | 1.93 |

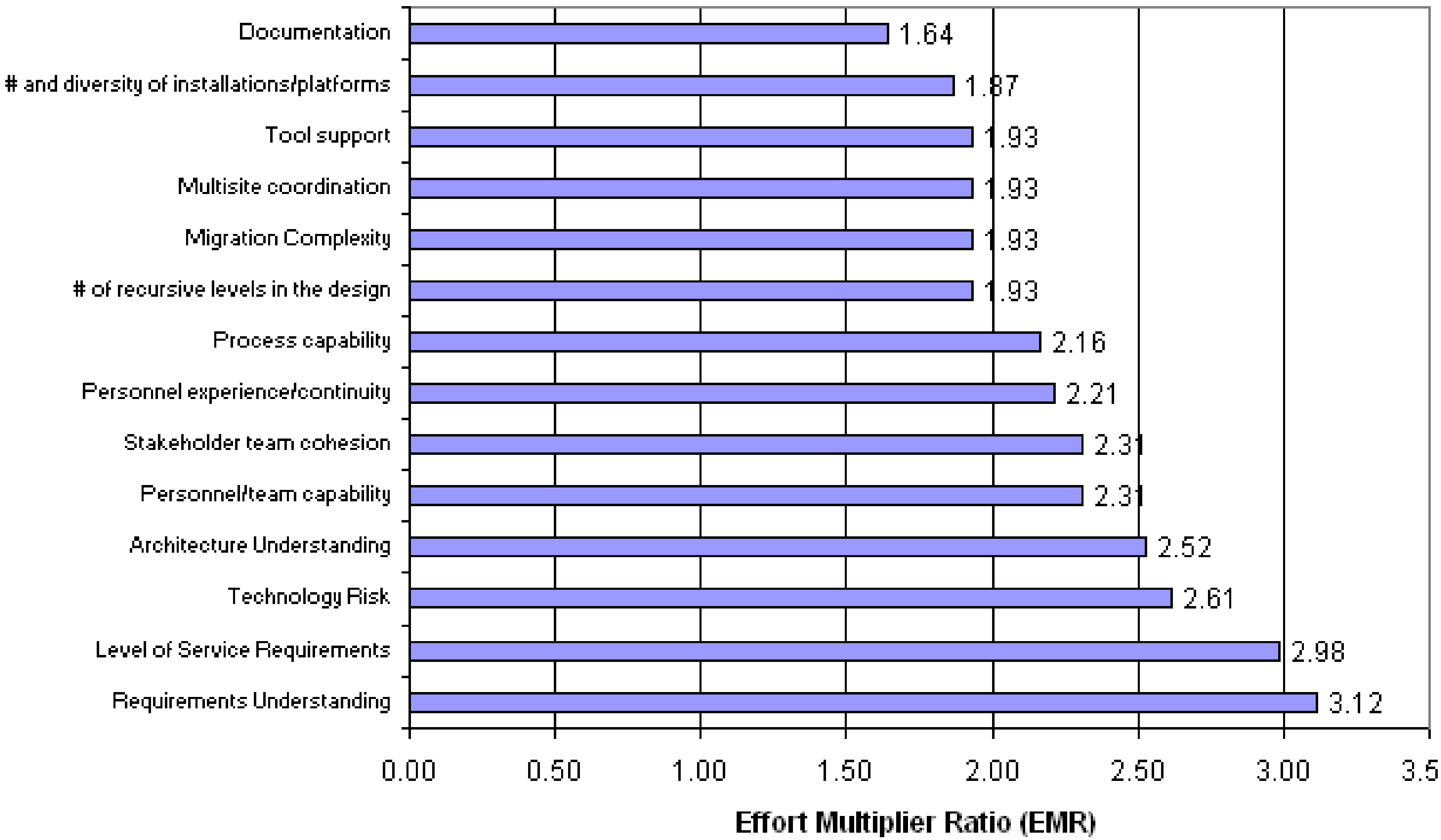
EMR = Effort Multiplier Ratio

# Example Effort Multiplier Values for Level of Service Requirements




E.g. a very highly critical system costs 85% more than a nominally reliable system (1.85/1.0=1.85) or a very highly critical system costs 198% more than one rated very low (1.85/.62=2.98)

# Cost Driver Productivity Ranges



# 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**

# of System Requirements

**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 is 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

**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

**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 |

# # of Operational Scenarios

**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** |

# Cost Driver Clusters

UNDERSTANDING FACTORS
- Requirements understanding
- Architecture understanding
- Stakeholder team cohesion
- Personnel experience/continuity

COMPLEXITY FACTORS
- Level of service requirements
- Technology Risk
- # of Recursive Levels in the Design
- Documentation Match to Life Cycle Needs

OPERATIONS FACTORS
- # and Diversity of Installations/Platforms
- Migration complexity

PEOPLE FACTORS
- Personnel/team capability
- Process capability

ENVIRONMENT FACTORS
- Multisite coordination
- Tool support

**Criteria**
**+ Matched driver polarity**
**+ Grouped by theme**
**+ Combined moderately correlated parameters**

# Cost Drivers

*Application Factors (8)*

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

# Requirements Understanding

**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

**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 unfamilar 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

**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 |
|---|---|---|---|---|---|
| ***Difficulty*** | **Simple; single dominant KPP** | **Low, some coupling among KPPs** | **Moderately complex, coupled KPPs** | **Difficult, coupled KPPs** | **Very complex, tightly coupled KPPs** |
| ***Criticality*** | **Slight inconvenience** | **Easily recoverable losses** | **Some loss** | **High financial loss** | **Risk to human life** |

# Migration Complexity

**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

**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 |
|---|---|---|---|---|---|
| ***Lack of 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** |
| ***Lack of Readiness*** | **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)** |
| ***Obsolescence*** | | | **- Technology is the state-of-the-practice<br>- Emerging technology could compete in future** | **- Technology is stale<br>- New and better technology is on the horizon in the near-term** | **- Technology is outdated and use should be avoided in new systems<br>- Spare parts supply is scarce** |

# Documentation Match to Life Cycle Needs

**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 |
|---|---|---|---|---|---|
| *Formality* | 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 |
| *Detail* | Minimal or no specified documentati on 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

**# 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 |

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# # of Recursive Levels in the Design

**# 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 |

# 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

**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 | ▪Stakeholders with diverse domain experience, task nature, language, culture, infrastructure<br>▪Highly heterogeneous stakeholder communities | ▪Heterogeneous stakeholder community<br>▪Some similarities in language and culture | ▪Shared project culture | ▪Strong team cohesion and project culture<br>▪Multiple similarities in language and expertise | ▪Virtually homogeneous stakeholder communities<br>▪Institutionalized project culture |
| Compatibility | ▪Highly conflicting organizational objectives | ▪Converging organizational objectives | ▪Compatible organizational objectives | ▪Clear roles & responsibilities | ▪Strong mutual advantage to collaboration |
| Familiarity | ▪Unfamiliar, never worked together | ▪Willing to collaborate, little experience | ▪Some familiarity | ▪High level of familiarity | ▪Extensive successful collaboration |

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# Personnel Factors

**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%** |

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# Process Capability

**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

**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

**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 |

# Model Demonstration

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# Agenda

- COSYSMO Introduction
- Expert COSYSMO Overview
- Systems Engineering Effectiveness Measures (Barry Boehm)
- Expert COSYSMO Project Implementation
  - Process and Measurement Frameworks
- Group Case Studies
- Wrap-up and Next Steps

# Expert COSYSMO Introduction

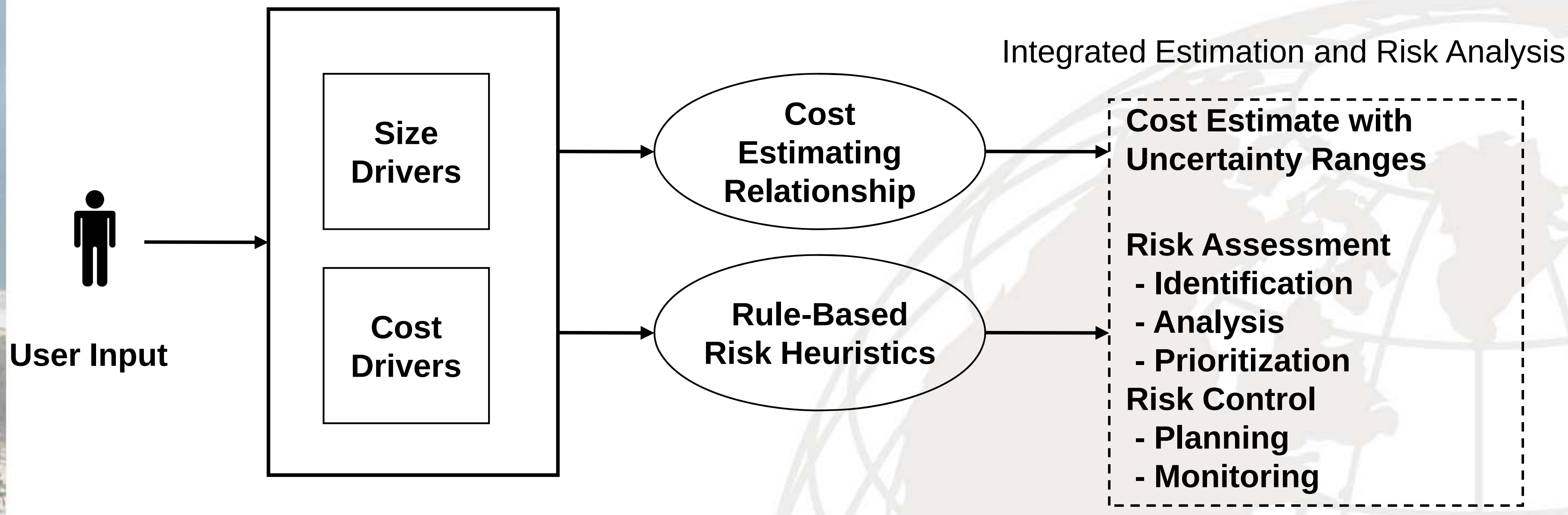
- An expert system tool for systems engineering risk management based on COSYSMO
  - Automatically identifies project risks in conjunction with cost estimation similar to Expert COCOMO [Madachy 1997] and provides related advice
  - Supports project planning by identifying, categorizing and quantifying system-level risks
  - Supports project execution with automated risk mitigation advice for management consideration
- Risk situations are characterized by combinations of cost driver values indicating increased effort with a potential for more problems
- Simultaneously calculates cost and schedule to enable tradeoffs with risk

**https://diana.nps.edu/MSAcq/tools/ExpertCOSYSMO.php**

or

**http://csse.usc.edu/tools/ExpertCOSYSMO.php**

# Expert COSYSMO Operation



# Method

- Analyzes patterns of cost driver ratings submitted for a COSYSMO cost estimate against pre-determined risk rules
  - Identifies individual risks that an experienced systems engineering manager might recognize but often fails to take into account
  - Helps users determine and rank sources of project risk. With these risks, mitigation plans are created based on the relative risk severities and provided advice

# Method (cont.)

- COSYSMO cost factor combinations used as abstractions for formulating risk heuristics
  - E.g. if Architecture Understanding = Very Low and Level of Service Requirements = Very High, then there is a high risk
    - Since systems with high service requirements are more difficult to implement especially when the architecture is not well understood
- Elicitation of knowledge from systems engineering domain experts in structured workshops
  - Surveys used to identify risks, quantify risks, and identify advice
- Devised knowledge representation scheme and risk quantification algorithm
- Risk rules are fired when the risk probability weights are > 0
- Further extension for risk mitigation advice linked to risk items

# Knowledge Base Created by Domain Experts

- Systems engineering and COSYSMO experts have identified and prioritized risks, and provided advice in a series of structured workshops
  - Hosted by USC Center for Systems and Software Engineering (USC CSSE)
  - Some have taken place at the International Forum on COCOMO and Systems/Software Cost Modeling
- PSM is the 5th workshop to mature the framework
  - We invite your comments on all aspects

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# Delphi Round 1 Initial Risk Conditions

| | SIZE | RQMT | ARCH | LSVC | MIGR | TRSK | DOCU | INST | RECU | TEAM | PCAP | PEXP | PROC | SITE | TOOL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SIZE (REQ + INTF + ALG + OPSC) | | 21 | 21 | 9 | 12 | 5 | 4 | 7 | 10 | 8 | 9 | 11 | 7 | 6 | 7 |
| Requirements Understanding | | | 17 | 9 | 7 | 8 | 3 | 5 | 9 | 5 | 10 | 8 | 5 | 4 | 1 |
| Architecture Understanding | | | | 9 | 10 | 12 | 3 | 7 | 11 | 6 | 11 | 11 | 5 | 6 | 4 |
| Level of Service Requirements (the ilities) | | | | | 5 | 7 | 4 | 5 | 3 | 6 | 4 | 4 | 2 | 3 | 2 |
| Migration Complexity (legacy system considerations) | | | | | | 8 | 1 | 10 | 1 | 4 | 7 | 7 | 3 | 5 | 4 |
| Technology Risk (maturity of technology) | | | | | | | 2 | 8 | 6 | 4 | 9 | 5 | 3 | 3 | 5 |
| Documentation match to life cycle needs | | | | | | | | 2 | 3 | 4 | 4 | 2 | 6 | 2 | 3 |
| Number and Diversity of Installations or Platforms | | | | | | | | | 4 | 3 | 5 | 6 | 4 | 8 | 5 |
| Number of Recursive Levels in the Design | | | | | | | | | | 4 | 8 | 7 | 7 | 2 | 5 |
| Stakeholder Team Cohesion | | | | | | | | | | | 7 | 9 | 3 | 8 | 3 |
| Personnel/team capability | | | | | | | | | | | | 12 | 9 | 8 | 5 |
| Personnel Experience and Continuity | | | | | | | | | | | | | 10 | 8 | 3 |
| Process Capability | | | | | | | | | | | | | | 5 | 8 |
| Multisite Coordination | | | | | | | | | | | | | | | 8 |
| Tool Support | | | | | | | | | | | | | | | |

high risk

medium risk

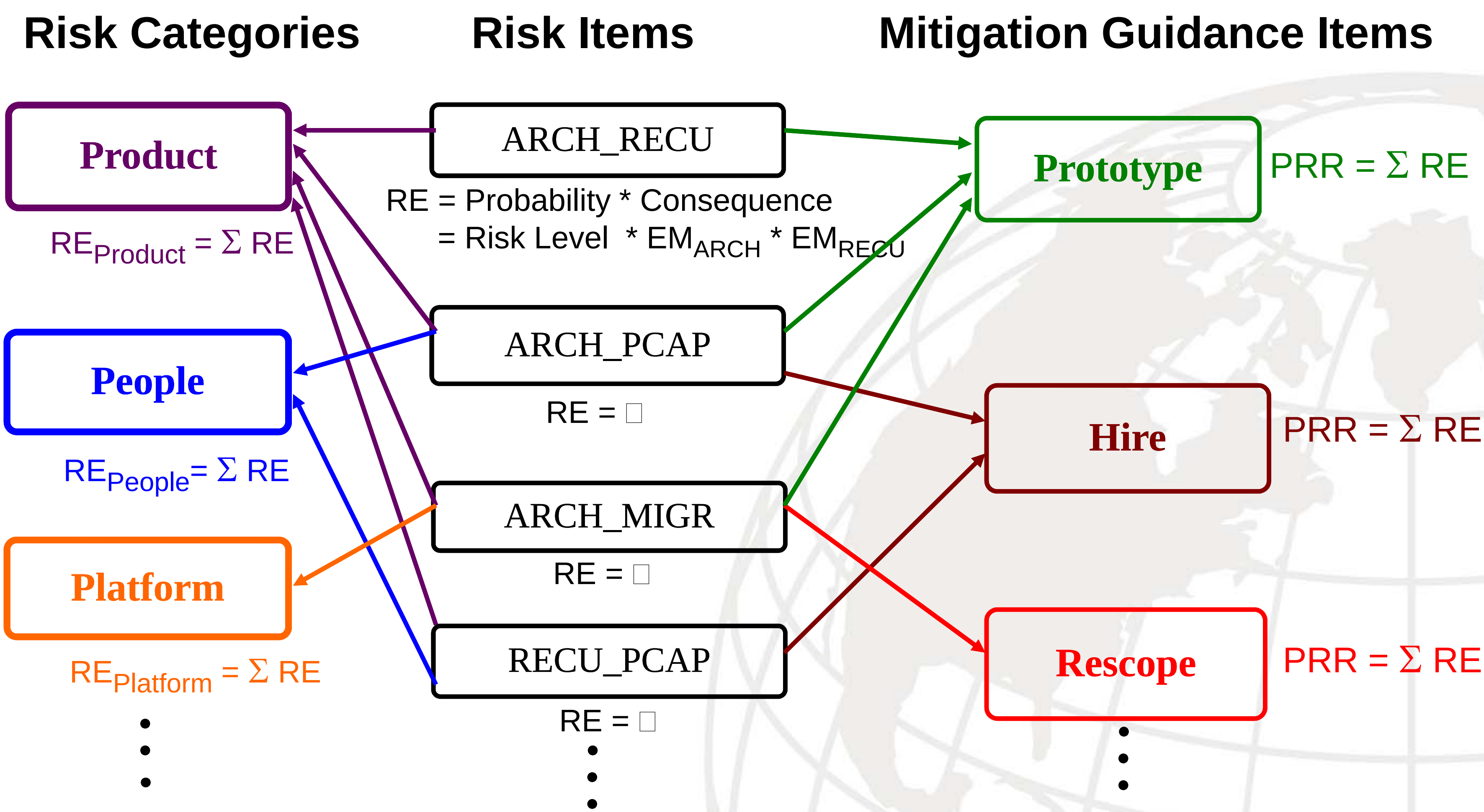
low risk

small x = 0.5; big X = 1

n = 19

- Subsequent refinements described in next slides

# Risk Network




RE = Risk Exposure
PRR = Potential Risk Reduction

# Taxonomy and Risk Exposure

**Project Risk**

**Product risk** **Process risk** **People risk** **Platform risk**

$$\text{Project Risk Exposure} = \sum_{j=1}^{\#categories} \sum_{i=1}^{\#category\ risks} \text{Probability} * \text{Consequence}$$

$$= \sum_{j=1}^{\#categories} \sum_{i=1}^{\#category\ risks} \text{risk probability weight}_{i,j} * \text{effort multiplier product}_{i,j}$$

where risk probability weight =

| | |
|---|---|
| 1 | moderate |
| 2 | high |
| 4 | very high |

effort multiplier product=
(driver #1 effort multiplier) * (driver #2 effort multiplier) ... * (driver #n effort multiplier).

# Risk Level Probability Weights

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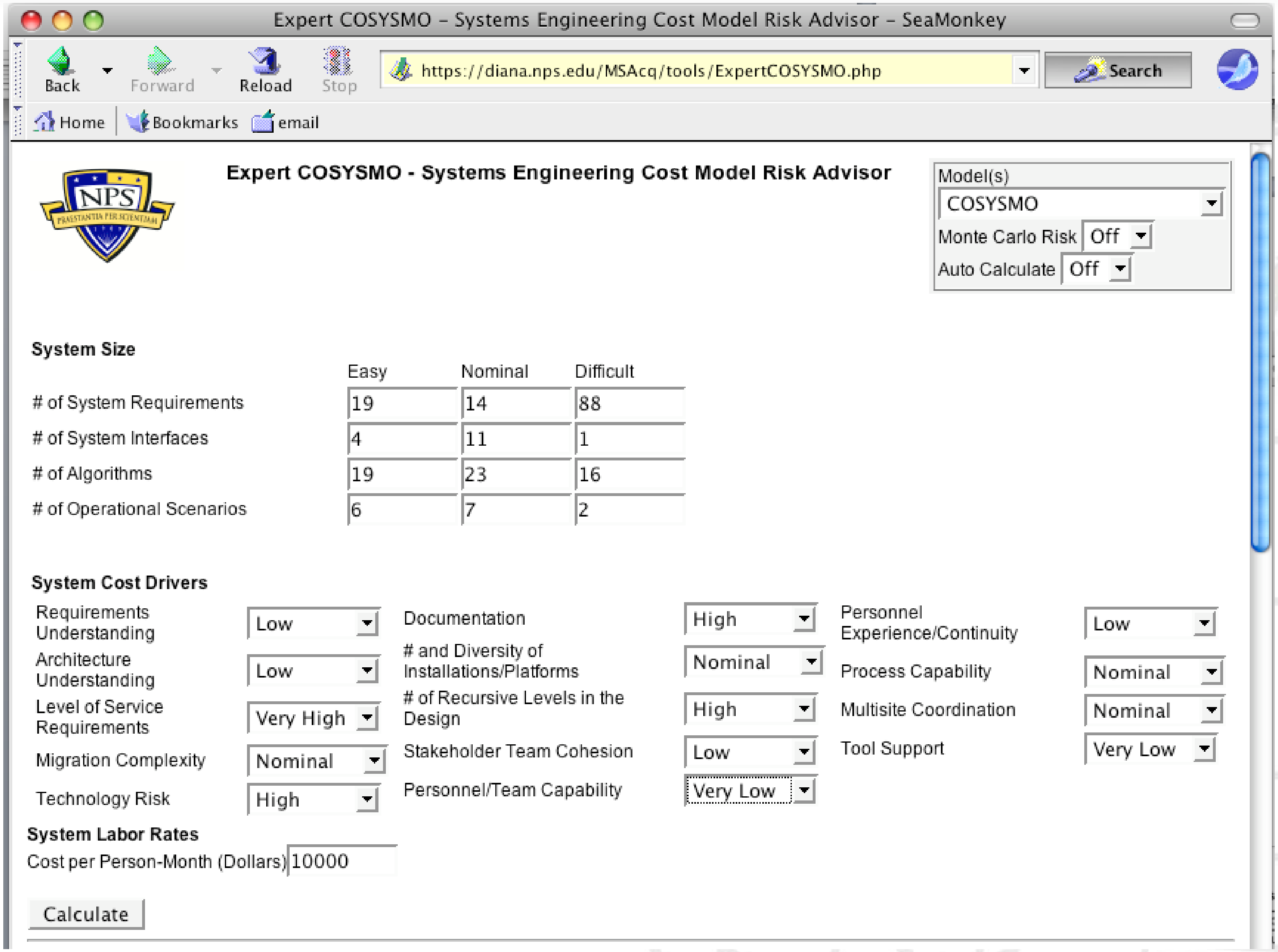
- Non-linear risk probabilities account for fine grained conditions
- Weighting matrices represent iso-risk contours between cost factors:

**Requirements Understanding / Architecture Understanding**

**Risk = High**

| | | **Architecture Understanding** | | | | |
|---|---|---|---|---|---|---|
| | | Very Low | Low | Nominal | High | Very High |
| **Requirements Understanding** | Very Low | 4 | 2 | 1 | 0 | 0 |
| | Low | 2 | 1 | 0 | 0 | 0 |
| | Nominal | 1 | 0 | 0 | 0 | 0 |
| | High | 0 | 0 | 0 | 0 | 0 |
| | Very High | 0 | 0 | 0 | 0 | 0 |

# Expert COSYSMO Inputs



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# Expert COSYSMO Outputs

Systems Engineering Effort = 3635 Person-months

**Effort Distribution (Person-Months)**

| Phase / Activity | Conceptualize | Develop | Operational Test and Evaluation | Transition to Operation |
|---|---|---|---|---|
| Acquisition and Supply | 71.3 | 129.8 | 33.1 | 20.4 |
| Technical Management | 136.0 | 234.9 | 154.5 | 92.7 |
| System Design | 370.9 | 436.3 | 185.4 | 98.2 |
| Product Realization | 70.9 | 163.6 | 174.5 | 136.3 |
| Product Evaluation | 202.9 | 304.3 | 450.9 | 169.1 |

**Risk Summary**

| | |
|---|---|
| Product | 60 |
| Process | 2 |
| Personnel | 20 |

**Prioritized Risks**

| High | Medium | Low |
|---|---|---|
| requ_arch<br>arch_trsk<br>arch_pexp | requ_serv<br>requ_migr<br>requ_trsk<br>arch_serv<br>arch_migr<br>arch_team<br>serv_trsk<br>serv_team<br>migr_trsk<br>migr_pexp | requ_team<br>requ_serv<br>requ_serv<br>requ_serv<br>requ_serv<br>arch_tool<br>serv_migr<br>serv_pexp<br>serv_tool<br>migr_team<br>migr_tool<br>trsk_team<br>trsk_pexp<br>trsk_tool |

# Outputs - Risk Mitigation Advice

- Guidance items ordered by risk exposure:

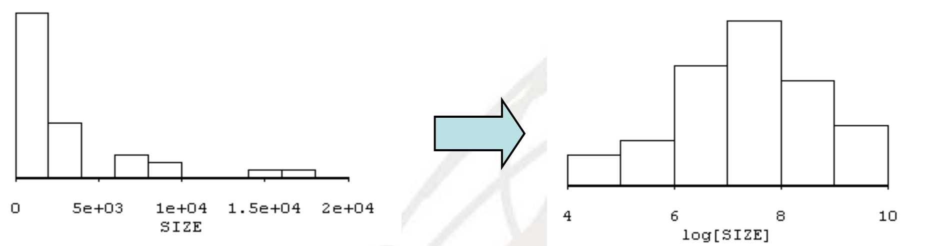
**Risk Mitigation Guidance**

The risk mitigation guidance below shows alternatives for consideration in specific project environments.

| Risk Severity | Description | Alternatives |
|---|---|---|
| High | Requirements Understanding = Very Low *and* Architecture Understanding = Very Low | Subcontract, prioritize requirements, cancel project |
| High | Architecture Understanding = Very Low *and* Technology Risk = Very High | Early prototyping, trade studies, negotiation on priorities |
| High | Architecture Understanding = Very Low *and* Personnel Experience/Continuity = Very Low | Hire experts, establish educational benefits, conduct training |
| High | Architecture Understanding = Very | Early prototyping, trade studies |

# Size Risk Elaboration

- Establishing size range thresholds for risk rules
- COSYSMO size distribution:




  - Min = 82, Max = 17,763 equivalent requirements
- Proposed ranges
  - Small: < 5,000 equivalent requirements
  - Medium: between 5,000 and 15,000 equivalent requirements
  - Large: > 15,000 equivalent requirements
- See listing on size related risks

# Current and Future Work

- Refactoring the guidance portion of the risk network so individual PRRs are automatically calculated
- Adding size-related risks and guidance
- Will calibrate the risk exposure point range for threshold regions after adding size risks
- Linking to other Systems Engineering Effectiveness Measure tools
  - Expert COSYSMO provides feasibility evidence artifacts with estimate rationale
- Add rules to detect COSYSMO input anomalies
- Considering 3-way risk interactions
- Collect and analyze empirical systems engineering risk data from projects to enhance and refine the technique
  - Perform statistical testing
- Domain experts from industry and government will continue to provide feedback and clarification
  - Supporting surveys and workshops will be continued

# Agenda

- COSYSMO Introduction
- Expert COSYSMO Overview
- Systems Engineering Effectiveness Measures (Barry Boehm)
- Expert COSYSMO Project Implementation
  - Process and Measurement Frameworks
- Group Case Studies
- Wrap-up and Next Steps

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# Process and Measurement Frameworks

- Expert COSYSMO implements best practices in frameworks such as the Capability Maturity Model Integration (CMMI) and Practical Software and System Measurement (PSM).
  - Provides practical, concrete artifacts for managing processes and projects
- The duality of Expert COSYSMO in cost estimation and risk management using objective measurements supports many of the CMM-I key process areas.
- Provides Systems Engineering Leading Indicators for continuous usage throughout lifecycle

# CMMI Implementation



- Expert COSYSMO is a primary enabler for best practices in the **Project Planning** and **Risk Management** process areas
  - **Project Planning (PP)** establishes and maintains plans that define project activities.
  - **Risk Management (RSKM)** identifies potential problems before they occur so that risk-handling activities can be planned and invoked as needed across the life of the product or project to mitigate adverse impacts on achieving objectives.
- Provides essential support for **Decision Analysis and Resolution** and **Measurement and Analysis**
  - **Decision Analysis and Resolution (DAR)** analyzes decisions using a formal process that evaluates identified alternatives against established criteria.
  - **Measurement and Analysis (MA)** develops and sustains a measurement capability that is used to support management information need.

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# Project Planning Goal/Practice Coverage

- SG 1 Establish Estimates
  - SP 1.1 Estimate the Scope of the Project
  - **SP 1.2 Establish Estimates of Work Product and Task Attributes**
    - System work breakdown described in cost model elements with attributes
  - SP 1.3 Define Project Lifecycle
  - **SP 1.4 Determine Estimates of Effort and Cost**
    - Based on estimation rationale using models and historical data
- SG 2 Develop a Project Plan
  - **SP 2.1 Establish the Budget and Schedule**
    - Based on the developed estimates to ensure that budget allocation, task complexity, and task dependencies are addressed

# Project Planning (cont.)

- **SP 2.2 Identify Project Risks**
- Identify and analyze project risks to support project planning including:
    - Identifying risks
    - Analyzing the risks to determine the impact, probability of occurrence
    - Prioritizing risks
- SP 2.3 Plan for Data Management
- SP 2.4 Plan for Project Resources
- SP 2.5 Plan for Needed Knowledge and Skills
- SP 2.6 Plan Stakeholder Involvement
- SP 2.7 Establish the Project Plan

- SG 3 Obtain Commitment to the Plan
    - SP 3.1 Review Plans that Affect the Project
    - SP 3.2 Reconcile Work and Resource Levels
- SP 3.3 Obtain Plan Commitment

# Risk Management Goal/Practice Coverage

- SG 1 Prepare for Risk Management
  - SP 1.1 Determine Risk Sources and Categories
    - Provides a risk taxonomy with risk sources
  - SP 1.2 Define Risk Parameters
  - SP 1.3 Establish a Risk Management Strategy
- SG 2 Identify and Analyze Risks
  - SP 2.1 Identify Risks
    - Automates a risk identification checklist
  - SP 2.2 Evaluate, Categorize, and Prioritize Risks
    - Categorizes and quantifies risks with expert knowledge-base
- SG 3 Mitigate Risks
  - SP 3.1 Develop Risk Mitigation Plans
    - Identifies beginning risk mitigation actions for further exploration and implementation
  - SP 3.2 Implement Risk Mitigation Plans

# Other Process Area Support

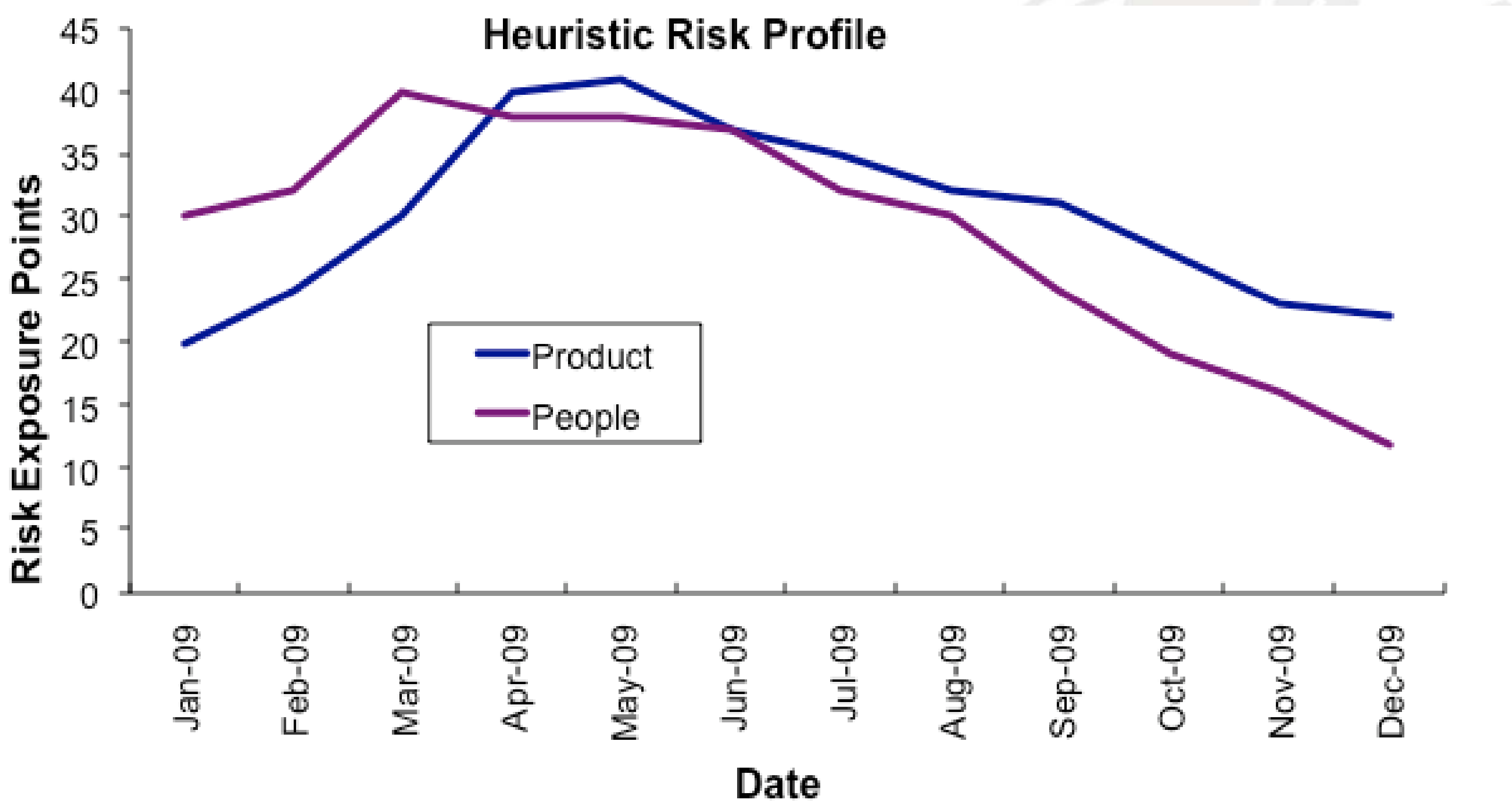
- The Expert COSYSMO method comprises measurements that may be specified and implemented for the **Measurement and Analysis** process area
- Provides quantitative evaluation methods for usage in **Decision Analysis and Resolution**
  - Various decisions based on Risk Exposures and Potential Risk Reductions of actions (to be coupled with costs of actions)
- May also provide management data for **Quantitative Project Management (QPM)** that formally monitors measurements for achieving project and process objectives

# Systems Engineering Leading Indicators

- The *Systems Engineering Leading Indicator Guide v. 1.0* focuses on leading indicators for evaluating the goodness of systems engineering on a program
- A leading indicator may be an individual measure, or collection of measures, that are predictive of future system performance before the performance is realized.
- Expert COSYSMO provides indicator data for Risk Exposure Trends and Risk Handling Trends

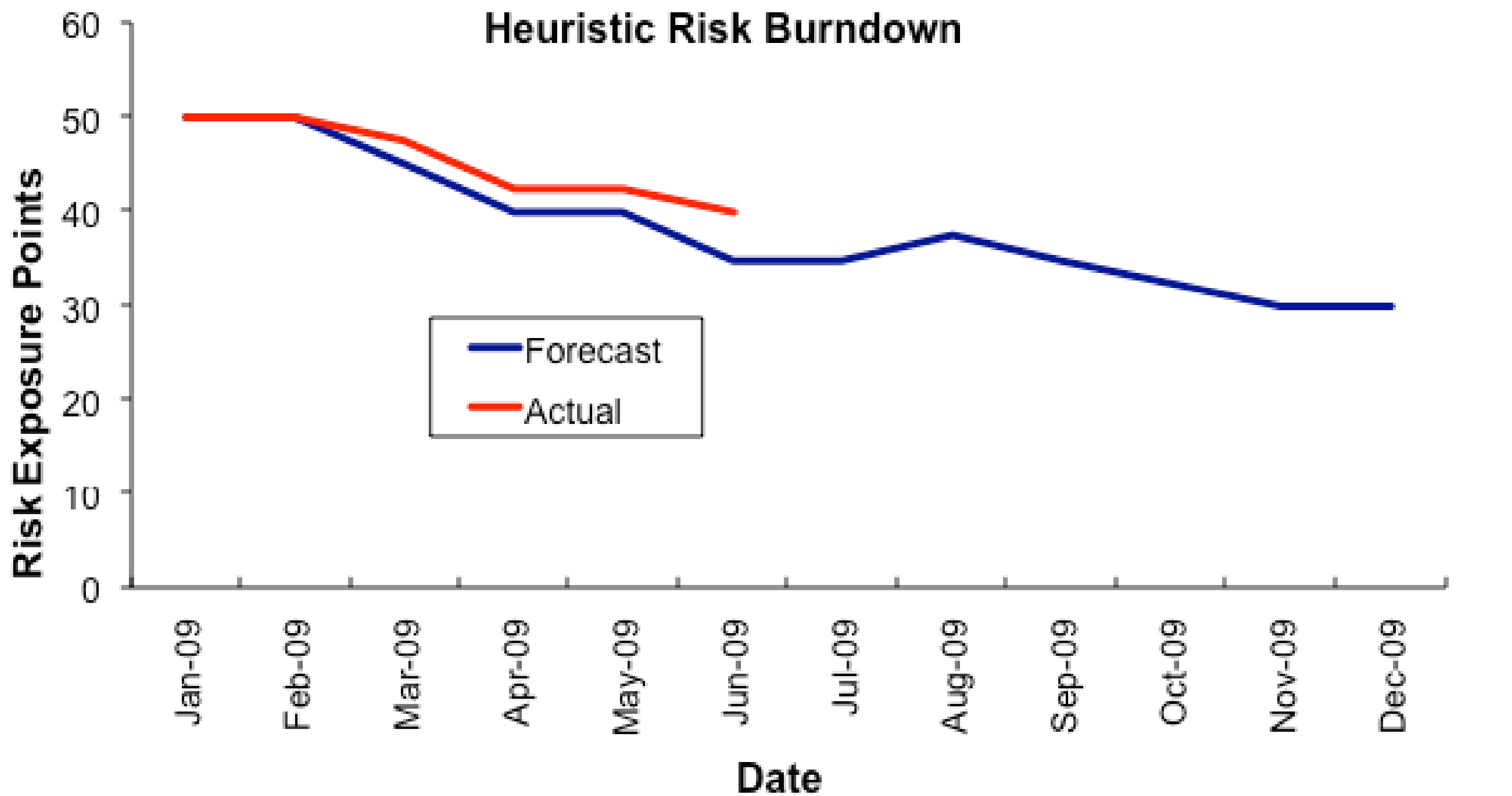
# Risk Exposure Trends

- Heuristic risk profile can be tracked at different levels of risk taxonomy



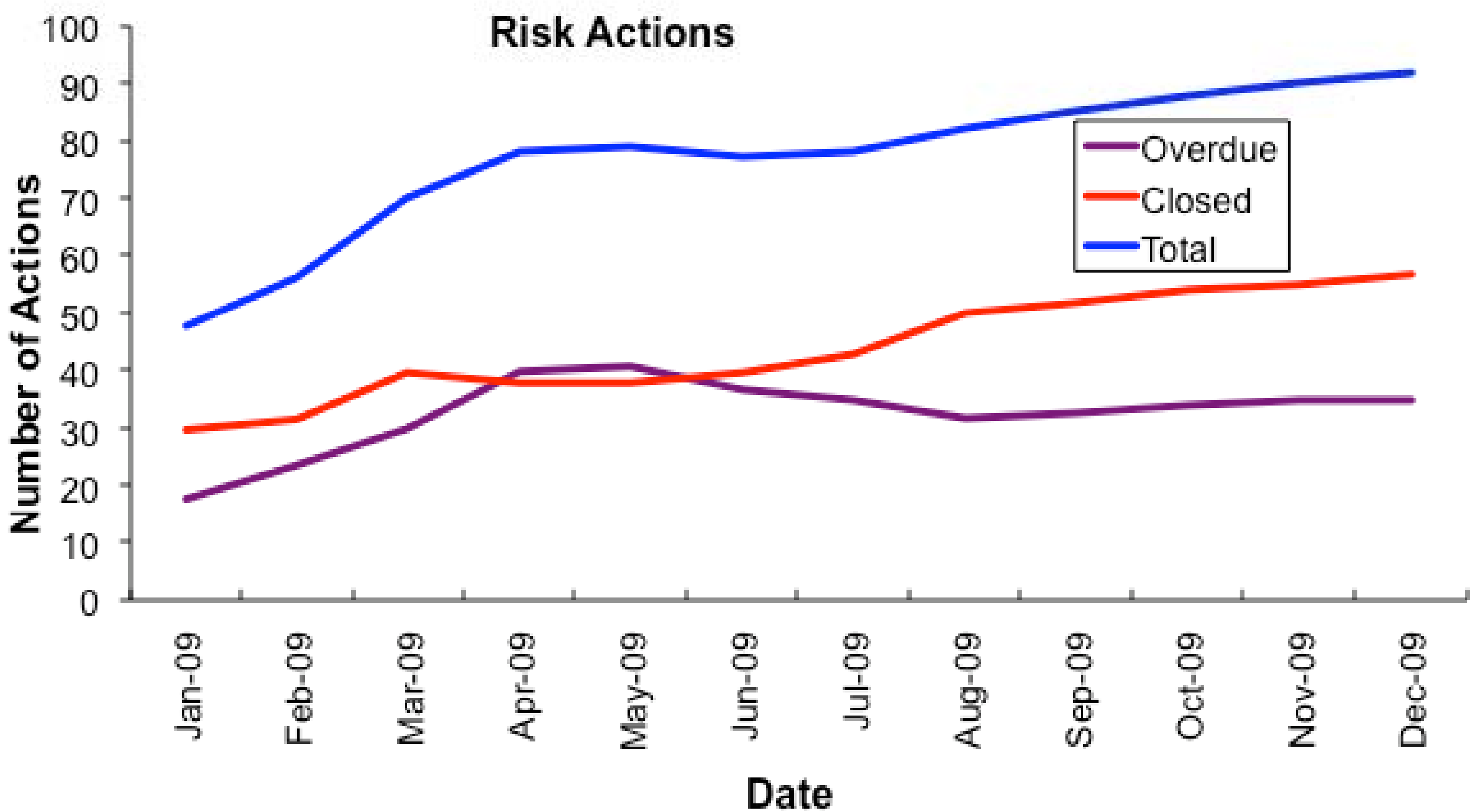
# Risk Exposure Trends (cont.)

- Risk burndown tracked as mitigation actions are executed and other changes occur



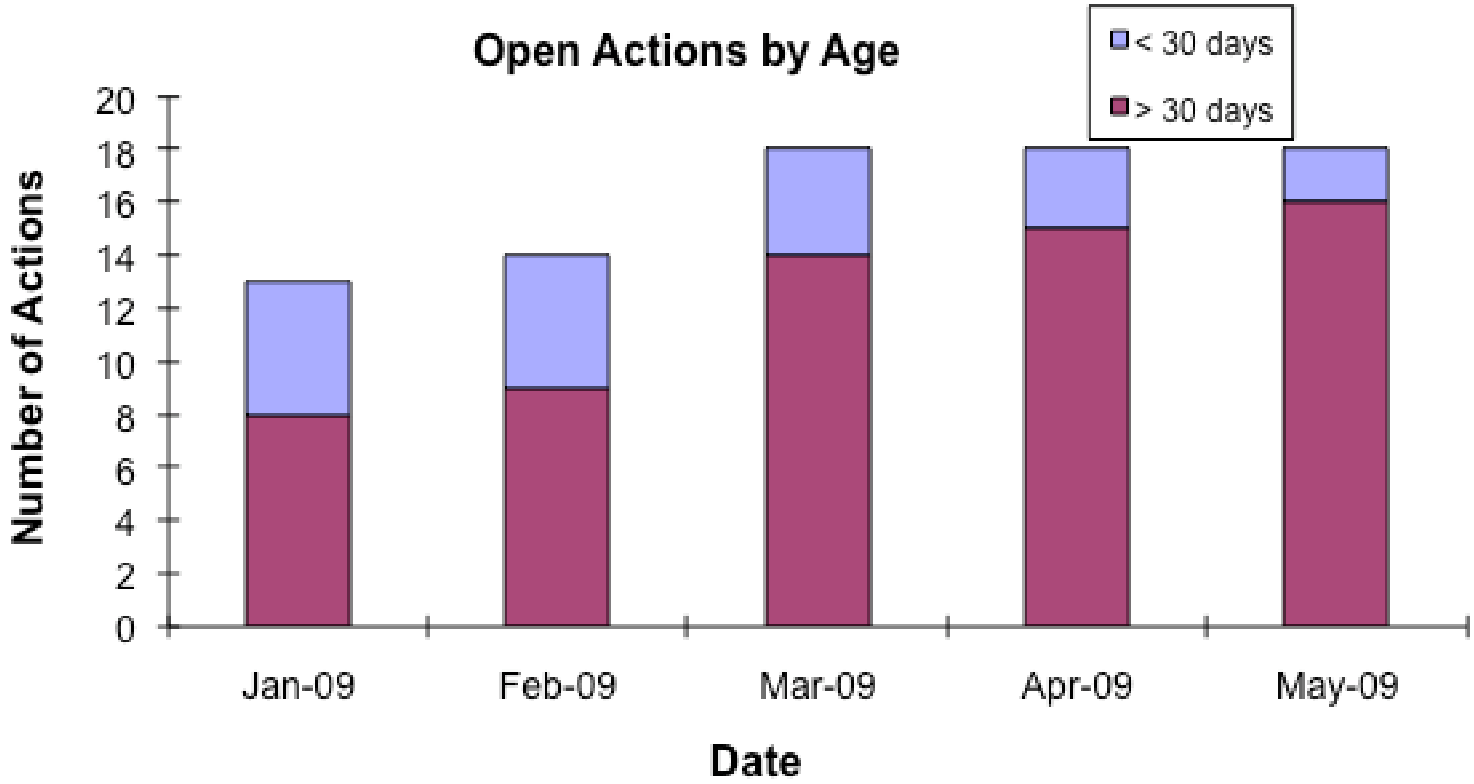
# Risk Handling Trends

- Tracking guidance action item trends



# Risk Handling Trends (cont.)

- Guidance action item statuses by age



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# Case Studies

- Apply Expert COSYSMO on current or proposed project(s)
  - Insights?  New actions?
- Apply Expert COSYSMO to reconstructed past project(s)
  - Enter best known parameter values at different lifecycle points.
  - How well does it show historical risk trends?  Did it identify actual risks?  Could it have helped manage better?
- Suggest improvements to method/tool

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# References


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- Madachy, R. and Valerdi R., *Knowledge-Based Systems Engineering Risk Assessment*, University of Southern California Center for Systems and Software Engineering Technical Report, USC-CSSE-2008-818
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- Valerdi R., *The Constructive Systems Engineering Cost Model (COSYSMO)*, PhD Dissertation, University of Southern California, Los Angeles, CA, May 2005


https://diana.nps.edu/MSAcq/tools/ExpertCOSYSMO.php

or

http://csse.usc.edu/tools/ExpertCOSYSMO.php