SYSTEMS ENGINEERING
Research Center

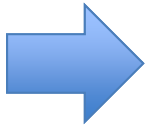
Early Identification of Systems Engineering-Related Risks

Barry Boehm, Dan Ingold

USC-CSSE

3 March 2010

Outline



- Evaluation of potential effectiveness measures
- Development of evaluation framework and tools
- Demonstration of SE Performance Risk Tool (SEPRT)
- Evaluation of the framework and tools

SYSTEMS ENGINEERING
Research Center

Revised Set of Measurement Methods

- NRC Pre-Milestone A & Early-Phase SysE top-20 checklist
- Air Force Probability of Program Success (PoPS) Framework
- INCOSE/LMCO/MIT Leading Indicators
- Stevens Leading Indicators (new; using SADB root causes)
- USC Anchor Point Feasibility Evidence progress
- UAH teaming theories
- NDIA/SEI capability/challenge criteria
- SISAIG Early Warning Indicators/ USC Macro Risk Tool

SYSTEMS ENGINEERING
Research Center

First-order EM evaluation process

- Examine revised list of candidate EMs
  - Use NRC SE checklist as concise starting point
  - Identify similar key elements of other EMs
  - 45x8 cross product of EMs and characteristics
- Evaluate EMs against identified criteria
  - Preliminary “quick-look” evaluation by USC
  - Evaluation by originators, where possible
  - Follow-up with independent evaluation by team
- Review coverage/commonality of elements
  - Incorporate suggested additions (now 51 items)

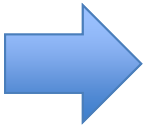
SYSTEMS ENGINEERING
Research Center

EM Coverage Matrix (v1.1)

	SERC EM Task Coverage Matrix v1.1	Effectiveness measure:	INCOSE Systems Engineering Leading Indicators		
	USC evaluation scale: x = covered by EM (x) = partially covered (unless stated otherwise)	**Originator's evaluation scale:** 5 = Fully addressed 4 = Adequately addressed 3 = Mostly addressed 2 = Somewhat addressed 1 = Slightly addressed 0 = Not addressed		**Your evaluation scale:** 0 = Not addressed 1 = Weakly addressed 2 = Mostly addressed 3 = Strongly addressed	
	Effectiveness Measure Element	**USC Evaluation**	**Originator's Evaluation**	**Your Evaluation**	**Comments**
	Concept Development				
1	At least two alternatives have been evaluated		3	0	
2	Can an initial capability be achieved within the time that the key program leaders are expected to remain engaged in their current jobs (normally less than 5 years or so after Milestone B)? If this is not possible for a complex major development program, can critical subsystems, or at least a key subset of them, be demonstrated within that time frame?	(x)	2-3	1	
3	Will risky new technology mature before B? Is there a risk mitigation plan?	x	5	2	
4	Have external interface complexities been identified and minimized? Is there a plan to mitigate their risks?	x	5	3	

SYSTEMS ENGINEERING
Research Center

Outline



- Evaluation of potential effectiveness measures
- Development of evaluation framework and tools
- Demonstration of SE Performance Risk Tool (SEPRT)
- Evaluation of the framework and tools

SYSTEMS ENGINEERING
Research Center

Three SE Evaluation Frameworks

- SE performance assessment tool (SEPAT)
  - Evidence- and judgment-based
  - Discrete evaluation (typically at milestones)
- SE competency assessment tool (SECAT)
  - Knowledge, skills & abilities (KSA) inventories
  - Discrete evaluation
- SE leading indicators (INCOSE/LAI)
  - Quantitative, based on performance data
  - Continuous evaluation

SYSTEMS ENGINEERING
Research Center

SE Performance Assessment Tool

- Organizes EMs according to taxonomy like SISAIG 5x5 matrix
  - Group EM elements around high-level criteria (“goals”)
  - Identify sub-criteria within each goal (“critical success factors”)
  - Design questions that help decide if criteria are being met
- Provides tool PMs, PEOs can use for periodic evaluations
  - Decide importance (impact) of each question for project
  - Select degree of evidence that supports evaluation question
  - Lack of evidence, poor evidence suggests higher risk
- Evaluates risk exposure for given responses
  - Impact x Risk = Risk Exposure
  - Dashboard (red, yellow, green) for indicator of trouble spots

SYSTEMS ENGINEERING
Research Center

SEPAT Taxonomy

High-level Goals	Critical Success Factors
Concurrent definition of system requirements & solutions	Understanding of stakeholder needs
	Concurrent exploration of solutions
	System scoping & requirements definition
	Prioritization/allocation of requirements
System life-cycle organization, planning & staffing	Establishment of stakeholder RAAs
	Establishment of IPT RAAs
	Establishment of resources to meet objectives
	Establishment of selection/contracting/incentives
	Assurance of necessary personnel competencies
Technology maturing & architecting	COTS/NDI evaluation, selection, validation
	Life-cycle architecture definition & validation
	Use of prototypes, models, etc. to validate maturity
	Validated budgets & schedules
Evidence-based progress monitoring & commitment reviews	Monitoring of system definition
	Monitoring of feasibility evidence development
	Monitoring/assessment/replanning for changes
	Identification and mitigation for feasibility risks
	Reviews to ensure stakeholder commitment

SYSTEMS ENGINEERING
Research Center

Candidate SE Competency Framework

- Developed by ODNI
- Comprehensive survey of core competencies
  - 10 candidate work activities
  - 173 candidate knowledge, skills & abilities (KSAs)
- To our knowledge, not yet validated
- Approved for limited release within SERC

SYSTEMS ENGINEERING
Research Center

ODNI SE Competency Survey Example

Scale used for rating KSAs

Importance Scale for KSAs

NR = Not relevant to job.
1 = Minor importance for effective performance
2 = Some importance for effective performance
3 = Important for effective performance
4 = Very important for effective performance
5 = Extremely important for effective performance

KSAs - #s 1-11 of 173	**Importance**
1. Skill in preparing technical documents which define, specify, and recommend system characteristics.	
2. Skill in initiating specifications, drawings, and other technical instructions supporting system acquisition and technical baselining.	
3. Skill in developing resource estimates (e.g., cost, equipment, software, people).	
4. Skill in contributing to the development of program budgets.	
5. Skill in addressing the scope of the technical effort required to develop the system.	
6. Knowledge of Systems Engineering Plans/Systems Engineering Management Plans (SEP/SEMP).	
7. Skill in developing a Systems Engineering Plan/Systems Engineering Management Plan (SEP/SEMP) that describes the program's systems engineering processes, resources, metrics, and technical review process.	

SYSTEMS ENGINEERING
Research Center

SE Competencies Evaluation Framework

- Concept like EM discrete-event evaluation framework
- Organize competencies against candidate framework
  - Group SE work activities/ KSAs around high-level criteria ("goals")
  - Identify sub-criteria within each goal ("critical success factors")
  - Choose questions that help decide if criteria are being met
- Scoring of importance dependent on project context

SYSTEMS ENGINEERING
Research Center

SE Competencies Evaluation Framework

Competencies	Work Activities / Knowledge, Skills and Abilities
Concurrent definition of system requirements & solutions	WAs: 1-3
	KSAs: 1-3, 5, 11, 12, 22, 23, 29, 30, 34-43, 46, 54, 61, 62, 73-76, 83-85, 92, 96, 100, 149
System life-cycle organization, planning & staffing	WAs: 9, 10
	KSAs:44, 45, 77-81, 98
Technology maturing & architecting	WAs: 7, 8
	KSAs:15-18, 20, 21, 24, 26, 28, 31, 32, 47, 48, 51, 55, 82, 83, 86-91, 93-95, 97, 98, 103-110, 113, 122, 124, 135, 136, 148, 159
Evidence-based progress monitoring & commitment reviews	WAs: 4-10
	KSAs: 3, 4, 6-10, 13, 14, 19, 25, 27, 33, 49, 52, 56, 57, 66, 71, 72, 101, 102, 112, 115, 123, 125-128, 132-134, 137-145, 153, 156-173

SYSTEMS ENGINEERING
Research Center

Continuous Evaluation Framework

- Ongoing evaluation, throughout program life-cycle
- Rely on information normally gathered in programs
- INCOSE/LAI/PSM/SEARI SE Leading Indicators Guide
  - Evaluate the goodness of systems engineering on a program
  - Draw on trend information to allow predictive analysis
  - Predict future performance before performance is realized
- Thirteen leading indicators already piloted and validated
- Detailed specifications of indicator, methods, attributes, etc.
- Additional leading indicators identified
- Present as management “dashboard”

SYSTEMS ENGINEERING
Research Center

Target EM Task Benefits

- Early warning vs. late discovery of SysE effectiveness problems
- Identification of current EM capability gaps
  - Recommendations for most cost-effective enhancements, research on new EM approaches
  - Ways to combine EM strengths, avoid weaknesses
- Foundation for continuous improvement of SysE effectiveness measurement
  - Knowledge base of evolving EM cost-effectiveness
  - Improved data for evaluating SysE ROI

SYSTEMS ENGINEERING
Research Center

Summary of SE EM Approach

- Consistent SE evaluation approach across multiple scales
  - Macro-level evaluates SE risk factors to program
  - Personnel-level evaluates SE competencies
  - Operational-level evaluates SE day-to-day performance & trends
- All levels permit forward-looking evaluation of SE risks
  - Macro- and personnel levels via Macro Risk-like tool
  - Operational level via data already gathered in typical programs
  - Tailorable to specific program domains & impacts of risks

SYSTEMS ENGINEERING
Research Center

Outline

- Evaluation of potential effectiveness measures
- Development of evaluation framework and tools
- Demonstration of SE Performance Risk Tool (SEPRT)
- Evaluation of the framework and tools

Systems Engineering Performance Risk Tool (SEPRT) Demonstration

SYSTEMS ENGINEERING
Research Center

Outline

- Evaluation of potential effectiveness measures
- Development of evaluation framework and tools
- Demonstration of SE Performance Risk Tool (SEPRT)
- Evaluation of the framework and tools

SYSTEMS ENGINEERING
Research Center

Pilot Evaluation Methodology

- Complete initial individual EM evaluations
  - Propose domains of use
  - Identify questions to determine evidence of performance
- Begin evaluation against Systemic Analysis Database (SADB)
  - Pose question, “Would this measure have identified problem?”
  - Focus domains of applicability for individual measures
- Pilot frameworks/tools in real project settings
  - Government contractors
  - Agency
  - Evaluate against case studies of historical successes/failures

SYSTEMS ENGINEERING
Research Center

Overview of Pilot Evaluations

- Tools piloted across five DoD projects, one NASA project
  - Applications include space, medical, logistics, systems of systems
- Found useful across all project phases, except Production
  - Most useful in SDD phase
  - More useful in early phases than later
  - "Early Phases" continue throughout evolutionary development
- Found at least somewhat effective in all but legacy systems
- Evaluation takes about 2-5 hours, easy to find material
  - For persons familiar with project
- Presently DoD-centric, non-specific to problem domain
- General impression was "too many findings"

SYSTEMS ENGINEERING
Research Center

Details of SEPAT Pilot Evaluation

- Particularly useful in SDD, somewhat useful earlier, less later
  - As expected, given sources of effectiveness measures
  - Expect higher leverage of SE in early phases
- Effectiveness from “very effective” to “somewhat effective”
  - Majority report “effective”
  - Only legacy project reported “ineffective”
- Clear that tailoring will be necessary
  - Project type: large new, small new, legacy, etc.
  - Terminology, even within DoD evaluations
  - Explore risks specific to problem domains
  - Supplement for later life-cycle phases (add testing, CM, etc.)

SYSTEMS ENGINEERING
Research Center

Details of SECAT Pilot Evaluation

- Most useful in SDD, earlier phases, less in later phases
- Split between “effective” and “somewhat effective”
- Again clear that further development & tailoring required
  - Questions not as well developed as SEPAT (not even questions)
  - Range of skills covered very broad
  - Issues of terminology, especially for non-DoD programs
  - Difficult for non-technical evaluator to judge competence
- “To be effective, must have some control over who assigned.”

SYSTEMS ENGINEERING
Research Center

Rating Scale Improvements

- Earlier workshop suggested red/yellow/green/{gray,blue} ratings in place of 1-5 scales to simplify assessment
- Also recommended red/yellow/green risk exposure ratings to provide traffic-light quick look at program status
- Several reviewers comment that R/Y/G RE makes the ratings too discrete – "if everything is critical, nothing is critical"
  - Increase RE scale to allow orange (between red-yellow) and light green (between yellow-green) results
  - Soften scales slightly: "no" impact/risk becomes "little-or-no"
  - Rephrase criticality scales, include probability, size of loss
  - Add count of CSF elements at highest risk level (i.e., Red-4 worse than Red-1)

SYSTEMS ENGINEERING
Research Center

Other Detailed Observations - 1

- Is “external” validation required to get a green rating?
  - If true, entire program would need external validation for success to be considered likely
  - Emphasis on “independent,” which may need to be external
- What constitutes sufficient evidence?
  - Something objectively verifiable
  - May need definitions of strictness of required evidence
- Guidance on definitions for impact would help consistency
  - Specified in terms of lives, dollars, project value, etc.
  - May need to specify goal for each question to determine impact

SYSTEMS ENGINEERING
Research Center

Other Detailed Observations - 2

- Pointers that direct to more detailed information
  - Expand awareness of issues that might be involved
  - Help avoid “blind spots” typical of similar programs
  - Example: areas that might be KPPs for systems in this domain
- Impact and evidence columns filled out independently
  - Also, perhaps hidden from each other to reduce “gaming”

SYSTEMS ENGINEERING
Research Center

Steps for Developing Feasibility Evidence

- Develop plans for developing work-products/artifacts
- Determine most critical feasibility assurance issues
  - Based on SEPAT, SECAT question impact/priority ratings
- Evaluate feasibility assessment options
  - Cost-effectiveness, rework avoidance, risk reduction ROI
  - Tool, data, mission scenario availability
- Select options, develop feasibility assessment plans
- Prepare evidence development plans and earned value milestones

"Steps" denoted by bullets rather than numbers to indicate that many are done concurrently

Steps for Developing Feasibility Evidence (cont.)

- Begin monitoring progress with respect to plans
  - Also monitor project/technology/objectives changes and adapt plans
- Prepare evidence-generation enablers
  - Assessment criteria
  - Parametric models, parameter values, bases of estimate
  - COTS assessment criteria and plans
  - Benchmarking candidates, test cases
  - Prototypes/simulations, evaluation plans, subjects, and scenarios
  - Instrumentation, data analysis capabilities
- Perform pilot assessments; evaluate and iterate plans and enablers
- Assess readiness for SEPAT-SECAT evidence assessment
  - Evidence shortfalls identified as risks and covered by risk mitigation plans
  - Proceed to Milestone Review if ready
- Hold Milestone Review when ready; adjust plans based on review outcomes

SYSTEMS ENGINEERING
Research Center

Future Directions

- Make tools easier to extend
  - Options: PHP, Access
- Develop initial domain extensions
  - In collaboration with early users
- Develop assessment summaries
  - Top risks; candidate mitigation options
- Develop non-DoD version
  - Possible NASA sponsor
- Develop, initially populate prototype Knowledge Base
- Coordinate with related efforts
  - INCOSE Leading Indicators; NDIA, other-DoD personnel competency initiatives, SERC Graduate SE Body of Knowledge and Reference Curriculum RT

SYSTEMS ENGINEERING
Research Center

Conclusions

- Tools show reasonable multi-phase, cross-domain utility
  - Improvements workable; some already worked
- Extensions to other domains, later phases beneficial
- Potential as method to bridge acquirer/contractor interaction
  - Common framework to structure, standardize discussion
  - Emphasis on objective evidence, independently verified
  - Add incentive by tying to portion of award fee

QUESTIONS…?

Backup Charts

SYSTEMS ENGINEERING
Research Center

Macro Risk Model Interface

USC MACRO RISK MODEL
Copyright USC-CSSE
NOTE: Evidence ratings should be done independently, and should address the degree to which the evidence that has been provided supports a "yes" answer to each question.

Question #	Impact (1-5)	Unavailable (U)	Meager (M)	Fragmentary (F)	Competent but Incomplete (C/I)	Strong (S)	Externally Validated (EV)	EVIDENCE	CSF Risk (1-25)
Goal 1:								**System and software objectives and constraints have been adequately defined and validated.**	
Critical Success Factor 1								**System and software functionality and performance objectives have been defined and prioritized.**	**6**
1(a)	3	○	○	○	○	◉	○	Are the user needs clearly defined and tied to the mission?	
1(b)	3	○	○	○	◉	○	○	Is the impact of the system on the user understood?	
1(c)	2	○	○	○	◉	○	○	Have all the risks that the software-intensive acquisition will not meet the user expectations been addressed?	
Critical Success Factor 2								**The system boundary, operational environment, and system and software interface objectives have been defined.**	**15**
2(a)	3	○	○	◉	○	○	○	Are all types of interface and dependency covered?	
2(b)	4	○	◉	○	○	○	○	For each type, are all aspects covered?	
2(c)	5	○	○	◉	○	○	○	Are interfaces and dependencies well monitored and controlled?	
Critical Success Factor 3								**System and software flexibility and resolvability objectives have been defined and prioritized.**	**21**
3(a)	5	○	◉	○	○	○	○	Has the system been conceived and described as "evolutionary"?	

SYSTEMS ENGINEERING
Research Center

Initial EM Coverage Matrix

SERC EM Task Coverage Matrix V1.0

	NRC	Probability of Success	SE Leading Indicators	LIPSF (Stevens)	Anchoring SW Process (USC)	PSSES (U. of Alabama)	SSEE (CMU/SEI)	Macro Risk Model/Tool
Concept Dev								
Atleast 2 alternatives have been evaluated	X			x	x	x (w.r.t NPR)	(x)	
Can an initial capability be achieved within the time that the key program leaders are expected to remain engaged in their current jobs (normally less than 5 years or so after Milestone B)? If this is not possible for a complex major development program, can critical subsystems, or at least a key subset of them, be demonstrated within that time frame?	X		(x)	x	x (5 years is not explicitly stated)		(x) (seems to be inferrable from the conclusions)	(x) (implies this)
Will risky new technology mature before B? Is there a risk mitigation plan?	x	x	x		(x)		x	x
Have external interface complexities been identified and minimized? Is there a plan to mitigate their risks?	x		x		x	x	x	x
KPP and CONOPS								
At Milestone A, have the KPPs been identified in clear, comprehensive, concise terms that are understandable to the users of the system?	x	(x)	x	(x)	x (strongly implied)	(x) (implied)	x	x
At Milestone B, are the major system-level requirements (including all KPPs) defined sufficiently to provide a stable basis for the development through IOC?	x	x	(x)	x	x	(x)	(x) (There is no direct reference to this but is inferrable)	x
Has a CONOPS been developed showing that the system can be operated to handle the expected throughput and meet response time requirements?	x	x	(x)	(x)	x	(x) (there is a mention of a physical solution. That's the closest in this regard)	x	x

Legend:
x = covered by EM
(x) = partially covered (unless stated otherwise)

SYSTEMS ENGINEERING
Research Center

EM Independent Evaluation

- Prepare evaluation matrix for each EM
  - Initial USC evaluation
  - Originator evaluation (where available)
  - Independent evaluator rating (0-3) and comments
- Compile results, iterate, try to reach consensus
- Expected results
  - Identify most effective EMs
  - Determine most relevant domain of use
  - Suggest evaluation questions for evidence-/judgment-based measures
- Now in process with independent evaluators

SYSTEMS ENGINEERING
Research Center

Independent EM Evaluations and Resolution

Candidate EM	USC	Stevens	FC-MD	UAH
PoPS Leading Indicators	X	X		X
INCOSE LIs	X		X	
Stevens LIs	X	X	X	
SISAIG LIs/ Macro Risk	X		X	X
NRC Top-20 List	X		X	X
SEI CMMI-Based LIs	X	X		X
USC AP-Feasibility Evidence	X	X	X	
UAH Team Effectiveness	X	X		X

SYSTEMS ENGINEERING
Research Center

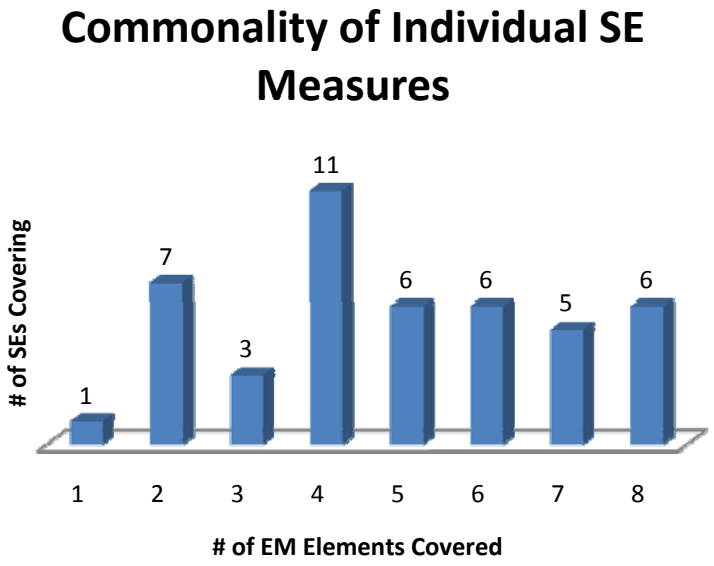
EM Coverage

Effectiveness Measure	Number Covered	Percent Covered
SEI SSEE*	36	80%
INCOSE SE LI*	35	78%
NRC	30	67%
USC Anchor Point	28	62%
SISAIG/Macro Risk	27	60%
UAH PSSES*	24	53%
Army PoPS	19	42%
Stevens LI-PSF*	18	40%

* Reviewed by originator

SYSTEMS ENGINEERING
Research Center

EM Commonality



# of Mentions	Effectiveness Measures
8	5, 6, 7, 8, 15, 18
7	3, 9, 11, 39, 42
6	1, 4, 17, 19, 24, 25
5	2, 10,12, 28, 29, 30
4	14, 16, 23, 26, 34, 36,37, 38, 43, 44, 45