Twelve Roles and Three Types of Systems Engineering

Sarah A. Sheard
Software Productivity Consortium
August 7, 2003
Agenda

• Why Systems Engineering?
• Twelve Roles
• Three Types of Implementation
What’s New in Systems Engineering?

• Systems are becoming far more software-intensive
• System complexity is increasing fast due to software complexity
• What’s the same as it was, and what’s different, and what should we do about it?
Original Reasons for Systems Engineering

• Systems of pieces built by different subsystem groups didn’t perform system functions
  – Often broke at the interfaces
• Problems emerged, and desired properties didn’t, when subsystems designed independently were integrated
• Managers and chief engineers tended to pay attention to the areas in which they were skilled
• Developed systems were not usable
• Cost overruns, schedule delays, performance problems

Photo from Dec 1999 Civil Engineering magazine

Vasa, Sweden, 1628
Concerns

• Software is becoming the brain of most systems
  – But: Software developers are often not trained in engineering
  – And: Systems engineers rarely know software deeply

• Managers and politicians are not engineers… value of systems engineering is not clear

• What systems engineering is needed?

• How should systems engineering work for software?
Goals

- Implement *interdisciplinary* engineering of systems
  - Reduce the risk and effects of system failures
  - Involve the right people at the right time
  - But we lack agreed-upon *operational definition* of “systems engineering” to use as rationale

- *INCOSE definition*: “An interdisciplinary approach and means to enable the realization of successful systems”
  - Leaves open how it should be done
  - Inclusive and vague
Can we answer these?

• Is systems engineering the engineering of the top-level system, or a process?

• Are systems engineers specialists or generalists?

• Are systems engineers some people or all engineers?

• How well do standards and capability models describe systems engineering?
Can we answer these? (cont’d)

• What tools are needed for systems engineering?

• What research should be done?

• How do you measure systems engineering?

• How do you train people to do systems engineering?

• How do you quantify the value of systems engineering?
Two Papers

  - Showed that INCOSE disagrees on what systems engineering is
  - Described twelve roles
  - Used as a definition of systems engineering

- “Three Types of System Engineering Implementation” 2000
  - How systems engineering (and roles) are implemented

At www.software.org at “Recent Papers”
Approach of 12 Roles Paper

• Describe roles considered part of systems engineering
  – Purpose: improve communication
  – Method: analyze INCOSE papers
Twelve Systems Engineering Roles

RO  Requirements Owner
SD  System Designer
SA  System Analyst
VV  Validation and Verification Engineer
LO  Logistics/Operations Engineer
G   Glue among subsystems
CI  Customer Interface
TM  Technical Manager
IM  Information Manager
PE  Process Engineer
CO  Coordinator
CA  Classified Ads SE
Requirements Owner

- Requirements Owner
- Requirements Manager, Allocator, Maintainer
- Specifications Writer or Owner
- Developer of Functional Architecture
- Developer of System and Subsystem Requirements From Customer Needs
System Designer

- System Designer
- Owner of “System” Product
- Chief Engineer
- System Architect
- Developer of Design Architecture
- Specialty Engineer (Some, Such As Human-Computer Interface Designers)
- “Keepers of the Holy Vision” [Boehm 94]
System Analyst

• System Analyst
• Performance Modeler
• Keeper of Technical Budgets
• System Modeler and Simulator
• Risk Modeler
• Specialty Engineer (Some, Such As Electromagnetic Compatibility Analysts)
Validation/Verification Engineer

- Validation and Verification Engineer
- Test Engineer
- Test Planner
- Owner of System Test Program
- System Selloff Engineer
Logistics/Ops Engineer

- Logistics, Operations, Maintenance, and Disposal Engineer
- Developer of Users’ Manuals and Operator Training Materials
Glue Among Subsystems

- Owner of “Glue” Among Subsystems
- Seeker of Issues That Fall “in the Cracks”
- System Integrator
- Owner of Internal Interfaces
- Risk Identifier
- “Technical Conscience of the Program” [Fisher 92]
Customer Interface

- Customer Interface
- Customer Advocate
- Customer Surrogate
- Customer Contact

Marketing Interface
- Technical sales rep
- Product engineering expert
- Competitive analysis
Technical Manager

• Technical Manager
• Planner, Scheduler, and Tracker of Technical Tasks
• Owner of Risk Management Plan
• Product Manager
• Product Engineer
Information Manager

- Configuration Management
- Data Management
- Metrics
Process Engineer

- Process Engineer
- Business Process Reengineer or Business Analyst
- Owner of the Systems Engineering Process
- Attention to enterprise needs rather than to needs of individual systems and customers – *product lines*
Coordinator

- Coordinator of the Disciplines
- Tiger Team Head
- Head of Integrated Product Teams (IPTs)
- System Issue Resolver
Classified Ads Systems Engineer

- “Skills must include shell scripting, SQL, performance analysis, and network integration.”
- “…five years of solid analytical & debugging expertise in a telecommunications environment”
- “Analyze and develop systems level software in C/C++ and UNIX scripts.”
Classified Ads Systems Engineer, cont’d

• “Object-Oriented/Design/Analysis/Programming... RDBMS (Oracle), ...CICS/PLI, ...STAIRS/ Search Manager...”

• “Provide UNIX Administration and service delivery for our ... Internet service”

• “Provide design, implementation, and ongoing support for Managed and Non-Managed Private X.25, Frame Relay, and ATM Networks…”

Not considered basic SE role; included to show that there are still other definitions.
## The Roles in INCOSE Papers

<table>
<thead>
<tr>
<th>Role Reference</th>
<th>1 RO</th>
<th>2 SD</th>
<th>3 SA</th>
<th>4 VV</th>
<th>5 LO</th>
<th>6 G</th>
<th>7 CI</th>
<th>8 TM</th>
<th>9 IM</th>
<th>10 PE</th>
<th>11 CO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bahill 94</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Beam 94</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Blanchard 94</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Boehm 94</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Dick 94</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Fabrycky 94</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Friedman 94</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Grady 94</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Hatley 94</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Lacy 94</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Lake 94</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Mar 94</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Rechtin 94</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Sage 94</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Wymore 94</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Bate 95 (SE-CMM)</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>CAWG 95 (SECAM)</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>DSMC 90</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Matty 95</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>McKinney 95</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Sheard 95</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>

▲=Primary assumption, ✓=Secondary Assumption
Twelve Roles Conclusions

• No two authors agree

• Most roles are controversial as to whether they are systems engineering roles

• “Systems Engineering” may mean any or all of the roles – clarify what you mean

Unintentionally:

• A systems engineering capability may be defined by determining who performs each of these roles
What’s Missing?

• What roles are important for which systems engineering tasks?

• Is systems engineering a process or an overarching function? a group or an approach?

• Is systems engineering mostly analysis and determination of measures of effectiveness, or does it include program coordination?

• How do you use standards and capability models to implement systems engineering?

• What kind of systems engineering research is needed?
Three Types of SE Implementations

• Again attempting to understand extremes
• What differences there are between concepts of “systems engineering”
  – Generally becomes “aspects” of any real SE job as opposed to a hard distinction
• Note where the polarities of SE apply (what is “the discipline” vs “the generalist, etc.”)
Three Types of Systems Engineering Implementation

- **Discovery**

- **Program Systems Engineering**

- **Approach**
Discovery

- Focus on determining whether a feasible solution exists
- Concept exploration and Definition (phases A&B)
- Systems engineers are analysts investigating unprecedented problems
- Very high complexity in problem space
- “Specialists in the SE Discipline”
- Examples: Atlas rocket, SAGE computer system, Boston Central Artery/Tunnel
Program Systems Engineering

• Systems engineering is the group responsible for engineering the top level system
  – Good SEing involves many other people
• Focus on solution space and building it competitively. Complexity in solution and organization.
• Precedented problems, new solutions
• Generalists
• Technical side of program management, coordinator
Approach

• The Systems Engineering Process
• What every engineer should do
• Focus on applying life cycle steps to any project and task
  – Setting up a colloquium talk
  – Developing a requirements document
• Problem solving using the scientific method
• Complexity in the variety of applications
Three Types (in paper)

- **Type 1**
  - Discovery
  - Unprecedented Problems

- **Type 2**
  - Program SE
  - Unprecedented Solutions

- **Type 3**
  - Approach
  - Any kind of engineering
Three Types

- **Type 1** Discovery
  - Unprecedented Problems

- **Type 2** Program SE
  - Unprecedented Solutions

- **Type 3** Approach
  - Any kind of engineering
## Systems Engineering Standards

<table>
<thead>
<tr>
<th>Discovery</th>
<th>None very applicable</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Program Systems Engineering</strong></td>
<td>EIA 632, IEEE 1220, EIA/IS 731</td>
</tr>
<tr>
<td><strong>Approach</strong></td>
<td>IEEE 1220 EIA/IS 731 (tailored)</td>
</tr>
</tbody>
</table>
If we do this can we answer...

• Is systems engineering a process or an overarching function? a group or an approach?

• Is systems engineering mostly analysis and determination of measures of effectiveness, or does it include program coordination?

• How do you use standards and capability models to implement systems engineering?

• What kind of systems engineering research is needed?
## Examples

<table>
<thead>
<tr>
<th></th>
<th>Discovery</th>
<th>Program Systems Engineering</th>
<th>Approach</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Tools</strong></td>
<td>Analysis, simulation, modeling</td>
<td>Templates for processes; requirement mgt; office tools</td>
<td>None specific to doing a task with the system in mind particular</td>
</tr>
<tr>
<td><strong>Research</strong></td>
<td>Analysis quality and applicability</td>
<td>Process cost effectiveness Coordination of best practices</td>
<td>Benefits of implementation Education</td>
</tr>
</tbody>
</table>
What Systems Engineering Do We Need?

• Systems engineering is both an umbrella function over software and other disciplines, and a necessary part of any product development process
  – Discovery is analysis-intensive; needed early to understand a complex problem space
  – Program systems engineering realizes design
  – Approach is needed for all tasks

• Systems engineering must involve others to create future systems that work
  – Determine who will perform what roles, when, and how
Can we answer these?

- Is systems engineering the engineering of the top-level system, or a process?
- Are systems engineers specialists or generalists?
- Are systems engineers some people or all engineers?
- Do standards and capability models describe systems engineering well?
Summary

- Agree that systems engineering consists of the sum of pieces
  - Roles
  - Types of implementation
- Clarify “Systems Engineering”
- Present a united front that systems must be engineered
  - Top level systems require *Program Systems Engineering*
  - All disciplines need *Approach*
Author Contact Information

Sarah A. Sheard  
Software Productivity Consortium  
2214 Rock Hill Road  
Herndon, Virginia 20170  
(703) 742-7106  
sheard@software.org
# Roles and Types

<table>
<thead>
<tr>
<th>Discovery</th>
<th>SA, RO, IM, TM</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Program Systems Engineering</strong></td>
<td>SD, CO, CI, G, VV, RO</td>
</tr>
<tr>
<td><strong>Approach</strong></td>
<td>RO, SD, VV, LO, CI, TM</td>
</tr>
</tbody>
</table>
Role Combinations and Capability Models

- **Life Cycle Roles** – RO, SD, (SA), VV, LO
  - Technical focus areas
- **Program Management Roles** – TM, G, IM, CO, (CI)
  - Management focus areas
- **Risk** – G, SA, TM – Manage Risk
- **Design Reviews** – TM, CI, G – Monitor and Control
- **Quality Assurance** – PE, TM – Ensure Quality
## EIA/IS 731 (SECM) Focus Areas

<table>
<thead>
<tr>
<th>Technical</th>
<th>Management</th>
<th>Environment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1 Define</td>
<td>2.1 Plan and Organize</td>
<td>3.1 Define and Improve the Systems Engineering Process</td>
</tr>
<tr>
<td>Stakeholder and System Level</td>
<td>2.2 Monitor and Control</td>
<td>3.2 Manage Competency</td>
</tr>
<tr>
<td>Requirements</td>
<td>2.3 Integrate Disciplines</td>
<td>3.3 Manage Technology</td>
</tr>
<tr>
<td>1.2 Define Technical Problem</td>
<td>2.4 Coordinate with Suppliers</td>
<td>3.4 Manage SE Support</td>
</tr>
<tr>
<td>1.3 Define Solution</td>
<td>2.5 Manage Risk</td>
<td></td>
</tr>
<tr>
<td>1.4 Assess and Select</td>
<td>2.6 Manage Data</td>
<td></td>
</tr>
<tr>
<td>1.5 Integrate System</td>
<td>2.7 Manage Configurations</td>
<td></td>
</tr>
<tr>
<td>1.6 Verify System</td>
<td>2.8 Ensure Quality</td>
<td></td>
</tr>
<tr>
<td>1.7 Validate System</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Use Example: 12 Roles and Organizational Processes