Empirical Research on Systems Thinking and Practice in the Engineering Enterprise

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Topics

- Research Motivations
- Research Landscape
- Traits of Systems Leadership
- Three Areas of Research
- Implications for the Practice
- Future Directions
Research Motivations (1)

Shortfalls in the systems engineering workforce

- Increasing demand for systems engineering skills in government and industry
- Erosion of engineering competency particularly in aerospace and defense
- Increased interdisciplinary emphasis as world becomes more connected
- Systems complexity demands more sophisticated systems architecting skills
- Nature of programs necessitates socio-technical rather than pure technical abilities
Research Motivations (2)

Advances in the practice of systems engineering

• Very large systems programs demand a collaborative distributed workforce

• Model-based systems engineering leads to new ways of performing systems work

• Systems engineering applied across many domains – critical infrastructure, energy, transportation, communications, others

• New/evolved practices required for systems of systems engineering
Research Needs

*Increasing demand for systems leaders coupled with the growing need to address significant socio-technical challenges motivates research in engineering systems thinking and practice*

- Empirical studies and case based research
- Better understanding of systems contexts
- Factors underlying competency in workforce
- Identification of enablers, barriers, precursors
- Systems thinking at multiple levels – individual, team, enterprise
Research Challenges

- Inhibited by traditional structure of academic institutions and funding agencies
- Requires in-depth understanding of engineering but at the same time an orientation in the social sciences
- Exploratory nature of research not well suited to typical engineering/science approach -- need to apply grounded theory and other qualitative methods
Research Landscape

A research landscape is the overall mental model under which research is formulated, performed, and transitioned to practice

1. Provides context for the research agenda, methods, and specific projects
2. Determines a community of interest
3. Opportunities/constraints on funding sources and sponsors
4. Significantly influences research outcomes and broader impact
Field of Engineering Systems as Research Landscape

Engineering systems is a field of study taking an integrative holistic view of large-scale, complex technologically enabled systems with significant enterprise level interactions and socio-technical interfaces.

- Multi-disciplinary focus via cross-cutting academic unit – engineering, management, social sciences
- Draws from both quantitative and qualitative approaches
- Deep engagement with real world industry and government projects
Four Perspectives for Engineering Systems Thinking

1. A very broad interdisciplinary perspective, embracing technology, policy, management science, and social science.

2. An intensified incorporation of system properties (such as sustainability, safety and flexibility) in the design process.
   - Note that these are lifecycle properties rather than first use properties.
   - These properties, often called “ilities” emphasize important intellectual considerations associated with long term use of engineering systems.

3. Enterprise perspective, acknowledging interconnectedness of product system with enterprise system that develops and sustains it.
   - This involves understanding, architecting and developing organizational structures, policy system, processes, knowledgebase, and enabling technologies as part of the overall engineering system.

4. A complex synthesis of stakeholder perspectives, of which there may be conflicting and competing needs which must be resolved to serve the highest order system (system-of-system) need.
Traits of Contemporary Systems Leaders

Hall (1962) …
1. An affinity for the systems point of view
2. Faculty of judgment
3. Creativity
4. Facility in human relations
5. A gift of expression

A.D. Hall, A Methodology for Systems Engineering, NJ; Van Nostrand, 1962
Traits of Contemporary Systems Leaders

1. Powerful integrative leaders focusing on societal needs
2. Utilize approaches beyond traditional engineering
3. Consider context as a design variable rather than a constraint
4. Intellectual skills to deal with many socio-technical dimensions
5. Higher order abilities for analysis and synthesis
6. Be capable of “situational leadership”
Three Areas of Research

1. Engineering Systems Thinking in Individuals
2. Collaborative Distributed Systems Engineering
3. Collaborative Systems Thinking

SEArI Research Structure
Engineering Systems Thinking in Individuals

General systems thinking has been studied empirically, but engineering systems thinking largely unexplored.

Frank (2000) characterized engineering systems thinking as unique.

Davidz (2006) performed study of 200 engineers in aerospace industry to identify enablers, barriers, precursors.


Experiential Learning
Individual Characteristics
Supportive Environment
Studies on Capacity for Engineering Systems Thinking
Moti Frank

Studies to characterize engineering systems thinking as distinct from systems thinking

Examples:

• Understanding whole system and seeing big picture
• Understanding a new system concept immediately on presentation
• Understanding analogies and parallelisms between systems
• Understanding limits to growth
Motivation
Davidz 2006

- Increasing complexity of engineering systems and the corresponding need for systems professionals
- Importance of systems engineering, demonstrated in policy mandates
- Importance of systems engineering workforce issues, also shown in policy documents
- **Data** needed on systems thinking development in order to know which methods are most effective in developing systems thinking in engineers

**Need for DATA on Systems Thinking Development**
Enabling Systems Thinking to Accelerate the Development of Senior Systems Engineers

Davidz 2006

Even though systems thinking definitions diverge, there is consensus on primary mechanisms that enable or obstruct systems thinking development in engineers.

Consensus on primary mechanisms that enable or obstruct systems thinking development in engineers:

- Experiential learning
- Individual characteristics
- Supportive environment
Example Systems Thinking Definitions – Davidz 2006

• “Big picture”
• “Interactions”
• “Worrying about everything”
• “System thinking is the ability to think about a system or system architecture holistically, considering the design elements, complexities, the “ilities”, the context that product or system will be used in, etc.”
• “You have to think extremely broadly. You can’t focus on a specific aspect. Think from the application of what a product is. Think from what the customer wants explicitly. Be able to think in all the areas that are related to that device. It’s broad and deep thinking. If you can’t do both, then you shouldn’t do systems stuff. You must be organized. Think without boundaries at the start. If you think that your job is the requirements, then you are a clerk, not a systems engineer.”
• “Connecting lots of dissimilar disciplines and weighing trade offs between them…”
Research Methods
Davidz 2006

- Literature review
- Pilot Interviews (N=12)
- Data Analysis Using QSR N6, SPSS, MS Excel
- Field Study of 10 Companies and 205 Subjects Using Interviews and Surveys
- Additional Interviews with “Blue Chip” Proven Experts (N=2)
Experiential Learning Develops Systems Thinking

Q: What were key steps in your life that developed your systems thinking abilities?

<table>
<thead>
<tr>
<th>Node Category</th>
<th>All Participants (N=202)</th>
<th>Expert Panels (N=37)</th>
<th>Senior Systems Engineers (N=61)</th>
<th>Senior Technical Specialists (N=52)</th>
<th>Junior Systems Engineers (N=52)</th>
</tr>
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<tbody>
<tr>
<td>Rank</td>
<td>Number</td>
<td>Percent</td>
<td>Rank</td>
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<tr>
<td>Work Experiences</td>
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<td>139</td>
<td>69%</td>
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<td>Education</td>
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<td>43%</td>
<td>3</td>
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<td>Individual characteristics</td>
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<td>64</td>
<td>32%</td>
<td>2</td>
<td>16</td>
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<td>Life experiences outside work</td>
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<td>72</td>
<td>36%</td>
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<td>5</td>
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<tr>
<td>Interpersonal</td>
<td>5</td>
<td>37</td>
<td>18%</td>
<td>4</td>
<td>5</td>
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<td>Training</td>
<td>6</td>
<td>16</td>
<td>8%</td>
<td>6</td>
<td>4</td>
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</table>

Source: Davidz 2006
“Systems Thinking Mindset”
Davidz 2006

• MUST be decomposed, since understandings can be contradictory
• Before designing an intervention, know what you are trying to produce

<table>
<thead>
<tr>
<th>Process-Centered SE Traits</th>
<th>System-of-Systems SE Traits</th>
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<tbody>
<tr>
<td>Detail oriented</td>
<td>Not detail focused</td>
</tr>
<tr>
<td>Structured</td>
<td>Thinks out-of-the-box</td>
</tr>
<tr>
<td>Methodical</td>
<td>Creative</td>
</tr>
<tr>
<td>Analytical</td>
<td>Abstract thinking</td>
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</table>

Define the Goal then Design the Intervention
How does your company determine if an employee displays strong systems thinking?

<table>
<thead>
<tr>
<th>Node Category</th>
<th>All Participants (N=185)</th>
<th>Senior Systems Engineers (N=62)</th>
<th>Senior Technical Specialists (N=51)</th>
<th>Junior Systems Engineers (N=52)</th>
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<tbody>
<tr>
<td></td>
<td>Rank</td>
<td>Number</td>
<td>Percent</td>
<td>Rank</td>
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<tr>
<td>Difficulty with this</td>
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<td>100</td>
<td>61%</td>
<td>2</td>
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<tr>
<td>Experience and observation</td>
<td>2</td>
<td>95</td>
<td>68%</td>
<td>1</td>
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<tr>
<td>Look for certain characteristics</td>
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<td>26</td>
<td>17%</td>
<td>3</td>
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<tr>
<td>Formal methods</td>
<td>4</td>
<td>23</td>
<td>14%</td>
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</table>
Empirically Derived Implications for Practice

1. Educate engineers to think more deeply about systems in their context and environment

2. Develop “situational leadership: abilities in engineers – capable of making decisions at component, system, systems of systems level

3. Provide classroom and experiential learning opportunities with systems across the life cycle phases – develop ability to make decisions in present for an uncertain future
Utter (2007) performed empirical case studies to identify successful practices and lessons learned. Social and technical factors studied: collaboration scenarios, tools, knowledge and decision management, culture, motivations, others. Can not be achieved without first overcoming possible barriers and issues. Preliminary set of success factors identified.

**Success Factor:** Invest in Up-front Planning Activities. Spending more time on the front-end activities and gaining team consensus shortens the implementation cycle. It avoids pitfalls as related to team mistrust, conflict, and mistakes that surface during implementation.
Empirical Data in Exploratory Study

Data Analysis Example

Company Transcripts

OR

CDSE Social and Cultural Environment

Interview Heading Topics

CDSE Benefits and Motivation

Description

Issue or Barrier

Recommendation

Lesson Learned

Success Factor

Irrelevant

Interviewee Experience

Tool Training

Tool Access

Network Reliability

Tool Versions

Learning Curves

Classified Data

Subtopic
**Perform Visual Management of Development Process**

Visual management of the development process may be useful in **establishing a sense of team**, as well as **keeping the team immediately up-to-date on important programmatic and product related issues**. This visual management may be possible by using the **collaboration tools or environments and/or team room displays**. Imagine an online collaborative environment, and upon logging in, **immediately being informed of a subsystem’s current testing or development status** (perhaps in red, yellow, green). Or similarly, entering a CDSE team room to find the color-coded schedule progress of each team. These visual cues provide immediate feedback without having to scour schedules, requirements, or test data and are relatively simple to implement.
Empirically Derived Implications for Practice

1. Thirteen socio-technical ‘success themes’ identified that may lead to best practices

2. Exploratory studies uncovered differences in maturity in regard to factors that foster or inhibit – suggesting a “collaboration maturity factor”

3. Desirable future outcome is development of assessment instrument to assist organizations in assessing readiness to undertake collaborative distributed systems engineering
It is not enough to understand systems thinking in individuals but also how it emerges in groups and enterprises.

Lamb (2008) performing empirical studies - focus on interaction of process and culture.

Research seeks to identify promising patterns that can lead to larger cross-cutting studies.

Pilot interviews have provided insights to inform the study.

**Factors in Collaborative Systems Thinking:**
These traits are not necessarily of one individual but emerge through interactions of a group of individuals as influenced by culture, team norms, environment, and processes.
Empirically Derived Implications for Systems Engineering Practice

1. Effective communication is necessary condition
2. Need ability to engage in divergent and convergent thinking
3. Product orientation vs single component/function is important
4. Overall team awareness within/across teams is an enabler
5. Hero culture, and associated incentives, is a barrier
6. Team segmentation results in negative behaviors
7. The interplay of culture and process appears to be critical
Limitations of Current Research

- Preliminary and exploratory
- Use of grounded methods to uncover findings and hypotheses
- Access to sensitive data and human subjects
- Organizations reluctant to share “bad” cases
- Difficult to fund this type of research
Future Directions

The understanding of the organizational and technical interactions in our systems, emphatically including the human beings who are a part of them, is the present-day frontier of both engineering education and practice.

Dr. Michael D. Griffin, Administrator, NASA
Boeing Lecture, Purdue University
28 March 2007

- Publication of case studies on social contexts
- Extension of exploratory studies to larger study projects
- Further research into collaboration factors
- New research on methods and infrastructure for virtual enterprises
- Conduct sufficient research and validation to inform enhancements to the practice
- Application of engineering systems thinking to SoS and enterprises
Access to Research
http://seari.mit.edu

Navigation
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Events
Sponsors
Community
Contact

Purpose
Web portal for sharing research within SEAr, MIT, and systems community