# MIT LAI and SEAri Research

## The Big Picture: Historical View of Systems Thinking and Social Competencies in Research and Practice


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# Topics

- Need
- Research Motivations
- Past Areas of Research
- Way Forward

# Need for Systems Competency

## URGENCY

- increasing complexity of programs and workforce demographics

## NEEDED COMPETENCY

- New competencies/shifting priorities of competencies

## STRATEGIC USE

- Use at individual, team, and enterprise level


 

LEAN ADVANCEMENT INITIATIVE ™

# MIT Research on Systems Engineering in the Enterprise

## 2003-present

***Empirical studies and case based research** for purpose of understanding how to **achieve more effective systems engineering practice***

- **Engineering systems thinking in individuals and teams**
- **Collaborative, distributed systems engineering practices**
- **Social contexts of enterprise systems engineering**
- **Alignment of enterprise culture and processes**
- **Socio-technical systems studies and models**

*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, 2007 Boeing Lecture, Purdue University

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# Motivation
# Skills Shortage/Demand

- **Increasing demand for systems engineering skills across all domains and sectors**
- **Concerns about erosion of engineering competency particularly in aerospace and defense**
- **Increased interdisciplinary emphasis as world becomes connected**
- **Complexity demands sophisticated architecting and decision making skills**
- **Nature of modern projects necessitates socio-technical rather than pure technical abilities**

**25 June 2008, NY Times, Efforts to Slow Defense Industry's Brain Drain**

***"…accurately assessing at the outset if the technological goals are attainable and affordable, then managing the engineering to ensure that hardware and software are properly designed, tested and integrated. The technical term for the discipline is systems engineering. Without it, projects can turn into chaotic, costly failures".***

# Motivation
# Understanding Program Failures

## Many program failures attributed to inadequate execution of sound processes

- Reality is that this often relates to factors beyond process execution and cost/schedule pressures
- Insufficient post-program assessment, particularly of soft factors
- Governance not always clear in SoS type programs

**Problem Statement for MITRE/MIT Joint Research in Social Contexts of Enterprise Systems Engineering**

***The Government programs that MITRE supports are suffering changes in requirements, cancellations, and shifting work areas. These difficulties reflect shifting interactions among powerful stakeholders who have competing interests, with no one effectively in control. While MITRE has always managed social, organizational, cultural, and political aspects of its business in tandem with the technical, these needs exceed our existing skill set.***

Brooks, J., Carroll, J., and Beard, J., Dueling Stakeholders and Dual-Hatted Systems Engineers: Engineering Challenges, Capabilities, and Skills in Government Infrastructure Technology Projects, IEEE Transactions on Engineering Management, Vol 58, No 3, Aug 2011

## Motivation
# Changes in SE Practice

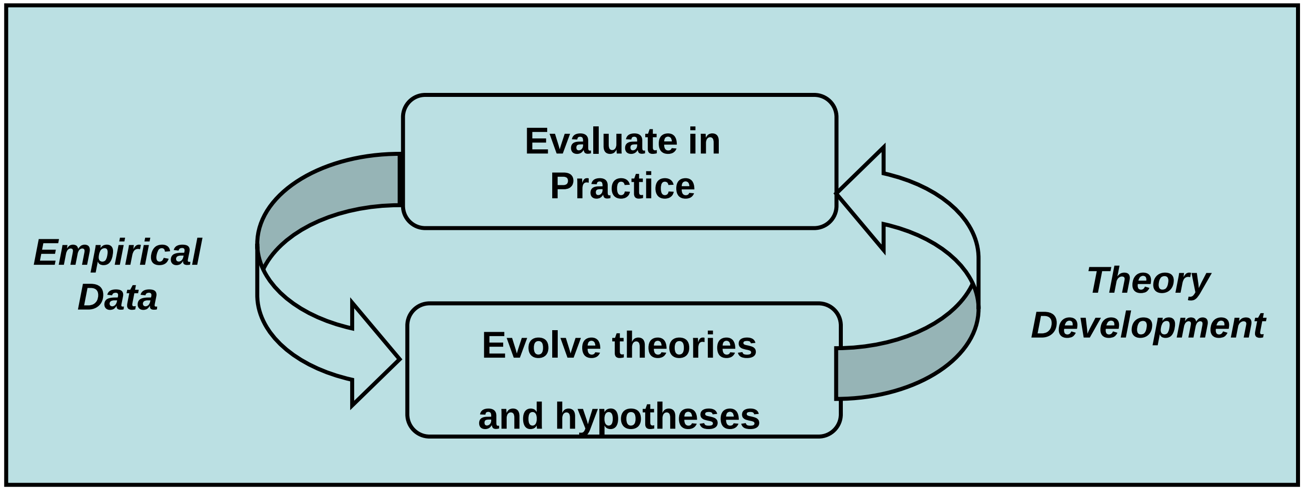
- New/evolved practices required for systems of systems engineering
- Very large programs demand a collaborative distributed workforce
- Model-based engineering leads to new ways of performing work
- Systems engineering applied across many domains – critical infrastructure, energy, transportation, communications, others

***The design and development of parts, engineering calculations, assembly, and testing was conducted by a small number of people. Those days are long gone. Teams of people, sometimes numbering in the thousands are involved in the development of systems….***

***Saunders, T., et al, System-of-Systems Engineering for Air Force Capability Development: Executive Summary and Annotated Brief, AF SAB TR -05-04, 2005***

# Research Challenges

- Inhibited by traditional structure of academic institutions and funding agencies
- Requires in-depth understanding of engineering but at 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





# Systems Thinking in Individuals

# 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**

- Rhodes & Wood (2007) find similar indicators in government agency

Rhodes, D.H., Lamb, C.T. and Nightingale, D.J., "Empirical Research on Systems Thinking and Practice in the Engineering Enterprise," 2nd Annual IEEE Systems Conference, Montreal, Canada, April 2008

# 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**

# How does your organization determine if an engineer displays strong systems thinking?

Davidz (2006) research shows 71% of junior engineers do not understand how their organizations define/measure systems thinking.

**Level**

**Difficulty**

Top Level 1 Coding for Determination of Strong Systems Thinking for All Classifications

(Node categories cited by 10% or more of the classification are shaded)

| Node Category | All Participants (N=165) | | | Senior Systems Engineers (N=62) | | | Senior Technical Specialists (N=51) | | | Junior Systems Engineers (N=52) | | | Chi-Square | Asymptotic Significance |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Rank | Number | Percent | Rank | Number | Percent | Rank | Number | Percent | Rank | Number | Percent | | |
| Difficulty with this | 1 | 100 | 61% | 2 | 30 | 48% | 1 | 33 | 65% | 1 | 37 | 71% | 6.659 | 0.036 |
| Experience and observation | 2 | 95 | 58% | 1 | 41 | 66% | 2 | 29 | 57% | 2 | 25 | 48% | 3.788 | 0.150 |
| Look for certain characteristics | 3 | 28 | 17% | 3 | 9 | 15% | 3 | 12 | 24% | 3 | 7 | 13% | 2.277 | 0.320 |
| Formal methods | 4 | 23 | 14% | 4 | 7 | 11% | 4 | 11 | 22% | 4 | 5 | 10% | 3.648 | 0.161 |

**Observation & Subjective Measure**

# What are Systems Engineers?

- **Two perspectives – can result in confusion and unmet expectations**
- **Understand the differences and how these are to be used (and communicated)!**

| Process-Centered SE Traits | Architecture-Centered SE Traits |
|---|---|
| Detail oriented | Not detail focused |
| Structured | Thinks out-of-the-box |
| Methodical | Creative |
| Analytical | Abstract thinking |

**Organizations needs to understand whether systems engineering covers one or both of these perspectives – and develop appropriate job descriptions and messaging.**

# Engineering Systems Thinking in Individuals

*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

# Collaborative Distributed Systems Engineering



# Collaborative Distributed Systems Engineering (CSDE)

- 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

Rhodes, D.H., Lamb, C.T. and Nightingale, D.J., "Empirical Research on Systems Thinking and Practice in the Engineering Enterprise," 2nd Annual IEEE Systems Conference, Montreal, Canada, April 2008

**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.*

# Collaborative Distributed Systems Engineering

*Empirically Derived Implications for Practice*

- **Thirteen socio-technical 'success themes' identified that may lead to best practices**
- **Exploratory studies uncovered differences in maturity in regard to factors that foster or inhibit – suggesting a "collaboration maturity factor"**
- **Desirable future outcome is development of assessment instrument to assist organizations in assessing readiness to undertake collaborative distributed systems engineering**

# Collaborative Systems Thinking

# Collaborative Systems Thinking Lamb 2009

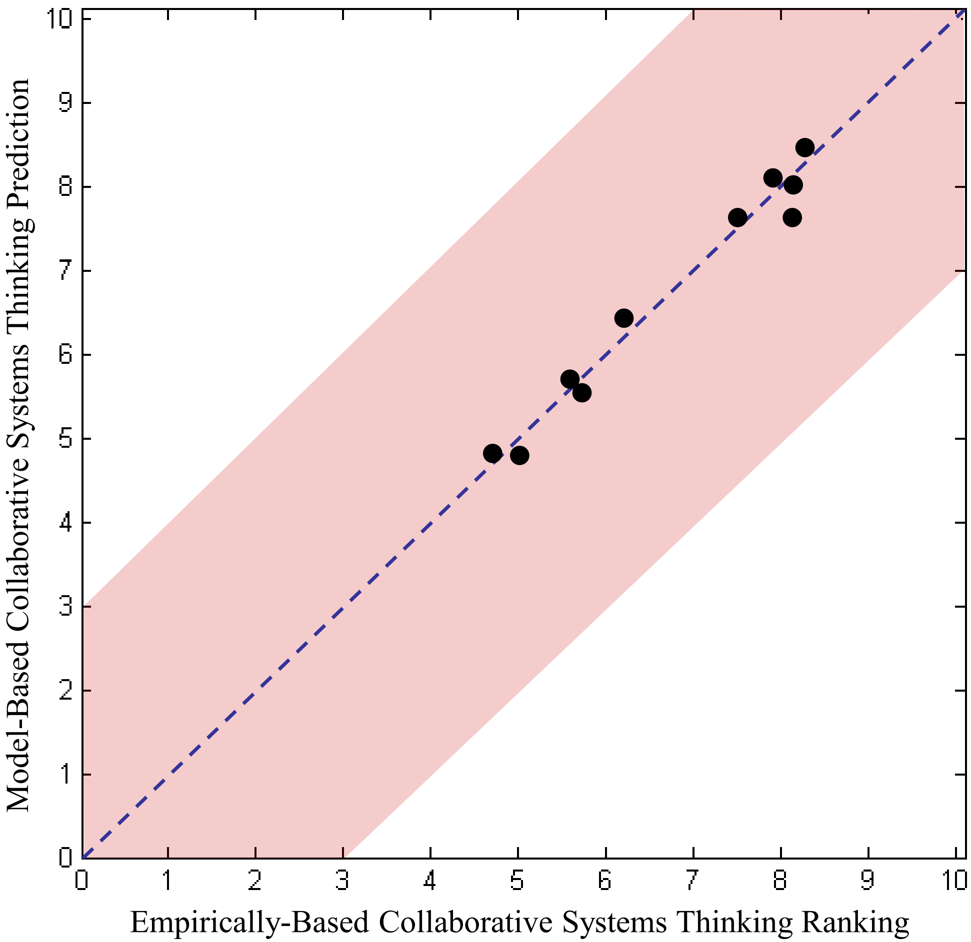
- It is not enough to understand systems thinking in individuals.
- Also need to understand how it emerges in groups and enterprises
- Lamb (2009) performed empirical study on systems thinking capacity of teams

**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*

Lamb, C.T. and Rhodes, D.H., "Collaborative Systems Thinking: Uncovering the Rules of Team-Level Systems Thinking," 3rd Annual IEEE Systems Conference, Vancouver, Canada, March 2009

# Regression Modeling Identified Five Best Predictors of CST

**Lamb 2009**




- **Purpose:**
  - **Identify 5 best predictors**
  - **Facilitate validation**
- **Results:**
  - **Model explains 85% of observed variability in CST rating**
  - **Each trait passed null hypothesis test**
- **Best Predicting Traits (high-low):**
  1. **Consensus Decision Making**
  2. **Concurrent Program Experience**
  3. **Realistic Schedule**
  4. **Overall Creative Environment**
  5. **Real-Time Interactions**

# Collaborative Systems Thinking

*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**

- **Collaborative systems thinking is a *distinct concept* from individual systems thinking**
- **Collaborative systems thinking teams have *differentiating traits***
- **CST team traits emphasize importance of *technical and social skills***

# The way forward …



# 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

Rhodes, D.H., SEAri Research Summit, 2008

# Traits of Contemporary Systems Leaders

1. **Powerful integrative leaders focusing on societal needs**
2. **Utilize approaches beyond traditional engineering**
3. **Intellectual skills to deal with many socio-technical dimensions**
4. **Higher order abilities for analysis and synthesis**
5. **Be capable of "situational leadership"**

Rhodes, D.H., SEAri Research Summit, 2008

# Future Research Directions

- Extending exploratory studies to more extensive and rigorous studies
- Additional research related to development of systems competencies in the workforce
- Field research to motivate theory and principles for developing and managing enterprises for context-harmonized interactions
- Understand the factors for effective systems engineering in product and service enterprises
- Case studies of enterprises using new methods to understand the impacts and benefits
- Conduct sufficient research and validation to inform enhancements to the practice
- Link research to competency models

# Limitations of Current Research

- **Preliminary and exploratory**
- **Use of grounded methods to uncover findings and form hypotheses**
- **Access to sensitive data and human subjects**
- **Organizations reluctant to share “bad” cases**
- **Difficult to find funding for this type of research**
- **Lack of agreed upon research agenda**

Community level research agenda and increased collaboration in research would accelerate our efforts