



**Systems Engineering Advancement Research Initiative**

**RESEARCH PROFILE**

**Systems Engineering in the Enterprise**

**October 21, 2008**

**Dr. Donna H. Rhodes**

**Massachusetts Institute of Technology**

**[rhodes@mit.edu](mailto:rhodes@mit.edu)**

# Topics

- Motivations
- Three Research Projects
  - Implications for Practice
- Future Research Directions

# SYSTEMS ENGINEERING in the ENTERPRISE

*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

# 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.***

# 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 systems architecting 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

## 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***

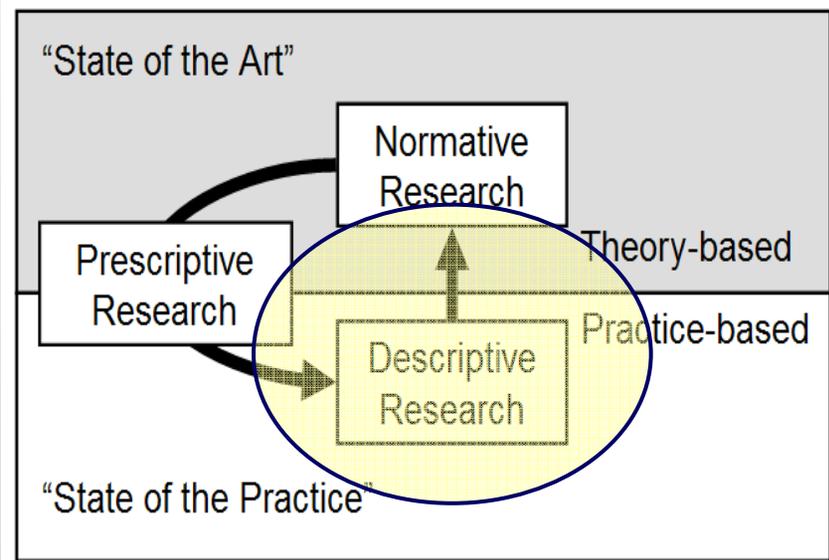
# Engineering Systems Four Important Perspectives

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.

# 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**

Rhodes & Adams (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

# 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** → **Too Level 1** Coding for Determination of Strong Systems Thinking for All Classifications  
(Node categories cited by 10% or more of the classification are shaded)

**Difficulty** →

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

Detail oriented  
Structured  
Methodical  
Analytical

## Architecture-Centered SE Traits

Not detail focused  
Thinks out-of-the-box  
Creative  
Abstract thinking

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

# 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”



# 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

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

Preliminary set of success factors

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*

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

# Collaborative Systems Thinking

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 for larger cross-cutting studies

Pilot interviews have provided insights to inform the study

Lamb, C.T. and Rhodes, D.H., "Systems Thinking as an Emergent Team Property: Ongoing Research into Enablers and Barriers to Team-level Systems Thinking," 2nd Annual IEEE Systems Conf, Montreal, Canada, April 2008



## **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*

# 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

# Future Research Directions

- More extensive and rigorous studies to understand collaborative distributed systems engineering
- 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



**Systems Engineering Advancement Research Initiative**

## QUESTIONS

<http://seari.mit.edu>

[rhodes@mit.edu](mailto:rhodes@mit.edu)