Systems Engineering Advancement Research Initiative

2009 SEAri Annual Research Summit

SEAri Overview and Motivations

Dr. Donna H. Rhodes *(Director, Principal Research Scientist, SEAri)*

October 20, 2009
Cambridge, MA
Massachusetts Institute of Technology

MIT ESD
Engineering Systems Division

SEA RI
Systems Engineering Advancement Research Initiative

The complexities of 21st century systems and system enterprises are driving changes in how we perform engineering ….

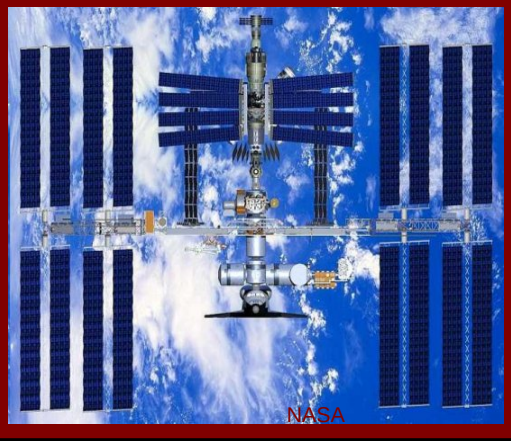
Systems and enterprises are more complex than ever before, and must be able to adapt to changes in environment and technologies

Systems need to be expandable, scalable, and designed to accommodate growth in capability

Advances in computing technology and advanced methods provide engineers with ability to do things previously not possible

System-of-Systems * Family of Systems * Product Families * Network Centric Systems


MTA


NASA


Deere & Company

Systems in a Dynamic World

NEEDS CHANGES

- unanticipated stakeholder needs
- needs related to unique factors (environmental, safety, aesthetic, etc)

POLITICAL and ECONOMIC CHANGES

- changes in multinational agreements
- change in political leadership driving shifts in lifespan or funding profiles

TECHNOLOGY and MARKET CHANGES

- availability of autonomous vehicles
- new emission standards imposed
- BRIC market escalates

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An Epoch is a period of time for which the system has fixed context and value expectations

Engineering Complex Systems

Five Aspects Taxonomy

Five aspects provide a taxonomy for defining useful constructs and methods, and also for defining strategies for management and innovation

1. **Structural:** related to form of system components and their interrelationships
2. **Behavioral:** related to function/operation and reactions to stimuli

Rhodes, D. and Ross, A., *Five Aspects of Engineering Complex Systems: Emerging Constructs and Methods*, IEEE Systems Conference, April 2010 (forthcoming)

Rhodes, D. and Ross, A., *Shaping Socio-technical System Innovation Strategies using the Five Aspects Taxonomy, 7th European Systems Engineering Conference, May 2010 (forthcoming)*

Engineering Complex Systems

Five Aspects Taxonomy

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1. **Structural:** related to form of system components and their interrelationships
2. **Behavioral:** related to function/operation and reactions to stimuli
3. **Contextual:** related to circumstances in which the system or enterprise exists
4. **Temporal:** related to the dimension of time
5. **Perceptual:** related to stakeholder preferences, perceptions and cognitive biases

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Five Aspects of Complex Systems

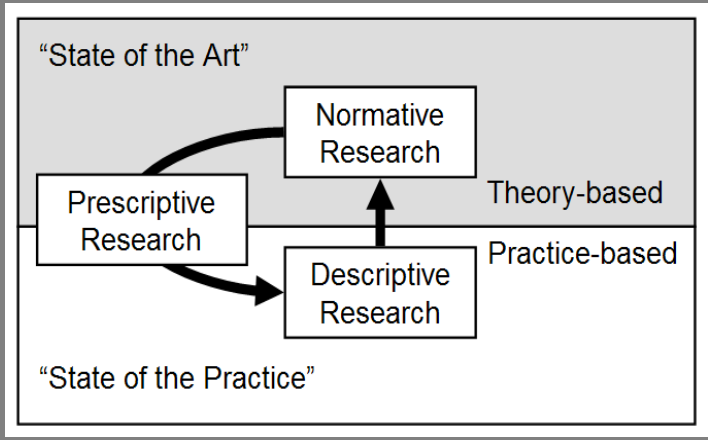
SEAri research projects address multiple aspects

STRUCTURAL	• heterogeneous components and constituent systems • elaborate networks, loose and tight couplings • layers, vertical/horizontal structures, multiplicity of scales
BEHAVIORAL	• complex variance in response to stimuli • unpredictable behavior of technological connections • emergent social network behavior
CONTEXTUAL	• many complexities and uncertainties in system context • political, economic, environmental, threat, market factors • stakeholder needs profile and overall worldview
TEMPORAL	• decoupled acquisition phases and context shifts • systems with long lifespan and changing characteristics • time-based system properties (flexibility, survivability, etc.)
PERCEPTUAL	• many stakeholder preferences to consider • perception of value shifts changes with context shifts • cognitive constraints and biases

SEAri Portfolio & Methods

RESEARCH PORTFOLIO

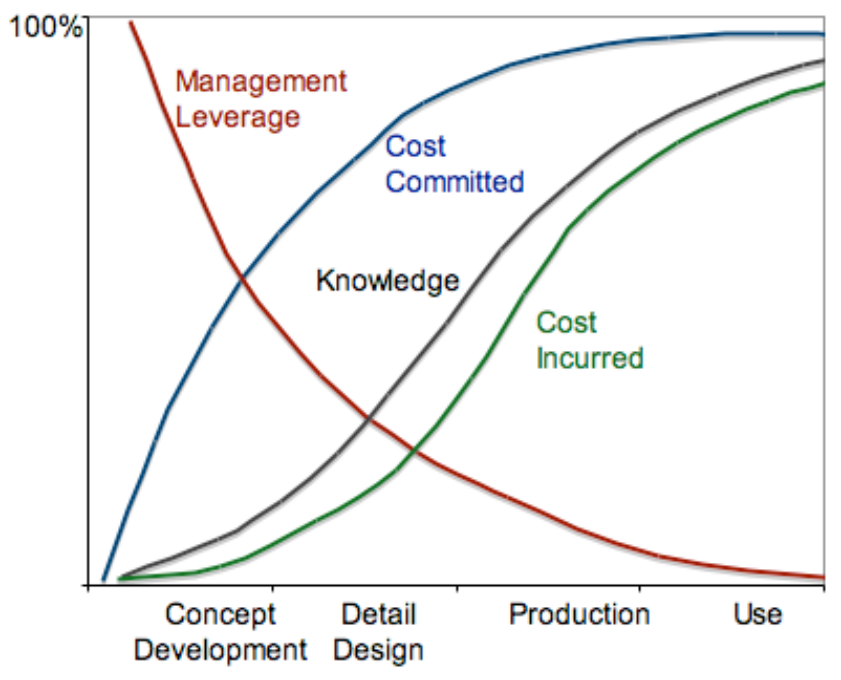
- Socio-Technical Decision Making
- Designing for Value Robustness
- Systems Engineering Economics
- Systems Engineering in the Enterprise
- Systems Engineering Strategic Guidance



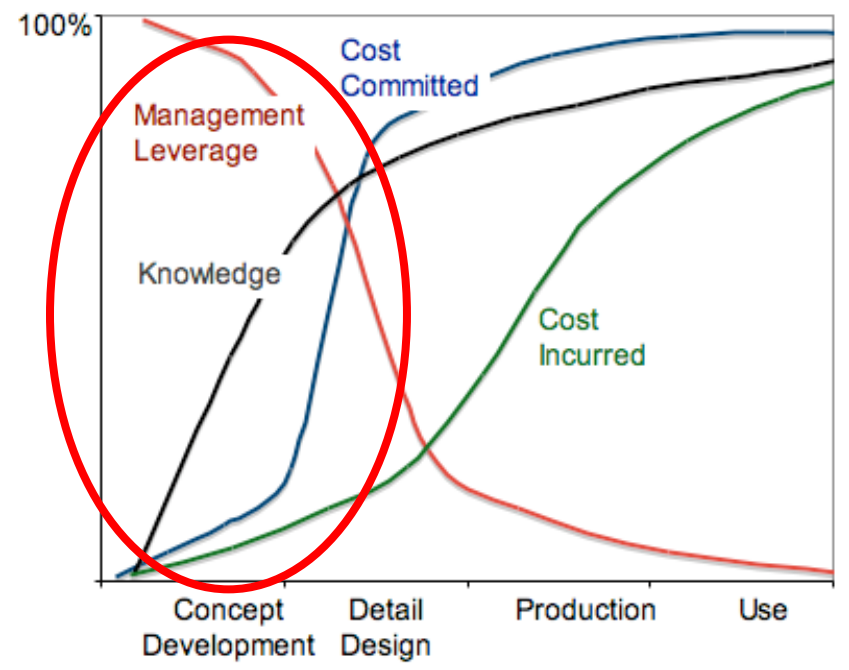
METHODS USED

- Models and Simulations: MATLAB Models, Agent-based Models, STK
- Empirical studies of historical systems, programs, and practices
- Grounded theory, coding/memo writing methods, latent semantic analysis
- Experiment-based studies: advanced analyses, visualizing complex data sets

Our Research Seeks to "Change the Picture"

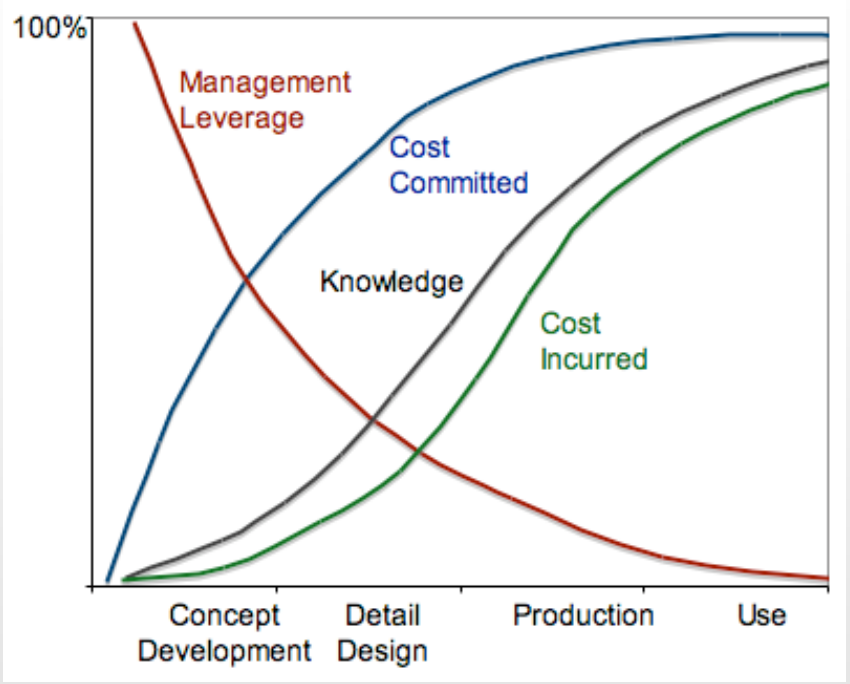


Classic paradigm



New paradigm

Our Research Seeks to "Change the Picture"



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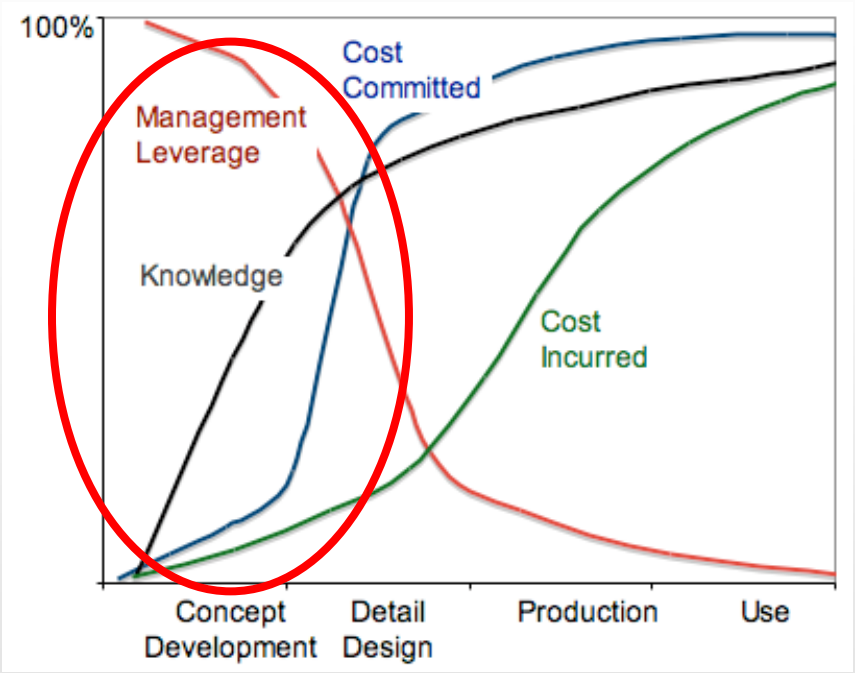

New paradigm

1. Existence of appropriate **competencies** in workforce
2. Advanced **methods** for performing anticipatory thinking, analysis, and decision making in design of systems
3. Enterprises with enabling strategies and model-based **environments**

Socio-Technical Decision Making

STRUCTURAL **BEHAVIORAL** CONTEXTUAL TEMPORAL **PERCEPTUAL**	***Distributed Decision Making in Systems of Systems*** Nirav Shah

While organizational theorists have well developed theories of how organizations function and make decisions, this understanding needs to be integrated into the design phase in a quantifiable way…then apriori the effects of the enterprise organization on the system will be predicted rather than being a surprise
Hastings, 2004

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STRUCTURAL BEHAVIORAL CONTEXTUAL **TEMPORAL** PERCEPTUAL	***An Integrated Real Options Framework for Model-based Identification and Valuation of Options under Uncertainty*** Dr. Tsoline Mikaelian

Socio-Technical Decision Making

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PERCEPTUAL	Dr. Tsoline Mikaelian

Uses agent-based model to identify influence factors that can be used to modify decision behaviors of constituent systems in SoS

Socio-Technical Decision Making

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Distributed Decision Making in Systems of Systems

Nirav Sh

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...gs, 2004

Seeks to recommend how best to structure approval committees to make effective decisions given multiple specialties (with unique preferences/cognitive biases)

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Decision-Making by Technical Expert Committees for Engineering Systems

David Broniatowski

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An Integrated Real Options Framework for Model-based Identification and Valuation of Options under Uncertainty

Dr. Tsoline Mikaelian

Socio-Technical Decision Making

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Research outcomes include a framework for structuring a portfolio of real options that can be exercised at designated points in time as uncertainties are resolved

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Designing for Value Robustness

STRUCTURAL	***Application of Multi-Attribute Tradespace Exploration to a Transportation System*** Julia Nickel
BEHAVIORAL	
CONTEXTUAL	
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Architecting value robust systems requires new methods for exploring the concept tradespace, as well as …architecting principles and strategies, an approach for the quantification of changeability, and improved ability for architects and analysts to classify value for purposes of dialogue and implementation
Ross and Rhodes, 2008

STRUCTURAL	***A Method for Tradespace Exploration of Systems of Systems*** Deb Chattopadhyay
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STRUCTURAL	***Multi-Attribute Tradespace Exploration for Survivability*** Dr. Matthew Richards
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Investigates use of tradespace exploration in transportation systems context, including the challenge of considering large and diverse stakeholder set

Designing for Value Robustness

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Architecting value robust systems ring the well as ategies, ation of ility for classify ue and ntation
es, 2008

Elaborates a method for evaluating single systems and SoS in same tradespace across multiple epochs

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Designing for Value Robustness

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Ross and Rhodes, 2008

Research outcomes include 17 principles and 2 metrics for designing survivable systems

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Systems Engineering Economics

STRUCTURAL	***Economics of Human Systems Integration*** Kevin Liu
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In a 2004 Air Force/MIT workshop, Dr. Marvin Sambur, (then) Assistant Secretary of USAF for Acquisition, noted that the average program is 36% overrun according to recent studies – disrupting the overall portfolio of programs

STRUCTURAL	***Evolving Decision Tools throughout the Enterprise to Address Human System Considerations*** Kacy Gerst
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STRUCTURAL	***Assessing the Impacts of Fractionation on Pointing-Intensive Spacecraft*** Greg O'Neill
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Systems Engineering Economics

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Economics of Human Systems Integration

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Evolving Decision Tools throughout the Enterprise to Address Human System Considerations

Kacy Gerst

Given the human systems integration context, investigates 'right' amount of effort to invest and application of COSYSMO cost model

Systems Engineering Economics

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Given the human systems integration context, examines strategic level and implementation level decision analysis tools

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Systems Engineering Economics

Given spacecraft assessment context, compares the value proposition for monolithic versus fractionated spacecraft

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Systems Engineering in the Enterprise

STRUCTURAL
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Understanding the Dynamics of Innovation in the Government Space Sector

Zoe Szajnfarber

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, 2007

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Enterprise Management of Systems of Systems in the DoD

Chris Roberts

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Collaborative Systems Thinking: An exploration of the mechanisms of team systems thinking

Dr. Caroline Lamb

Systems Engineering in the Enterprise

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Enterprise Management of Systems of Systems in the DoD

Chris Roberts

Seeks to understand formal institutional structures and dynamics of innovation

Systems Engineering in the Enterprise

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Understanding Dynamics of Innovation in th Government Space Sector

Zoe Szajnfa

Investigates aspects of SoS management including network structures of SoS decision makers, and temporal correlations of milestones and program issues

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Enterprise Management of Systems of Systems in the DoD

Chris Roberts

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Collaborative Systems Thinking: An exploration of the mechanisms of team systems thinking

Dr. Caroline Lamb

Systems Engineering in the Enterprise

Research identified factors for collaborative systems thinking in system design teams based on observing their behavior and examining cognitive factors

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Strategic Guidance

Selected Recent Contributions

- tradespace exploration method
- changeability taxonomy
- 17 survivability design principles
- integrated real options framework
- new metrics for several “ilities”
- fractionated spacecraft study
- epoch-era analysis
- traits of systems thinking teams*

The full impact of systems engineering research can only be achieved through synthesis of research outcomes…. for developing prescriptive strategic guidance to inform the development of policies and systems engineering practice

Anticipated Contributions

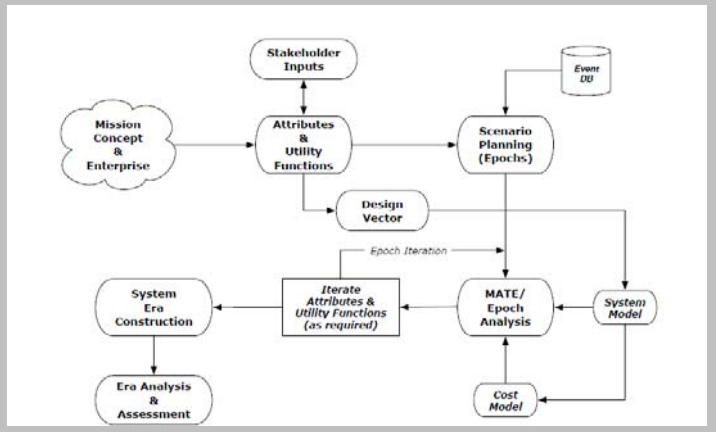
- team structures for innovation and effective decision making
- cost model and leading indicators for human systems integration
- enhanced analysis/visualizations for tradespace exploration
- and more…

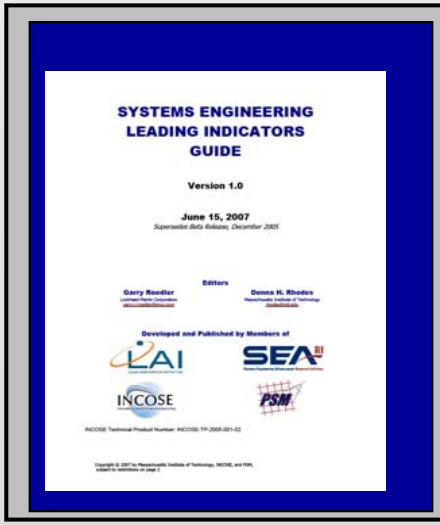
* collaborative research with LAI

Adoption of Our Methods by Government and Industry

US Air Force SMC/Aerospace Corporation AIAA 2009 Paper (Ewart et al):

"To analyze value robustness over time we adopt the Epoch-Era analysis (EEA) approach described by Ross and Rhodes."



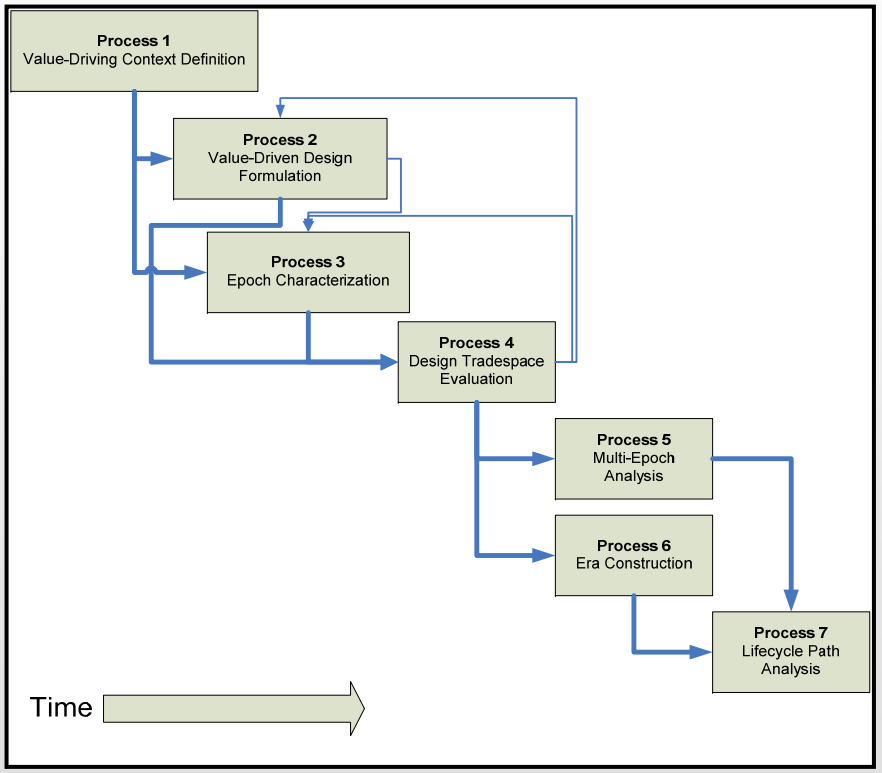


Based on six years of collaborative research of LAI, INCOSE, PSM and SEAri – the guide has been implemented as standard practice in many companies and government agencies in multiple domains of practice in several countries

Responsive Systems Comparison Method
synthesis of a decade of research

Using Multi-Attribute Tradespace Exploration, Epoch-Era Analysis, and other approaches, a coherent set of processes were developed into the RSC method

RSC is presently being applied for the first time on a real-world project within a US Government Agency

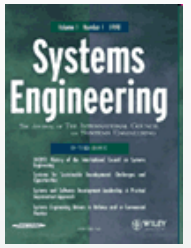


Ross, A.M., McManus, H.L., Long, A., Richards, M.G., Rhodes, D.H., and Hastings, D.E., "Responsive Systems Comparison Method: Case Study in Assessing Future Designs in the Presence of Change," AIAA Space 2008, San Diego, CA, September 2008

Ross, A.M., McManus, H.L., Rhodes, D.H., Hastings, D.E., and Long, A.M., "Responsive Systems Comparison Method: Dynamic Insights into Designing a Satellite Radar System," AIAA Space 2009, Pasadena, CA, September 2009

Sharing Research Outcomes with the Systems Community

- Over 80 Publications in last three years
  - INCOSE Best Journal Paper for 2008
  - Best Conference Paper Awards
    - 2008 IEEE Systems Conference Best Paper
    - 2008 INCOSE Symposium Best Papers (2 of 2 awards)
    - 2008 Responsive Space Conference Student Award
    - 2009 Responsive Space Conference Student Award
    - 2009 Best Student Paper, IEEE Systems Conference



- MIT Professional Short Course on Value Driven Tradespace Exploration

- SEAri Website as Knowledge Repository

Access to Research Information

Systems Engineering Advancement Research Initiative

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Purpose

Web portal for sharing research within SEAri, MIT, and outside world