Evolving Systems Engineering as a Field within Engineering Systems

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INCOSE Symposium 2008

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Topics

- Comparison of SE and ES
- ES as “Context Field”
- Impact
- Example of SE Research Initiative within ES
- Summary

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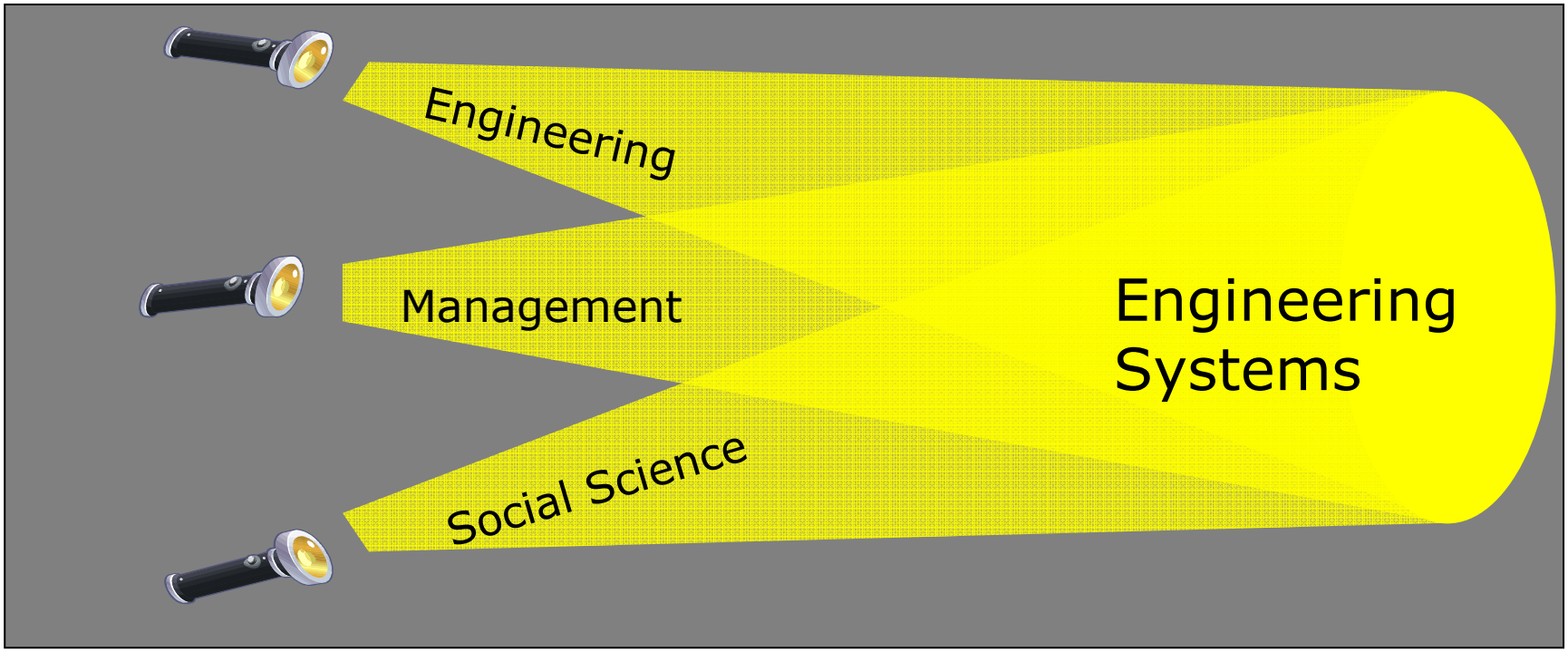
Engineering Systems: Field of Scholarship



ENGINEERING SYSTEMS

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.

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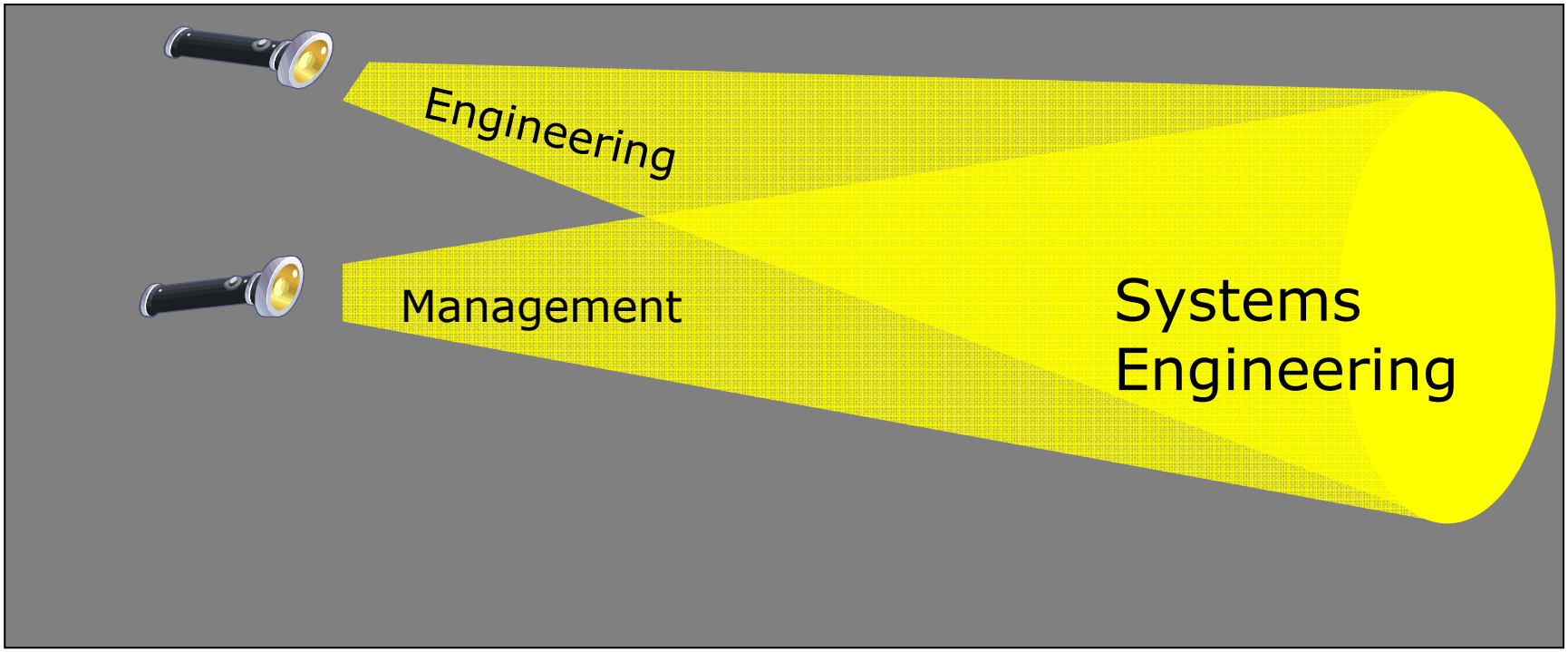
Systems Engineering
Field of Practice



Systems Engineering

Considers both the business and the technical needs of all customers with the goal of providing a quality product that meets the user needs.

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SE versus ES
What Is the Difference?

SYSTEMS ENGINEERING (Traditional)

Systems engineering is the **process** of selecting and synthesizing the application of the appropriate scientific and technical knowledge in order to translate system requirements into system design. (Chase)

SYSTEMS ENGINEERING (Advanced)

Systems engineering is **a branch of engineering** that concentrates on design and application of the whole as distinct from the parts… looking at the problem in its entirety, taking into account all the facets and variables and relating the social to the technical aspects. (Ramo)

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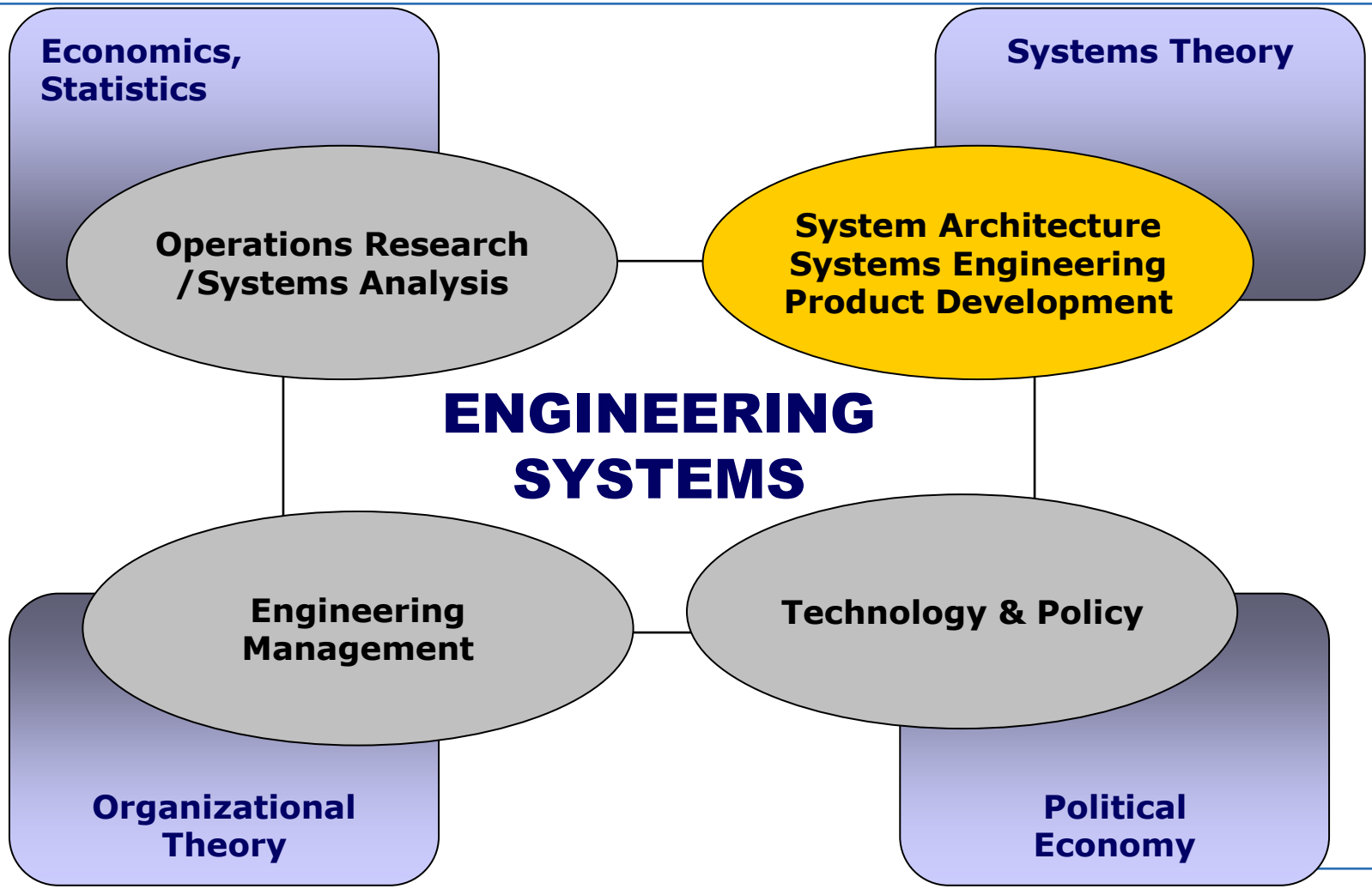
Engineering Systems as a Field of Scholarship



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Engineering Systems -- Important Perspectives

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

An **intensified incorporation of system properties** (such as sustainability, safety and flexibility) in the design process.

Enterprise perspective, focusing on interconnectedness of product system with enterprise system that develops and sustains it.

A **complex synthesis of stakeholder perspectives**, of which there may be conflicting and competing needs to be resolved to serve the highest order system need.

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	Systems Engineering	*Engineering Systems*
Scope	Small to large scale subsystems, systems, system of systems	Very large-scale, complex open systems that are technologically enabled
Focus	Primary focus is on product/service system	Holistic attention to product/service system and larger enterprise system
Policy	Viewed as fixed and constraining system solution	Viewed as variables --can be created or adapted to optimize overall solution
Socio-technical	Viewed as considerations in engineering	Viewed as primary in an overall system solution
Primary Stakeholders	Primary focus on customer and end-users with secondary focus on other stakeholders	Balanced focus on all stakeholders impacted by engineering system -- product, enterprise, environment
Roles	System architects, systems engineers, related specialists performing systems engineering process	System architects, enterprise architects, engineers, operations analysis, project managers, policy makers, social scientists, and many others involved in total engineering system

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Essential Points

1. Engineering Systems is **not renaming or replacing** Systems Engineering!

2. Engineering Systems is a **field of academic study** – not a practice, profession, or process.

3. Engineering Systems is **not equivalent in scope** to Systems Engineering

4. Evolving the field of ES can have a **positive impact on evolving** SE – as a field and practice

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How can Engineering Systems Have Positive Impact on Evolving Systems Engineering?

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Classical systems engineering principles and practices need to be adapted and expanded to fully support engineering of highly complex systems

What SE principles and practices are too limited at present to effectively deal with large-scale complex systems with socio-technical interfaces?

How can these be adapted and expanded with contributions from of the field of Engineering Systems?

What lifecycles, practices and methods, when harmonized or adapted, can result in an emergent approach that can better serve the needs of the entire engineered system?

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ES and SE are both evolving fields… it is critical that they evolve synergistically and not as decoupled fields

How can the varied definitions and views of Systems Engineering converge within the context of Engineering Systems?

Is there a common taxonomy that will serve the needs of Engineering Systems and Systems Engineering?

What other sub-fields of Engineering Systems are highly interrelated to Systems Engineering, and what research is needed to explore convergence or cooperation of these sub-fields?

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For ES to become the context field for SE, there must be changes in systems education strategies, policies, structures

Can ES provide the context field for SE which has never quite fit as engineering science or management science?

How will universities need to evolve their structures and policies?

How will existing Systems Engineering curricula need to change to embrace Engineering Systems as its context field?

What strategies can be used to transition current educational models to a new model to support this vision?

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Impact of Engineering Systems on Systems Engineering

personal perspective

ES provides a broader academic field of study (context field) for SE

ES has been a catalyst for universities coming together around a broader systems education agenda

ES brings together a more diverse set of researchers and scholars who can benefit from (and contribute to) systems engineering principles and research

ES establishes a larger footprint in an university to drive a strong research focus and investment in systems research

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MIT Engineering Systems Division Doctoral Program

Context: The Engineering Systems Division (ESD) at MIT is helping to pioneer Engineering Systems as a new field of study – designed to transform engineering education and practice.

Mission: The ESD doctoral research programs conduct original and generalizable scholarship on complex engineered systems in order to advance theory, policy, or practice. Main objective of the program is to prepare colleagues who can seed engineering schools with the integrative ideas of engineering systems.

Transforming engineering education, research, and practice through the emerging field of engineering systems

Preparing engineers to think systemically, lead strategically, and address the complex challenges of today's world, for the benefit of humankind

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MIT ESD Doctoral Program

ESD Doctoral Seminar

Quantitative Methods

Social Science Research Methods

Courses in:

- **Systems Theory -- to design or refine a system**
- **Systems Policy -- to influence or direct a system**
- **Systems Evaluation -- to evaluate / analyze / characterize a system**

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Example ESD Doctoral Theses

The Duality of Innovation: Implications for the Role of the University in Economic Development

A Life-Cycle Flexibility Framework for Designing, Evaluating, and Managing "Complex" Real Options: Case Studies in Urban Transportation and Aircraft Systems

Stakeholder-Assisted Modeling and Policy Design Process for Engineering Systems

Shaping the Terms of Competition: Environmental Regulation and Corporate Strategies to Reduce Diesel Vehicle Emissions

Architectural Innovation, Functional Emergence and Diversification in Engineering Systems

Managing Unarticulated Value: Changeability in Multi-Attribute Tradespace Exploration

Climate Policy Design: Interactions among Carbon Dioxide, Methane, and Urban Air Pollution Constraints

Symbiotic Strategies in Enterprise Ecology: Modeling Commercial Aviation as an Enterprise of Enterprises

System Architecture Analysis and Selection Under Uncertainty

Corporate Decision Analysis: An Engineering Approach

Real Options "in" Projects and Systems Design – Identification of Options and Solution for Path Dependency

Effective Information Integration and Reutilization: Solutions to Technological Deficiency and Legal Uncertainty

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Engineering Systems Research Landscape

an intellectual environment for systems research

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

1. **Provides context for research agenda, methods, and specific projects**
2. **Determines a community of interest**
3. **Opportunities for/constraints on funding sources and sponsors**
4. **Significantly influences research outcomes and impact**

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– engineering, management, social sciences
Draws from both quantitative and qualitative approaches
Deep engagement with real world industry and government projects

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Example of SE Research Initiative within ES Context

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Systems Engineering Advancement Research Initiative within MIT ESD

MIT SEAri Mission

Advance the theories, methods, and effective practice of systems engineering applied to complex socio-technical systems through collaborative research

Considerations:

1. **Mental model and strategic focus**
2. **Underlying structure for research**
3. **Core methods and theoretical base**
4. **Research Portfolio – organizing projects**
5. **Sponsor engagement models**
6. **Sharing research knowledge**
7. **Transitioning research to practice**

RESEARCH PORTFOLIO

1. **Socio-Technical Decision Making**
2. **Designing for Value Robustness**
3. **Systems Engineering Economics**
4. **Systems Engineering in the Enterprise**
5. **Systems Engineering Strategic Guidance**

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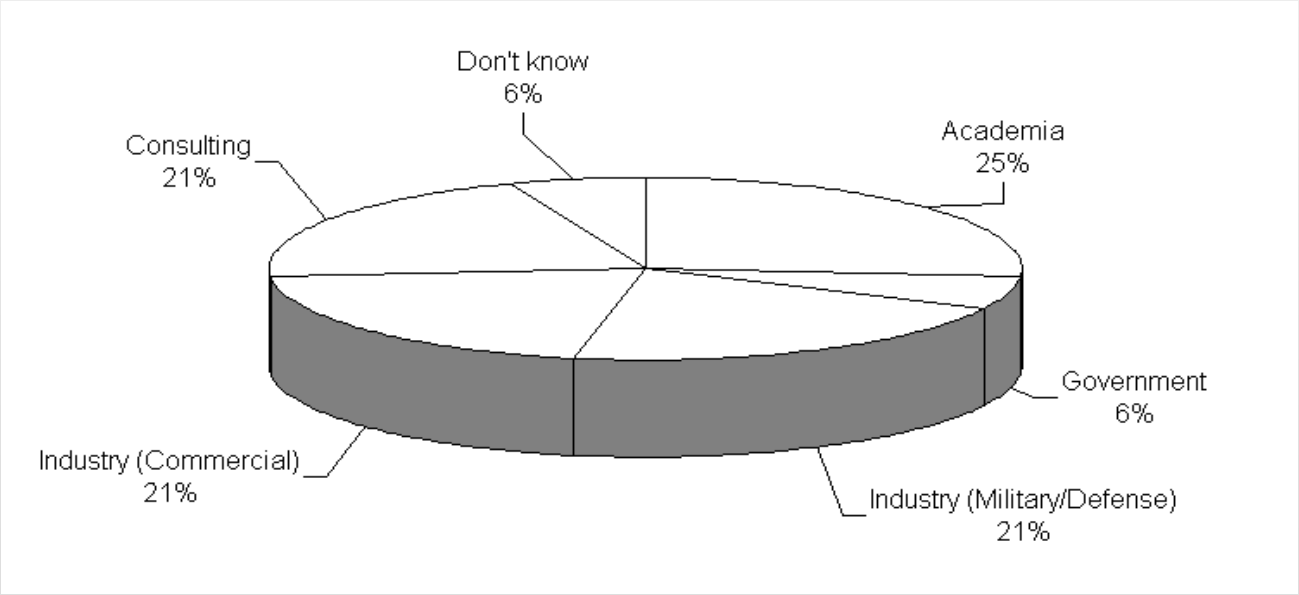
Research Predisposed Toward Application

For most engineering students, the goal of a career in industry motives their pursuit of advanced study and this will increasingly be the case on the future. Because of this, engineering students' outlook on research is predisposed toward application in engineering practice

National Academy of Engineering, 2005

Survey of SEANET doctoral students shows only 25% plan academic careers



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Seven Research Challenges Identified by SEANET Doctoral Students

- Selecting best research method
- Ensuring adequate rigor in the research
- Difficulties performing data collection in industry
- Limitations of being part of small research cohort
- Strategies for validating research findings
- Broad scope of systems engineering discipline
- Scoping research topic to “thesis size”

Engineering Systems context is designed to address most of these.

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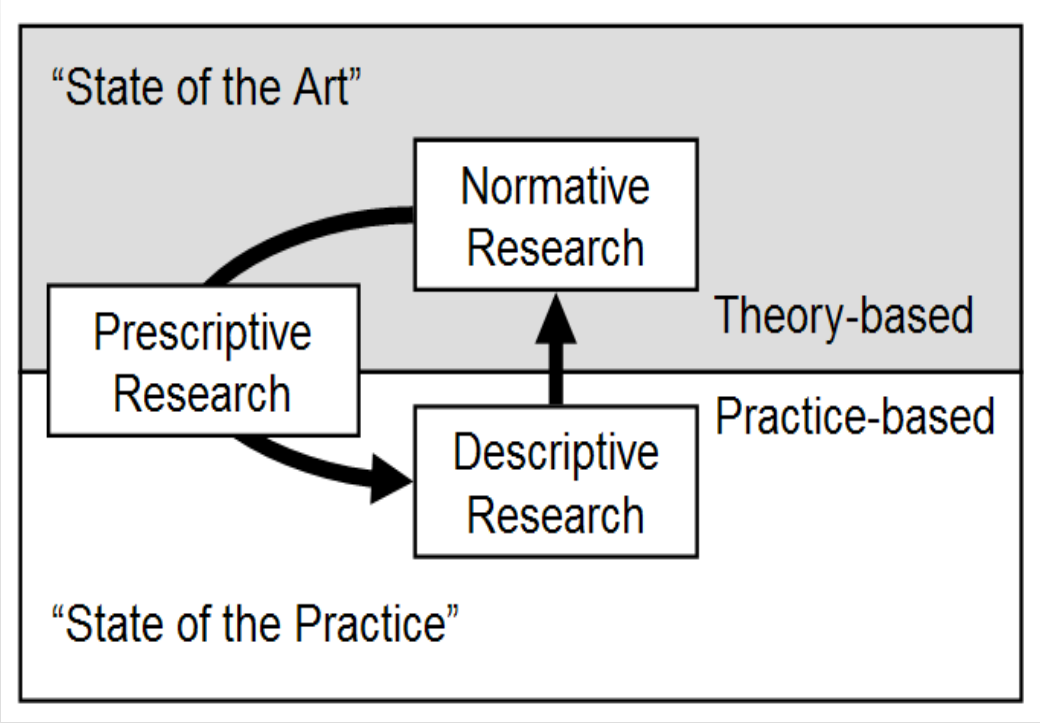
SEAri Underlying Research Structure

Prescriptive methods seek to advance state of the practice based on sound principles and theories, as grounded in real limitations and constraints

- **Normative research: identify principles and theories -- "should be"**
- **Descriptive research: observe practice and identify limits/constraints**

Qualitative and quantitative methods



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Sponsor Engagement Models

- Classical "basic research" sponsors
  - Targeted topic toward broad scientific goals
- Innovation grant sponsors
  - Higher risk/higher payoff research
- Contract research sponsors
  - Toward solving sponsor problem
- Consortium sponsors
  - Pooled funds for shared research benefits
- "Deep engagement" partnerships
  - Symbiotic relationship

SE Research requires real world laboratory

Larger research footprint of ESD enables multiple sponsor engagement models

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Examples of Research

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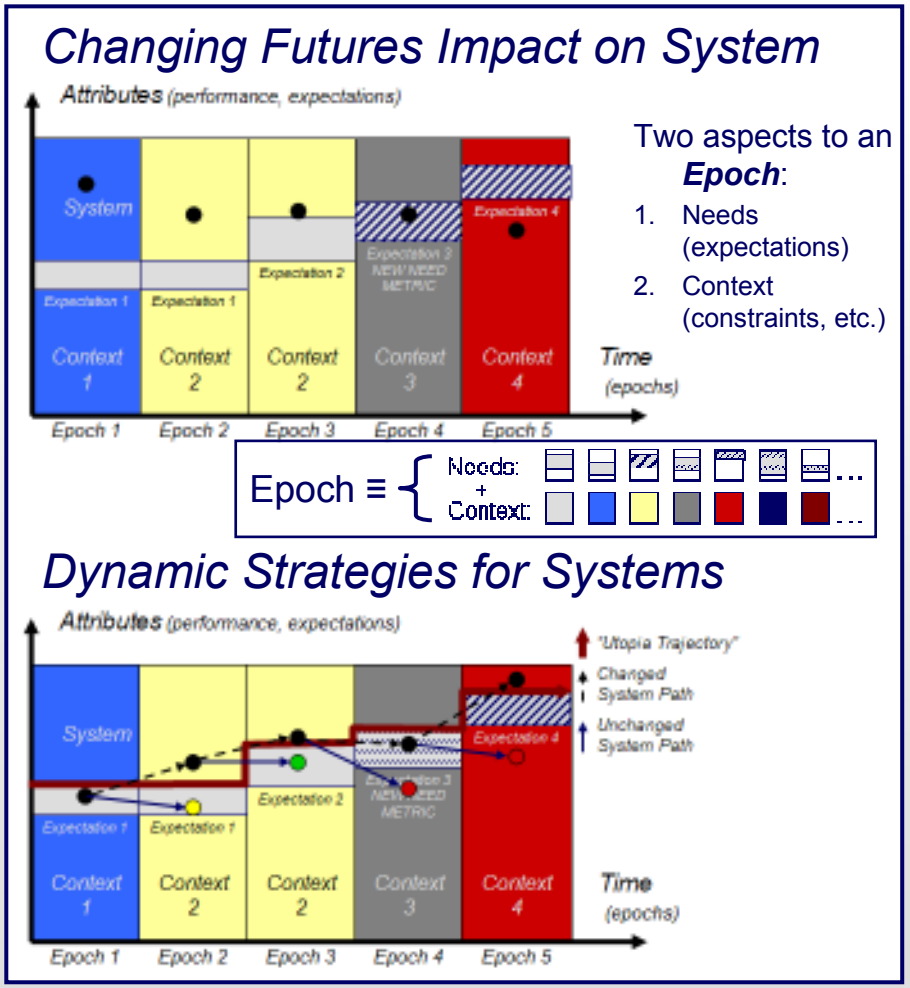
Epoch-Era Analysis for Evaluating System Timelines in Uncertain Futures

- Dynamic analysis technique for evaluating system performance under large number of future contexts and needs
- Draws from theories and approaches from multiple disciplines
- Involves the enumeration of future needs and contexts including technology, policy, social and environmental factors, and others



Ross and Rhodes, 2008

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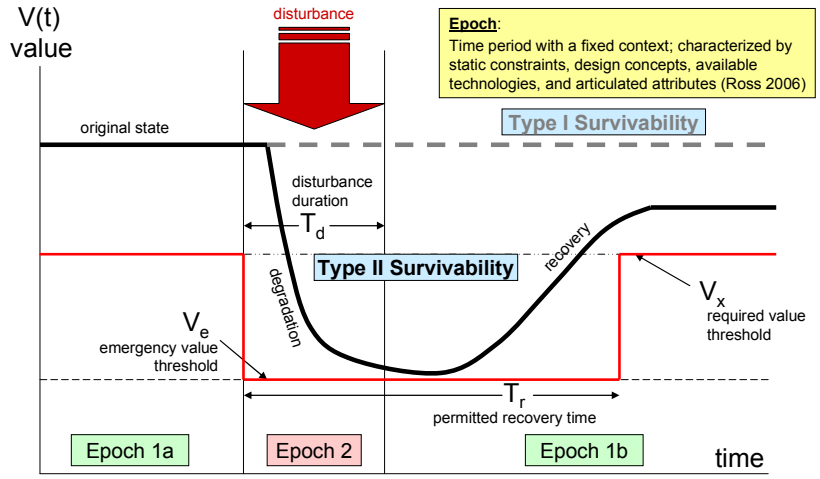
Architecting for Survivability

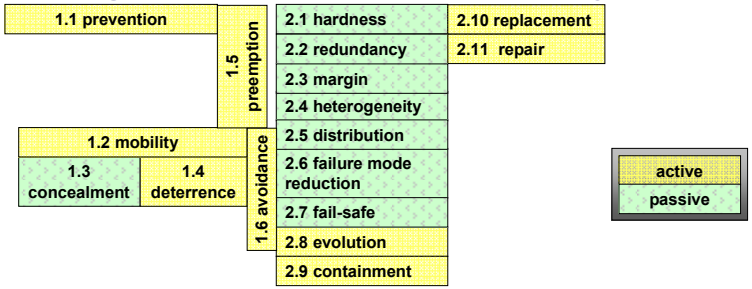
- **Dynamic, value-centric conceptualization of survivability**
- **Set of general design principles for survivability**
- **Empirically validated**
- **Extensions of dynamic tradespace exploration to accommodate hostile and natural disturbances**

Definition of Survivability

Ability of a system to minimize the impact of a finite disturbance on value delivery through either (I) the reduction of the likelihood or magnitude of a disturbance or (II) the satisfaction of a minimally acceptable level of value delivery during and after a finite disturbance



Design Principles of Survivability



Richards, et al 2008

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Collaborative Distributed Systems Engineering

- Empirical case studies to identify successful practices and lessons learned when SE teams collaborate across geographic locations
- Enterprise social and technical factors studied: collaboration scenarios, tools, knowledge and decision management, culture, motivations, others
- Successful development of the technical product dependent on upon socio-technical factors in the enterprise

<u>Success Factor</u>: 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.

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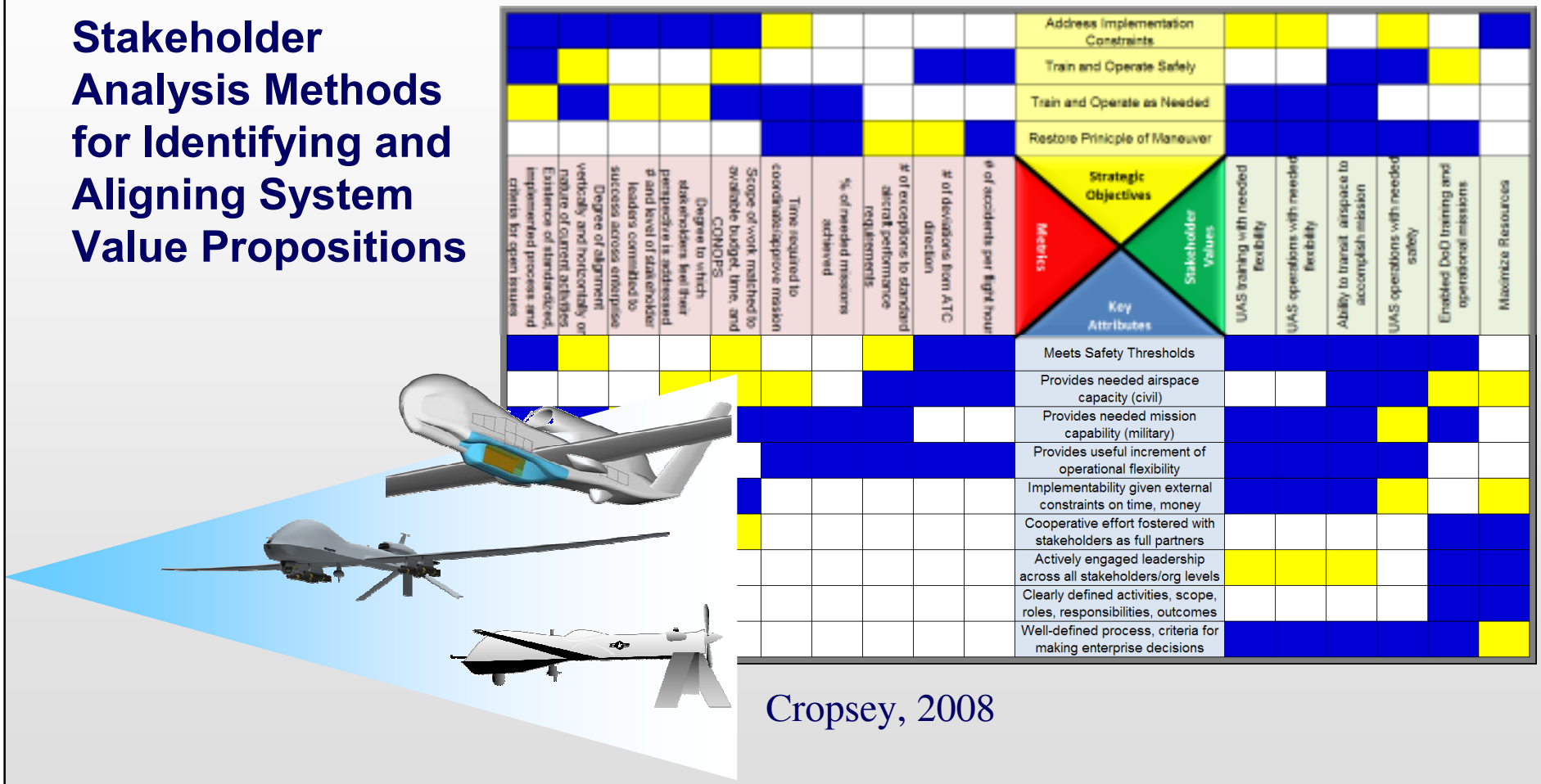
Stakeholder Alignment

Stakeholder Analysis Methods for Identifying and Aligning System Value Propositions



Cropsey, 2008

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Summary

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Reiteration of Essential Points!

1. Engineering Systems is **not renaming or replacing** Systems Engineering!
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4. Evolving the field of ES can have a **positive impact on evolving** SE – as a field and practice (and vice versa)

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Co-Evolution

Systems engineering can evolve without the academic context field of *engineering systems*, but will likely encounter limits that will result in the inability to address the most complex systems challenges of this century.

Engineering systems, if evolved independently of *systems engineering*, risks becoming only a theoretic field of the academic realm and limit its ability to contribute to real engineering problems of society.

Their co-evolution will be of mutual and synergistic value to the stakeholders of each as well as their related fields.

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