Engineering Systems Doctoral Seminar

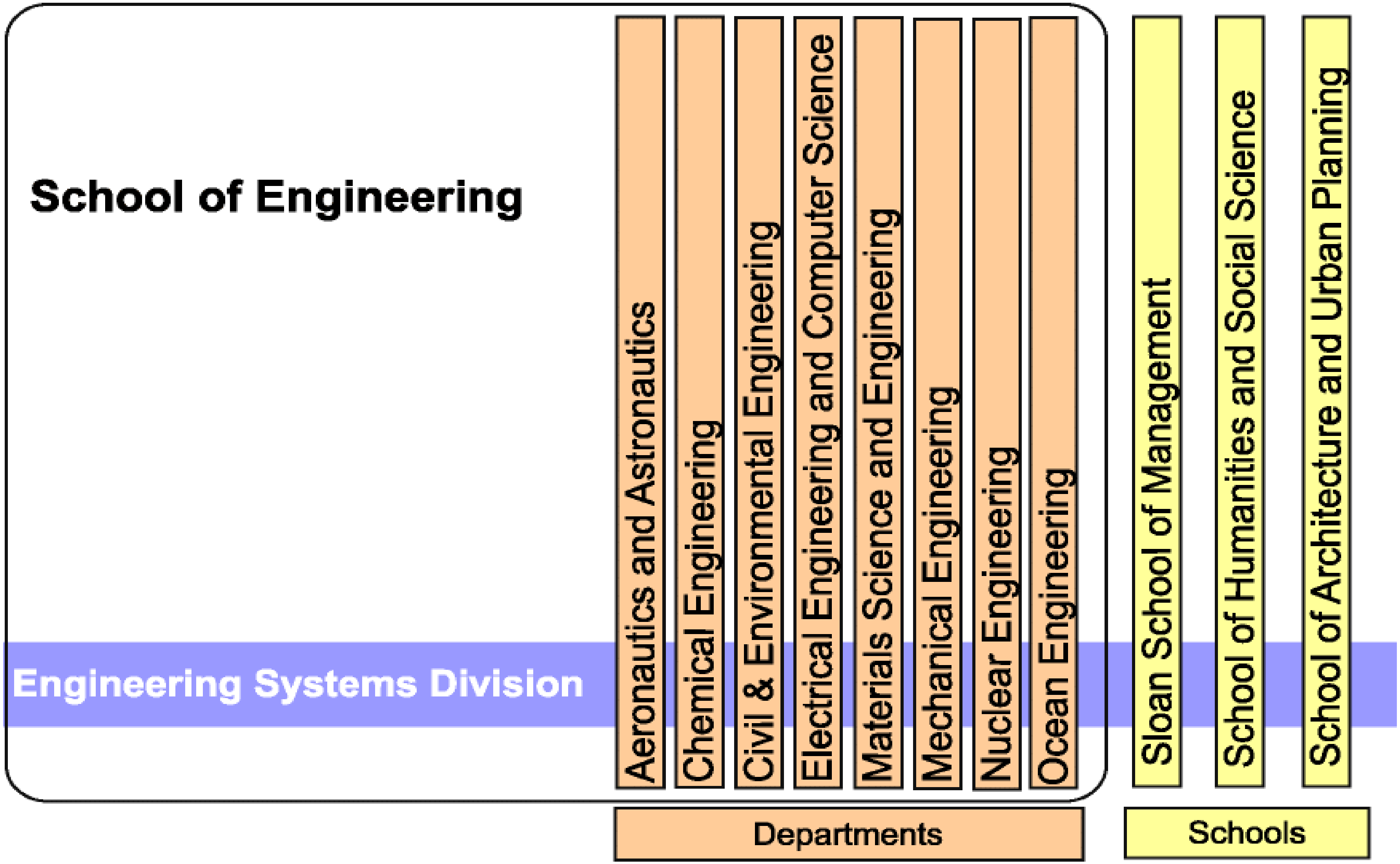
ESD.84 – Fall 2002

Session 1
September 4, 2002
Chris Magee and Joel Cutcher-Gershenfeld
Guests: Dan Roos, David Mindell

Session 1: Overview

- Welcome, Overview and Introductions (20-30 min.)
- Engineering Systems as a Field of Study: An Institutional Leadership Perspective (10-15 min.)
- Seminar Logistics (10-15 min.)
- The Doctoral Seminar on Engineering Systems: Context and History (10-15 min.)
- Engineering Systems Learning Center Overview (10-15 min.)
- Break (15 min.)
- Review and Dialogue on Key Themes from ESD Internal Symposium (30-45 min.)
- Critical Review of Seminar Syllabus – Small Groups and Full Group (30-45 min.)
- Next Steps (10-15 min.)

ESD at MIT


School of Engineering
Engineering Systems Division
Aeronautics and Astronautics
Chemical Engineering
Civil & Environmental Engineering
Electrical Engineering and Computer Science
Materials Science and Engineering
Mechanical Engineering
Nuclear Engineering
Ocean Engineering
Sloan School of Management
School of Humanities and Social Science
School of Architecture and Urban Planning
Departments
Schools

ESD at MIT (cont.)

Academic: 400 Graduate Students/Year

- **TPP - Technology & Policy Program**
- **LFM*- Leaders for Manufacturing,**
- **SDM*- Systems Design and Management**
- **MLOG- Logistics and Supply Chains**
- **MST-Master of Science in Transportation**
- **TMP- Technology Management & Policy PhD**

* Joint with Sloan

Research: $20 Million/Year

- **CTS- Center for Transportation Studies**
- **CTPID- Center for Technology, Policy, and Industrial Development**
- **IPC- Industrial Performance Center**
- **CIPD*-Center for Innovation in Product Development**

MIT esd

- Proven track record
- Partnerships and innovation with industry and government
- Going the next step

Spirit of the Seminar

- Engineering Systems Division as a bold experiment – bringing together diverse areas of expertise into what is designed to be a new field of study
- The full scale and scope of Engineering Systems as a field is still emerging
- This seminar is simultaneously designed to codify what we presently know and to give direction for future development
- The entire syllabus should be viewed as a living document – subject to adjustment based on student and faculty input throughout the term
- This seminar will directly help shape the structure and operation of the ESD Ph.D. curriculum

Engineering Systems Doctoral Seminar, Part I (Fall 2002)

- Week 1 (9/4): Introduction and Overview
- Week 2 (9/11): Engineering Systems as a Field of Study
- Week 3 (9/18): ESD Foundations: **Systems Thinking**
- Week 4 (9/25): *ESD in Context: Systems Engineering*
- Week 5 (10/2): *ESD in Context: Product Design*
- Week 6 (10/9): ESD Foundations: **Systems Design and Systems Architecture**
- Week 7 (10/16): *ESD in Context: Aerospace Industry*
- Week 8 (10/23): ESD Foundations: **Complex Adaptive Systems**
- Week 9 (10/30): *ESD in Context: Supply Chains*
- Week 10 (11/6): ESD Foundations: **Uncertainty and Decision Theory in Complex Systems**
- Week 11 (11/13): *ESD in Context: Regulatory Systems*
- Week 12 (11/20): ESD Foundations: **Socio-Technical Systems and Systems Change**
- Week 13 (11/27): *ESD in Context: Global Systems*
- Week 14 (12/4): ESD Foundations: **Agent Models, Genetic Algorithms, and Evolutionary Theory**
- Week 15 (12/11): Conclusion: Architecting Engineering Systems as a Field of Study, Part I

Engineering Systems Doctoral Seminar, Part II (Spring 2003 – tentative listing, subject to further revisions)

- Week 1: Introduction and Overview
- Week 2: What is Systems Thinking?
- Week 3: ESD Foundations: **Feedback and Control Theory**
- Week 4: ESD Foundations: **Systems Dynamics, General Systems Theory**
- Week 5: *ESD in Context: Manufacturing Operations*
- Week 6: ESD Foundations: **Complexity Science**
- Week 7: *ESD in Context: Software Engineering*
- Week 8: ESD Foundations: **Systems Engineering, Systems Analysis, Cybernetics**
- Week 9: ESD Foundations: **Optimization**
- Week 10: *ESD in Context: Transportation Sector*
- Week 11: ESD Foundations: **Accidents**
- Week 12: *ESD in Context: Civil and Environmental Engineering*
- Week 13: ESD Foundations: **The Mind, Brain, and Complex Biological Systems**
- Week 14: Conclusion: Architecting Engineering Systems as a Field of Study, Part II

Class Session Pro-Forma (3 hours)

- Introduction and Overview (5-10 min.)
- Seminar Faculty or Guest Presentation (30 min.)
- Discussion (20 min.)
- Book Reviews (5 min. x 3)
- Break
- Seminar Faculty or Guest Presentation or Student Presentation (30 min.)
- Discussion (20 min.)
- Student Presentation (30 min.)
- Discussion (20 min.)
- Next Steps/Course Logistics (5-10 min.)

Learning Objectives Pro-Forma

Learning Objectives Pro-Forma – ESD Foundations:

- **Basic Literacy:** Understanding of core concepts and principles – base level of literacy on the various aspects of engineering systems
- **Historical Roots:** Understanding of historical/intellectual roots of key concepts and principles in engineering systems
- **Critical Analysis:** Ability to critically assess research and scholarship aimed at furthering knowledge in a particular aspect of engineering systems
- **Links Across Domains:** Ability to identify links/connections across different domains relevant to engineering systems

Learning Objectives Pro-Forma – ESD in Context:

- **Basic Literacy:** Understanding of key behavioral and structural aspects of the given context/setting – base level of literacy on the key readings and concepts concerning the given context/setting
- **Historical Roots:** Understanding of historical/intellectual roots of key concepts, principles, and historical turning points associated with the given context/setting
- **Critical Analysis:** Ability to critically assess research and scholarship aimed at furthering knowledge in this particular context/setting
- **Links Across Domains:** Ability to identify links/connections across different contexts/settings and to foundation principles

Course Assignments

Student Presentations (2-3 presentations, totaling 50%)

- At least twice during the term, students will be expected to prepare and lead discussion on a specific topic. Students are encouraged to select at least one topic that is at the core of their scholarly interests (either a "foundation" topic or a "context" topic) and at least one topic that represents a completely new area of inquiry. Briefing slides and other learning materials are to be handed in and will join other course materials made available through the Engineering Systems Learning Center. A common template will be provided and professional quality learning materials are expected.

Book Reviews or Equivalent (3 book reviews, 2-3 double spaced pages, each 10%, totaling 30%)

- At least three times during the term, students will be expected to prepare and present brief book reviews selected from the options listed – or books independently suggested by the student. Each book review should be written in a format comparable to a published book review in a professional journal – conveying the key message of the book and providing appropriate critical analysis as well.
- An equivalent assignment might be to outline a detailed syllabus for a recommended course to add to the ESD curriculum.

Seminar Participation (regular attendance and contributions, 20% of total)

- It is assumed that regular preparation, attendance and contributions to discussions will be driven by a shared interest in the subject material. Still, a portion of the course grade is allocated to seminar participation to highlight just how central this is to the success of the seminar.

Engineering Systems Learning Center Overview

- Advancing Engineering Systems as a Field
  - Conceptual “map” of the field – intellectual architecture for materials
  - Transmission of research findings into education, practice and policy
- Transforming Engineering Education
  - Interactive, multi-perspective approach to learning about complex systems
  - “System studies” as a signature product
- Learning Materials
  - Modular, scalable, and regularly updated
  - Designed for use in the classroom, workplace, and distance/e-learning formats
- Target Audience(s)
  - MIT faculty
  - Faculty at partner universities
  - Instructors in industry and government operations
  - Learners interested in Engineering Systems

ESLC Value Stream

Inputs	*Identification or Development of Learning Materials*	*"Value Add" Activities*	*Delivery of Learning Materials*	*Outcomes*
Core Theory Field Research Problems & Puzzles – In Policy & Practice Learning Principles	Presentations Simulations System and Case Studies Audio & Video Clips Course Syllabi Learning Support Materials	•Engineering Systems Architecture •Editing & Design •Tagging •IP Protections •Electronic Platform •Updates •Linked Materials •User Support	MIT Courses (ESD Professional Practice Degrees and Others) Courses at Partner Universities and Other Universities Life-Long Learning, Executive Education, & Field Training	Impact on field practice Impact on public policy Impact on theory & research Impact on engineering education

Feedback

Engineering Systems: Key Concepts from ESLC Intellectual Architecture

- Engineering Systems Theory, Design, Architecture and Methods
  - Defining systems
  - System characteristics (including all of the "ilities")
  - Systems models and types
  - Systems thinking
  - Systems engineering
  - Systems dynamics
  - Systems design and architecture
  - General systems theory
  - Complex adaptive systems and complexity science
  - Socio-technical systems theory
  - Systems analysis and cybernetics
  - Optimization in complex engineering systems
  - Uncertainty and decision theory in complex engineering systems
  - Accidents in complex engineering systems
  - Agent models, genetic algorithms and evolutionary theory
  - The mind, brain and complex biological systems
  - Time and complex engineering systems
  - Systems methods and tools

Engineering Systems: Key Concepts from ESLC Intellectual Architecture (cont.)

Socio-Technical/Enterprise Engineering Systems by Discipline and Sector

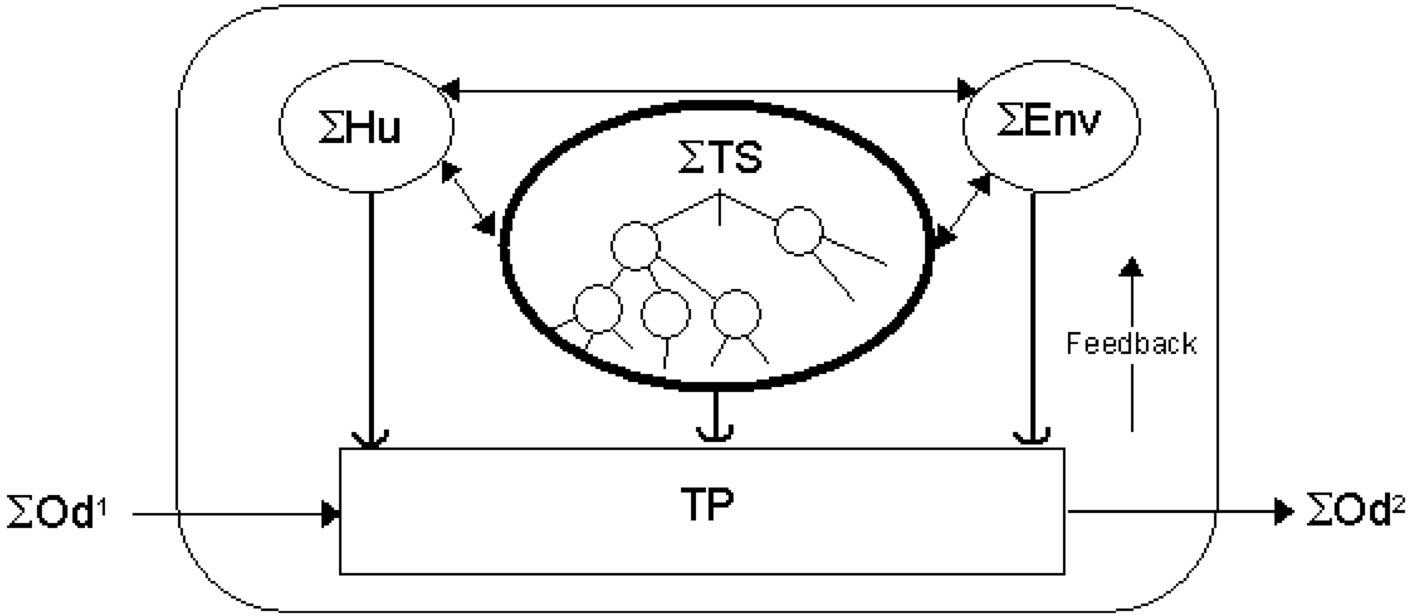
- Aerospace engineering systems
- Chemical and bio-chemical engineering systems
- Civil and environmental engineering systems
- Electrical and computer engineering systems
- Material science engineering systems
- Mechanical engineering systems
- Nuclear engineering systems
- Ocean engineering systems

Socio-Technical/Enterprise Engineering Systems by Application

- Lean enterprise systems
- Production systems
- Product development systems
- Supply chain systems
- Information systems
- Financial and accounting systems
- Software development systems
- Sustainment systems
- Recycling systems
- Regulatory systems
- Global systems
- Systems management
- Systems change
- Social systems interdependent with technical systems

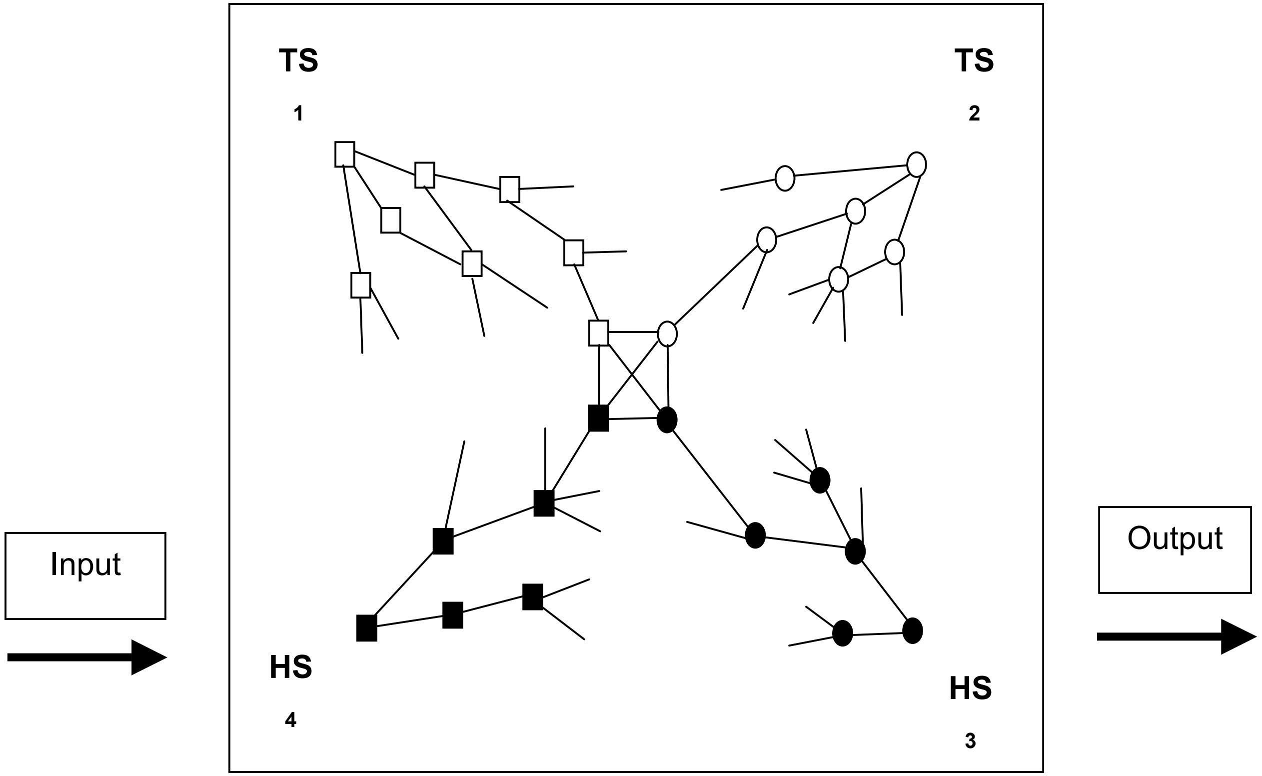
ESD INTERNAL SYMPOSIUM THEMES

- Engineering Systems Involve Technical and Social Complexity



Hubka’s depiction of a complex Technical System (∑TS) as interacting with a technical process (TP) which turns inputs (∑Od1) into outputs (∑Od2). The environment (∑Env) and humans (∑Hu) are separate from the Technical System and the Technical Process.

ENGINEERING SYSTEM REPRESENTATION



Schematic representation of an engineering system emphasizing the multiple and deep interactions among the complex human and technical subsystems.

Technical Dimension: 6 Levels

0 - Parts or lines of code
1 - Components or major software units
2 - Major subsystems or subassemblies: both hardware and software
3 - The aircraft and/or related systems
4 - The air transportation system or the air defense system
5 - Physical environment of the world

"Inters" within and between technical levels

Examples

- Within levels
  - Wing and Engine (level 2)
- Between levels
  - Part and aircraft (levels 0 and 3)
  - Engines and environment (levels 2, 4, and 5)

"Inters" within and between social levels

Social Dimension: 6 Levels

0 - Individuals
1 - Working groups/teams
2 - Organizational units
3 - Single organizations
4 - Extended multi-organization enterprises, including partners and suppliers
5 - Society, nations, communities, etc.

Examples

- Within levels
  - Airbus and Boeing (Level 3)
- Between levels
  - Manufacturer and society (Levels 3 and 5)
  - Enterprise and employee (Levels 0 and 3)

Technical Dimension: 6 Levels

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Product Development

- Suppliers on IPTs
  - Social levels 1 & 2
  - Technical levels 1, 2, 3

“Inters” between dimensions

Operation

- Mode confusion
  - Social level 0
  - Technical levels 2 & 3

Social Dimension: 6 Levels

0 - Individuals
1 - Working groups/teams
2 - Organizational units
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5 - Society, nations, communities, etc.

Interaction Matrix

	Individuals	Working Groups/Teams	Organizational Units	Single Organizations	Extended Enterprises	Society, Nations, Communities
Parts or Lines of Code						
Components or Major Software units	Instrument/Pilot	Design Teams			Supplier Relations	
Major Subsystems or Subassemblies		Flight Crews	Integrated Product Teams (IPTs)	Matrix Organizations	Supplier Relations	
Aircraft and/or Related Systems		Project Teams IPTs		Matrix Organizations	Supplier Relations	Noise and Pollution
Air Transport/Defense system					Traffic Control and Airport Malls	Hub/Spoke System and Airport Malls
World Physical Environment						Cumulative Environmental Effects

Systems

Natural Systems

Artificial Systems*

Complex Natural Systems

Artificial Systems with Complex Behavior, but Simple Structure

Artificial Systems with Simple Behavior, but Complex Structure

Artificial Systems with Complex Behavior and Structure (Artificial Complex System)

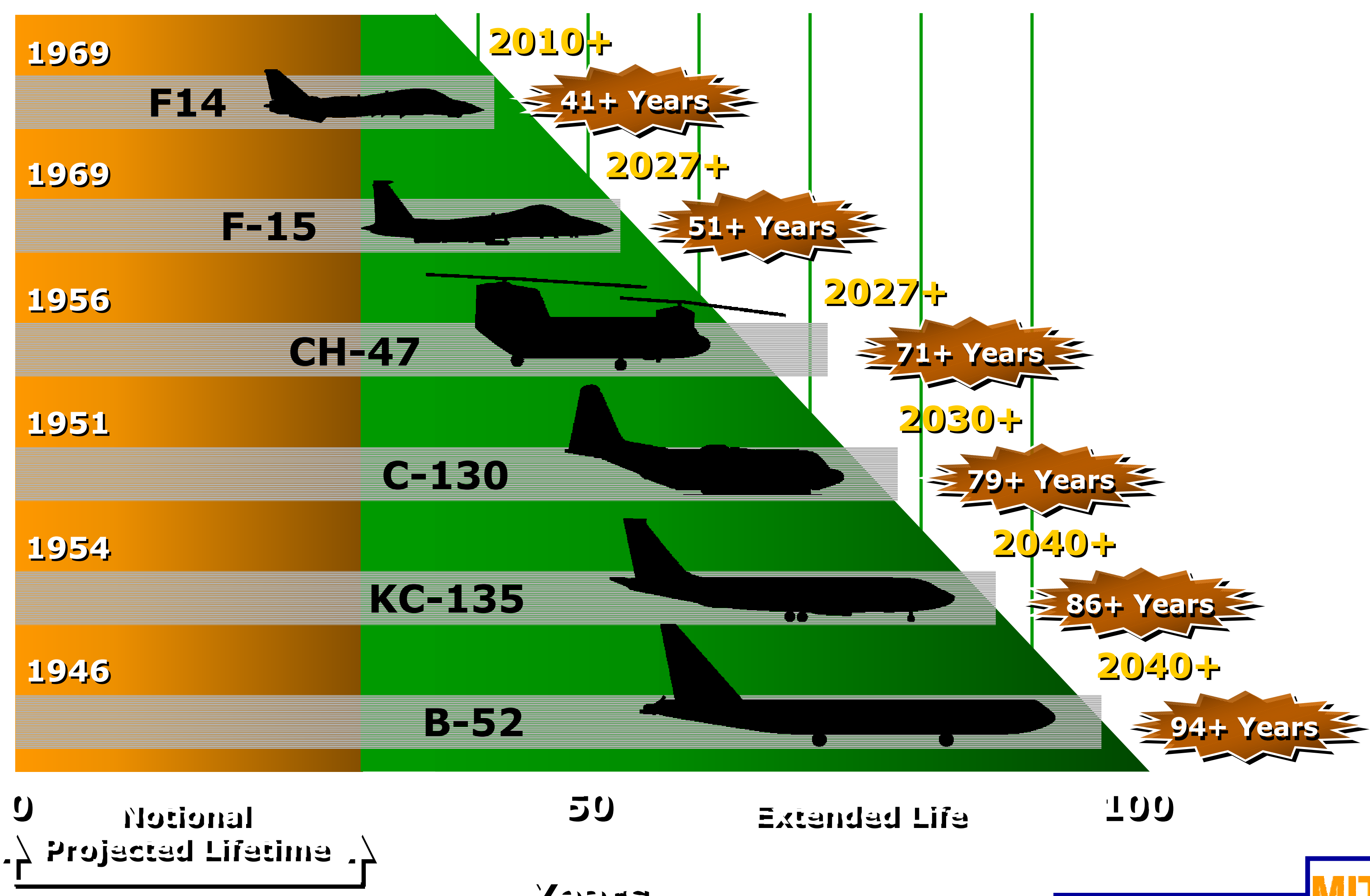
Artificial Complex systems with Complex Technical, but Simpler Human, Structure

Artificial Complex systems with Complex Human, but Simpler Technical, Structure

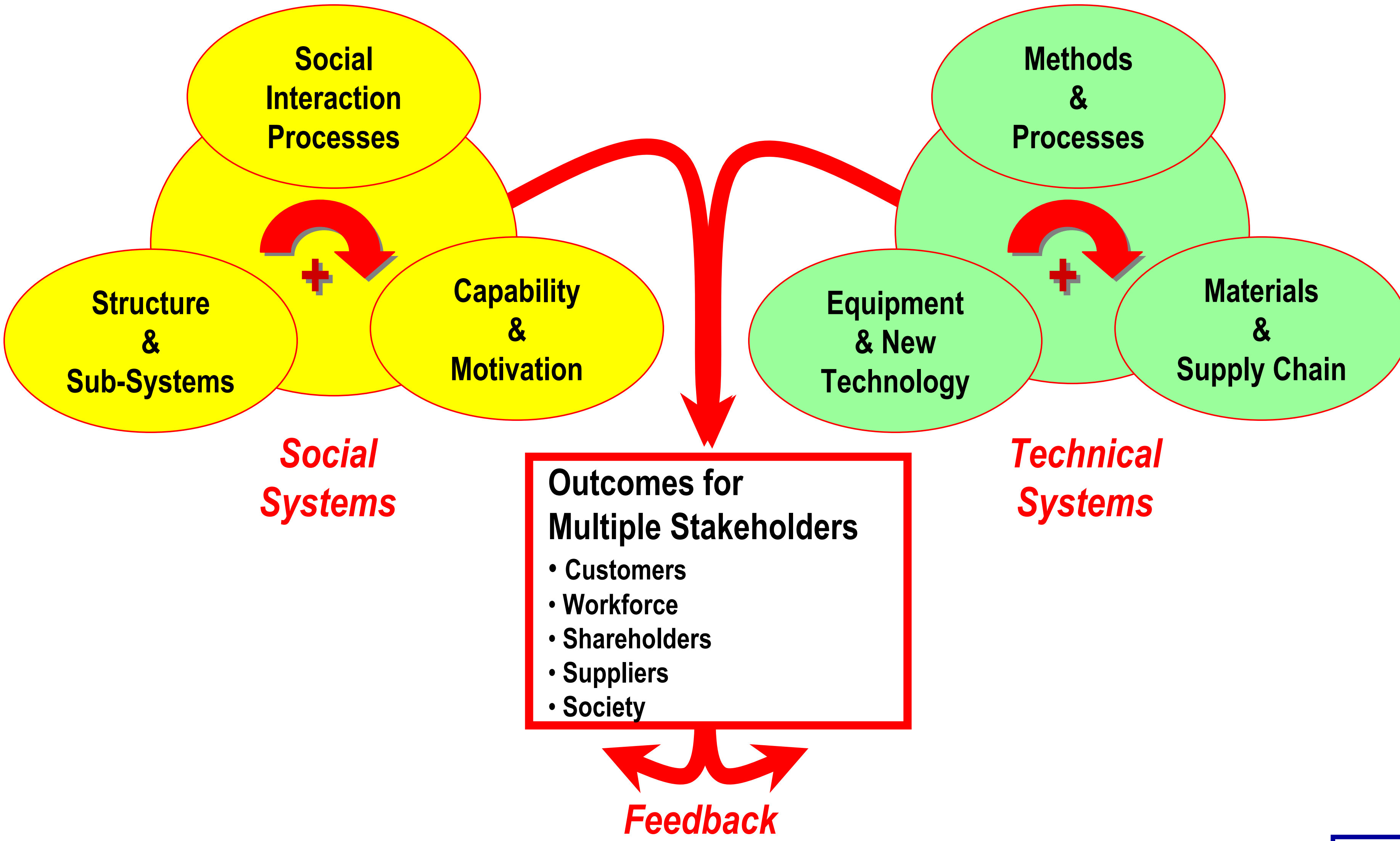
Artificial Systems with Technical and Human Structural (and Behavioral) Complexity

*May Include Natural Sub-Systems or Components, However, Overall System Design is of Human Origin

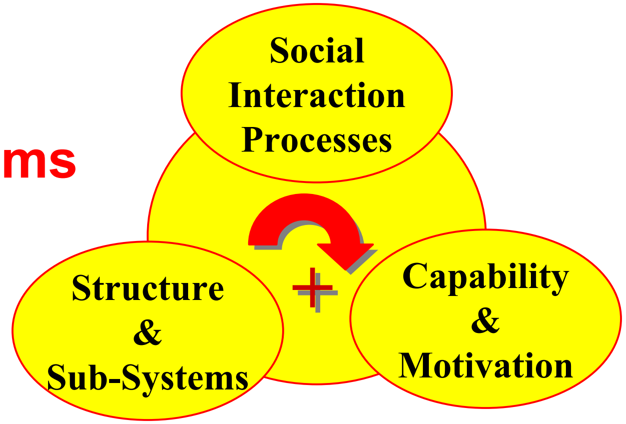
Weapon System Life Cycles



Sample Social and Technical Systems Framework: Delivering Value to Multiple Stakeholders



Focus on Social Systems



Structure & Sub-Systems

- Structure
  - Groups
  - Organizations
  - Institutions
- Sub-Systems
  - Communications
  - Information
  - Rewards & reinforcement
  - Selection & retention
  - Learning and feedback
  - Conflict resolution

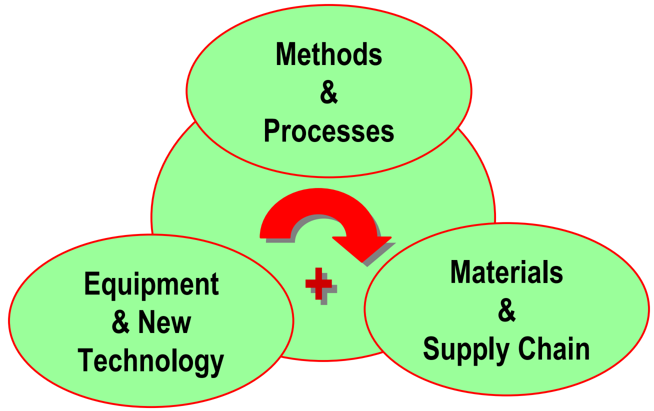
Social Interaction Processes

- Leadership
- Negotiations
- Problem-solving
- Decision-making
- Partnership

Capability & Motivation

- Individual knowledge, skills & ability
- Group stages of development
- Fear, satisfaction and commitment

Focus on Technical Systems



Equipment & New Technology

- Equipment and machinery
- Physical infrastructure
- Information technology
- Nano-technology, bio-technology, and other frontiers of science

Methods & Processes

- Job design/office design
- Work flow/process mapping methods
- Value stream mapping
- Constraint analysis
- Statistical Process Control (SPC)
- System optimization and decomposition methods

Materials & Supply Chain

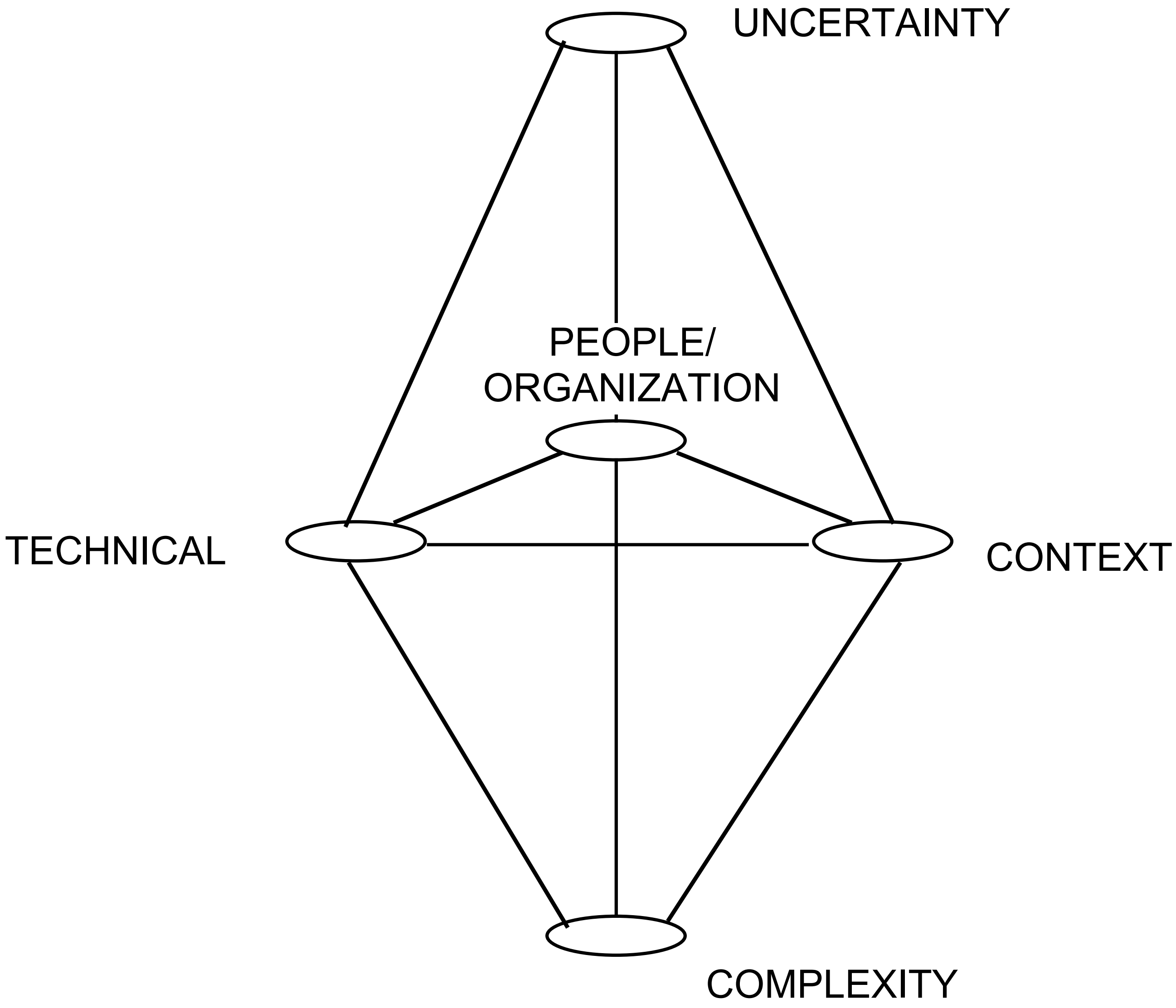
- Interchangeable parts and mass production systems
- Just-In-Time delivery (JIT) systems
- Synchronous material flow systems
- e-commerce

Illustrative Example: Japanese Model of Production System and "Humanware"

Source Haruo*Shimada and John Paul MacDuffie, Industrial Relations and"Humanware" (Slaon School of Management Work Paper, September, 1986)*

ESD INTERNAL SYMPOSIUM THEMES

- Engineering Systems Inherently Involve ***Technical and Social Complexity***
- ***Methods for designing*** (and managing, etc.) ***with (extreme) uncertainty*** are fundamental to complex systems


UNCERTAINTY
PEOPLE/
ORGANIZATION
TECHNICAL
CONTEXT
COMPLEXITY

Uncertainty
The "Twin Handmaiden"

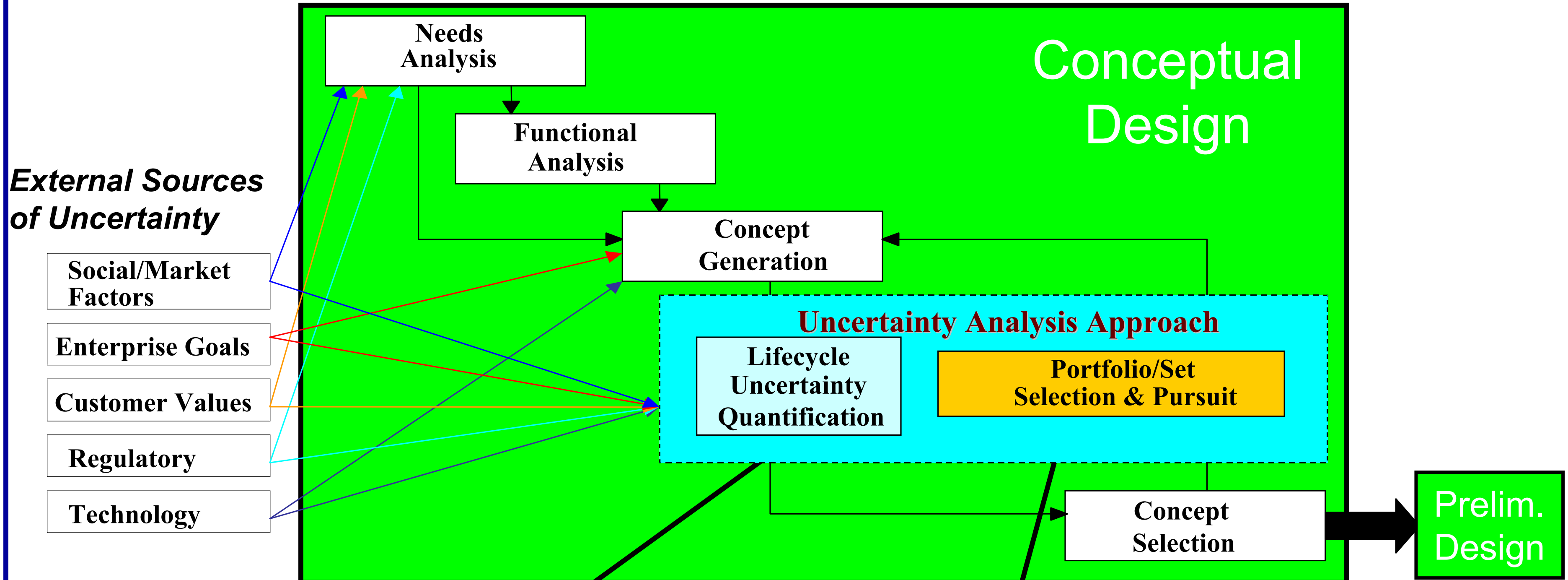
- Uncertainty

  A lack of knowledge regarding:

  1. The inputs to a model or process
  2. The model or process itself
  3. Future events that will influence the outcome of a decision

Risk/Noise/Variation/Ambiguity

Research Context



- Capture embedded uncertainty of potential architectures
  - –Identify and quantify individual sources of uncertainty
  - –Use uncertainty propagation to capture embedded architectural uncertainty

- Explore the design space with uncertainty perspective
  - –Use portfolio optimization to understand "best sets" to explore

Sources of Uncertainty in Space Systems

- Development uncertainty: Uncertainties of development of a product/service
  - Political uncertainty—Development funding stability
  - Requirements uncertainty—Requirements stability
  - Development cost uncertainty—Development within cost targets
  - Development schedule uncertainty—Development within schedule targets
  - Development technology uncertainty —Technology provides expected performance
- Operational uncertainty: Uncertainties of contributing value once product/service is developed
  - Political uncertainty—Operational funding stability
  - Market Uncertainty—Meet the demands of an uncertain market
  - Lifetime uncertainty—Performing to requirements for life
  - Obsolescence uncertainty—Performing to evolving expectations
  - Integration uncertainty—Operating within other systems
  - Operations cost uncertainty—Meeting operations cost targets
- Model uncertainty: Uncertainties in our system tools/models

Develop a life-cycle perspective on uncertainty

Uncertainty: Near-Term Cost of Program Instability

Cost growth (average annual)	Program Managers Government (N=101)	Contractor (N=80)
- Budget changes	2.3%	1.8%
- Technical difficulties	2.4%	2.7%
- Changes in user requirements	2.5%	2.7%
- Other sources	0.1%	0.8%
- Total	7.3%	8.0%

Finding: The "average" program can expect 4.5-5% cost growth resulting from budget and requirements changes, year after year

Impact: Research identified factors contributing to program risk and mitigating lean practices incorporated in DoD risk management guidance (DoD 5000.2 and Deskbook)

SOURCE: 1996 LAI Government PM survey, 1996 LAI Contractor PM survey.

Degrees of Uncertainty

1. Can be eliminated
2. Can be reduced
3. Can be modeled
   - Statistics (probability)
   - Fuzzy sets (possibility)
   - Information-Gap
   - Other models
4. Unk – Unks
   - (complexity and creativity– driven?)
   - (future catastrophes)

ESD INTERNAL SYMPOSIUM THEMES

- Engineering Systems Inherently Involve ***Technical and Social Complexity***
- ***Methods for designing*** (and managing, etc.) ***with (extreme) uncertainty*** are fundamental to complex systems
- ***Shared Language and Concepts*** associated with the architecture, design and properties of systems (including the "illities")
  - See Appendix A and B from Internal Symposium Paper

ESD INTERNAL SYMPOSIUM THEMES

- Engineering Systems Inherently Involve ***Technical and Social Complexity***
- ***Methods for designing*** (and managing, etc.) ***with (extreme) uncertainty*** are fundamental to complex systems
- ***Shared Language and Concepts*** associated with the architecture, design and properties of systems (including the "illities")
- Importance of Quantification and Experimentation
- Systems Thinking
- What else did you observe?

Review of Doctoral Seminar Syllabus

- What is missing?
- What needs to be adjusted?
- What is not necessary?
- What does this tell us about Engineering Systems as a field of study?