SEArI Research Summit 2007

Welcome and Introductions

October 16, 2007

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Motivations, Research Landscape and Program Structure

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What is Systems Engineering?

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)
What is Systems Engineering?

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)
Changing Face of Systems Engineering

**TRADITIONAL SE**
- Transformation of customer requirements to design
- Requirements clearly specified, frozen early
- Emphasis on minimizing changes
- Design to meet well specified set of requirements
- Performance objectives specified at project start
- Focus on reliability, maintainability, and availability

**ADVANCED SE**
- Effective transformation of stakeholder needs to fielded (and sustainable) solution
- Focus on product families and systems-of-systems
- Complex interdependencies of system and enterprise
- Growing importance of systems architecting
- Designing to accommodate change
- Emphasis on expanded set of "ilities" and designing in robustness, flexibility, adaptability in concept phase
What is Systems Engineering?

Systems Engineering is an **interdisciplinary approach and means to enable the realization of successful systems**.

Systems Engineering **integrates all the disciplines and specialty groups** into a team effort forming a structured development process that proceeds from concept to production to operation.

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.

*International Council on Systems Engineering*
Motivations for Research in Advanced Systems Engineering
Findings:

Cost has replaced mission success as the primary driver in managing space development programs

Unrealistic estimates lead to unrealistic budgets and unexecutable programs

Undisciplined definition and uncontrolled growth in system requirements increase cost and schedule delays

Government capabilities to lead and manage the acquisition process have seriously eroded

Industry has failed to implement proven practices on some programs
Critical Need for Systems Engineering for “Robustness”

In a 2004 workshop, Dr. Marvin Sambur, (then) Assistant Secretary of the AF for Acquisition, noted that average program is 36% overrun according to recent studies -- which disrupts the overall portfolio of programs.

The primary reason cited in studies of problem programs state the number one reason for programs going off track is systems engineering.

Systems Engineering for robustness means developing systems/system-of-systems that are:
- Capable of adapting to changes in mission and requirements
- Expandable/scalable
- Designed to accommodate growth in capability
- Able to reliably function given changes in threats and environment
- Effectively/affordably sustainable over their lifecycle
- Easily modified to leverage new technologies

Mr Yuri Bakhvalov, First Deputy Director General of the Khrunichev Space Centre on behalf of the Russian State Commission officially confirmed that the launch of CryoSat ended in a **failure due to an anomaly in the launch sequence** .... missing command from the onboard flight control system...

This loss means that Europe and the worldwide scientific community will not be able to rely on such data from the CryoSat mission and will not be able to improve their knowledge of ice, especially sea ice and its impact on climate change.

**Will this event have an impact on ESA’s relationship with Russia?**

Space has always been a risky business. Failures can happen on each side. From this end I do not expect any impact on relations with Russia. I wish to underline that in this particular case we, ESA, were customers to Eurockot, the launch service provider, which is a joint venture between EADS Space Transportation (Germany) and Khrunichev (Russia).
DOD IG: Lack of systems engineering imperils missile system

Published on Mar. 20, 2006

A lack of systems engineering plans could derail a $30 billion effort to field an integrated Ballistic Missile Defense System (BMDS), the Defense Department’s inspector general said in a report released earlier this month.

The Missile Defense Agency (MDA) has not completed a systems engineering plan or developed a sustainment plan for BMDS, jeopardizing the development of an integrated BMDS, the DOD IG said.

The report emphasizes that DOD must practice strong systems engineering to effectively sustain weapons systems. That begins with design and development.
Contemporary Systems Engineering

Systems of systems
Extended enterprises
Network-centric paradigm
Delivering value to society
Sustainability of systems
Design for flexibility
Managing uncertainty
Predictability of systems
Spiral capable processes
Model-based engineering
... and more

This requires a broader field of study for future systems leaders and enabling changes in education and research ...
The Research Landscape
Why is the Research Landscape an Important Consideration?

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

- Provides the context for the research agenda, research methods, and specific projects
- Determines community of interest on which research should have impact
- Opens possibilities for and also constrains funding sources and sponsors
- Has stated or implied outcomes and measures of success
MIT is tackling the large-scale engineering challenges of the 21st century through a new organization….

The Engineering Systems Division (ESD) creates and shares interdisciplinary knowledge about complex engineering systems through initiatives in education, research, and industry partnerships.

– Cross-cutting academic unit including engineering, management, social sciences

– Broadens engineering practice to include context of challenges as well as consequences of technological advancement

– Dual mission: (1) evolve engineering systems as new field of study and (2) transform engineering education and practice

Council of 40+ universities is collaborating on this goal (http://www.cesun.org)
ES versus SE
What Is the Difference?

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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.
Engineering Systems as a Field of Study

Economics, Statistics

Operations Research /Systems Analysis

System Architecture & Eng /Product Development

Systems Theory

Engineering Management

Technology & Policy

Organizational Theory

Political Economy

ENGINEERING SYSTEMS
Engineering Systems Requires Four 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.
Impact of Engineering Systems on Systems Engineering

ES can provide a **broader context** field for SE

ES brings together **researchers and scholars** from many disciplines

ES encompasses both the **quantitative and qualitative research methods** that are necessary for broad systems research

ES establishes a **larger footprint in the university**, driving a stronger, more diverse research focus and increases investment possibilities

ES seeks **dual impact**:
- Transform engineering education, research, and practice through the emerging field of engineering systems
- Prepare engineers to think systemically, lead strategically, and address the complex challenges of today’s world, for the benefit of humankind

*The Engineering Systems Division provides the research landscape for a new initiative on advanced systems engineering…*
Engineering research while still dependent upon individual contributors must evolve to be more synergistic.

Our society is faced with large scale problems demanding a multi-faceted and interdisciplinary systems approach.

Requires researchers from diverse disciplines to collaboratively work on problems using shared data sets and aligning around harmonized research threads.

Need to understand how to synthesize individual research efforts, with good mechanisms for research succession planning and transition of research to practice.

We strive for research leading to sustainable engineering systems meeting broad societal needs … we are challenged by current policies, funding approach, and traditional university/research stovepipes.
Engineering education and research must be a collaborative endeavor of government, industry, and academia.

Complex engineering research can not take place solely in a laboratory within university walls but rather real world enterprises must be our “learning laboratories”.

Expanded view of who an “educator” is -- faculty, researchers, practitioners, policy makers, peers.

Additionally, we need more cross cutting experiences for educators and practitioners alike.

Faculty have a very urgent need for case studies for use in the classroom … without practitioner involvement these will lack depth to have educational impact.

Engineering education and research can not be just a cooperation; must be a true collaboration.
Structure for SEArI Research
Mission

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


3 Cambridge Center
NE20 – 388/343
People of SEArI

• Leadership
  – Dr. Donna Rhodes, Principal
  – Professor Warren Seering, Faculty Co-Lead
  – Dr. Adam Ross, V-STARS Lead
  – Dr. Ricardo Valerdi, R-STARS Lead

• Internal Advisory Board
  – Professor Warren Seering, Faculty Co-Lead (Chair)
  – Professor Daniel Hastings, Aero/Astro, ESD
  – Professor Deborah Nightingale, Aero/Astro, ESD
  – Mr. Pat Hale, SDM Program, ESD

• Affiliated faculty
  – Ten across ESD, Civil E., Mech E., and Aero/Astro E.

• Graduate Research Assistants
  – Ten masters and doctoral students
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<th>Traditional Systems Engineering</th>
<th>Advanced Systems Engineering</th>
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<tbody>
<tr>
<td><strong>Purpose</strong></td>
<td>Development of single system to meet stakeholder requirements and defined performance</td>
<td>Evolving new system of systems capability by leveraging synergies of legacy systems</td>
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<tr>
<td><strong>System Architecture</strong></td>
<td>System architecture established early in lifecycle; remains relatively stable</td>
<td>Dynamic adaptation of architecture as needs change</td>
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<td><strong>System Interoperability</strong></td>
<td>Defines and implements specific interface requirements to integrate components in system</td>
<td>Component systems can operate independently of SoS in a useful manner Protocols and standards essential to enable interoperable systems</td>
</tr>
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<td><strong>System “ilities”</strong></td>
<td>Reliability, Maintainability, Availability are typical “ilities”</td>
<td>Enhanced emphasis on “ilities” such as Flexibility, Adaptability, Composeability</td>
</tr>
<tr>
<td><strong>Acquisition and Management</strong></td>
<td>Centralized acquisition and management of the system</td>
<td>SoS component systems separately acquired, and continue to be managed and operated as independent systems</td>
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<td><strong>Anticipation of Needs</strong></td>
<td>Concept phase activity to determine system needs</td>
<td>Intense concept phase analysis followed by continuous anticipation, aided by ongoing experimentation</td>
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<td><strong>Cost</strong></td>
<td>Single or homogenous stakeholder group with stable cost/funding profile and similar measures of success</td>
<td>Multiple heterogeneous stakeholder groups with divergent cost goals and measures of success</td>
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Structured with four interacting “clusters” that undertake research in a portfolio of five topics:

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
## Research Cluster-Portfolio Mapping

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<th>V-STARS</th>
<th>R-STARS</th>
<th>SE-Field</th>
<th>SE-Synthesis</th>
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<tr>
<td>Socio-Tech Decision Making</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<tr>
<td>Designing for Value Robustness</td>
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SOCIO-TECHNICAL DECISION MAKING
This research area seeks to develop multi-disciplinary representations, analysis methods, and techniques for improving decision making for socio-technical systems.

DESIGNING for VALUE ROBUSTNESS
This research area seeks to develop methods for concept exploration, architecting and design using a dynamic perspective for the purpose of realizing systems, products, and services that deliver sustained value to stakeholders in a changing world.

SYSTEMS ENGINEERING ECONOMICS
This research area aims at developing a new paradigm that encompasses an economics view of systems engineering to achieve measurable and predictable outcomes while delivering value to stakeholders.

SYSTEMS ENGINEERING in the ENTERPRISE
This research area involves empirical studies and case based research for the purpose of understanding how to achieve more effective systems engineering practice in context of the nature of the system being developed, external context, and the characteristics of the associated enterprise.

SYSTEMS ENGINEERING STRATEGIC GUIDANCE
This research area involves synthesis of theory with empirical and case based research for the purpose of developing prescriptive strategic guidance to inform the development of policies and procedures for systems engineering in practice.
Constructs for Socio-Technical System Representation
Toward Impact Assessment and Prescriptive Analysis

Constructing Knowledge

Engineering Systems Matrix

Prescriptive Analysis (Hot/Cold Spot Analysis)

Benefit Calculation:

Cost Calculation:

Uncertainty/Volatility Measure:

Sensitivity Analysis

Network Analysis

Forecast

SYSTEM DRIVERS DSM

STAKEHOLDERS DSM

SYSTEM BOUNDARY

OBJECTS DSM

ACTIVITIES DSM

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Strategies and Methods for Value Robust Systems
Toward Improved Practice

Strategies for Active and Passive Value Robustness

Filtered Outdegree
# outgoing arcs from design at acceptable “cost”
(measure of changeability)

Quantifying Flexibility

Architecting for Survivability

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Models, Measures, and Leading Indicators for Project Success
Through Better Execution of Systems Engineering

Cost and schedule modeling

Project Risk Assessment

Leading Indicators for Performance

Systems Engineering ROI

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Descriptive Studies
Better Understanding of Systems Engineering Practice


Empirical Studies of Systems Thinking (Davidz 2006)

Collaborative Distributed SE (Utter 2007)

Data Analysis Example

Company Transcripts

Interview Heading Topics

Description
Issue or Barrier
Recommendation
Lesson Learned
Success Factor
Irrelevant

Interviewee Experience

Tool Training
Tool Access
Network Reliability
Tool Versions
Learning Curves
Classified Data

Subtopic
SYSTEMS ENGINEERING STRATEGIC GUIDANCE

This research area involves synthesis of theory with empirical and case based research for the purpose of developing prescriptive strategic guidance to inform the development of policies and procedures for systems engineering in practice.

- Systems Engineering research guidelines
- Participation in focus groups and pilot-phase reviews
- Position papers on proposed policies
- Recommendations for integrating SE research into curriculum
- Identification of SE research gaps and opportunities
MIT-Porugal
Engineering Systems Education

• The Portuguese Government, through the Ministry of Science, Technology and Higher Education, is engaged in a long-term collaboration with MIT focusing on basic research and education
  
  – Project is part of the “anchor program” within the overall effort, of which one objective is: “in anticipation of a future workforce that will have to "think differently," create educational material on engineering systems that can be taught in Portuguese schools and that can be incorporated in the educational initiatives underway in the separate focus areas

• SEAri undertook a project in summer 2007 to develop education materials in the area of architecting and design decision making, based on its research in this area

• Modular set of teaching materials developed, along with several recommended options for the future packaging and integration of the material into existing curricula and courses

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Influencing Proposed Policy

• As a first step toward a prescriptive model, the Department of Defense (DoD) is developing a Guide to System of Systems Engineering (SoSE) based on best present state knowledge
  – The guide provides 16 DoD technical and management processes to help sponsors, program managers, and chief engineers address the unique considerations for DoD SoS

• SEArI participated as an academic review body in the pilot phase of the development of the guide

• A recent position paper by SEArI researchers included recommendations for how a normative, descriptive and prescriptive framework can be used to contribute to evolving SoSE guidance

SEArn Seeks To Impact Theory, Methods, And Practice

MIT Engineering Systems Division (ESD) provides an interdisciplinary research venue

Strategic collaboration with other MIT education and research centers (e.g., LAI, SDM)

Hybrid research model for collaboration
  - Single sponsor research projects
  - Consortium research

Realization of research goals is predicated on deep collaboration with industry and government
Access to Research

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Purpose
Web portal for sharing research within SEArI, MIT, and systems community

seari.mit.edu

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Additional References

ESD Website
http://esd.mit.edu/

ESD Research Centers
http://esd.mit.edu/research_industry.html

ESD Working Papers
http://esd.mit.edu/WPS/

ESD Symposium Monographs and Papers
http://esd.mit.edu/symposium/monograph/
http://esd.mit.edu/symposium/agenda_day3.htm

Lean Aerospace Initiative
http://lean.mit.edu
QUESTIONS

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