SERC Sponsor Research Review

Georgetown University Hotel and Conference Center

Washington, DC

February 25, 2014

Summary of Presentations
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## Agenda

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<td>8:45a–9:00a</td>
<td>Welcome: Dr. Spiros Dimolitsas, Senior Vice President for Research &amp; Chief Technology Officer, Georgetown University</td>
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<td>9:00a–9:30a</td>
<td>Keynote Address: Mr. Alan R. Shaffer, Acting Assistant Secretary of Defense for Research and Engineering and SERC Sponsor</td>
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<td>9:30a–9:45a</td>
<td>SERC Progress and Strategic Direction: Dr. Dinesh Verma, SERC Executive Director and Dean of the School of Systems and Enterprises, Steven Institute of Technology</td>
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<td>9:45a–10:00a</td>
<td>2014-18 SERC Technical Plan: Dr. Jon Wade, SERC Chief Technology Officer</td>
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| 10:30–11:10a| Human Capital Development: Dr. Dave Olwell, Naval Postgraduate School  
Helix – “DNA” of Systems Engineers: Deva Henry, Stevens  
SE Body of Knowledge and Graduate Curriculum: Dr. Dave Olwell, Naval Postgraduate School  
SE and Systems Management Transformation: Ittles Tradespace and Affordability: Dr. Barry Boehm, University of Southern California |
| 11:15–11:55a| Engineering Capstone Marketplace: Dr. Mark Ardis, Stevens  
Interactive Model-Centric SE: Dr. Adam Ross, Massachusetts Institute of Technology |
| 12:00–12:30p| LUNCH |
| 12:30p–1:00p| Keynote Address: Mr. Stephen P. Welby, Deputy Assistant Secretary of Defense for Systems Engineering, Office of the Assistant Secretary of Defense for Research and Engineering |
| 1:00p–1:40p| Experience Accelerator: Dr. Jon Wade, Stevens  
Agile and Lean/Kanban SE: Dr. Richard Turner, Stevens |
| 1:45p–2:25p| Enterprise SE & Modeling: Dr. Bill Rouse, Stevens  
Enterprise and Systems of Systems: Trust under Uncertainty – Quantitative Risk: Dr. Gary Witus, Wayne State University |
| 2:30p–3:10p| SoS Analysis pt. 1: Dr. Dan DeLaurentis, Purdue University  
Systemic Security: Dr. Rick A. Jones, University of Virginia |
| 3:15p–3:55p| SoS Analysis pt. 2: Dr. Cihan Dagli, Missouri S&T University  
Systemic Assurance: Dr. Bill Scherlis, Carnegie Mellon University |
| 4:15p–5:30p| Executive Advisory Board (by invitation only)  
Chair: Ms. Kristen Baldwin, Principal Deputy, Office of the Deputy Assistant Secretary of Defense for Systems Engineering |
| 4:15p–5:30p| Panel on Networked Research and Education  
Chair: Dr. Bill Rouse, Panelists: Dr. Dan DeLaurentis, Dr. Dave Olwell, Dr. Bill Scherlis |
| 5:30p–5:45p| First Annual SERC Best Paper Award – Dan Ingold, University of Southern California |
## Attendee List

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<tr>
<th>University – SERC Collaborators</th>
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<td>Air Force Institute of Technology</td>
<td>David Jacques</td>
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<td>Auburn University</td>
<td>Alice Smith</td>
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<td>Carnegie Mellon University*</td>
<td>John Foreman (SEI)</td>
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<td>Michael McLendon (SEI)</td>
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<td>Kenneth Nidiffer (SEI)</td>
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<td>Georgetown University</td>
<td>Robin Dillon-Merrill</td>
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<td>Georgia Institute of Technology</td>
<td>Doug Bodner</td>
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<td>Danny Browne (GTRI)</td>
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<td>Tommer Ender (GTRI)</td>
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<td>Massachusetts Institute of Technology</td>
<td>Donna Rhodes</td>
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<td>Missouri University of Science and Technology</td>
<td>Cihan Dagli</td>
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<td>Naval Postgraduate School</td>
<td>Dave Olwell</td>
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<td>North Carolina A &amp; T State University</td>
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<td>Stevens Institute of Technology</td>
<td>Mark Ardis</td>
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<td>Deva Henry</td>
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<td>University of Alabama in Huntsville</td>
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<td>Dan Ingold</td>
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<td>University of Virginia</td>
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<td>Wayne State University</td>
<td>Walter Bryzik</td>
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<td>Darin Ellis</td>
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### University - Other

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<td>Worcester Polytechnic Institute</td>
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<td>Stephen Welby, Deputy Assistant Secretary of Defense for</td>
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<td>Larrie Ferreiro</td>
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<td>Defense Intelligence Agency</td>
<td>Brian Lassahn</td>
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<td>Defense Threat Reduction Agency</td>
<td>Hossam Ahmed</td>
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<td>Department of Homeland Security</td>
<td>James Tuttle</td>
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<td>Federal Aviation Administration</td>
<td>Steve Bradford</td>
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<td>Michele Merkle</td>
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<td>Missile Defense Agency</td>
<td>Pamela Knight</td>
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<td>NASA</td>
<td>Joe Smith</td>
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<td>Michael Watson (Marshall Space Flight Center)</td>
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<td>National Institute of Standards and Technology</td>
<td>Vijay Srinivasan</td>
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<td>National Oceanic and Atmospheric Administration</td>
<td>Thomas Day</td>
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<td>Naval Research Laboratory</td>
<td>Vijay C. Kowtha</td>
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<td>Office of the Assistant Secretary of the Air Force for Acquisition (SAF/AQR)</td>
<td>Thomas F. Christian</td>
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<td>Office of the Assistant Secretary of the Army (Acquisition, Logistics and Technology)</td>
<td>Jon Engelbrektson</td>
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<td>Office of the Deputy Assistant Secretary of the Navy (RDT&amp;E)</td>
<td>Lynn Petersen</td>
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<td>Jessica Delgado (NSWCDD Engagement System Safety Branch)</td>
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<td>Office of the Under Secretary of Defense (Acquisition, Technology and Logistics)</td>
<td>Robert Flowe (ARA/EI&amp;OS)</td>
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<td>Michael McGrath</td>
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<td>Troy Peterson</td>
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<td>Booz Allen Hamilton</td>
<td>Lindon Lewis</td>
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<td>John Gormally</td>
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<td>National Academies</td>
<td>Terry Jaggers</td>
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<td>Potomac Institute for Policy Studies</td>
<td>Lois Hollan</td>
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<td>William Harkness</td>
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<td>Gary Motchan</td>
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3 Presentations

Keynote Address

Mr. Alan R. Shaffer, Acting Assistant Secretary of Defense for Research and Engineering and SERC Sponsor

Systems Engineering Research Center (SERC)
Sponsor Research Review

Al Shaffer
Acting Assistant Secretary of Defense for Research and Engineering
February 2014

Distribution Statement A: Approved for public release; distribution is unlimited
Key Elements of Defense Strategic Guidance

• The military will be smaller and leaner, but it will be agile, flexible, ready and technologically advanced.

• Rebalance our global posture and presence to emphasize Asia-Pacific regions.

• Build innovative partnerships and strengthen key alliances and partnerships elsewhere in the world.

• Ensure that we can quickly confront and defeat aggression from any adversary – anytime, anywhere.

• Protect and prioritize key investments in technology and new capabilities, as well as our capacity to grow, adapt and mobilize as needed.
“Our current security challenges are more formidable and complex than those we faced in downturns following Korea, Vietnam, and the Cold War. There is no foreseeable “peace dividend” on our horizon.”

GEN DEMPSEY, CJCS
Testimony to SASC, 12 Feb 2013

- Sequestration hit 2013- 9% reductions to all accounts
- Dec 2013- Bipartisan Budget not affirmed sequestration but added funds in FY14 - FY15
  - 4% reduction in FY14 ($-27B)
  - 8% reduction in FY15 ($-41B)
  - 10% reduction FY16 - FY19
“The Orange Triangle”

- Budget Control Act directs $50Billion reduction each year FY13 – FY22
- Bipartisan budget action provided relief in FY14 & FY15
- Budget has 3 levers:
  - Readiness
  - Force Size
  - Investment
- Therefore, if DoD has the ability to move money, Investment Research Developmental Test & Evaluation (RDT&E) and Procurement will be disproportionately hit over the next couple of years
Top 10 DoD Labs by S&E Population

- Naval Air Warfare Center – Patuxent River, MD (3284)
- Naval Surface Warfare Center – Dahlgren, VA (2676)
- Aviation & Missile RDEC – Redstone Arsenal, AL (2503)
- Armament RDEC – Picatinny Arsenal, NJ (2455)
- Naval Surface Warfare Center – Carderock, MD (2352)
- Space & Naval Warfare Center – San Diego, CA (2066)
- Naval Undersea Warfare Center – Newport, RI (1977)
- Naval Research Laboratory – Washington, DC (1602)
- Communications & Electronics RDEC – (1521)
- Naval Air Warfare Center – China Lake, CA (1462)
Lab Demographics (FY’13)

- DoD civilian S&E population is tracked via the DCPDS
Age Demographics by Fiscal Year

FY2007 Mean Age: 43.6 years
FY2008 Mean Age: 43.4 years
FY2009 Mean Age: 43.0 years
FY2010 Mean Age: 42.7 years
FY2011 Mean Age: 42.9 years
FY2012 Mean Age: 43.1 years
Q2FY2013 Mean Age: 43.3 years

Source: AT&L Defense Acquisition Workforce Data Mart
USD(AT&L) Priorities
Concern of Losing Technological Edge

Frank Kendall
USD (AT&L)
Mr. Kendall on the
Department's Technological
Edge, January 2014

• “I’m very concerned about eroding technological superiority”

• DoD’s R&D spending declined 14% since 2009
  • We have to preserve the future capability

“We’re in a cyclical downturn right now. It will end, and then there will be an upturn. The people who are prepared with products that we need or who have done the technology to build the products that we will need will be much better positioned when that upturn occurs.”
We are trading away tomorrow’s force capabilities to pay for today’s force.
Defense R&E Strategy

“Protect and prioritize key investments in technology and new capabilities, as well as our capacity to grow, adapt and mobilize as needed.”

-SECDEF, January 2012 Strategic Guidance

1. **Mitigate** new and emerging threat capabilities
   - Cyber
   - Electronic Warfare
   - Space Capability
   - Counter-WMD

2. **Affordably** enable new or extended capabilities in existing military systems
   - Systems Engineering
   - Modeling and Simulation
   - Prototyping
   - Interoperability
   - Develop Test

3. Develop technology **surprise** through science and engineering
   - Autonomy
   - Data-to-Decisions
   - Human Systems
   - Basic Research

Technology Needs

- Cyber / Electronic Warfare
- Engineering / M & S
- Capability Prototyping
- Protection & Sustainment
- Advanced Machine Intelligence
- Anti-Access/Area Denial
Military Operations Increasingly Depend on Being Able to Operate in Places “No One Owns” – The Commons
Prototyping

The Department can cost-effectively drive innovation in aviation, space, maritime and ground combat systems through prototyping

Proof of Concept:

“X”- Plane Prototyping

Prototype Development Programs have expanded the state of the possible in military aviation without each necessarily driving a follow-on procurement activity
# Capability Prototyping

## Example: High Speed X-Planes

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<tr>
<td>Speed: Mach 1.26</td>
<td>Speed: Mach 3.2</td>
<td>Speed: Mach 4.31</td>
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<td><img src="image5" alt="X-15" /></td>
<td><img src="image6" alt="X-43" /></td>
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<tr>
<td>First Flight: 1959</td>
<td>First Flight: 2001</td>
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<tr>
<td>Speed: Mach 6.7</td>
<td>Speed: Mach 6.83</td>
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<td><img src="image7" alt="X-43" /></td>
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<tr>
<td>First Flight: 2010</td>
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<td>Speed: Mach 5.1</td>
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The Department can cost-effectively drive innovation in aviation, space, maritime and ground combat systems through prototyping.
A New Reality:
Global Dimensions Affect DoD S&T

Pace of Technology

Black Swan Syndrome

Rise of the Commons

Technology Commercialization

Expanding Global Knowledge Base

Economic and S&T Mega-Trends

Information Agility

Mass Collaboration

Cloud Computing

Skype

Facebook

Second Life

Wikipedia

YouTube

Del.icio.us

Flickr

Twitter

Nokia

Black Swan Syndrome
It took 23 years to go from modeling germanium semiconductor properties to a commercial product.

The carbon nanotube was discovered in 1991; recognized as an excellent source of field-emitting electrons in 1995, and commercialized in 2000.

The Pace of Technology Development and Market Availability is Exceeding the Pace of Acquisition.
Systems Engineering: Critical to Defense Technologies

Innovation, Speed, Agility

http://www.acq.osd.mil/se
Defense Innovation Marketplace
Resources For Industry And DoD

Improve Industry understanding of DoD needs

Marketplace: Resources for Industry
- DoD R&D Roadmaps; Investment Strategy
- Business Opportunities with the DoD
- Virtual Interchanges & Events
- Secure Portal for IR&D Project Summaries
- Top Downloads/Pages visited
- DoD IR&D SEARCH Trends

Marketplace: Resources for DoD
- Secure portal with 8,000+ IR&D Project Summaries
- Access for DoD R&D and Acquisition Professionals
- DoD Searchers encouraged to contact the Industry POC listed on project summaries of interest

SERC 2014-2018 Strategic Technical Plan

Jon Wade
SERC Chief Technology Officer
and
Associate Dean of Research, School of Systems and Enterprises
Stevens Institute of Technology

5th Annual SERC Sponsor Research Review
February 25, 2014
Georgetown University
Hotel and Conference Center
Washington, DC

www.sercurc.org

The Systems Research and Impact Network

SSRR 2014
February 25, 2014
SERC 2014-2018 Technical Plan

• Provide the vehicle to align the SERC Vision and Research Strategy with the Sponsor’s Core funding priorities

• Describe the SERC Vision, the Sponsor’s needs, and the SERC’s response to these needs

• State DoD’s SE research grand challenges and how the SERC will apply core and other funding during 2014-2018 to address them

• Provide a multi-year roadmap of research programs to support this strategy.

Achieving DoD Impact

By forging relationships with organizations, contributing their resources and energy to the SERC

CONDUCTING IMPACTFUL RESEARCH that makes significant progress on the grand challenges

With a focus on collaboration and impact

STRENGTHENING THE RESEARCH NETWORK

TRANSFORMING RESEARCH TO PRACTICE

To valuable future systems engineers and engineers, that leverage the full strength and diversity of the collaboration

Within DoD, DARPA, defense industrial base, and other federal agencies; and by developing more powerful ways to facilitate such interaction
Create the foundational SE principles and develop the appropriate MPTs to enable the DoD to architect, design, analyze, monitor and evolve complex enterprises and systems of systems to provide the DoD with an overwhelming competitive advantage over its current and future adversaries.

Strategy:

- **Model**: Develop MPTs that allow quick and insightful modeling of enterprises/SoSs so that the effects of changes in policies, practices, components, interfaces, and technologies can be anticipated and understood in advance of their implementation.

- **Acquire**: Develop MPTs that allow insight into enterprise/SoS acquisition approaches in the face of significant uncertainty and change to minimize unintended consequences and unforeseen risks.

- **Evolve**: Develop MPTs that facilitate evolving and growing an enterprise/SoS, including insight into different architectural and integration approaches that facilitate evolution in the face of uncertainty and change in how an enterprise/SoS is employed, the technologies available to realize it, and the environment in which it exists.

- **Verify**: Develop MPTs that allow the properties of an enterprise/SoS to be anticipated, monitored and confirmed during development and evolution, including an enterprise/SoS which includes legacy systems that are in operation while development and evolution are underway.
Trusted Systems Grand Challenge

Achieve much higher levels of system trust by applying the systems approach to achieving system assurance and trust for the increasingly complex, dynamic, cyber-physical-human net-centric systems and systems of systems of the future

Strategy:

- **Design for System Security**: Develop design patterns and security architectures, with corresponding systems engineering principles guiding application, that enable security to be based on the specific properties of the system and its implementation rather than on traditional perimeter strategies.

- **Understand the Cost of Security and Ensure Cost-Effective Security**: Develop MPTs that enable understanding, predicting, and ensuring the cost-effectiveness of implementing specific security policies and requirements, especially on complex systems and complex systems of systems.

- **Understand and Ensure Balanced Tradeoffs Between Security “ilities” and Other “ilities”**: Develop MPTs that enable understanding, predicting, and ensuring cost-effective relationships between specific security policies/requirements and other “ilities”, such as reliability, safety, and maintainability.

- **Measure System Security**: Develop MPTs that allow measuring “how much” security a system has and that permit comparison of the relative security between two alternative systems.

Systems Engineering and Management Transformation Grand Challenge

**Transform the DoD community’s systems engineering and management MPTs and practices to enable much more rapid, concurrent, flexible, scalable definition and analysis of the increasingly complex, dynamic, multi-stakeholder, cyber-physical-human DoD systems and systems of systems of the future**

Strategy:

- **Make Smart Trades Quickly**: Develop MPTs to enable stakeholders to be able to understand and visualize the tradespace and make smart decisions quickly that take into account how the many characteristics and functions of systems impact each other.

- **Rapidly Conceive of Systems**: Develop MPTs that allow multi-discipline stakeholders to quickly develop alternative system concepts and evaluate them for their effectiveness and practicality.

- **Balance Agility and Assurance**: Develop SE MPTs that work with high assurance in the face of high uncertainty and rapid change in mission, requirements, technology, and other factors to allow a system to be rapidly acquired and responsive to both anticipated and unanticipated changes in the field.

- **Align with Engineered Resilient Systems**: Align research to both leverage the research and technology results of the Engineered Resilient Systems (ERS) program, and contribute to it; e.g., ERS efforts to define new approaches to tradespace.
Human Capital Development Grand Challenge

Discover how to dramatically accelerate the professional development of highly capable systems engineers and technical leaders in DoD and the defense industrial base and how to sustainably implement that discovery.

Strategy:

• Create and Provide Easy Knowledge Access: Make it easy for systems engineers to understand the SE discipline and to access the information needed to expertly perform SE so that the workforce can master the most important competencies

• Educate and Train Faster: Develop innovative approaches and technology to educate and train systems engineers and systems teams at all levels, engineers, effectively and efficiently than with classical means

• Develop Effective Technical Leaders: Develop innovative approaches to educate DoD technical leaders with the right mix of technical, business, and enterprise skills

• Improve SE and STEM Education: Develop recommendations and systems curricula for the next generation of systems engineers, engineers and STEM students

• Track Progress: Track the changes in SE workforce demographics and performance over time to understand how the workforce is improving and how improvement programs are working

SERC Core Programs

• Enterprise Systems and Systems of Systems
  — Enterprise Modeling: Bill Rouse, Stevens
  — System of Systems Modeling and Analysis, Dan DeLaurentis, Purdue

• Human Capital Development
  — Evolving Body of Knowledge, Art Pyster, Stevens
  — Experience Acceleration, Jon Wade, Stevens
  — SE and Technical Leadership Education, Val Gavito, Stevens

• Trusted Systems
  — Systemic Security, Barry Horowitz, UVA
  — Systemic Assurance, Bill Scherlis, CMU

• Systems Engineering and Systems Management Transformation
  — Affordability and Value in Systems, Barry Boehm, USC
  — Quantitative Risk, Gary Witus, Wayne State University
  — Interactive Model-Centric Systems Engineering (IMCSE), Donna Rhodes, MIT
  — Agile Systems Engineering, Rich Turner, Stevens

SSRR 2014 February 25, 2014
Enterprise Systems and Systems of Systems: SoS Modeling and Analysis

**Summary:** Develop and test MPTs for analyzing and evolving systems of systems and provide support for their technical assessment in an Analytic Workbench construct.

**Status:**
- Developed and refined 5 MPTs as initial candidates for the Workbench
- Receiving continuous feedback on MPTs and Workbench concept via conference presentations and direct engagement with candidate users within DoD
- Started focus proof-of-concept with Navy NSWC Dahlgren Division

**Impact:**
- Provide decision-support for SoS architecture evolution (e.g., Wave Model)
- Create meaningful link between simulation and architecture analysis
- Provide design for Analytic Workbench that can evolve in response to user needs
- 9 professional publications, 5 funded students

---

trusted Systems: Systemic Security

**Summary:** Create, validate, and transition MPTs to ensure systemic security using knowledge of system objectives and operation

**Status:**
- Developed secure electronic subsystem (Sentinel) for monitoring unmanned surveillance system and auto-pilot onboard an autonomous vehicle
- SBIR co-funding development effort
- Expect to start flight evaluations in summer

**Impact:**
- Providing the basis for a complementary approach to cyber security that addresses insider and supply chain attack vectors
- Developed a decision support process for selecting specific design patterns in a solution based upon the shifts in asymmetries
SE and Management Transformation: Affordability and Value in Systems

Summary: Create, validate, and transition MPTs to make better decisions on affordability and value in systems, particularly for non-functional requirements or -ilities.

Impact:
- Engagements with NAVSEA, Army RDECOM on -ility tradespace analysis in set-based design, use of GaTech FACT tradespace analysis capability
- Engagements with USAF/SMC, Aerospace Corp., and aerospace companies on definition and development of next-generation, full-coverage space system cost estimation model
- Development and iteration with DoD, industry of initial framework and quantification of -ility definitions, stakeholder value-based, means-ends relationships, and -ility strategy synergies and conflicts with other -ilities

Status:
- Tradespace and affordability analysis foundations
  - More precise -ility definitions and relationships
  - Stakeholder value-based, means-ends relationships
  - -ility strategy effects, synergies, conflicts
  - U. Virginia, MIT, USC
- Next-generation system cost-schedule estimation models
  - Initially for full-coverage space systems (COSATMO)
  - Extendable to other domains
  - USC, AFIT, GaTech, NPS
- Applied ITAP methods, processes, and tools (MPTs)
  - For concurrent cyber-physical-human systems
  - Experimental MPT piloting, evolution, improvement
  - Wayne State, AFIT, GaTech, NPS, Penn State, USC

Human Capital Development: Engineering Capstone Registry

Summary: Building and piloting the infrastructure to affordably scale capstone projects nationwide between 2014 and 2018 and improve how thousands of students are taught engineering across the US.

Impact:
- Create robust infrastructure to support large-scale involvement of universities, students and organizations
- Integration of systems engineering into engineering curricula

Status:
- Created registry website
- Matched schools and sponsors on 3 projects in pilot year
- Solicited 24 project proposals from sponsors in 2014-2014 academic year
- Identified successful capstone practices
The Networked National Resource to further systems research and its impact on issues of national and global significance

The systems research and impact network
BKCASE: Successful transition

Prof. Dave Olwell

5th Annual SERC Sponsor Research Review
February 25, 2014
Georgetown University
Hotel and Conference Center
Washington, DC

www.sercuarc.org

The BKCASE Project

• The Body of Knowledge and Curriculum to Advance Systems Engineering (BKCASE) project, initiated in 2009, delivered two products to the SE community in 2012:

  2. Graduate Reference Curriculum for Systems Engineering
BKCASE Sponsors / Stewards

• 2009 – 2012

Office of the Deputy Assistant Secretary of Defense (DASD)

Systems Engineering

• 2013 -

SEBoK Governance

• 2013 -

BKCASE Governing Board

Editor- and Co-Editor-in-Chief

BKCASE Authors

BKCASE Editorial Board
SEBoK Users

2013 Usage Statistics

Cumulative since SEBoK v. 1.0 release
Total visits > 60,000 Page views > 201,000

INCOSE and SEBoK

- Co-Steward, along with SERC and IEEE-CS

- Represented in the BKCASE Governing Board

- INCOSE Working Groups review and contribute articles

- INCOSE Handbook sources material from the SEBoK (next version expected later this year)

- SEBoK and GRCSE: INCOSE Products of the Year 2012
SEBoK vs. INCOSE Handbook vs. ISO/IEC/IEEE 15288

• They complement each other; information cross-flow

• Nature of content:
  — INCOSE Handbook & IEEE 15288: Prescriptive
  — SEBoK: Descriptive

• Update cycles:
  — IEEE 15288: 5 to 10 years
  — INCOSE Handbook: ~ 2 years
  — SEBoK: 2 updates every year

• Overlap of Authors / Editors

• Influencing each other

GRCSE

• Influencing curricular discussions across the world

• Influential in the design of new curricula in the US and in Italy

• Influencing curricular reviews of existing curricula across US and the world
  — Content checklist and weighting
  — Especially the addition of systems science to SE curricula.

• Informing the discussion of program criteria for graduate systems engineering accreditation
  — Used in the UK for the review of the Cranfield program by the UK Council on Engineering
Conclusion

• OSD funded the initial phase on the expectation sustainment would be transitioned to professional societies
  —This has occurred and is working. New governance structure and funding models in place. New EIC selected and installed.

• OSD desired to positively influence the practice of SE through BKCASE
  —This has also occurred. Influencing standards, handbooks, and curricula world-wide.

• Products were delivered on time and on budget, and exceeded expectations for quality and content.

• Conclusions:
  —Success for RT1!
  —Follow-on projects (e.g. SEEK) likely to be equally as successful
Helix
“DNA” of Systems Engineers

Deva Henry

5th Annual SERC Sponsor Research Review

February 25, 2014

Georgetown University Hotel and Conference Center
Washington, DC

www.sercuarc.org

Outline

• Overview of Helix Project
• Helix in 2013
• Initial Findings
• Plans for 2014 and Beyond
Helix Project Overview

• Helix is a multi-year longitudinal study designed to build an understanding of the systems engineering workforce in the DoD and the Defense Industrial Base (DIB) \(\textit{that scope may expand}\)

• Helix is focusing on three main research questions:
  1. What are the characteristics of systems engineers?
  2. How effective are systems engineers and why?
  3. What are employers doing to improve the effectiveness of their systems engineers?

• Data collection has primarily been through face-to-face, semi-structured interviews with systems engineers

• Reporting is done in an aggregated anonymous manner that does not reveal the identities of participating individuals or organizations

Outline

• Overview of Helix Project
  • Helix in 2013
  • Initial Findings
  • Plans for 2014 and Beyond
Helix in 2013

- 7 DoD and DIB organizations participated in Helix interviews
- **110** systems engineers interviewed
- Over **1000** pages of raw data
- Qualitative and quantitative research methods applied, based on a modified grounded-theory approach
- Early findings reported in December 2013
- Interactions with additional DoD and DIB organizations for potential participation in 2014

Outline

- Overview of Helix Project
- Helix in 2013
- Initial Findings
- Plans for 2014 and Beyond
Participating Organizations

### Interview Sessions per Organization

<table>
<thead>
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<th>Organization</th>
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<td>Org. 6</td>
<td>2</td>
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<td>Org. 7</td>
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### Interviewees per Organization

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</tr>
</thead>
<tbody>
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<tr>
<td>Org. 6</td>
<td>2</td>
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<tr>
<td>Org. 7</td>
<td>23</td>
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</tbody>
</table>

Helix Interviews

### Interviewees per Session

- 1 interviewee: 32%
- 2 interviewees: 28%
- 3 interviewees: 36%
- 4 interviewees: 4%

### Size of Interview Team per Session

- 2 interviewers: 43%
- 3 interviewers: 55%
- 4 interviewers: 2%

### Audio Recording

- Yes: 60%
- No: 40%

### Interview Mode

- Face-to-Face: 96%
- Telecon: 4%
First Look at Senior Systems Engineers

**Initial Findings - Categories**

1. The most important characteristics and competencies of effective systems engineers
2. The greatest contributions of systems engineers
3. What makes systems engineers most effective
4. What makes systems engineers least effective
5. Perceived risks to the systems engineering workforce
Important CHARACTERISTICS of Effective Systems Engineers

1. Paradoxical Mindset
   - Big Picture Thinking and Attention to Detail
   - Strategic and Tactical
   - Analytic and Synthetic
   - Courageous and Humble
   - Methodical and Creative

2. Effective Communication
   - Modes (oral and written; good speakers and listeners)
   - Audience (bridge between problem domain and solution domain)
   - Content (social, managerial, technical)
   - Purpose (understanding needs, negotiation, information brokering, technical arbitration, driving consensus)

3. Flexible Comfort Zone
   - Open Minded
   - Rational Risk Taking
   - Multidisciplinary
   - Enjoys Challenges

4. Smart Leadership
   - Quick Learning and Abstraction
   - Knowing when to stop
   - Focused on ‘Vision’ for System
   - Ability to Connect the Dots
   - Patience

5. Self Starter
   - Curiosity
   - Passionate and Motivated
   - Eager to Learn

Important TECHNICAL COMPETENCIES of Effective Systems Engineers

• Types of Competencies: General Engineering and Systems Engineering Competencies

• At Present: More Breadth than Depth
  - To be familiar with technical language
  - To appreciate the expertise and value of technical experts
  - To understand and integrate the various disciplines related to the system
  - To understand the needs of the customers and constraints of the disciplinary experts, and to evaluate technical feasibility

• In the Past: Depth in One (or more) Disciplines
  - To appreciate the value of disciplinary analysis and design, and to understand the time, effort, and resources required
  - To evaluate the validity of responses provided by disciplinary experts
  - To appreciate aspects of sub-system level optimization and the need for system level optimization
  - For credibility and respect within the team and among stakeholders
Greatest CONTRIBUTIONS of Systems Engineers

- Translating highly technical information from subject matter experts (SMEs) into common language that other stakeholders can understand
- Balancing traditional project management concerns of cost and schedule with technical requirements
- Asking the right questions
- Seeing relationships between the disciplines
- Staying “above the noise” and identifying pitfalls
- Managing emergence in both the project and the system
- Projecting into the future
- Getting the “true” requirements from the customer

What Makes Systems Engineers MOST Effective

*(Baseline definition of “Effectiveness” is established)*

- Diverse Experiences
  - Different parts of the SE life cycle
  - Different types of life cycles
  - Different aspects of a system (part, component, subsystem, system)
  - Different critical orthogonal attributes of the system (e.g. weight, size, etc.)
- Mentoring
- Value of Systems Engineering – understood and desired
### What Makes Systems Engineers LEAST Effective

- Ambiguous Definition of Systems Engineering
- Unclear Use of “Systems Engineer” Title
- Limited Value of Systems Engineering in Organizational Culture
- Lack of Systems Engineering Tools
- Greater Visibility of Failures than Successes
- Valuing Process over Critical Thinking
- Younger Systems Engineers Fail to Recognize the Importance of Process
- Inadequate Knowledge Management

### Perceived RISKS to the Systems Engineering Workforce

- High Percentage of Senior Systems Engineers
  - Mixed reactions:
    - Bath-tub curve does not exist in all organizations
    - Some organizations have formal succession plans
    - Some interviewees said “good riddance!”
- Shifting Environment
  - Shift from war-time to peace-time posture
  - Decreased need for QRCs
  - Smaller and fewer programs expected
- Expectations of Young Systems Engineers
  - To become “senior” systems engineers quickly (in 5 – 10 years)
  - Moving to organizations, looking for upward mobility
Outline

• Overview of Helix Project
• Helix in 2013
• Initial Findings
• Plans for 2014 and Beyond

Proposed Data Collection in 2014

• Continue data collection from DoD and DIB
  (include non-systems engineers: other engineers, managers, customers of systems engineering, etc.)

• Conduct interviews with individual systems engineers not currently affiliated with an organization
Other Plans for 2014

- Refine research methodology and initial findings
- Build early version of “Theory of Systems Engineers”
- Analyze INCOSE certification applications
- Analyze data from AT&L DAW Data Mart
- Hold Helix workshop (details to be planned)
- Publish 3 reports; write 2 journal papers
- Provide individual feedback to participating organizations
- Lay foundation for longer-term plans

Plans for 2015 and Beyond

- Satellite Research Teams
  - Established in other countries within universities, sponsored by INCOSE
  - Independently staffed and funded
  - Helix team will offer training in data collection, data handling, and research methodology
  - Satellite Research Teams report data at country level; Helix team aggregates data for global perspective
- Enrich and validate “Theory of Systems Engineers”
- Analyze commercial SE workforce in the US
Systems Engineering Capstone Marketplace

Mark Ardis
5th Annual SERC Sponsor Research Review
February 25, 2014
Georgetown University
Hotel and Conference Center
Washington, DC

http://www.capstone2013.sercuarc.org/

Acknowledgments

- Michael DeLorme, Stevens Institute of Technology, Co-PI
- Collaborating Faculty:

<table>
<thead>
<tr>
<th>Faculty</th>
<th>School</th>
</tr>
</thead>
<tbody>
<tr>
<td>Christina Carmen</td>
<td>UAH</td>
</tr>
<tr>
<td>Charles Gooding</td>
<td>Smith</td>
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<tr>
<td>Eirik Hole</td>
<td>Stevens</td>
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<tr>
<td>Vikki Hazelwood</td>
<td>Stevens</td>
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<tr>
<td>Nathan Scott</td>
<td>Johns Hopkins</td>
</tr>
<tr>
<td>Mick West</td>
<td>Georgia Tech</td>
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25, 2014
Building Education & Workforce Capacity in Systems Engineering

Research Question

What is needed to establish a marketplace for undergraduate capstone projects with an emphasis on multidisciplinary projects involving development of systems engineering competencies?

Approach

Develop templates and guidelines to support best practices in systems engineering capstone projects, especially those involving multiple engineering disciplines at multiple universities, plan for transition of pilot marketplace to another organization.

First Year Partners

Civilian Universities
1. Auburn University
2. Missouri University S & T
3. Penn State
4. Southern Methodist University
5. Stevens Institute of Technology
6. University of Maryland
7. University of Virginia
8. Wayne State

Service Academies
1. Air Force Institute of Technology
2. Naval Postgraduate School
3. Air Force Academy
4. Military Academy – West Point
5. Coast Guard Academy
6. Naval Academy
**DoD Problems Addressed**

<table>
<thead>
<tr>
<th>Problem Area 1: Low-cost, low-power computers</th>
<th>Problem Area 4: Immersive training technologies</th>
<th>Problem Area 2: Expeditionary assistance kit</th>
<th>Problem Area 3: Expeditionary housing systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>% Serious</td>
<td>% Serious</td>
<td>% Serious</td>
<td>% Serious</td>
</tr>
<tr>
<td>57.10%</td>
<td>28.60%</td>
<td>14.30%</td>
<td>21.40%</td>
</tr>
</tbody>
</table>

**Disciplinary Character of Student Body**

- Students from multiple disciplines
- Students from the same discipline
- Students from multiple disciplines, plus a mandatory SE major on each

72% 14% 14%
All Institutions by Major or Program

Number of Students, n=264

<table>
<thead>
<tr>
<th>Major/Program</th>
<th>Number of Students</th>
</tr>
</thead>
<tbody>
<tr>
<td>Systems Engineering</td>
<td>70</td>
</tr>
<tr>
<td>Mechanical Engineering</td>
<td>60</td>
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<tr>
<td>Electrical Engineering</td>
<td>30</td>
</tr>
<tr>
<td>Computer Science</td>
<td>27</td>
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<tr>
<td>Industrial Engineering</td>
<td>15</td>
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<tr>
<td>Civil Engineering</td>
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<tr>
<td>Software Engineering</td>
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<td>Engineering Management</td>
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<tr>
<td>Biomedical Engineering</td>
<td>1</td>
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<tr>
<td>Aeronautics Engineering</td>
<td>1</td>
</tr>
<tr>
<td>Other</td>
<td>52</td>
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</tbody>
</table>

DoD/Industry Mentors

<table>
<thead>
<tr>
<th>University/Academy</th>
<th>Mentors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Auburn</td>
<td>Advisory board (SE professionals from govt. and industry) Industry Mentor (automotive arena) PhD TAs (support team)</td>
</tr>
<tr>
<td>Missouri S&amp;T</td>
<td>Boeing Company engineers: Dale Waldo, Louis Pape, Nancy Pendleton, Robert Simmons and Robert Scheurer Office of Naval Research: Pete Muller</td>
</tr>
<tr>
<td>Penn State</td>
<td>DoD Mentors: Col. Nancy Grandy, and Mr. Phil Stockdale</td>
</tr>
<tr>
<td>Southern Methodist</td>
<td>U.S. Marine Corps Office of Naval Research: Pete Muller</td>
</tr>
<tr>
<td>Stevens Institute</td>
<td>Naval Surface Warfare Center: Eric Shields Red Gate Group, Ltd: Joseph Barnsak</td>
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<tr>
<td>U of Maryland</td>
<td>Lockheed Martin: Sandy Friedenthal DoD Mentors: Dr. David Robie, Kim Watkins</td>
</tr>
<tr>
<td>U of Virginia</td>
<td>DoD Mentor: Bill Campbell Northrop Grumman engineers</td>
</tr>
<tr>
<td>Wayne State</td>
<td>Army Shelter Expert, Claudia Quigley Army TARDEC; Dr. Rakesh Kumar</td>
</tr>
<tr>
<td>Military Academy</td>
<td>SRI/Sarnoff; Dr. Rakesh Kumar DoD Mentors: LTC Joe Nolan, LTC Chris Vaughn [Joint Advanced Training Technologies Lab]</td>
</tr>
<tr>
<td>Air Force Academy</td>
<td>DoD Mentors: a reserve AF Colonel, a retired USMC officer</td>
</tr>
</tbody>
</table>
“These individuals were vital to the success of the systems engineering capstone because they brought a level of legitimacy, relevancy, and real-world context to the problem that was a catalyst for student learning and mastery of course outcomes.” [Faculty]

“[Our mentor’s] industry experience allowed him to foresee debilitating problems; his managerial skills enabled him criticize in a gentle, useful manner; and his credentials as former vice president of manufacturing for a large motor company lent credence to his comments.” [Faculty]
SE Approach was Eye-Opening

“This is a different approach [compared] to engineering design approaches I was familiar with, where the focus was more on developing the best product with the most features. I believe that the systems engineering approach is a better one because the perfect useless gadget is still useless.” [Student]

“I was not aware of the amount of types of documentation that a systems engineering project required. The different competencies like requirements management and verification and validation showed how important organizational aspects are to a successful project.” [Student]

Multi-Disciplinary Teams

“Without a doubt, the greatest accomplishment of RT 19 is the demonstration that truly cross-disciplinary capstone design projects can be developed by groups of seniors at the undergraduate level.” [Faculty]

“[Our project] shows very well how teams of people from different backgrounds should communicate and work together. In the real job world almost all teams consist of people from different academic backgrounds so it is very useful.” [Student]
Promising Practices (1/2)

1. Fall semester tools/techniques/approaches SE theory course, followed by spring semester design project course
2. Cross-disciplinary student teams
3. Regular, direct involvement of mentors with student project teams
4. Established relationships with nearby DoD commands and facilities
5. Creative use of mentors from defense prime contractors

Promising Practices (2/2)

6. Structured design reviews with DoD and industry mentors serving as reviewers
7. Use of SE Ph.D. candidates as project advisors
8. Creative imposition of technical, budget, and schedule constraints by faculty to model "real world"
9. For civilian institutions that have on-campus ROTC units, established relationships with ROTC units for requirements analysis, use case testing, and solution viability
Second Year Emphasized Partnerships

- 16 schools participated on 10 projects
- Different partnering models were used:
  - sub-teams
  - service organization
  - faculty training

Third Year Created a Marketplace
Marketplace for Innovative Projects

- **Stakeholders** propose challenging projects
  - Require systems thinking across multiple disciplines

- **Students** volunteer to participate
  - Select their own projects
  - Teams are self-organizing

- **Faculty** provide guidance and academic assessment
  - Advise stakeholders on expectations
  - Advise students on plans and methods
  - Assign grades to students

Student View

- Browse the registry for a project
- Select a project and volunteer to participate
- Get approval from stakeholders and faculty mentor to receive credit for the project as part of their academic program
- At the beginning of each term meet with stakeholders, other students and faculty mentors to review objectives and plans
- Work with stakeholders and peers at different schools to complete project objectives
- At the end of each term provide peer feedback to other students, stakeholders and academic project mentors
**Stakeholder View**

- Prepare project description
- Allocate resources for project expenses (material and transportation)
- Allocate staff to advise and mentor students
- Review credentials of student applications
- At the beginning of each term meet with students and faculty mentors to review objectives and plans
- Work with students during project
- At the end of each academic term provide feedback to academic project mentors

**Faculty View – Flip the Project**

- Review proposed projects from students
- Approve/deny student participation on projects
- At the beginning of each term meet with stakeholders, students and other faculty mentors to review objectives and plans
- During the term may advise and monitor students
- At the end of the term review results, peer feedback and feedback from stakeholders
- Assign grades to local students
Dimensions of the Marketplace

• Projects might span multiple years
• Projects might require multiple teams that collaborate
• Projects might include multiple teams that compete
• A team might be composed of students from same school
• Stakeholders might hire faculty as consultants to projects
• Students might propose projects that are adopted by appropriate stakeholders

3 Capstone Projects in Pilot (First Year)

• Humanitarian assistance and disaster recovery kit and Dual use ferry
  — Stevens Institute of Technology (Engineering Management and Naval Architecture)
  — University of Alabama in Huntsville (Mechanical Engineering)

• Satellite radiometer
  — Southern Methodist University (Elec. Engineering and Computer Engineering)
  — University of Hawaii at Manoa (Info. Systems)

• Immersive training system
  — Missouri University of Science and Technology (Systems Engineering.)
  — University of Hawaii at Manoa (Info. Systems)
Dual-Use Ferry Project

- Navy sponsored a project to design a safe ferry that could also deploy a Humanitarian Assistance/Disaster Relief (HADR) kit in developing countries

- Stevens Institute of Technology
  - 2 Naval Engineering students: ferry design
  - 4 Engineering Management students: CONOPS, management and communication

- University of Alabama in Huntsville
  - 6 Mechanical and Aerospace Engineering students: HADR kit design and prototype

- CONOPS useful in coordinating sub-teams

Second Year of Marketplace

- United States Special Operations Command (SOCOM) proposed 22 projects

- DoD Corrosion Policy and Oversight proposed 2 projects

- Matched 6 projects with 5 universities:
  - Georgia Institute of Technology: Situational Awareness
  - Johns Hopkins University: Corrosion Detection
  - Smith College: Tactical Assault Light Operator Suit (TALOS)
  - Stevens Institute of Technology: Medical Monitoring
  - Stevens Institute of Technology: Sailboat Disablement 1
  - University of Alabama in Huntsville: Sailboat Disablement 2
Website Demo

http://www.capstone2013.sercuarc.org/

About the Capstone Marketplace

Our mission is to match interdisciplinary student teams with challenging engineering projects. Project sponsors provide domain expertise and direction, while faculty advisors help guide the teams and guide their work. The Capstone Marketplace makes it easier for sponsors to reach out to potential students and helps students find projects best matched to their interests and needs.

Previous research has demonstrated that students who worked on multidisciplinary capstone projects had increased interest and learning in basic systems engineering concepts. They also developed a better appreciation of the differences in methods and tools of different engineering disciplines.

Browse Projects

Projects

The following projects are part of the Capstone Marketplace. Each proposed project is under the umbrella of undergraduate engineering students.

- Advanced Body Armor and Helmets
  - Design lighter-weight body armor with similar ballistic protection
  - Learn More

- Austere or Unimproved Landing Zone Assessment
  - Assess a potential landing site under nighttime conditions
  - Learn More
Project

Sailboat Disablement

Sponsor
Special Operations Forces (USO)

Status
Active: University of Alabama in Huntsville and Stevens Institute of Technology

Summary
Provide capability to safely disable sailboats

Description
Current Capability

- No capability currently exists to mechanically stop sailboats while underway

Issues

- Stopping sailboats permits SOF to defeat various types of maritime adversaries and will enhance SOF maritime capabilities.
- Specific research outcomes that benefit SOCOM should include:
  - A report
  - Possible model simulations demonstrating efficacy of concept

Capability Needs

- SOCOM requires myriad techniques and hardware with which to carry out maritime disablement operations.
- SOF desires the capability to stop sailboats. More sophisticated possibilities, such as direct energy, SCADA attack or computer network operations are being considered separately, where appropriate.

Student Application  Faculty Application
Apply for Project (1/2)

Faculty Application Form

Project Name:

Sailboat Disablement

1. Information about you

Name:* 

Email Address:* 

Phone Number:

School or Organization:

Department:

Apply for Project (2/2)

2. Please list the names of the students you will supervise:

Student Names:

3. Information about the project(s) you want to join

in one or two sentences, what do you think the students can produce or achieve on the project(s):

Submit
Corrosion Project

- DoD Corrosion Policy and Oversight needs a tool to inspect properties of material coatings, especially in areas that are difficult to access

- Team of Mechanical Engineering students from Johns Hopkins University are developing a prototype tool

Sailboat Disablement Project

- Conventional means to stop ships are ineffective against sailboats due to their unusual keel designs
2 Teams Interested in Project

• Stevens Institute of Technology
  — 3 Mechanical Engineering students
  — 2 Naval Research Engineering students

• University of Alabama in Huntsville (UAH)
  — 10 Aerospace Engineering students

• Initially the 2 teams agreed to collaborate

• SOCOM sponsor requested that teams work independently

Stevens Institute Team Initial Designs
Plans for This Year

• Identify successful practices
• Collect resources to support practices
• Prepare templates and guidelines for participants
• Assess results of Second year of marketplace
• Prepare for Third year of marketplace
• Plan for transition of marketplace
Templates and Guidelines

• Expectations and activities for participants
  —Sponsors: Financial support, schedule
  —Mentors: Meetings and reviews, availability
  —Faculty: Meetings and reviews, feedback
  —Students: Meetings and reviews, deliverables, self-leadership

• Lifecycle models for projects
  —Include good SE practices
  —Agile: time-boxed, flexible

• Agreements
  —Intellectual property
  —Nondisclosure


• Expect to have continued participation by SOCOM

• Looking for additional sponsors
  —Most projects cost $10K or less
  —Great opportunity to meet and influence talented engineering seniors
  —Need 2 or 3 paragraph problem statement

• Looking for academic participants
  —Expect to have projects on website by early April

• If you are interested or have suggestions please contact:
  mark.ardis@stevens.edu
  http://www.capstone2013.sercuar.org/
Transition to Independence

• Looking for champions to take over the marketplace
  ― Might be someone from a professional society, like INCOSE
  ― Might be someone from academia
  ― Might be someone from the entrepreneurial community

• If you are interested or have suggestions please contact:
  mark.ardis@stevens.edu
  http://www.capstone2013.sercuar.org/
RT16 Experience Accelerator
Progress and Future Plans

SERC Sponsor Research Review
February 25, 2014

www.sercuarc.org

Outline

• EA Overview
• Year end results
• Future work
• Demo
Overview

Hypothesis & Goals

**Hypothesis:** By using technology we can create a simulation that will put the learner in an experiential, emotional state and effectively compress time and greatly accelerate the learning of a systems engineer faster than would occur naturally on the job.

**Goals:** To build insights and “wisdom” and hone decision making skills by:
- Creating a “safe”, but realistic environment for decision making where decisions have programmatic and technical consequences
- Exposing the participants to job-relevant scenarios and problems
- Providing rapid feedback by accelerating time and experiencing the downstream consequences of the decisions made
Maturity in Systems Engineering requires:

- Viewing a program through the entire lifecycle
- Seeing the relationships between elements of the system, and the system developing the system
- Encountering the challenges faced in a complex system development
- Being able to navigate through the “gray” zone
- Creating mental templates which can be applied to similar future situations

## Learning Process

The Learning Process consists of several stages:

- **Concrete Experience (Experiencing)**: Decision and Actions, Communication with team, and stakeholders, Profile building, Active Experimentation (Doing), Re-experiencing / testing of lessons learned, Developmental objective setting.
- **Feedback on performance**
- **After action reflection**
- **Synthesis of lessons learned**
- **Reflective Observation (Reflecting)**: Accelerated Development
- **Abstract Conceptualization (Theorizing)**
The Experience: A Day in the Life of a PSE

UAV System:
- S0 – System
- S1 – Airframe and Propulsion
- S2 – Command and Control
- S3 – Ground Support

UAV KPMs:
- Schedule
- Quality
- Range
- Cost

Phases:
- EA Introduction
  - Phase 0: New Employee Orientation
- Experience Introduction
  - Phase 1: New Assignment Orientation
- Experience Body
  - Phase 2: Pre-integration system development -> CDR
  - Phase 3: Integration -> FRR
  - Phase 4: System Field Test -> PRR
  - Phase 5: Limited Production and Deployment
  - Phase 6: Experience End
- Experience Conclusion
  - Phase 7: Reflection
- Each session = 1 day

Experience Accelerator Team

Experience Design:
- Jon Wade, PI – Stevens
- Rich Turner, Stevens
- James Armstrong - Stevens
- Rick Abell – consultant
- John Griffin – consultant
- John McKeown – consultant

Technology & Tools:
- George Kamberov – Stevens
- Brent Cox – Stevens
- Hao Kang – Stevens (H2 Y3)
- Wang Yang – Stevens (Y2)
- Vinnie Simonetti – Stevens (H1 Y2)
- Yagiz Mungan – Purdue (H1 Y2)

Evaluation:
- Bill Watson, CoPI – Purdue
- Pete Dominick – Stevens (H1 Y2)
- Dick Reilly – Stevens (H1 Y2)
- Dana Ruggiero – Purdue (Y2)

Simulation:
- Doug Bodner – Georgia Tech
- Anqi Zou – Georgia Tech (Y3)
- Arya Irani – GTRI (Y3)
- Subbu Ramanathan – Georgia Tech (Y2)
- Pradeep Jawahar – Georgia Tech (H1 Y2)
- Kyle Crawford – Georgia Tech (H1 Y2)
Year End Results

Major Increment 2 Research Activities

- **Pilot System Development:**
  - Refinement based on evaluation findings
  - Architecture, Design, Technology and Tools for Flexibility & eventual Open Source

- **Develop Multi-Learner Technology**

- **Pilot System Evaluation:**
  - Plan Update
  - Learner Identification
  - Prototype Evaluation

- **Open Source Preparation and Deployment:**
  - Prototype Completion
  - Migration, Open Source Hosting & Development, and Ticketing
  - Tool Development
  - Design Flow
  - Documentation

- **External Developers Engagement**

- **Final Report**
Pilot System Development

- **Experience Design**
  - User interface and status visibility
  - Dialog enhancement
  - Instructor interaction in class environments

- **Technology**
  - Multi-learner Capabilities
  - Dialog system
  - Stability: replication of state, communication and network improvements

- **Simulation**
  - Execution engine & charting improvements
  - Simulation model enhancements
  - Simulation chart syntax supporting new features
  - New output charts

- **Tools**
  - Chatmapper translator and integration
  - System dynamics GUI model building tool
  - Simulator XML syntax for charts and code that generates charts
  - Templates for recommendation forms and emails

Dashboard Status

<table>
<thead>
<tr>
<th>KPIs and TPMs</th>
<th>Range</th>
<th>Dev Ctrt</th>
<th>Propag Cutty</th>
<th>APS Weight</th>
<th>CYS Weight</th>
<th>Total Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contract Performance FYM (SF)</td>
<td>Dev Cutty</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sched (Yr)</td>
<td>Sched (Yr) ratio</td>
<td>Budget (Y)</td>
<td>Budget (Y) ratio</td>
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<td></td>
<td></td>
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<tr>
<td>Overall</td>
<td>8.52</td>
<td>0.95</td>
<td>-35.77</td>
<td>0.84</td>
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<td></td>
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<tr>
<td>Milestones (T) &amp; Prop</td>
<td>8.75</td>
<td>1.00</td>
<td>-22.07</td>
<td>0.93</td>
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<tr>
<td>Milestone and Proposals</td>
<td>6.35</td>
<td>0.95</td>
<td>-12.54</td>
<td>0.74</td>
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<td></td>
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<tr>
<td>System Command and Control</td>
<td>6.35</td>
<td>0.95</td>
<td>-18.56</td>
<td>0.68</td>
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<tr>
<td>TerraFirma</td>
<td>5.00</td>
<td>1.00</td>
<td>-6.48</td>
<td>0.81</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CCM Requirements (% complete)</td>
<td>Test Range</td>
<td>Digital Data Links</td>
<td>SW Driver</td>
<td>Stk</td>
<td>SLIP</td>
<td>SLIP</td>
</tr>
<tr>
<td>BAD</td>
<td>60</td>
<td>3</td>
<td>100</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>BAD SCI</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>BAD SCI Q (5 of Defects)</td>
<td>Outstanding</td>
<td>Defect Rate</td>
<td>Removal Rate</td>
<td>Projected Time To Release</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Critical Defects</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-critical Defects</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BAD - beyond threshold or &gt; 1% worse than plan, Yellow = 10-19% worse than plan, Green = within 10% of plan, Change from last cycle</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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Recommendation Forms

Multi-Learner

Modes:
- Single Learner mode
- Single Learner with supervisor (PM & Mentor)
- Multiple Learner
- Multiple Learner with supervisor

Prototype multi-learner capabilities have been developed for the Experience Accelerator. The capabilities have been provided for multiple learners to create and join games asynchronously, share documents, communicate directly with one another, and make decisions that affect the outcome of the simulations.
Instructor Interaction

Three specific ways of instructor interaction emerged:

- **Mentor** - This is the role that ended up being closest to the DAU traditional instructor role and was used in the pilot. It includes having the instructor watch over the student teams as they work. The instructor can provide guidance or answer questions, but is not directly involved in the scenario.

- **Passive Program Manager** - This is an extension of the Mentor role with an ability to accept or reject the recommendations by the team.

- **Active Program Manager** - This is the expected role for multi-player supported experiences. The instructor replaces the system NPC PM as an active player with the Program Manager’s role. It is up to the instructor to receive and respond to the recommendations of the teams. Tools are provided that allow the instructor to view all of the experiences of the members of the team, communicate via chat, and accept or reject the team’s recommendations.
## DAU Meetings & Milestones

<table>
<thead>
<tr>
<th>Current Date</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oct 16, 2012</td>
<td>Initial DAU Integration meeting</td>
</tr>
<tr>
<td>Mar 4, 2013</td>
<td>Logistics/Joint Competency Proposal meeting</td>
</tr>
<tr>
<td>Apr 15, 2013</td>
<td>EA Demo, DAU Integration meeting</td>
</tr>
<tr>
<td>Apr 23, 2013</td>
<td>DAU Integration meeting</td>
</tr>
<tr>
<td>May 5, 2013</td>
<td>DAU Integration meeting</td>
</tr>
<tr>
<td>Aug 13, 2013</td>
<td>DAU Instructor Familiarization meeting</td>
</tr>
<tr>
<td>Sep 4-5, 2013</td>
<td>DAU Instructor Pilot</td>
</tr>
<tr>
<td>Oct 15, 2013</td>
<td>DAU Pre-Student Pilot Review</td>
</tr>
<tr>
<td>Oct 29-30, 2013</td>
<td>DAU Student Pilot</td>
</tr>
<tr>
<td>Dec 31, 2013</td>
<td>Complete Final Report</td>
</tr>
</tbody>
</table>

---

## SYS302 Deployment Schedule

<table>
<thead>
<tr>
<th>Time</th>
<th>Instructors</th>
<th>Students</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tuesday</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1400-1430</td>
<td>Introduce Exercise</td>
<td>Team formation, role clarification/alignment</td>
</tr>
<tr>
<td>1430-1530</td>
<td>Mentor and Support</td>
<td>Individuals complete EA Phase 0 and Phase 1</td>
</tr>
<tr>
<td>1530-1630</td>
<td>EA PM/Mentor/Control</td>
<td>Team completes Phase 2A Cycle 1</td>
</tr>
<tr>
<td>1630-1700</td>
<td>EA PM/Mentor/Control</td>
<td>Team completes Phase 2A Cycle 2</td>
</tr>
<tr>
<td>Wednesday</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0800-0830</td>
<td>EA PM/Mentor/Control</td>
<td>Team completes Phase 2A Cycle 3</td>
</tr>
<tr>
<td>0830-0900</td>
<td>EA PM/Mentor/Control</td>
<td>Team completes Phase 2A Cycle 4</td>
</tr>
<tr>
<td>0900-1000</td>
<td>Mentor and support</td>
<td>Presentation Development</td>
</tr>
<tr>
<td>1000-1100</td>
<td>View presentations &amp; note items for reflection material</td>
<td>Teams deliver presentations</td>
</tr>
<tr>
<td>1100-1130</td>
<td>Monitor and support</td>
<td>Phase 2B (Receive &amp; discuss CDR Results)</td>
</tr>
<tr>
<td>1130-1230</td>
<td>Lunch (develop reflection material?</td>
<td>Lunch</td>
</tr>
<tr>
<td>1230-1315</td>
<td>Monitor and Support</td>
<td>Phase 3/Phase 4/Phase 5 speed through</td>
</tr>
<tr>
<td>1315-1340</td>
<td>Monitoring guidance</td>
<td>individuals complete Phase 7 - Reflection</td>
</tr>
<tr>
<td>Homework</td>
<td>Review logged results after completion</td>
<td>individuals replay experience</td>
</tr>
</tbody>
</table>

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Pilot System Evaluation

The instructor familiarization, instructor and student pilots:

- generated 140+ action items for EA enhancements,
- proved the need for stability and performance improvements,
- provided feedback affirming the potential of the EA with students in a classroom

Targeted Lessons

- Problem solving and recovery
  - Identify weight and drag problems, remediate with TPM targets and allocation changes
  - Identify schedule problem, remediate with additional staff and a small schedule delay
  - Identify software quality problem, remediate with increased software design review frequency

- Product integration
  - All sub-systems need to be done at the same time ideally for integration to begin. Adding resources to airframe/propulsion (AP) and command/control (CC) sub-systems brings there schedule more in line with the other sub-system and the systems integrator, who are not having schedule issues.
  - The solution could be improved by not hiring as many AP senior staff and reducing staff for the systems integrator and ground station sub-contractor so that they meet their targets at the three-month delay, instead of the original CDR schedule. This is left as an exercise for the learner and/or instructor.
  - Transferring weight allocation from AP to CC illustrates the relationships between these two sub-systems and how a win-win can be achieved (or at least a win and no-loss).

- Cutting corners to make short term goals while ignoring long term outcomes
  - Make decisions early, even though they have negative cost implications initially. This is better than facing the bigger problems later on of schedule delays that make the cost overruns worse.
Lessons Learned: Team 1

“What would we do differently?

• Over correcting the Aerodynamic Drag target
  — The error was made during the 3rd and 4th cycles where another change was made to the drag target from 2.5 to 2.45, attempting to further optimize the range. During the 4th cycle no change was made to the drag target and thus we spent a lot more money on decreasing the drag and increasing the range when it was not necessary. This partially contributed to our cost overrun of 9%.

• Hire more staff early in the project to ensure there won’t be a schedule slip to integration testing”

Lessons Learned: Team 2

“Conclusions

• Based on current trends, CDR readiness NOT likely - No progress goals have been met.
• Suspect that Cycle 1 changes were not dramatic enough, in enough areas

What to do differently:

• More dramatic changes to staffing
• Leave weight targets as-is
• Identify changes more directly linked to C2 progress”
Lessons Learned: Team 3

“Lessons Learned

• Shift staffing earlier to improve quality/test
• Reduce FTE from better performing sub-systems
• Pay closer attention to CDR entry criteria”

Lessons Learned: Team 4

“Hindsight is 20/20

• Early software emphasis worked
• Focus on KPP early
• Maintain focus on CDR entrance criteria
• Airframe/Propulsion subsystem CPI suffered because we spent extra resources to maintain range KPP
• Our initial top 3 issues were not the main issues we encountered
• KPP was in good shape
• We got FIRED! Don’t slip CDR!”
Lessons Learned: Team 5

“Lessons Learned

• Ramped up staff quicker
• Taken staff away from Ground Control to save money
• Raised weight limit prematurely
• Focused on drag coefficient earlier”

Learning Results

These examples demonstrate that for two targeted learning outcomes in particular, nearly all of the teams learned the outcomes as they very clearly highlighted them in their presentations as the lessons they had learned. Other learning objectives were also highlighted by the different teams.

• These lessons were learned despite the fact that the learners only fully completed the first two phases of the experience before speeding through the remaining phases in order to see their results.

• Furthermore, the EA was designed to be played multiple times by learners, so these results are indicative of impressive learning gains given the limited implementation of the experience.
Future Work

Program Goals

**Program Goal:** Transform the education of SE by creating a new paradigm capable of halving the time to mature a senior SE while providing the skills necessary to address emerging system’s challenges.

1. Successfully integrate EA into DAU course SYS30X
2. Create additional EA experiences deployed at multiple sites
3. Create sustaining open source development community
1. Integrate EA into SYS30x

- EA System Capabilities
  - Completion and stabilization of multi-learner mode
  - Provide means of informing learner of impact of recommendations
  - Ensure that dialog is synchronized with recommendations
  - Improve learner interface with status charts to eliminate need to page through entire set

- Tools
  - Create set of tools that allow the DAU to customize and create new Experiences

- Deployment Deliverables
  - Define explicit EA deliverables to support DAU deployment

- Hosting Requirements
  - Specify technical details of hosting requirements

Program Goals

2. Create additional EA experiences deployed at multiple sites
   - Develop joint competency to fill out EA experience through the life-cycle
   - Develop 2-3 other experiences for different domains
   - Trial tools through these experience development efforts

3. Create sustaining open source development community
   - Develop tool suite using SERC core funding
   - Release EA technology, tools and experiences to open-source community
   - Create consortia to provide long-term support
## EA Tools

<table>
<thead>
<tr>
<th>Limitation</th>
<th>Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Complex simulation models with limited reuse supported</td>
<td><strong>Sim Builder</strong> - Simulation model builder utilizing libraries/templates</td>
</tr>
<tr>
<td>Complex simulation outputs dependent on hundreds of variables/parameters</td>
<td><strong>Sim Tuner</strong> - Parameter tuner that automates the tuning of parameters to yield desired outputs via batch processing of different combinations</td>
</tr>
<tr>
<td>Manual nature of phase and cycle development</td>
<td><strong>Phase Editor</strong> - GUI-based tool for phase, cycle and event specification with code generation</td>
</tr>
<tr>
<td>Manual nature of specifying events and their triggers in the Experience</td>
<td><strong>Event Editor</strong> - GUI or text-based tool to specify events and their triggers with code generation</td>
</tr>
<tr>
<td>Manual nature of artifact integration involving re-linking and recompilation</td>
<td><strong>Artifact Integrator</strong> - Artifact entry application that allows designer to take an artifact file and enter it into EA application with automatic recompilation and re-linking</td>
</tr>
<tr>
<td>Manual nature of assessment of learner performance</td>
<td><strong>Learning Assessor</strong> - Assessment tool-suite that provides automated performance scoring, decision comparisons against proven baselines, etc.</td>
</tr>
</tbody>
</table>

## Funding & Joint Research

- **Extended Capabilities**
  - DAU: Option Year 3, Pilot + Multi-Learner Technology Support
  - SERC: Content Creation Tools funding

- **New Experiences**
  - DAU: Logistics Experience, proposal submitted
  - ONR: Team experience, white paper submitted
  - NSF: Learning in Formal and Informal Settings, proposal submitted
  - NRO: Spacecraft experience, will pilot SEEA
  - MITRE: Team experience, discussions
  - LMC: Interest
  - SI Corporation: Proposal interest
  - Sponsored doctoral research: 2 Stevens students
Join the Experience Accelerator Team!

Contact for information:

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Bill Watson  
brwatson@purdue.edu

Doug Bodner  
doug.bodner@gatech.edu

This material is based upon work supported, in whole or in part, by the Defense Acquisition University through the Systems Engineering Research Center (SERC). SERC is a federally funded University Affiliated Research Center (UARC) managed by Stevens Institute of Technology in partnership with University of Southern California.
Systems Engineering and Systems Management Transformation

- Ilities Tradespace and Affordability Project (iTAP)

  - Barry Boehm, Jo Ann Lane, Nupul Kukreja, USC
  - David Jacques, Erin Ryan, AFIT
  - Tommer Ender, Mike Curry, Russell Peak, Val Sitterle, GaTech
  - Adam Ross, Donna Rhodes, MIT
  - Ray Madachy, NPS
  - Kevin Sullivan, Xi Wang, U. Virginia
  - Gary Witus, Walt Bryzik, Wayne State University

SE and Management Transformation:
Ilities Tradespace and Affordability Project (iTAP)

Summary: Create, validate, and transition MPTs to make better decisions on affordability and value in systems, particularly for non-functional requirements or -ilities

Funding: pre-2014 $1.0M, 2014-15 $875K, 2016-18 20% annual reduction

Status:
- Tradespace and affordability analysis foundations
  - More precise itility definitions and relationships
  - Itility strategy effects, synergies, conflicts
  - U. Virginia, MIT, USC
- Next-generation system cost-schedule estimation models
  - Initially for full-coverage space systems (COSATMO)
  - Extendable to other domains
  - USC, AFIT, GaTech, NPS
- Applied iTAP methods, processes, and tools (MPTs)
  - For concurrent cyber-physical-human systems
  - Experimental MPT piloting, evolution, improvement
  - Wayne State, AFIT, GaTech, NPS, Penn State, USC

Impact:
- Engagements with NAVSEA, Army RDECOM on itility tradespace analysis in set-based design, use of GaTech FACT tradespace analysis capability
- Engagements with USAF/SMC, Aerospace Corp., and aerospace companies on definition and development of next-generation, full-coverage space system cost estimation model family
- Development and iteration with DoD, industry of initial framework and quantification of itility definitions, stakeholder value-based, means-ends relationships, and itility strategy synergies and conflicts with other ilities
Context: SERC iTAP Initiative Elements

- Tradespace and affordability analysis foundations
  - More preciseility definitions and relationships
  - Stakeholder value-based, means-ends relationships
  - Ility strategy effects, synergies, conflicts
  - U. Virginia, MIT, USC

- Next-generation system cost-schedule estimation models
  - Initially for full-coverage space systems (COSATMO)
  - Extendable to other domains
  - USC, AFIT, GaTech, NPS

- Applied iTAP methods, processes, and tools (MPTs)
  - For concurrent cyber-physical-human systems
  - Experimental MPT piloting, evolution, improvement
  - Wayne State, AFIT, GaTech, NPS, Penn State, USC

SERC Value-Based ilities Hierarchy
Based on ISO/IEC 9126, 25030; JCIDS; previous SERC research

- Individual ilities
  - Resource Utilization: Cost, Duration, Personnel, Scarce Quantities (capacity, weight, energy, ...); Manufacturability, Sustainability
  - Protection: Security, Safety
  - Robustness: Reliability, Availability, Maintainability, Survivability
  - Flexibility: Modifiability, Tailorability, Adaptability
  - Composability: Interoperability, Openness, Service-Orientation

- Composite ilities
  - Comprehensiveness/Suitability: all of the above
  - Dependability: Mission Effectiveness, Protection, Robustness
  - Resilience: Protection, Robustness, Flexibility
  - Affordability: Mission Effectiveness, Resource Utilization
Means-Ends Framework: Affordability

Get the Best from People
- Staffing, Incentivizing, Teambuilding
- Facilities, Support Services

Make Tasks More Efficient
- Kaizen (continuous improvement)
- Tools and Automation
- Work and Oversight Streamlining
- Collaboration Technology

Eliminate Tasks
- Lean and Agile Methods
- Task Automation
- Model-Based Product Generation

Eliminate Scrap, Rework
- Early Risk and Defect Elimination
- Evidence-Based Decision Gates
- Modularity Around Sources of Change
- Incremental, Evolutionary Development
- Value-Based, Agile Process Maturity

Simplify Products (KISS)
- Risk-Based Prototyping
- Value-Based Capability Prioritization
- Satisficing vs. Optimizing Performance

Reuse Components
- Domain Engineering and Architecture
- Composable Components, Services, COTS
- Legacy System Repurposing

Reduce Operations, Support Costs
- Automate Operations Elements
- Design for Maintainability, Evolvability
- Streamline Supply Chain
- Anticipate, Prepare for Change

Affordability Improvements and Tradeoffs

Value- and Architecture-Based Tradeoffs and Balancing

COSYSMO Sys Engr Cost Drivers

- Documentation
- Tool support
- Migration
- Model complexity
- Early feedback in design
- Process capability
- Personnell interaction
- Architecture understanding
- Technology Risk
- Level of Given Requirements
- Requirement Understanding

Effort Multiplier Ratio (EMR)

02-25-14
Product Line Engineering and Management: NPS

Architecture Strategy Synergy-Conflict Matrix

Reliability

- Non-normalized data monitoring improves reliability, but requires more effective toolset archiving (longer domain knowledge in defining assortment)
- Reliability (high module collection, low module coupling) improves modularity and reliability
- Reliability-based smart manufacturing improves reliability, inter-dependability, with the correct high volume, low coupling modules improve inter-modularity and reliability
- Domain architecture improves reliability, inter-modularity and reliability
- Modularization around key components of change reduces lifecycle costs
- Domain architecture enables module-based systems, improves modularity and inter-modularity
- Domain architecture reduces lifecycle costs
- Domain architecture reduces lifecycle costs
- Domain architecture reduces lifecycle costs
- Domain architecture reduces lifecycle costs

Modifiability

- Data redundancy, data collection, separate data systems, integrates systems, improves inter-modularity and reliability
- Domain architecture improves modularity, inter-modularity and reliability
- Modularization around critical components of change reduces lifecycle costs
- Modularization around key components of change reduces lifecycle costs
- Domain architecture enables module-based systems, improves modularity and inter-modularity
- Domain architecture reduces lifecycle costs
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- Domain architecture reduces lifecycle costs

Interoperability

- Domain architecture improves modularity, inter-modularity and reliability
- Modularization around key components of change reduces lifecycle costs
- Domain architecture enables module-based systems, improves modularity and inter-modularity
- Domain architecture reduces lifecycle costs
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Cost

- Increased modularity increases acquisition costs
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- Increased modularity increases acquisition costs
AFIT: CEVLCC Methodology

Current Expected Value of Life Cycle Cost

1. Establish system design options
2. Construct time-phased PDFs associated with all existing key cost, schedule, & tech performance parameters of program
3. Estimate costs associated with mods (consistent w/ PDFs) to baseline cost, schedule, & tech performance parameters
4. Assign time-phased probabilities for potential new capabilities of the system
5. Estimate costs associated with the addition of new capabilities
6. Calculate standard (i.e., traditional) LCC estimate
7. Calculate CEVLCC for each system design option and select alternative with the lowest CEVLCC

AFIT: CEVLCC Tool

1. Specify design options
2. Identify reqmmts that will be useful for discriminating between designs
3. Estimate probabilities of threshold value changes in each reqmnt
4. Relative to each design, estimate cost impacts for each potential threshold value change
5. Evaluate expected LCC curve (CDF) and choose design that corresponds to most favorable curve
COSATMO Concept

- Co-sponsored by OSD, USAF/SMC
- Focused on current and future satellite systems
  - Accommodating rapid change, evolutionary development, Net-Centric
    SoSs, families of systems, future security and self-defense needs,
    microsats, satellite constellations, model-based development
  - Recognizes new draft DoDI 5000.02 process models
    - Hardware-intensive, DoD-unique SW-intensive, Incremental SW-intensive,
      Accelerated acquisition, 2 Hybrids (HW-, SW-dominant)
  - Covers full life cycle: definition, development, production, operations,
    support, phaseout
  - Covers full system: satellite(s), ground systems, launch
  - Covers hardware, software, personnel costs
- Extensions to cover systems of systems, families of systems
- Several PhD dissertations involved (as with COSYSMO)
  - Incrementally developed based on priority, data availability
- Upcoming workshop at Aerospace Ground Systems Architectures Workshop Feb 26
SysML Building Blocks for Cost Modeling
GaTech-USC Work in RT46 Phase 2 (Oct-Dec 2013)

- Implemented reusable SysML building blocks
  - Based on SoS/COSYSMO SE cost (effort) modeling work by Lane, Valerdi, Boehm, et al.

- Successfully applied building blocks to healthcare SoS case study from [Lane 2009]

- Provides key step towards affordability trade studies involving diverse “-ilities” (see MIM slides)

Healthcare SoS Case Study [Lane 2009] Implemented Using SysML Building Blocks: Selected SysML Diagrams
Health care example of Kanban Scheduling System (KSS) Network

Example: KSS simulation result analysis

Value:

![Graph showing simulation result analysis with 'random' and 'kss' lines]
### SE and Management Transformation: Agile SE Enablers

**Summary:** Research, package, and deploy the most valuable SE enablers, based primarily on the enablers and risk factors identified in the RT-34 Expediting SE study.

**Funding:** pre-2014 $500K, 2014 $100K, 2015 $100K, 2016-2018 20% annual reduction.

**Status:**
- Identified people, process, product, and project enablers as well as risk factors.
- Delivered prototype quantitative schedule acceleration model; Plan to calibrate and evolve.

**Impact:**
- Cooperation and coordination with ongoing non-SERC agile SE work (INCOSE, NDIA, LSS, FFRDC).
- Leveraging results of other SERC tasks.

---

### Case Study: From Plan-Driven to Agile

**Initial Project:** Focus on Concurrent SE.

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<th>Accelerators/Ratings</th>
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**Expected schedule reduction of 1.09/0.96 = 0.88 (green arrow)**
**Actual schedule delay of 15% due to side effects (red arrows)**
**Model prediction: 0.88*1.09*1.04*1.06*1.06 = 1.13**

02-25-14
Case Study: From Plan-Driven to Agile

Next Project: Fix Side Effects; Reduce Bureaucracy

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| Risk Acceptance Factor | 1.13 | 1.06 | 1.0 | 0.94 | 0.89 | 0.84 |

Model estimate: \(0.88 \times (0.92/0.96) \times (0.96/1.05) = 0.77\) speedup
Project results: 0.8 speedup
Model tracks project status; identifies further speedup potential

GaTech – FACT Tradespace Tool
Being used by Marine Corps

- Configure vehicles from the “bottom up”
- Quickly assess impacts on performance
WSU: Versatility Factors and Physical Organization
Components that Can be in Different Positions or Orientations
Isolated or Separated Compartments

Mass & Structure Properties
- Mass
- Angular moments
- Imbalances*
- Load bearing wall strength
- Deck surface area
- Interior volumes**
- Interior surface areas**

*Angular moments of the CG about axes of rotation
** By crew station and compartment

02-25-14
Interactive Model-Centric Systems Engineering (IMCSE)

Dr. Adam M. Ross, MIT

5th Annual SERC Sponsor Research Review
February 25, 2014
Georgetown University
Hotel and Conference Center
Washington, DC

www.sercuarc.org

Collecting Vast Information: Big Data

We live in a world with big data...

The impact of big data is felt across many fields, and will only increase...

Privacy?

Application Areas
- transportation, consumer products, entertainment, banking, life sciences, physical sciences, ...
- communications, education, sports, insurance, manufacturing, retail, healthcare, utilities, dating ...

Big data is being leveraged in many ways to gain insights into phenomena and to create predictive models...

Big data provides a foundation for large scale analytics to predict the future
Making Sense of the Data: Visual Analytics

What is Visual Analytics?

Visual analytics is the science of analytical reasoning buffeted by interactive visual interface.

Enabling Software Tools

*observable “ground truth” possible

Application Areas

• homeland security, intelligence community, law enforcement, financial markets, anti-fraud
• banking, communications, education, insurance, life sciences, manufacturing, retail, utilities, …

Visual analytics is resulting in a transformative capability, bridging human and computer analysis for natural* data

Our Domain: Complex Systems

Our application domain is the development of (artificial) systems that serve the purpose of delivering value to stakeholders…

The complexity of our systems has been growing over time, not only due to scale and interconnectedness, but also due to increased scope in our ability to describe the system

Five aspects of system complexity

Developing complex systems necessitates an approach to generate, manage, and analyze artificial data across these five aspects
Model-based Systems Engineering

"Model-based systems engineering (MBSE) is the formalized application of modeling to support system requirements, design, analysis, verification and validation activities beginning in the conceptual design phase and continuing throughout development and later life cycle phases."

NDIA SE Division: Model-Based Engineering (MBE) Subcommittee Report (2011)

- Reduce acquisition time of first article systems and solutions
- Reduce time to implement planned and foreseen changes
- Enhance reliability
- Enhance interoperability

...each of these benefits enhance affordability

Model-based systems engineering generates “artificial data” about our systems which we use to make decisions that impact the future/continuing success of that system

Merging the Four: Interactive Model-Centric Systems Engineering

- Big Data + Visual Analytics:
  + Complex Systems + MBSE = IMCSE
    - Volume, variety, velocity, and veracity of data
    - Collect data, visualize, interact, model, find patterns, generate insights, repeat
    - Structural, behavioral, contextual, temporal, and perceptual complexities
    - Integrated models including requirements, structure, behavior, parametrics

- Potential use for this merged capability for decision support within and across systems engineering throughout lifecycle

On the power of humans with computers:

"statistics (computing) + humans is much more powerful than statistics alone or humans alone"

- Professor Remco Chang, Tufts University

Developing complex systems necessitates an approach to generate, manage, and analyze artificial data across these five aspects, which result in improved SE decision making.
What is IMCSE?

More than just visual analytics...

Our data is generated by models (e.g. “M” of MBSE)...

In SE, our job is to make decisions that result in systems that deliver value to our stakeholders...

Two critical gaps in current approaches:
1. Visual analytics of artificial (model-generated) data
2. Active tradeoffs of the models themselves

Key questions:
— How can techniques from VA result in better model-enabled SE decisions?
— How can we determine proper trust and truthfulness for various types of models?
— Ultimately, how can this approach help to manage complexity in modern SE and deliver more affordable and valuable systems?

IMCSE Goal: leveraging visual analytics applied to model-generated “big data,” develop a rigorous framework, with associated MPTs, that results in transformative new capabilities for SE decision making

Interaction between Humans and Models Enables Anticipatory Capacity

Systems scientists have long recognized that humans possess unique abilities for anticipation rather than simple reactive response

• Anticipation (ability to look forward in order to take a future decision or action)
• Pattern recognition skills
• Subject to cognitive limits, preferences, and biases...

Interactive Model-Centric Systems Engineering
Decision Science – Visual Analytics – MBSE

Anticipatory Capacity
Key Enablers

Mindset – systems thinking
Methods – model-based
Environment – h/w/s enhanced

Anticipatory Capacity is the capacity to continuously develop and apply knowledge acquired through a structured approach to anticipate: (1) changing scenarios as stakeholder needs and systems context change over time; (2) to consider their consequences; and (3) to formulate design decisions in response.

Rhodes and Ross 2008

SSR 2014
February 25, 2014
7

SSR 2014
February 25, 2014
8
IMCSE Role in Decisions

- Make portfolio decisions using discovered capability gaps and synergies
- Select resilient concepts by anticipating and evaluating future uncertainties
- Determine proactive resourcing adjustments to accelerate development schedule
- Select optimal prior program models for reuse with trade-off of alternative models
- Reach agreement on change impact assessments through interactive model-based sessions

IMCSE will leverage many of the benefits of MBSE and Visual Analytics.

Vision for IMCSE Research Program

- IMCSE will pursue a balanced basic and applied research approach
  - leveraging strengths of academic environment (e.g. fundamentals, rigor, neutral party view of problem), and
  - keeping the research relevant to the sponsor community, and
  - enabling opportunities for knowledge and MPT transfer to sponsors
- As the program matures, collaborations inside and outside of SERC

Knowledge Transfer Opportunities

Workshops, teleconferences and meetings, reports, papers, collaboration with other SERC activities, prototypes, MPTs, government partner applications, potential student internships

The IMCSE research program aims to develop transformative results through enabling intense human-model interaction, to rapidly conceive of systems and interact with models in order to make rapid trades to decide on what is most effective given present knowledge and future uncertainties, as well as what is practical given resources and constraints.
Approach in Three Thrusts

1. Foundations: Pathfinder
2. Applications: Interactive EEA
3. Fundamentals: Interactive Schedule Reduction Model

- To have most impact, IMCSE uses three complimentary thrusts with different timescales for impact:
  1. Foundations: 1 year, set the stage for IMCSE
  2. Applications: 1 year, short timescale impact, deployment opportunities
  3. Fundamentals: multi-year, medium timescale impact, potentially broad applicability

- Following year one, we anticipate additional projects within applications and fundamentals, plus updates to foundations

**Thrust 1: Foundations**

**IMCSE Research Pathfinder**

- **Enabling Software Tools**
  - Gi 1.3, www.graphinsight.com
  - Starlight Visual Information System, www.futurepointsystems.com

- The Pathfinder project will focus on identification of past and present related state of art and practice, and will begin to build a community of interest around IMCSE

- **Lead:** Dr. Donna H. Rhodes, Dr. Adam M. Ross

- **Summary:** Investigation of state of art and practice, conduct of an invited workshop including SERC and selected outside entities

- **Example Anticipated Outcomes:** Workshop summary report, literature review, research agenda report
Thrust 2: Applications
Interactive Schedule Reduction Model

Complex Systems Design and Analysis – META Approach

Leveraging prior work from DARPA META, the Schedule Reduction Model will be extended with interactivity as a central aspect, promoting sensitivity analyses and benchmarking to be the central use case.

- **Lead:** Professor Olivier de Weck
- **Summary:** Exploratory extension of system dynamics-based Schedule Reduction Model, w/prototype model for pilot-application
- **Example Anticipated Outcomes:** Report, Demo, Prototype, Potential Deployment Partner

Thrust 3: Fundamentals
Interactive Epoch-Era Analysis

EEA is a framework that supports narrative and computational scenario planning and analysis for both short run and long run futures.

- **Lead:** Dr. Adam M. Ross, Dr. Donna H. Rhodes
- **Summary:** Exploratory development of interactive Epoch-Era Analysis, including human interface and reasoning considerations for epoch and era characterizations, as well as single and multi-epoch-era analyses
- **Example Anticipated Outcomes:** Report, Papers, Proof of concept demo via mission planning support
IMCSE Going Forward

• Looking forward to beginning this research program soon...
• This program is just a start with clear growth opportunities
  — E.g. Leverage MIT initiatives
  ![bigdata](image)
  — E.g. Leverage other SERC initiatives
    - Full lifecycle MBSE, including Concept Engineering
• IMCSE has applicability across DoD and government in general
  — Looking for additional collaborators within SERC
  — Looking for additional government partners for case applications and field testing
• While starting in defense-oriented applications, IMCSE can be leveraged for use in government more generally

Future of SE Decision Making

• In the future, SE decisions must be more rapid, holistic, and better than "good enough"...
  — Q: How to manage system and program given dynamic uncertainties through the lifecycle?
  — A: IMCSE will enable more rapid and transparent decision making that will result in more affordable and valuable system solutions
• How could IMCSE turn out in 5-10 years?
  — Current visual analytics research shows how interaction reveals domain knowledge, which could then be used for learning systems (e.g. intelligent systems that further augment humans by anticipating queries and pre-fetching large data sets)
• Future IMCSE will show its value by enabling systems and programs to be more anticipatory and empowered to discover superior dynamic strategies, resulting in transformative capabilities

This type of capability could be used to address a host of questions, such as:

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<tr>
<td>• How to write source selection criteria in RFP?</td>
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<td>• How to implement changes to save the program today without killing the program in five years?</td>
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<td>• How to trade changing requirements for building a &quot;better&quot; yet delayed system versus building a less-capable system on schedule?</td>
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<td>• How to assess the impact of infrastructure improvements on program performance and cost?</td>
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<td>• How to assess the impact of other asset availability to augment primary system performance during operations?</td>
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<td>• What are the implications of a staged deployment strategy versus single deployment?</td>
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“Models can easily become so complex that they are impenetrable, unexaminable, and virtually unalterable.”

“There are many specific techniques that modellers use, which enable us to discover aspects of reality that may not be obvious to everyone... but they are not as important as the ability to understand the underlying dynamics of a complex system well enough to assess whether the assumptions of a model are correct and complete. ...whether a model reflects reality, and to identify and deal with divergences between theory and data”

“Essentially, all models are wrong, but some are useful.”

“Artificial things are synthesized (though not always and usually with full forethought) by human beings”

How can we enable more deliberate forethought in our systems throughout their lifecycle using interactive models?

Back up slides
Using an “Epoch”-based Framework is Not New...

Era Variable:
- Environment
- “Systems”
- Value

Epoch Shift
Change in:
- Environment
- “Systems”
- Value

Epoch Fixed:
- Environment
- “Systems”
- Value

Various Epochs Define the World for our Systems...
... and Can be Assembled into Possible Eras (Futures)

Our Path Today

Cold War ➔ War on Terror

Alternative Eras

(EEA example slide courtesy of Andrew Long, 2010)

Example: Modern HMMWV

(EEA example slide courtesy of Andrew Long, 2010)
**Generating Epochs**

Many possible contexts and needs may unfold in the future, impacting actual and perceived system utility and cost.

“Epoch-based thinking” can be used to structure anticipatory scenario analysis.

Today Possible futures (epochs)

**Example triggers for epoch shifts impacting a system**
- Change in political environment
- Entrance of new competitor in market
- Emergence of significant new or changed stakeholder need(s)
- Policy mandate impacting product line, services or operations

Categories of epoch variables can aid in thinking about key changing factors:

E.g., Resources, Policy, Infrastructure, Technology, End Uses (“Markets”), Competition, etc.

**Storyboarding with Epochs**

Two aspects to an Epoch:
1. Needs (expectations)
2. Context (constraints including resources, technology, etc.)

Example system: Serviceable satellite
Epochs and Eras to Consider Long Run Uncertainties

• System Development Lifecycle (SDLC) is a crucial organizing construct for managing system design activities, but does not facilitate management of uncertain contexts and mission needs

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<tr>
<th>Year</th>
<th>Era</th>
<th>Epoch</th>
</tr>
</thead>
<tbody>
<tr>
<td>2020</td>
<td>2-8 years</td>
<td>2-8 years</td>
</tr>
<tr>
<td></td>
<td>2-8 years</td>
<td>2-8 years</td>
</tr>
<tr>
<td></td>
<td>2-8 years</td>
<td>2-8 years</td>
</tr>
</tbody>
</table>

• Epoch
  - A period of time during which the context and mission needs are static
  - Duration is determined by underlying dynamics of contextual factors considered

• Era
  - Spans the total lifecycle of a system
  - Constitutes an integrated set of epochs
  - Allows analysis of system evolution strategies

Epoch-Era Analysis provides a structured way to consider the impact of context changes and mission needs over the SDLC

Using Epochs for Proposing Time-Based Strategies across Eras

Discretization of change timeline into short run and long run enables analysis

Epoch: Time period with a fixed context; characterized by static constraints, design concepts, available technologies, and articulated needs

Era: Time-ordered sequence of epochs

In order to pursue dynamic strategies, a system must have temporal properties, i.e., “-ilities” such as flexibility, evolvability, or survivability
IMCSE Summary

Summary: Catalyze human-model interaction capabilities and MPTs to rapidly conceive of systems, and to accelerate rapid trades for deciding on what is most effective, given present knowledge and future uncertainties, and what is practical, given resources and constraints.

- Project 1: IMCSE Pathfinder
  - Investigation of state of art and practice
  - Invited research workshop with report
  - Pathfinder project report
- Project 2: Interactive Schedule Reduction Model
  - Exploratory extension w/prototype model for pilot application, and project report
- Project 3: Interactive Epoch-Era Analysis
  - Exploratory development of interaction capability w/ demo case via mission planning support, and project report
- Build community and publish several papers

Prior Related Work

- Prior SERC research: RT-30: Graphical CONOPS
- Prior/ongoing MIT research under other sponsors:
  - Research lab with interactive tradespace exploration capability (prior-NRO, foreign gov’ts)
  - Prototype schedule reduction model (prior-DARPA)
  - Epoch-Era Analysis (EEA)
    - Method development for considering alternative futures (prior-NRO)
    - Method refinement (prior-AFOSR, NPS, foreign gov’ts)
    - Method application cases within multiple domains (prior-NRO, AFOSR, NPS, USCG, Army, foreign gov’ts)
  - Development and transition of MPTs embodying research outcomes (prior-foreign gov’ts)
Basic Information RT35/35A

- Researchers:
  Richard Turner: Stevens; Boehm, Lane, Ingold: USC; Madachy: NPS; Industry Working Group

- Task start: August 2011

- Funding: Total of $495K (through December 2013)

- Deliverables: 4

- Conference Presentations: 13

- Papers Published: 8 (all to refereed conferences or journals)

- Workshops: 4
Traditional systems engineering assumptions

- Requirements are predefined and generally stable
- Resources and technologies are predictable and stable
- Values remain stable
- There is sufficient time to complete the work
- Reductionism is the best way to approach large problems

The Results

The V model
- Focus on plans/schedules rather than value and solutions
- Focus on requirement precision and coherence (if not accuracy)
- Change (and the customer who wants it) seen as the enemy
- Reductionism and deep engineering specialization
- Local process & design optimization
• SE Disengaged from SwE
  • Poor management visibility into relationships between products, requirements, architecture, change impacts
  • Operational environment overwhelms traditional governance methods

• The World is Changed
  • System contexts have multiplied
  • Change in needs and solution technologies has accelerated
  • Requirements are less tangible, evolving, and often emergent
  • Systems are complex and constantly adapting
  • Actual terrain has changed, we need new maps, tools and techniques
Need Proof Of The Change?

- The venerable PMI has (finally) “adapted”
  - 5th Edition of the PMBOK Guide provides for both predictive (plan-driven) and adaptive (agile) project lifecycles!
  - A new PMI/IEEE-CS SW Extension is now available that deals specifically with software management issues

“Fundamental things apply”

**Values**
- Agile: Flexibility, Evidence
- Lean: Value, Flow

**Principles**
- Stakeholder Value-based Evolution
- Incremental Commitment and Accountability
- Concurrent Multi-discipline Engineering
- Evidence- and Risk-based Decisions

Adapted from
*The Incremental Commitment Spiral Model*
Boehm, Lane, Koolmanojwong, and Turner (2014)
Sticking Points

• Large-scale budgeting and estimation
• Long-lead items
• Operational systems of independently evolving systems
• Highly regulated domains (e.g. defense, financial, health)
• Command and control environments (low trust, bureaucratic)

Some Answers?

• There is still no Silver Bullet
• ICSM principles
• Service orientation is promising
• Trust is a key ingredient and often difficult to find
• “Maybe...” is better than “Hell, No!”
• Executive/Management patience, not abdication
• Believing *Creativity and Collaboration* can be better than *Command & Control*
• Santayana was half right – it’s only the mistakes that you don’t want to repeat, not the successes
Caution! Specific Target Environment for the SERC Research Under Way

- Systems engineering where rapid response software development projects incrementally evolve capabilities of existing systems or SOSs

- That does NOT, however, preclude it from being applicable outside that target; of course it doesn’t guarantee it, either.

Predicted (Desired) Results

- Better *visibility* and *coordination* managing multiple concurrent development projects
- More effective *integration* and use of scarce SE resources
- Increased project and enterprise *value* delivered earlier
- More *flexibility* while retaining *predictability*
- Less blocking of product team tasks waiting for SE response
- Lower governance overhead
Our Concept

- Pull (kanban) scheduling
  - Value-based selection
  - Limited WIP
  - Classes of Service
- SE as a Service
  - Scarce resource-driven
  - Collaborative/Negotiated
- Integrated work and data flow
- Information radiators at all levels

A Multi-level Network of Kanban-based Scheduling Systems

- SE as a Service
- Scarce resource-driven
- Collaborative/Negotiated
- Integrated work and data flow
- Information radiators at all levels
A Generic Kanban-based Scheduling System

Upstream Customers
Work (Backlog)

Ready Queue
(Limit=6)

Activity
(WIP Limit=8, Resources=4)

Completed
Work

Examples of Networked KSSs

Work Item waiting for selection
- Normal Class of Service Work Item (NCOS)
- Special Class of Service Work Item (SCOS)
- Expedite Class of Service Work Item (ECOS)
- Resource (Individually numbered)
Rationale for SE as a Service

• SE activities need to be defined and available for projects and the system owners to select for the ready queue
• The concept of services fits the need to encapsulate work, and provide a common value stream among project development personnel, SE, and the enterprise

Value/Priority in Servicing

• Maintaining prioritization across stakeholders is resource-intensive
  Kanban forces stakeholders to agree about next item in queue
• Stakeholders include customers/users, projects, executive management, and higher level systems engineering management
• Value functions balance local and
Healthcare SoS

- Custom software SoS constituent systems include patient management, pharmacy, laboratory, radiology, and telemetry
- Systems share a single database for all patients and personnel related to a given health care site
- Interfaces to other health care systems are maintained.
- Key overarching requirements are to ensure patient-safety and to protect patient information
**Proposed KSS Network Structure**

```
Product/Domain Engineering

User Support
- Customer relations
- Initial Triage

Individual Product Team
- Product SE
- Identify SW Features
- Allocate features to SWDT
- egrate features into requirements
- SW Development Team

Pharmacy Domain Team

Network Domain Team

Capability Engineering
- Strategic planning
- Capability prioritization

Needs Backlog*

ork Flow

*All organizations can contribute to the Needs Backlog
```

---

**Classes of Service**

<table>
<thead>
<tr>
<th>CoS</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Critical</td>
<td>Safety, security, or other emergency work items. Disruptive: requires necessary resources to stop current work and complete it.</td>
</tr>
<tr>
<td>Expedite</td>
<td>Very high priority work items such that this work takes priority over other work in the ready queue. Not Disruptive.</td>
</tr>
<tr>
<td>Important</td>
<td>Work items that must be completed by a specific date or there will be significant consequences.</td>
</tr>
<tr>
<td>Data Certain</td>
<td>The normal CoS for the development organizations work.</td>
</tr>
<tr>
<td>Standard</td>
<td>Work that must go on but is usually not time critical. It includes things like architectural enhancements, low-level technical debt, or research and environmental scanning.</td>
</tr>
</tbody>
</table>

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*SSRR 2014*
Flow among and between KSSs

New Capabilities

- Interface to a new health insurance company
  - requires capture of additional information about patients, diagnoses, and physician orders

- Integrate and analyze information from multiple patient telemetry systems to improve diagnostic capabilities
  - COTS option: Identify and evaluate any COTS data fusion products that apply to the telemetry devices, select the “best” one, then integrate it into the enterprise
  - If no COTS available for all telemetry systems, two options:
    - Change non-compatible telemetry systems for more compatible ones and use a COTS product to integrate/analyze the desired information
    - Develop a custom application to do the integration and analysis.
Upgrade and Enhancement

• User response improvement
  — system response time is unacceptably slow and is potentially putting patient safety at risk
  — evaluate alternatives for improving the user response time and recommend one or more for funding.

• Periodic upgrade of pharmacy formulary information
  — Data on formularies and drug interactions updated quarterly (subscription service)
  — Updates analyzed against existing DB structures, any necessary updates to the data structures made, data structure updates tested and deployed, then populated with updated data

Normal Capability Development
Critical Issue: Interoperability Problem

- Feature to electronically send patient records to an external health care system was implemented, fully tested and seemed to function well during the first 30 days after deployment.

- Later one night, a physician noticed that an important entry by the external health care system was not properly entered in the time log.

Critical Task Operation
Results

- Aligned, unified view of work in progress and status of work
- Predictability through measures easily SPC’d and projected
- Value-based scheduling considers all priorities
- Better use of C/SE resources; better servicing of team SE needs
- Unlinks planning, scheduling, integration, and deployment cadences
- Enhances decision making
- Supports continuous improvement
- Provides for right conversations, right people, right time

Next Steps

- Proposal in coordination
  - Continue KSSN Research
    - Develop additional mechanisms to support value-based scheduling, SE as a service, etc.
    - Refine simulations to include new mechanisms
    - Build transition package
    - Build collaborations and infrastructure for in vivo KSSN piloting
    - Conduct pilots (Separately funded as sub tasks)
  - Support lean and agile enablers
    - INCOSE, NDIA, SEI and other organizations have working groups on agile-lean SE
    - Participate in and leverage working groups, conferences and Symposia
References

Overview

- Complex Enterprise Systems
- Overall Methodology
- Thinking in Terms of Phenomena
- Abstraction, Aggregation & Representation
- Methodological Support
- Value of Immersion
- Example of Urban Resilience
- Fundamental Issues
- Summary
Complex Enterprise Systems

- Complex Public-Private Systems Laced with Behavioral and Social Phenomena in the Context of Physical and Organizational Systems, Both Natural and Designed

- Examples Being Pursued
  - Deterring or Identifying Counterfeit Parts
  - Traffic Control Via Congestion Pricing
  - Impacts of Investments in Healthcare Delivery
  - Human Responses and Urban Resilience

Archetypal Enterprises

<table>
<thead>
<tr>
<th>Levels of Phenomena</th>
<th>Counterfeit Parts</th>
<th>Congestion Pricing</th>
<th>Healthcare Delivery</th>
<th>Urban Resilience</th>
</tr>
</thead>
<tbody>
<tr>
<td>Historical Narrative</td>
<td>Evolution of defense ecosystem in terms of decision processes</td>
<td>Evolution of transportation ecosystem in terms of technologies &amp; expectations</td>
<td>Evolution of healthcare ecosystem in terms of needs supported and means provided</td>
<td>Evolution of urban ecosystem in terms of social development</td>
</tr>
<tr>
<td>Ecosystem Characteristics</td>
<td>Defense ecosystem – norms, values and supplier economics</td>
<td>Transportation ecosystem – norms, values &amp; expectations of convenience</td>
<td>Healthcare ecosystem – norms, values and resource competition</td>
<td>Urban ecosystem – norms, values and social resilience</td>
</tr>
<tr>
<td>Organizations &amp; Processes</td>
<td>System assembly and deployment networks and controls</td>
<td>Transportation infrastructure networks and flows, and control systems</td>
<td>Provider, payer and supplier organizations – investments, capacities, flows, outcomes</td>
<td>Urban infrastructure networks and flows – water, energy, people</td>
</tr>
<tr>
<td>People or Basic Elements</td>
<td>Flow of parts in supply chain to assembly and deployment</td>
<td>Individual vehicles and driver decision making in context to flows and controls</td>
<td>People’s health and disease incidence, progression and treatment</td>
<td>Peoples’ evolving perceptions, expectations and decisions</td>
</tr>
</tbody>
</table>
Overall Methodology

1. Decide on the Central Questions of Interest
2. Define Key Phenomena Underlying These Questions
3. Develop One or More Visualizations of Relationships Among Phenomena
4. Determine Key Tradeoffs That Appear to Warrant Deeper Exploration
5. Identify Alternative Representations of These Phenomena
6. Assess the Ability to Connect Alternative Representations
7. Determine a Consistent Set of Assumptions
8. Identify Data Sets to Support Parameterization
9. Program and Verify Computational Instantiations
10. Validate Model Predictions, at Least Against Baseline Data

Thinking in Terms of Phenomena

- Rule Setting
  - Incentives – Behaviors Rewarded
  - Inhibitions – Behaviors Penalized
- Resource Allocation
  - Money, Time, Capacities
  - Attention – Displays, Signals, Routes,
- State Transitions
  - Position, Velocity, Acceleration
  - Solid, Liquid, Gas
  - Incidence, Progression, Queues
- Flow of Resources
  - People, Materials, Vehicles
  - Energy, Information
  - Laminar, Turbulent, Congested
- Task Performance
  - Execution, Monitoring, Control
  - Detection, Diagnosis, Compensation
Earth as a System

Population
- Education
- Work
- Consumption
- Children
- By-Products
- Votes

Environment
- Land
- Oceans
- Atmosphere
- Cryosphere

Industry
- Investments
- Production
- By-Products
- Employment
- Products
- Services

Government
- Policies
- Incentives
- Regulations
- Enforcement
- Education

By-Products

Resources

Work & Consumption

Current State & Projected State

Abstraction Hierarchy

- Functional Purpose
  - Objectives, constraints
- Abstract Purpose
  - Causal structure, mass, energy information flow
- Generalized Functions
  - Processes, feedback loops, heat & mass transfer
- Physical Functions
  - Electrical, mechanical, chemical processes
- Physical Form
  - Appearance, anatomy, location
**Aggregation Hierarchy**

- Systems of Systems
- Systems
- Subsystems
- Assemblies
- Components
- Parts
- All People
- All Patients
- Populations of Patients
- Cohorts of Patients
- Individual Patients

**Abstraction & Aggregation**

<table>
<thead>
<tr>
<th>Level of Abstraction</th>
<th>Level of Aggregation</th>
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<tbody>
<tr>
<td></td>
<td>Highly Disaggregated</td>
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<tr>
<td>Ecosystem</td>
<td>Each regulator</td>
</tr>
<tr>
<td></td>
<td>Each payer</td>
</tr>
<tr>
<td>Organizations</td>
<td>Each provider</td>
</tr>
<tr>
<td></td>
<td>Each clinician practice</td>
</tr>
<tr>
<td>Processes</td>
<td>Each operating room</td>
</tr>
<tr>
<td></td>
<td>Each imaging capability</td>
</tr>
<tr>
<td>People</td>
<td>Individual clinicians</td>
</tr>
<tr>
<td></td>
<td>Individual patients</td>
</tr>
</tbody>
</table>
Multi-Level Models

Representations

<table>
<thead>
<tr>
<th>Level</th>
<th>Phenomena</th>
<th>Models</th>
</tr>
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<tbody>
<tr>
<td>Ecosystem</td>
<td>GDP, Supply/Demand, Policy</td>
<td>Macroeconomic</td>
</tr>
<tr>
<td>Economic Cycles</td>
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<td>System Dynamics</td>
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<tr>
<td>Intra-Firm Relations, Competition</td>
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<td>Network Models</td>
</tr>
<tr>
<td>Organizations</td>
<td>Profit Maximization</td>
<td>Microeconomic</td>
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<td>Competition</td>
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<td>Game Theory</td>
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<td>Investment</td>
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<td>DCF, Options</td>
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<td>Processes</td>
<td>People, Material Flow</td>
<td>Discrete-Event Models</td>
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<td>Process Efficiency</td>
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<td>Learning Models</td>
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<td>Workflow</td>
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<td>Network Models</td>
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<td>People</td>
<td>Consumer Behavior</td>
<td>Agent-Based Models</td>
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<tr>
<td>Risk Aversion</td>
<td></td>
<td>Utility Models</td>
</tr>
<tr>
<td>Perception Progression</td>
<td></td>
<td>Markov, Bayes Models</td>
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</tbody>
</table>
Methodological Support

• An interactive environment that supports the set of nominal steps outlined above.
  ― Steps are “nominal” in that users are not required to follow them.
  ― Advice is provided in terms of explanations of each step and recommendations for methods and tools that might be of use.

• Compilations of physical, organizational, economic and political phenomena are available
  ― Includes standard representations of these phenomena, in terms of equations, curves, surfaces, etc.
  ― Advice is provided in terms of variable definitions, units of measure, etc., as well typical approximations, corrections, etc.
  ― Advice is provided on how to meaningfully connect different representations of phenomena.

Support – Cont.

• Visualization tools are available, including block diagrams, IDEF, influence diagrams, and systemograms.

• Software tools for computational representations are recommended
  ― Emphasis is on commercial off-the-shelf platforms that allow input from and export to, for example, Microsoft Excel and Matlab.
  ― Examples include AnyLogic, NetLogo, Repast, Simio, Stella, and Vensim.

• Support is not embodied in a monolithic software application.

• Framework operates as fairly slim application that assumes users have access to rich and varied toolsets elsewhere on their desktops.
  ― Support provides structured guidance on how to best use this toolset.

• Model development occurs within the confines of one or more desktops or laptops.

• Capabilities to export interactive visualizations to much more immersive simulation settings.
Value of Immersion

- Many of the phenomena in our critical public-private systems are very complex and becoming more so.

- Many of the key stakeholders in these systems are not technically sophisticated yet they have enormous influence on outcomes.

- These stakeholders can be engaged and influenced by being immersed in the complexity of their domain.

- The Immersion Lab attracts key stakeholders and sponsors – many report that they did not realize what they experienced was possible.

Virtual Antarctica

![Image of Virtual Antarctica session]
New York City & Long Island

A Synthetic Category 3 Hurricane
Mantoloking, NJ

Hoboken, NJ
Research Questions

• Where will the water be?
  —What streets? What depth? When?

• How will the urban infrastructure react?
  —Transportation, energy, food, water, etc.?

• What will be people’s perceptions, expectations, and intentions?
  —Government decision makers
  —Industry decision makers
  —Population in general

People’s Questions

• At First
  —What is happening?
  —What is likely to happen?
  —What do others think?

• Somewhat Later
  —Will we have power, transportation?
  —Will we have food and water?
  —What do others think?

• Further On
  —Where should we go?
  —How can we get there?
  —What are others doing?
Fundamental Issues

- Creating valid and useful combinations of
  - Partial differential equation models of water flow
  - Network models of urban infrastructures
  - Agent-based models of population response
- Accounting for information sharing among members of the population
- Incorporating real-time sensing, including tweets, to update predictions as situations evolve
- Creating immersive decision support systems for government and industry decision makers

Combining Models

- Combining multiple, specialized models would seem to be an ideal solution for analyzing complex enterprise systems
- However, this implicitly creates overlapping representations of the same underlying phenomena
- Overlaps create conflicts and feedback loops that can be difficult or impossible to manage
  - These only occur in models, not the real world
Overlaps Can Be Subtle

• Some overlaps are obvious
  — Drivers make decisions based on the perceived traffic flow and the traffic flow is created by the decisions of drivers

• But others can be more subtle
  — A classic model for asset price may be inconsistent with an agent-based model of investor behavior

• Capturing the complexities of enterprise systems often requires more models, hence, more overlaps

Example: Pilot Workload

• An analyst wants to develop a simulation by composing “off the shelf” models to estimate aircraft cockpit workload

• The analyst has two models:
  — A discrete event simulation that models the arrival of in-flight events, including emergencies
  — A differential equation based simulation that models the flight response of the aircraft

• If the two models are compliant with well-defined simulation standards, the analyst should be able to combine the two according to established rules
Example: Pilot Workload

- After combining the simulations, the analyst discovers that the flight response model is for a commercial aircraft and the in-flight events model is for a military fighter aircraft.

- Obviously this is not a valid combination (and is exaggerated to make the point) – “events” in a fighter are quite different from “events” in a commercial transport.

- But what if the models were for two different variants of commercial transports? Would that be close enough?

Addressing Overlaps

- Overlaps can be addressed by partitioning the problem into manageable pieces
  - Using a low resolution map for traveling cross country and a high resolution map for navigating city streets.

- Partitions must achieve complete separation
  - Compatible data exchanges are not enough.

- Some incomplete partitions may be addressed by trading accuracy versus separability
  - A high fidelity model of engine performance used to generate parametric functions as inputs to other models.
Summary

- Complex Enterprise Systems
- Overall Methodology
- Thinking in Terms of Phenomena
- Abstraction, Aggregation & Representation
- Methodological Support
- Value of Immersion
- Example of Urban Resilience
- Fundamental Issues
Advances towards a System of Systems Analytical Workbench

By
Daniel A. DeLaurentis
Director, Center for Integrated Systems in Aerospace (CISA)
Purdue University

5th Annual SERC Sponsor Research Review
February 25, 2014
Georgetown University
Hotel and Conference Center
Washington, DC

www.sercuarc.org

Introduction

• Need → What people want out of systems of systems:
  — New capability ... but also: risk mitigation, robustness, resiliency in both developmental and operational domains
  — Tools to conceive, establish, and evolve SoS

• Response → Advancements brewing in many facets
  — Representation documentation: MBSE ... and towards MBSoS-SE
  — Interoperability of tools and systems: “Contracts” and meta-languages
  — Architecting and Decision-Making:
    o Our RT-108 (and prior) work has focused here: Answer questions like:
      Which SoS configurations?, Which metrics?, Which rules / incentives? Which evolution paths?
    o Combine M&S with decision-making (design) analytics – back to original MBSE (e.g., Wymore, A. Wayne. Model-based systems engineering. CRC, 1993.)

• Larger Context → Many synergies with other SERC and international endeavors
  o e.g., research in security, human systems, and enterprises
  o e.g., European Commission FP7 Efforts in SoS
    — Trans-Atlantic Research and Education Agenda in SoS (T-AREA-SoS); a Support Action
    — Several SoS Research Projects (DANSE, COMPASS, etc.)
Challenges- In Abstract ...

**SoS as complex endeavor**

*One notion of Complexity:*
The amount of information necessary to describe regularities in the system effectively

<table>
<thead>
<tr>
<th>Sources of Complexity</th>
</tr>
</thead>
</table>
| **α** | Aggregation  
| **β** | Requirements & ops uncertainty  
| **γ** | Modeled & un-modeled interdependencies  
| | - Within and between levels of abstraction  
| | Dynamic connectivity & porous boundary  
| | Nature of an open system  
| | Multiplicity of perspectives in participants  
| | - A root cause of interoperability issues  

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**Challenges- In Particular ...**

*From: “Systems of Systems Pain Points”, Dr. Judith Dahmann, INCOSE Webinar Series on Systems of Systems, 22-FEB, 2013*

<table>
<thead>
<tr>
<th>Pain Points</th>
<th>Question</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SoS Authority</strong></td>
<td>What are effective collaboration patterns in systems of systems?</td>
</tr>
<tr>
<td>Leadership</td>
<td>What are the roles and characteristics of effective SoS leadership?</td>
</tr>
<tr>
<td>Constituent Systems</td>
<td>What are effective approaches to integrating constituent systems into a SoS?</td>
</tr>
<tr>
<td>Autonomy, Interdependencies &amp; Emergence</td>
<td>How can SE provide methods and tools for addressing the complexities of SoS interdependencies and emergent behaviors?</td>
</tr>
<tr>
<td>Capabilities &amp; Requirements</td>
<td>How can SE address SoS capabilities and requirements?</td>
</tr>
<tr>
<td>Testing, Validation &amp; Learning</td>
<td>How can SE approach the challenges of SoS testing, including incremental validation and continuous learning in SoS?</td>
</tr>
<tr>
<td>SoS Principles</td>
<td>What are the key SoS thinking principles, skills and supporting examples?</td>
</tr>
</tbody>
</table>

Survey identified seven ‘pain points’ raising a set of SoS SE questions
Analytic Workbench: Target Capabilities

- **Open**
  - Accommodates insertion of new SoS analytic methods (from Purdue or others)

- **Interoperability**
  - Outcomes produced in form suitable for additional SoSE phases
  - 'Domain agnostic', cross platform operations
  - Address uncertainty in data/simulation outcomes

- **Usable**
  - (Scalability) → reasonable scaling of computational need to problem sizes
  - (Ease of Use) → Users can translate problem to inputs required by relevant methods and tools

SSRR 2014    February 25, 2014

SoS Analytic Workbench

RT-108: SoS Analytic Workbench

Methods in Toolset:
- Bayesian Networks (BN)
- Robust Portfolio Optimization
- Appro. Dynamic Programming
- Stand-In Redundancy
- Functional/Developmental Dependency Networks

Input Data (e.g. DoDAF OV, SV, PV declarations and other sources for SoS architecture definition)
Archetypal Analysis

Operational Analysis
Evaluating event-trigger based interactions between SoS elements in an architecture

Data Driven Analysis
Historical/Simulation data that drives interconnected SoS elements performance

Architecture Design (or Re-design)
Selection of collections of compatible systems to achieve optimal performance

Risk Assessment
Assessing potential consequences of architecture configurations (e.g. if a system goes down, what effect on overall SoS)

Mapping to Workbench Methods

<table>
<thead>
<tr>
<th>Method</th>
<th>FDN/DDNA</th>
<th>Bayesian Networks</th>
<th>Robust Portfolio Optim.</th>
<th>Approx. Dynamic Program</th>
<th>Stand-in Redundancy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operation Analysis</td>
<td>x</td>
<td></td>
<td></td>
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<tr>
<td>Data Driven</td>
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<tr>
<td>Architecture Design</td>
<td>x x</td>
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<tr>
<td>Risk Assessment</td>
<td>x x</td>
<td></td>
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</tr>
</tbody>
</table>

SoS Analytic Workbench

Analytic Workbench – Inputs for SoS Analysis

Data elements for analysis

<table>
<thead>
<tr>
<th>Methods</th>
<th>Required Input Data Elements</th>
</tr>
</thead>
<tbody>
<tr>
<td>FDNA/DDNA</td>
<td>COD, SOD, Inter-system connectivities</td>
</tr>
<tr>
<td>Bayesian Networks</td>
<td>Probability distributions of system capabilities</td>
</tr>
<tr>
<td>Robust Portfolio Optimization</td>
<td>Capabilities, development risk, System cost</td>
</tr>
<tr>
<td>Approximate Dynamic Programming</td>
<td>Capabilities, development risk, System cost, Development horizon</td>
</tr>
<tr>
<td>Stand-in Redundancy</td>
<td>System capabilities, development risk, Inter-system compatibilities</td>
</tr>
</tbody>
</table>

Legend
- COD: Criticality of Dependency
- SOD: Strength of Dependency
- Connectivity: Connection between systems based on individual capabilities
Analytic Workbench - Outputs of SoS Analysis & Verification

Workbench – Verification via ‘Truth Model’
(e.g. Agent Based Model)

Output of SoS Analysis

SoS Performance evaluation based on ‘new architecture’

SoS new architecture

Bayesian Networks (BN)

BN: Analyzing Cascading Interdependencies

Inputs:
- Failure probabilities of constituent systems
- Conditional probabilities
- Architectures

Bayesian Networks Model
Assumption:
- Directional graph

Req. 1 (Mine counter-measure (MCM))
Req. 2 (Surface warfare (SUW))
Req. 3 (Anti-submarine warfare (ASW))

Outputs:
- Criticality of systems
- Resilience patterns
Bayesian Networks (BN)

- The systems that, once failed, produce low conditional resilience values are deemed critical systems.
- The figure indicates that MCM LCS and ASW MH60S are most critical.

Note: Architecture type and order of system failure affect SoS resilience.

Functional/Developmental Dependency Network Analysis (FDNA/DDNA)

Data driven methods to analyze and quantify interdependencies and cascading effects of risks through networks of systems.

FDNA (developed by Garvey & Pinto, MITRE)
Assess the effect of operational dependencies when partial failures (degraded operability) occur in operational networks (FDNA); Purdue created stochastic version

DDNA (Purdue extension)
Assess the effect of development dependencies when delays occur in development networks

- Directed acyclic networks
- Links are operational/developmental dependencies
- Nodes can be systems or capabilities

- Strength of Dependency (SOD): \( q_{ij} \) is the fraction of the operability of node \( N_j \) due to the dependency on node \( N_i \). Ranges between 0 and 1.
- Criticality of Dependency (COD): \( \beta_{ij} \) is the maximum level of operability reachable by node \( N_j \) when the operability of node \( N_i \) is 0. Ranges 0-100.

Propagation of dependencies.
- DDNA results in a schedule of development (here reported as a Gantt chart)
- Final development, which accounts for partial dependencies, requires a shorter time than that resulting from PERT
- However, some system requires longer development (higher cost). Trade-off required

- Complex behavior due to Strength and Criticality of Dependencies (SOD, COD), and multiple dependencies
- Differences from Bayesian approach for failure propagation:
  - Propagation is not probabilistic. It is a given function of Operability (O), Self-Effectiveness (SE), SOD, COD
  - Partial failures are considered
FDNA/DDNA – Applications

Cyber Security of Naval Warfare Scenario

- FDNA allows for analysis of cascading effects of cyber-attacks on communications links upon overall NWS SoS operability.

Solar Systems Exploration SoS

- The combined use of FDNA and DDNA allows us to quantify the partial capabilities that can be achieved during the development of the Solar Exploration SoS.

Robust Portfolio Optimization

- Treat SoS as ‘portfolio’ of systems
- Analyze operational ‘layers’ under uncertainty
- Model individual systems as ‘nodes’
  - Functional & Physical representation
- Rules for node connectivity
  - Compatibility between nodes
  - Bandwidth of linkages
  - Supply (Capability)
  - Demand (Requirements)
  - Relay capability
- Represent as mathematical programming problem

Robust Operational Analysis for SoS
Robust Portfolio Optimization

Decision support approach from financial engineering/operations research to identify ‘portfolios’ of systems by leveraging performance against risk under uncertainties

- Represent behaviors as connectivity constraints
- Formulate as mathematical programming problem
- Employ robust optimization techniques to deal with data uncertainty
- Computationally efficient tools to solve even large problems

Robustification to include data uncertainties

Enabling tradespace exploration and identifying optimal ‘portfolios’ of systems (e.g. here in evaluating communications assets)

<table>
<thead>
<tr>
<th>Systems</th>
<th>Available System Packages</th>
<th>Gamma (Level of Conservation)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASW</td>
<td>Variable Depth</td>
<td>0.01 0.21 0.41 0.61</td>
</tr>
<tr>
<td>MCN</td>
<td>Multi-Fon Tow</td>
<td>-                -</td>
</tr>
<tr>
<td>SW/W</td>
<td>Lightweight Tow</td>
<td>-                -</td>
</tr>
<tr>
<td></td>
<td>RAMCS II</td>
<td>-                -</td>
</tr>
<tr>
<td></td>
<td>ALOMS (MH-60)</td>
<td>-                -</td>
</tr>
<tr>
<td>SeaFrame</td>
<td>NLOS Missiles</td>
<td>-                -</td>
</tr>
<tr>
<td></td>
<td>Griffin Missiles</td>
<td>-                -</td>
</tr>
<tr>
<td></td>
<td>Package 1</td>
<td>-                -</td>
</tr>
<tr>
<td></td>
<td>Package 2</td>
<td>-                -</td>
</tr>
<tr>
<td></td>
<td>Package 3</td>
<td>x                x x</td>
</tr>
<tr>
<td>Comm.</td>
<td>System 1</td>
<td>-                -</td>
</tr>
<tr>
<td></td>
<td>System 2</td>
<td>x                x x</td>
</tr>
<tr>
<td></td>
<td>System 3</td>
<td>x                x x</td>
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<tr>
<td></td>
<td>System 4</td>
<td>-                -</td>
</tr>
<tr>
<td></td>
<td>System 5</td>
<td>-                -</td>
</tr>
<tr>
<td></td>
<td>System 6</td>
<td>x                x x</td>
</tr>
</tbody>
</table>

Trade SoS Performance for Conservatism in Communications

Portfolios of systems at prescribed conservatism
Current Ext. Portfolio Approach

Current efforts in extending portfolio approach:

- Work has so far utilized generated utilities/defined metrics in objective
- Employ approximate strategies in portfolio management based on:
  - Sampling via ABM simulation of operations
  - Value Function Approximations
- Use simulation data to generate piece-wise linear representation of metrics (computationally tractable)
- Adopt financial portfolio approaches (e.g. Conditional Value at Risk) to mitigate very complex risks.

Stand-In Redundancy

Quantitatively assessing impact of compensating for a loss of performance in one or more constituent systems through re-tasking of remaining systems.

- Traditional reliability analysis tools not suitable for SoSs:
  - Heterogeneity, geographical distribution, interdependencies
  - Backup systems are costly and impractical
- Using stand-in redundancy, systems can:
  - Contribute to SoS-level capabilities in ideal case, and
  - “Stand-in” for failed functions during disruptions
Outreach Engagements

Currently working with following collaborators on AWB development:

- **Naval Surface Warfare Center Dahlgren Division (NSWCDD):** Memorandum of Understanding (MOU) signed for collaborative work on development of AWB tools towards in analyzing interstitial spaces of SoSE engineering environments. Progressed to CRADA agreement.

- **USAF Space Command (El Segundo, CA):** Initial exchanges and exposure on potential use of AWB methods towards representative case studies in SoS architectural analysis and decision-making.

- **MSCI & (Army Research Labs) ARL:** Initial exchanges towards how AWB can be used towards supporting Army Always-On initiatives for 2014-2015 period.

General collaborations also involve a demonstration version of Analytic Workbench to solicit core feedback in developing MPTs for AWB.

Recent Dissemination Activities

- 3 journal article submissions and numerous conference papers/presentations:
  - Conference on System Engineering Research (CSER) 2014:
    - 7 abstract submitted / 7 abstract accepted
    - An Analytic Workbench Perspective to Assessing Impact of Disruptions in System of Systems Architectures
    - An Analytic Portfolio Approach to System of System Evolutions
    - Managing System of Systems Architecture Evolution using Approximate Dynamic Programming
    - Exploiting stand-in redundancy to improve resilience in a system-of-systems
    - Bandwidth Allocation in Tactical Data Networks
  - AIAA Space Conference 2013
  - IAF International Astronautical Congress (IAC) 2013

- **Webinars/Workshops**
  - SoSCIE Webinar (10th October 2013) - A Portfolio Approach to System-of-Systems Acquisition and Architecture
  - SEI hosted workshop on SoS, Washington DC
  - EU-US Collaborative Strategic Research Agenda in Systems of Systems
  - ERS (Engineering Resilient Systems) Workshop Washington D.C.
  - INCOSE SoS Webinar Series
**RT-108 Near and Far Term Plans**

- Mature AWB through collaborative exchange with MSCI, NSWCDD, USAF Space Command towards deploying demo tool set

- Planned deployment for broader DoD-SE community using HubZero technology → tighter integration with data input definitions (e.g. DoDAF)

- Development of visual analytics driven interface for toolset (tradespace visualization)

- Incorporating group decision-making considerations into AWB toolset → how do I cooperate with other entities using tools?

---

**Back up slides**

---

SSRR 2014
February 25, 2014
• Development time (DT) of a node is computed according to its SE

• Completion time is the maximum between one term not accounting for the dependency and one term evaluated through the SOD.

\[
DT_j = \text{MINIT}_j + (100 - \text{SE}_j) \times (\text{MAXIT}_j - \text{MINIT}_j) / 100
\]

\[
CT_j = \max(\text{BT}_j + DT_j, CT_i + \text{SOD}_{ij} DT_j)
\]

• CT: Completion Time
• MINIT, MAXIT: Minimum and Maximum Development Time
• BT: Beginning Time
• SE: Self-Effectiveness
• SOD, COD: Strength, Criticality of Dependency
• B: Minimum Completion Time
• D: Completion time Corresponding to COD

Overview – Approach Supporting A

SoS

Stakeholder A
  System a1
  System a2

Stakeholder B
  System b1
  System b2

Stakeholder C
  System c1
  System c2

SE Engineer

Decisions of Stakeholder A
- Affect exogenous information
- Affect Stakeholder B’s future approximation
• Low level decisions are required for two reasons:
  — Satisfy short time requirements
  — Provide more accurate feedback and new information to high level decision makers to facilitate learning

Illustrative Example – Surface Warfare Module

Notional Surface Warfare Problem

Objective: maximize the total SoS capability over time
SoS Capability Index: percentage of systems surviving after attack

Strategic Level:
Time Scale: annually (or longer)
Decision Variables: whether to develop new systems (LCS, UAV, MH-60R) to support future littoral surface warfare

Operational Level:
Time Scale: seasonally (or shorter)
Decision Variables: whether to put systems (LCS, UAV, MH-60R) in service or out of service

Surface Warfare (SUW) in Littoral Combat Ship Naval Warfare SoS
**Objective:** maximize the expected sum of SoS capability at operational level after being attacked during each stage, with the constraints of budget on the investment of new systems at the beginning of each year

**Decision Variables:**
- $x_t$: develop systems at the beginning of each year; $y_{ts}$: put available systems in service

**State Variables:**
- $R_{sa}^{ts} = \text{number of systems of type } a \text{ at season } s \text{ of year } t$
- $R_{sa}^{new} = \text{new systems available}$
- $R_{sa}^{in} = \text{put in service}$

**Attribute of ‘state’:**
- 
  $a = \begin{cases} 
  \text{system type (LCS, UAV, MH-60R)} \\
  \text{availability (0,1)} \\
  \text{in use (0,1)} 
  \end{cases}$

**Transition Function:**
- $R_{sa}^{new} = R_{sa}^{new} + x_{ts}$
- $R_{sa}^{in} = R_{sa}^{new} + y_{ts}$

**Exogenous Information (uncertainty):**
- Probability of threats occurring $\psi' = [0.6, 0.6, 0.6]$
- Probability of success attack $\psi'' = [0.3, 0.5, 0.5]$

**Model Formulation**

**Objective:** maximize the expected sum of SoS capability at operational level after being attacked during each stage, with the constraints of budget on the investment of new systems at the beginning of each year

$$obj \max E \sum_{t=1}^{3} \sum_{s=1}^{4} c^s (R_{sa}^{in} + y_{ts}) (1 - \hat{w}_{ts})$$

subject to:
- $c' x_t \leq B_t \quad (t = 1..3) \quad \text{and} \quad y_{ts} \leq R_{sa}^{in} \quad (t = 1..3, \quad s = 1..4)$

=> Can be solved by recursively computing the optimal value function:

$$V(S) = \text{current contribution} + \text{future value}$$

What is the approximation of future value?
- Currently assume it is a linear function of number of resources (LCS, UAV, MH-60R)
- Need estimation of future characteristics (including resources, effect of other stakeholders, etc)

How to update the approximation?
- Learning from new coming information

Agent base Model will be incorporated to generate new information
Introduction (1): Context at Purdue

  - Community of faculty from several schools (e.g., AAE, IE, ME, Civil,...)
  - NOT a new department, but authorized for special faculty hires in SoS (I was first, in 2004)
  - Multi-faceted domains: Transportation, Healthcare Delivery, Logistics, Defense, etc.
  - Recent Col Strategic Plan created Purdue Systems Institute, with SoS focus

  - Research and curriculum for Aerospace-oriented SoS
  - My home department
  - Distance Education MS degree available

- Center for Integrated Systems in Aerospace, CISA (2011)
  - Established in 2012 and dedicated to advancement of theories/methods and application domains
  - Spans 3 Colleges, including Cyber center (CISPA) and Predictive Reliability (PCRI) at Purdue
  - Directed by yours truly (but is an Acknowledgement SoS, at most!)
  - NASA, FAA, Industry, and DoD-funded work in Aerospace-oriented systems and SoS

Systems Engineering education spans all of these organizations

e.g., Industrial Eng. & AAE led effort to establish SE and SoS graduate concentration

Overview

- Introduction and Context Setting
- Towards an Analytic Workbench for SoS Modeling
  - What is it?
  - Why is it needed?
  - What are some initial tools for it? Example applications.
- Outreach & Future
  - Current outreach efforts with DoD community
  - Future vision of Analytic Workbench development
Flexible and Intelligent Learning Architectures for SoS (FILA-SoS)
SoS Analysis part 2

By
Cihan H. Dagli

5th Annual SERC Sponsor Research Review
February 25, 2014
Georgetown University
Hotel and Conference Center
Washington, DC

www.sercuarc.org

Outline of the Presentation

• Motivations and background
  • Model overview-FILA-SoS
  • Capabilities of the Model-FILA-SoS
  • Domain Specific Inputs to the Model-FILA-SoS
  • Architecture assessment model (domain specific)
  • Meta architecture generation models
  • Acknowledged system of systems negotiation model
  • Individual system behavior models
  • Integrated system model implementation
  • Current results
  • Research focus for 2014
Motivations of the Research

- Current lack of understanding of system participation choice on the overall SoS capability.
- Simulation and Modeling techniques for Acknowledged SoS are still in their infancy.

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FILA-SoS Model overview

- The SoS achieves the required capability goal by combining existing system capabilities and adding new capabilities.
- The integrated system model is comprised of three main elements: SoS acquisition environment, SoS behavior, and Individual system behavior.
- Meta architecture generation models.
  - Multi-Level optimization model
  - Fuzzy-Genetic optimization model
- Architecture assessment models (domain specific).
- Acknowledged system of systems negotiation model.
- Individual system behavior models (selfish, opportunistic markov chain, and semi-cooperative fuzzy negotiation models).

FILA-SoS Model Overview - 2

Like collaborative SoS, modifications in systems to meet SoS needs are based on agreement and collaboration, not top down authority from the SoS.

Just like directed SoS has objectives, management and funding without authority over the constituent systems.
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Capabilities of the FILA-SoS

• The FILA-SoS follows the Wave model of analysis and update.

• Extensive multi-level SoS meta architecture generation covers the entire design space.

• Extensible architecture assessment allows multiple key performance parameters to be evaluated using user defined assessment models.
Capabilities of the FILA-SoS

- The meta architecture generated is negotiated for possible implementation by the acknowledged SoS manager through game theory based incentive contracting negotiation model.
- Individual systems providing required capabilities can use three kinds of negotiation models based on their negotiation strategies (Selfish Linear Optimization model, Semi-cooperative fuzzy negotiation model, and Opportunistic Markov chain model).
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Domain Specific Inputs to FILA-SoS

- Key performance attributes and relative weights and operational scenarios.
- Desired SoS capability \( C \), available resources.
- Required capabilities \( c_1 \ldots c_n \).
- Desired SoS architecture performance.
- Candidate systems that can provide capability \( c_i \).
- Performance, deadline, and cost of integration for each system that can provide required capability \( c_i \).
### Domain Specific Inputs to FILA-SoS
(an illustration)

EO/IR, SAR

Exploitation center

EO/IR, BLOS

Exploitation center, Command & Control, BLOS

EO/IR, BLOS

EO/IR

Exploitation center

EO/IR

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Fuzzy Assessor Overview

• The Fuzzy Assessor is used to evaluate the fitness of an architecture chromosome

• Fitness will be judged by a combination of the attributes of an architecture, such as
  — Affordability, Performance, Robustness, Flexibility, Scalability...
  — Others, as developed through guided discussions with Stakeholders and Subject Matter Experts (SMEs)

• The attributes will be domain adjusted and selectable, using guidance from SMEs

• Fuzzy membership functions $\Phi_k$ (derived from stakeholder views) describe the degrees of goodness in each attribute area

• Fuzzy rules $\rho_k$ (also derived from stakeholder views) combine attributes into an overall fitness grade

Fuzzy Assessment for Multi-Attribute SoS Architectures

Attribute Value Membership Functions

Attribute evaluations themselves are well suited to fuzzy logic approaches because of the difficult nature of boundaries between subjective evaluation ranges. A particular SoS architecture (chromosome) may fall partially into an Acceptable, and partly into a Marginal set.
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Representation of SoS Meta-Architecture

<table>
<thead>
<tr>
<th>Systems</th>
<th>Interfaces</th>
</tr>
</thead>
<tbody>
<tr>
<td>$X_1$</td>
<td>$X_1$ with $m$</td>
</tr>
<tr>
<td>$X_2$</td>
<td>$X_2$ with $j$</td>
</tr>
<tr>
<td>$X_3$</td>
<td>$X_3$ with $i$</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>$X_m$</td>
<td>$X_m$ with $(m-1)$</td>
</tr>
</tbody>
</table>

Chromosome in linear array form. The meta-architecture allows any combinations of ones and zeroes

Upper Triangular form of the chromosome, systems along the diagonal.

Fuzzy-Genetic Optimization Model

- Genetic Algorithm is used to generate candidates for SoS meta-architecture.
- Genetic algorithms work in an iterative process through many generations.
- A new set of genes is a result of random parent selection, cross over and mutation.
- As a result, the new combinations are efficiently explored based on available knowledge to find a new generation with better fitness.
Fuzzy-Genetic Optimization Model

Math Model
Genetic Algorithm
MATLAB

Population of Chromosomes
SoS.M₁
SoS.B₁ (Fitness from Fuzzy Assessor)

SoS.A₀ = \max(\text{Fitness. SoS.C}_{m,n})

Highest Fitness Chromosome = Initial SoS Architecture

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Final GA selection; Fitness = 3.7389

Systems are on diagonal, interfaces at i-j intersections
Yellow/green – feasible/used; Blue – feasible/unused
Red – infeasible/used; Brown – infeasible/unused

Initial population best chromosome
Fitness = 3.571 (worst was 1.28)
Searching for SoS Meta-Architecture

The SoS meta-architecture includes:
1. The systems selected.
2. The selected interfaces within the systems.
3. The capabilities possessed by the systems

Problem Formulation
- The Acknowledged SoS manager is the leader of the Stackelberg game
  - Decides capabilities required from and funds allocated to each individual system.
- The systems are the followers
  - Announce deadline and performance level.
  - An individual decision maker with no information about the SoS and other systems.
- Bi-level model of the Stackelberg game between the SoS manager and the systems.
Multi-level Optimization Model

- **System contracting** stage: given the requested capabilities from the systems, a heuristic method to build individual system contracts is constructed.

- **Capability assignment** stage: genetic algorithm is structured for determining a set of capabilities for the solutions.

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SoS Negotiation Model

- Negotiation protocol:
  - Individual systems either accept or send a counter-offer to the SoS manager which may include changes in performance, funding or deadline
  - If there is a counter-offer from the individual systems, the SoS manager starts negotiation with the individual systems
    - Objective is to find the optimal strategy for the SoS manager

- Game theory based Incentive contracting:
  - SoS Manager problem
    - Provide a contract and convince the individual systems to join the SoS architecture
    - Motivate individual systems to do their tasks well
  - Individual system success (outcomes)
    - Depends on the time and work intensity which is referred to as effort level

Game Theory Based Negotiation

- SoS Manager’s objective:
  - Give lower rewards and obtain larger outcomes

- Individual systems’ objective:
  - Do as little as possible (min effort) and gain the highest rewards

- Multi-constraint problem for the SoS manager:
  - Choose a reward mechanism to maximize SoS manager’s expected utility subject to two constraints:
    - Individual rationality
      - Reward for the individual system must be large enough to motivate the individual system to prefer the contract rather than reject it
      - Thus expected utility of the individual system should be at least as much as its reservation price
    - Participation constraint
      - Provide the individual system with the motivation it needs to choose the effort level that the SoS manager prefers, given the contract it is offered.
Model Elements of Negotiation

• Finding the optimal strategy for the SoS manager:
  — Contracts under certainty:
    o SoS manager can observe individual system’s actions and there is no uncertainty about the individual system’s actions
    o Outcome is a function of the individual system’s effort
    o The contract should at least provide the individual system a reward where its utility will equal its reservation price.

• SoS Manager utility function

• Individual systems’ utility function:

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    • Semi-cooperative fuzzy negotiation
    • Selfish Linear Optimization
    • Opportunistic Markov chain
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• This model of semi-cooperative behavior is based on an agent’s preferences and the negotiation length.

• Each systems agent has two inherent behaviors of cooperativeness which in is referred to as *Purposive* behavior and behavior driven by unforeseen circumstances which is referred to as *Contingent*.

• Models the tradeoff between the two behaviors for the systems.

• A fuzzy weighted average approach is used to arrive at the final proposal value.

• To design the negotiation strategy of SoS manager and the systems we chose two families of functions namely: exponential and polynomial.
The necessary condition for an individual system to collaborate with the SoS is to obtain nonnegative incremental profit (hence, termed selfish).

Formulated as resource allocation problem.

The SoS provides the following along with the request for participation to individual systems:

- Requested capabilities, $C_t$
- Requested interfaces between the system $k$ and other individual system $j$ on capability $i$, $X_{ij}$
- Deadline of delivery, $SoS.d$
- Funding for providing the requested capabilities, $SoS.f$
- The performance requirement on each of requested capabilities, $SoS.p$

The outputs sent from the individual system to the SoS include:

- Provided capabilities, $C_i$
- Provided interfaces between the system $k$ and other individual system $j$ on capability $i$, $X_{ij}$
- Delivery time deviation (additional time needed), $SoS..d$
- Funding deviation (additional fund needed), $SoS..d$
- Performance deviation (under performance is any), $SoS..d$

Two linear programming (LP) models are built for two scenarios of negotiations

1. the SoS is informed possible performance deviation (if any) at the provided funding and time.
   
   The objective of is to minimize the weighted sum of under performances.
   
   Helps identify the best performance of system $k$ on the requested capabilities and interfaces with the given funding and deadlines.

2. the SoS may be provided the capabilities and interfaces as it desires, yet it may be asked to provide additional funding and/or time.
   
   The objective of is to minimize the total costs, including the additional fund used and the virtual penalty on additional time used.
   
   Helps determine the minimum additional funding and/or minimum additional time to meet the goal of forming all the capabilities and interfaces that system $k$ is capable of providing.
Opportunistic Markov Chain Model

- Opportunistic model allows the system to behave selfishly as well as unselfishly (or selflessly) by tweaking a certain tunable parameters.

- A project management model based on Markov chains is used for estimating the outputs.

- The work assigned by the SoS to the system is assumed to be a “project” that takes a random amount of time and a random amount of resources (funding) to complete.

- The internal phases of this project is modeled as a Markov chain:
  - Used to estimate the expected (mean/average) amount of time and funds needed by the system.
  - The internal phases are: “initial,” “intermediate,” and “completion.” are modeled as states in an absorbing Markov chain in which the absorbing state is completion.

- The willingness to cooperate is based on how quickly the system will be able to complete the task at hand and its own workload.

$\eta$: selfishness parameter in the interval [0,1] that SoS can adjust to obtain a spectrum of participating systems ranging from very unselfish to very selfish; 0 being very selfish and 1 being very unselfish (selfless)

$f$ and $m$: additional system behavior parameters, each taking values in the interval [1,2], which the SoS can change to obtain a whole spectrum of participating systems ranging from very fast to very sluggish; 1 being very fast and 2 being very sluggish.

We will need some additional notation required in the internal calculations of the model that we will define later. The Markov chain of the internal system dynamics will be defined by the following transition probability matrix:

$$
\begin{pmatrix}
  k & 1-k & 0 \\
  m & 1-m & 0 \\
  0 & k & 1-k \\
  0 & 0 & 1
\end{pmatrix}
$$

where state 1 is the initial phase, state 2 the intermediate phase, and state 3 the completion phases. In the above, $k$ will denote the number of systems with which system $f$ will interact.
Outline of the Presentation

- Motivations and background
- Model overview - FILA-SoS
- Capabilities of the Model - FILA-SoS
- Domain Specific Inputs to the Model - FILA-SoS
- Architecture assessment models (domain specific)
- Meta architecture generation models
- Acknowledged system of systems negotiation model
- Individual system behavior models
  - Semi-cooperative fuzzy negotiation
  - Selfish Linear Optimization
  - Opportunistic Markov chain
- **Integrated system model implementation**
- Current results
- Research focus for 2014

Demonstration of the Model
**ISR Domain Model Detail**

The ISR Domain Model contains the following types of Systems:

- Fighter aircraft with ElectroOptic/Infrared (EO/IR) pods,
- Fighters with Synthetic Aperture Radar (SAR),
- U-2 aircraft and Satellites with EO/IR,
- DSP missile launch detection satellites,
- JSTARS aircraft with SAR, 6) Remotely Piloted Aircraft (RPA),
- Line of sight (LOS), that is, tactical; and Beyond Line of Sight (BLOS) data links,
- Exploitation centers in theater as well as in Continental United States (CONUS) for analyzing ISR data, and
- Control stations for the RPAs.

The five types of capabilities (SOS.C) provided by Systems are listed below:

- EO/IR
- SAR
- Communications links
- Exploitation Centers
- Control Centers

**Implemented ISR Model**

- **System Selected and their Capabilities in an Meta-Architecture**

<table>
<thead>
<tr>
<th>Systems Selected for Negotiation (11)</th>
<th>Capabilities Possessed</th>
</tr>
</thead>
<tbody>
<tr>
<td>System 1,2,7</td>
<td>(1 and 5)</td>
</tr>
<tr>
<td>System 8</td>
<td>(1) only</td>
</tr>
<tr>
<td>System 11,12, 13</td>
<td>(2 and 5)</td>
</tr>
<tr>
<td>System 14</td>
<td>(3 and 5)</td>
</tr>
<tr>
<td>System 18</td>
<td>(4 and 5)</td>
</tr>
<tr>
<td>System 21, 22</td>
<td>(5) only</td>
</tr>
</tbody>
</table>

- **SoS Architecture and KPP’s Quality**

<table>
<thead>
<tr>
<th>Quality</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall Architecture</td>
<td>3.64</td>
</tr>
<tr>
<td>Performance</td>
<td>2.59</td>
</tr>
<tr>
<td>Affordability</td>
<td>3.57</td>
</tr>
<tr>
<td>Flexibility</td>
<td>3</td>
</tr>
<tr>
<td>Robustness</td>
<td>3.75</td>
</tr>
</tbody>
</table>
SAR Domain Model Detail

The SAR Domain Model contains the following types of Systems:

- Cutter
- helicopter
- Aircraft
- UAV
- Fish Vessel
- Civilian Ship
- Control stations for the RPAs.
- Communication systems

The capabilities provided by Systems are listed below:

- IR – range 3 nm
- Night Vision – range 3 nm
- Visual – range 3 nm
- Maritime Radar – range 30 nm
- RF Direction Finding – range 70 nm
- Deliver Medical Aid (Deliver Paramedic too specific)
- Remove survivor(s) to Emergency Medical Care
- Speed 300 mph
- Speed 15 mph
- Communications

Adaptive Learning Strategies

![Graphs showing convergence of global and local strategies over the number of regulation rounds.](image)

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Outline of the Presentation

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  - Selfish Linear Optimization
  - Opportunistic Markov chain
- Integrated system model implementation
  - Current results
  - Research focus for 2014
Capability Inputs and System Deadlines, Funding & Performance Outputs of the Opportunistic Model

Outline of the Presentation

- Motivations and background
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  - Semi-cooperative fuzzy negotiation
  - Selfish Linear Optimization
  - Opportunistic Markov chain
- Integrated system model implementation
- Current results
  - Research focus for 2014
Research focus for 2014

- **Research Track I:** Further development and refinement of integrated model FILA-SoS and demonstrate the performance and capability of the model at one customer organization selected by DASD/SE.

- **Research Track II:** Conduct research for finding possible answers to the following questions for the purpose of building mathematical models that can be integrated to next version of FILA-SoS in 2015.

- What is the impact of different constituent system perspectives regarding participating in the SoS on the overall mission effectiveness of the SoS?

- How do differing levels of cooperativeness in participating in the SoS impact the ability and timeliness of a group to agree on a SoS or system architecture? Or impact the ability to effectively use the architecture already in place?

- How should decision-makers incentivize systems to participate in SoS, and better understand the impact of these incentives during SoS development and effectiveness?
Acknowledgement
This material is based upon work supported, in whole or in part, by the U.S. Department of Defense through the Systems Engineering Research Center (SERC) under Contract H98230-08-D-0171. SERC is a federally funded University Affiliated Research Center managed by Stevens Institute of Technology.

Project Team

- **Principal Investigator:** Dr. Cihan Dagli, Missouri S&T
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- Dr. John Colombi, Assistant Professor, Air Force Institute of Technology
- Dr. Kristin Giammarco, Associate Professor, Naval Postgraduate School
- Dr. David Enke, Professor, Missouri S&T
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- Dr. Ruwen Qin, Assistant Professor, Missouri S&T
- Dr. Dincer Konur, Assistant Professor, Missouri S&T
- Khaled Haris, Louis Pape, Siddhartha Agarwal, System Engineering PhD Students, Missouri S&T

Publications

Accepted: 2014 Conference on Systems Engineering Research - Systems Architecting and Tradespace Analysis

Published
**Concept**

**Traditional Risk Management**
- Tornado watch: “A tornado has been sighted in your area”
- Arterial plaques mean there is risk of clotting or rupture causing blockage and heart damage

**Risk Leading Indicators, Risk Scores & Risk Exposure**
- Tornado warning: “Conditions are right for the formation of tornados”
- High triglyceride levels, limited exercise and smoking level indicate potential risk of heart disease: *practical warning thresholds and guidelines for proactive behavior*; no definitive chain of cause-and-effect; predicting risk of heart attack in 5 years remains controversial
- Credit scores combine diverse factors into *useful metrics* to identify “high risk” people for loan default, auto insurance, etc.

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**Need and Opportunity**

- Extend and complement traditional risk management
- Quantitative and Objective
  - Leading indicators from standard acquisition artifacts
  - Evidence-based norms and benchmarks based
- Early warning
  - Conditions favoring future problems and amplifying adverse consequences
  - Detect conditions in time for pro-active actions
- Inform decision making of the risk-exposure of alternative choices
- Relate risk conditions to sources and causes for mitigation
- Leading indicators & scoring depend on phase & type of program
### End-User Collaboration and Proof-of-Concept Piloting

<table>
<thead>
<tr>
<th>• Active</th>
<th>• TARDEC Co-Developer</th>
</tr>
</thead>
<tbody>
<tr>
<td>• US Army TARDEC</td>
<td>• Verify Practicality and Relevance</td>
</tr>
<tr>
<td>• Armored Multi-Purpose Vehicle (AMPV) Program Office</td>
<td>• Access reference program artifact repositories</td>
</tr>
<tr>
<td>• OUSD ATL SE, Major Program Support</td>
<td>• Integrate with and Transition to Systems Engineering Framework</td>
</tr>
<tr>
<td></td>
<td>• Pilot the MPT with AMPV PMO</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>• Pending</th>
<th>• AMPV PMO Pilot</th>
</tr>
</thead>
<tbody>
<tr>
<td>• US Army ERDC</td>
<td>• Integrate With Traditional Risk Management</td>
</tr>
<tr>
<td>• NAVAIR</td>
<td>• Assess Practicality and Value to AMPV Program Risk Management</td>
</tr>
</tbody>
</table>

### Armored Multi-Purpose Vehicle (AMPV)

<table>
<thead>
<tr>
<th>• AMPV Program</th>
</tr>
</thead>
<tbody>
<tr>
<td>— Non-Developmental Vehicle replacement for the M113, 5 variants, interoperable with M1 and M2, multiple functional modules</td>
</tr>
<tr>
<td>— No formal Tech Dev competitive prototyping - requirements, costs, &amp; schedule refined by iterations of draft RFPs &amp; analysis</td>
</tr>
<tr>
<td>— Single source EMD award envisioned</td>
</tr>
<tr>
<td>— RFP issued Nov 2013, proposals due March 2014, decision May 2014</td>
</tr>
<tr>
<td>— $1.8M per vehicle and $90/mile (raised from initial targets)</td>
</tr>
<tr>
<td>— 5 year EMD $388M 29 prototypes, $1.08B 289 LRIP, $5B for 2,897 units</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>• Pilot Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>— Agreement with AMPV PMO in Dec 2013</td>
</tr>
<tr>
<td>— Analyzing risk exposure as of RFP release, annex to Technical Risk Assessment</td>
</tr>
<tr>
<td>— Additional risk exposure assessment pending source selection</td>
</tr>
</tbody>
</table>
Root Causes & Indicators

Root Cause Risk Breakdown Structure

Risk Scoring By System Type & Acquisition Stage

Artifacts
- Requirements
- Architecture
- Program Plan
- Program Organization
- Execution Past Performance

Work Content
- Turbulence
- Size & Density
- Ambiguity
- Novelty
- Margin

Plans & Estimates
- Assumptions
- Organization
- Scheduling
- Resourcing
- Margin

Execution & Management
- Staffing
- Stability
- Performance

Risk Leading Indicators & Risk Exposure Scoring

• Work Content
  - Size, complexity, stability, maturity (by WBS) of requirements, architecture, organization & execution plan
  - Number of “moving parts”, scope, interdependencies & novelty
  - “Safety margin” / “Margin for error”

• Plans & Planning
  - Requirements, architecture, product teams and IPTs, & tasks / IMS
  - Consistency, resolution, stability
  - “Safety margin” / “Margin for error”

• Estimating
  - Performance, schedule, and EMD, AUPC & O&S costs
  - Resources allocated to WBS work elements matched to work content
  - “Safety margin” & “Margin for error”

• Execution & Management
  - Stability of work content, plans & estimates
  - Outcomes vs estimates on this program
  - “Safety margin” / “Margin for error”
**Decision Breakdown Structure for Risk Informed Decision Making**

**Decision Choices Create the Exposure-to-Risk Environment**

- Material Solution Analysis
  - Concept, Functions and Capabilities
  - New Start, Non-Developmental Conversion or Block Upgrade
  - Number & Diversity of AOA Alternatives
  - Waived Technical Review Entrance and/or Exit Criteria
- Technology Development
  - CDD KPP, KSA & APA Parameters and Values
  - Prototyping Source Selection (Criteria, Weights and Scoring)
  - Extent of Testing, M&S, Analysis etc.
  - Waived Technical Review Entrance and/or Exit Criteria
- EMD
  - Strategy: Single Source or Multiple EMD Awards
  - Source Selection & Down-Selection (Criteria, Weights and Scoring)
  - P-Spec, time & cost targets
  - Component Technology Choices (TRL, MRL & IRL)
  - Extent of Testing (DT and OT)
  - Changes to P-Spec; Deferred or Waived Requirements
  - Waived Technical Review Criteria and/or supporting analyses & testing

**Method/Procedure/Tool Organization**

1. **Risk Leading Indicators**
   - Objective measures from program artifacts and updates

2. **Risk Profile & Score**
   - Score: “How many standard deviations from the norm?” or “Which quartile?”
   - Profile: Breakdown by WBS, source and type of risk

3. **Risk Exposure**
   - Profile similarity to programs with breaches vs programs without breaches
   - Probability of delay > X; Expected delay if delay > X

4. **Statistical aggregates of RLI for similar programs & acquisition stage**

5. **Risk Exposure**
   - Detect Outliers
   - Direct Mitigation
   - Inform need to act
Risk Leading Indicators

- RLI Areas
  - Requirements
  - Architecture & Technology
  - Planning & Scheduling
  - Organization & Staffing
  - Technical Management

- RLI Types
  - Density & Interdependence
  - Turbulence/Stability
  - Completeness & Consistency
  - Sensitivity & Margins
  - Ambiguity & Equivocation

- Performance margins
- Number of new or changed requirements since last review
- Numbers of variants, functions, configuration items & interfaces
- Proportion of configuration items without architecture diagrams
- Schedule margin by task
- Number and proportion of interfaces not covered by an IPT and an integration task
- TRL/IRL/MRL by config item
- Technical review element waivers
- Etc.

Risk Exposure Classification

How much does the risk profile resemble programs with breaches vs programs without breaches?

Initially we may not have many data points

Evidence is being accumulated as repository and acquisition visibility initiatives

All programs are different, but risk profile patterns should emerge

This kinds of “AI” cluster analysis and analytics are widely used commercially

Which factors matter and the sensitivity and specificity of classification remains to be determined and will change as more evidence is accumulated
Potential Reference Programs and Artifact Repositories

- **TARDEC**: Requirements documents
- **DCARC (DACIMS & EVM CR)**: IMS, CPR, WBS, Progress Curve Reports, etc.
- **AIR**: AoA, PDR & CDR reports & assessments, TRA, SEP (for IPT organization)
- **DAMIR**: APB, SAR and DAES reports
- **Individual PM Offices**: Architecture diagrams, FMECA, Acceptance scoring, Etc.

Risk Scoring norms:
- Cross stovepipes by program, then aggregate for sanitized statistical aggregates
- Statistical aggregates can be updated without storing individual component data

Plan & Schedule

- **Risk Leading Indicator, Scoring and Exposure tools**
  - Initial: May 2014
  - Final: Feb 2015
- **Pilot application reports**
  - Quarterly
- **Technical report on tools, transition and pilot application**
  - Feb 2015
**Concept, Needs & Opportunities**

### “Long-Lived” DoD Systems

**Adaptive Adversary Risks & Technology Opportunities for Long-Lived DoD Systems**

- Product lines / families / classes in the inventory for 30-60 years
- Individual items with upgrades have 15-60 year service lives

**Risks and Opportunities**

- Adversaries adapt to avoid our systems’ strengths and exploit their limitations by their choice of battlefields, tactics, and equipment
- US systems design to be adapted to counter adversary adaptations and exploit maturation of our emerging technologies
- Challenge: System requirements
  - To deter and defeat current threats
  - To enable cost-effective upgrade & adaptation

---

**Reserve Capacity & Adaptability Issues**

- Levels of reserve capacity to build into the system infrastructure to enable cost-effective upgrade options
- Tradeoffs between initial, integral capabilities and cost versus later upgrade/modification capabilities and costs
- Risks of adversary adaptation within our acquisition cycle to avoid our systems’ strengths and exploit their limitations
- Keeping open options for potential new technologies despite uncertain maturation, change costs, burdens, and performance

---

*Practical and relevant issues in the current DoD acquisition environment*
Marine Corps on Amphibious Combat Vehicle (ACV) Adaptability

“I don’t foresee a grand slam on the first pitch where we’re going to deliver a fixed capability for the life of the vehicle. We’ve got to be knowledgeable enough to recognize the environments change, threats change, new technology starts to come to pass, and we want to make sure this design will allow for that growth in the future. … I think we’re at a point in time where you really wanting deep thinking, good ideas that can help influence design, requirements, trade and cost at a stage in the program where it can make a difference.”

Dr. J. Burrow, Executive Director, Marine Corps Systems Command & Director, USMC ACV Team, Inside the Navy, March 25, 2013

- 30 to 50 year system service life
- 7 to 10 years from program initiation to IOC
- 15 to 20 year useful life for individual vehicles
- Continuous modernization
  - In-theater upgrade kits
  - RECAP at depot
- New production

Army 2012 Posture Statement On Equipment Modernization

“The Army aims to develop and field a versatile and affordable mix of equipment to enable Soldiers and units to succeed across a full range of missions today and tomorrow and to maintain our decisive advantage over any adversary we face. “Versatile” encompasses the characteristics of adaptable (to changing missions and environments); expansible (able to add, update or exchange capabilities in response to changed circumstances); and networked (to enable interoperability within our formations and with those of our partners). “Affordable” relates to making fiscally informed decisions that provide greatest capability value in accordance with senior leader priorities, within projected resources and within acceptable risk parameters.

Transformational equipping strategies from the turn of the century were envisioned to skip marginal technology improvements and orient on “game-changing”, “leap-ahead” technologies intended to revolutionize military operations. A more appropriate force development concept, Incremental Modernization, enables us to deliver new and improved capabilities to the force by leveraging mature technologies, shortening development times, planning growth potential and integrating increments of those capabilities that give us the greatest advantage in the future while hedging against uncertainty.”
Upgrade Kits –
Real Options to Extend Capabilities

• Platforms provide infrastructure for upgrade kits
• Kits for different functions, enhance capabilities, improve interoperability, and/or improve sustainability
  — Reliability growth – replace low reliability subsystems
  — O&S cost reduction – more efficient engine and/or transmission
  — Survivability enhancement – armor “B” kit, APS
  — Mission Function – Air Defense pod, RSTA pod, winch and excavator arm, etc.
  — Commonality (logistics footprint) – common components between systems
  — Interoperability – replace comms & software for compatibility

• “Kits” are also a design and manufacturing practice

HMMWV Kit Conversions

Bolt on armor required
upgraded suspension, engine, and steering

Additional armor and
cupola raise the CG
and increase rollovers

Mattracks or wheels

Suspension and steering
for CG shift

Upgrades:
• Increased cab space
  • Increased payload capacity
  • Strengthened frame

Upper deck space is always at a premium

Imbalance in cupola
required motorized drive

Base cab & flatbed with
mission modules

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Reserve Capacity Conceptual Framework

- Enhanced Set-Based Design with Real Options
  - Infrastructure reserve capacity keeps options open & costs down for future upgrades & enables future capability tailoring decisions
  - Initial design consideration: What is the region of capability space that can be reached with affordable upgrade options?
  - Goal: Near-optimal over a range of maturity, budget scenarios & adversary adaptation models

- Adversarial Risk Analysis
  - Intelligent adaptive adversaries favor battlefields, tactics and equipment where the capabilities needed are “inverse” to the capabilities we field

- Technology Maturation Risks and Opportunities
  - Robust solutions can exploit emerging technologies, but are effective even without them

---

Capability Upgrade Options and Costs

Each capability dimension scaled from zero to one from threshold to objective capability levels

- **Proven Options**
- **Possible Future Options**

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### Capability Shortfall & Adversarial Risk

#### Conditional Shortfall
- Average distance from points in the unachievable region to the closest point in the achievable region
- Adversary situations are independent of fielded capabilities

#### Adversarial Shortfall
- Conditional shortfall weighting based on the distance from the achievable region
- Adversaries seek situations in which the capabilities needed are farther from our capabilities
- Adversary “adapt to” models
  - Initial configuration only
  - Game sequence of upgrade “moves”

---

### Choosing a Robust and Versatile Initial Configuration

**Goal:**
An initial configuration with capability shortfall near optimum at cost, over a range of budget scenarios, whether or not technologies mature
Status And Plans

• Prototype tool under development
  — Extend for capability hierarchies and response times
  — Adversarial model sensitivity
    o Number of moves
    o Distance function

• Discussions with potential end-users and collaborators in progress
  — NAVSEA Rapid Ship Design Environment & Engineered Resilient Systems projects
    o Ship and Marine Corps Amphibious Combat Vehicle potential applications
  — TARDEC
    o Ground Combat Vehicle may be reorganized as a Technology Demonstrator
    o Program goals remain to develop a adaptable & extensible platform

High-Fidelity Modeling and Simulation

Risks & Risk Reduction in Model-Based Acquisition & Virtual Development

Opportunities
• Rapid assessment of more alternatives
• Learn more from limited prototyping
• Avoid cost-prohibitive destructive testing

Needs
• Methods to limit the risks of M&S limitations
  • On system performance and cost
  • On development program time, cost and
Partners & Interests

• NAVAIR (sponsoring RT48 “Transforming Acquisition with MBSE”)
  — MSA phase to generate and screen move and diverse options
  — Tech Dev phase to ensure feasibility of requirements & preview risks
  — EMD phase for virtual integration, transitioning to prototype system

• NAVSEA Rapid Ship Design Environment & CREATE-Ships
  — Uncertainty propagation in high-fidelity physics based modeling of complex systems subject to high-energy events
  — Mine blast tests on ship are a cost-prohibitive development strategy
  — Complicated multi-functional systems with many failure & degraded modes
  — Highly non-linear, multi-stage, multi-scale, multi-physics events
  — Making the best use of limited and sub-scale testing
  — Limitations interpreting M&S results

• TARDEC Survivability interests similar to NAVSEA

Modeling & Simulation Concerns

• Calibration and validation strategies for highly non-linear events and limited test & observation opportunities
• Models used out of context, outside validation & calibration
• Limitations, assumptions, and phenomena omitted, not often not well articulated
• Deterministic chaos phenomena where small change in boundary conditions (inputs) produces rapid divergence in outputs
• Sensitivity to complex and often unknown boundary conditions
• Gaps in understanding multi-scale, multi-physics phenomena
• Human behavior, knowledge, cognition – flight safety, damage control
• Level of M&S different form level of analysis and decision
• Incompatible scope, resolution, terminology with test procedures
Approach Components

- Multi-scale experimental design to calibrate and validate M&S for complex systems and highly non-linear events
- Knowledge integration framework for limited field observation and limited test data with M&S outputs across multiple scales, physics, measurement uncertainty and test control
  - Hybrid system with virtual prototypes, subscale testing, etc
  - M&S sensitivity analysis test and observation data points
  - Boundary condition uncertainty scattering/resampling around test and observation data to reduce biasing
  - Estimate expected reduction in overall uncertainty value of additional testing
  - Expert judgment, informed by observation and test, designs tests and models, and is another component of the hybrid mix

Mine Blast Modeling and Analysis Issues

- Difficult to instrument
- Complex phenomena
  - Initial blast
  - Bubble collapse and water jet effects
  - Reflected waves
- Complex effects
  - Shock wave structural effects, damage to pipes and electronics
  - Compartment penetration, gas overpressure & fireball, flooding
  - Secondary projectiles, fire, ammunition deflagration
  - Damage to battle damage control systems – pumps, fire suppression, evacuation routes
Quantitative Risk (QR) Portfolio

- **DoD Acquisition Risk Leading Indicators** – Informing Decisions, Warning (“conditions are right for”) complementing traditional RM “watch” (for a specific thing)

- Engineering Resilience for Long-Lived Systems using **Adversarial Risk** and **Real Options** Possibility Analyses – Sizing the Infrastructure for Cost-Effective Extension and Adaptation

- **Risk in Model-Based Acquisition** and Model-Based Systems Engineering Transformation – Risks in MBA & MBSE, Modeling Risk for MBA and MBSE

- Error and Uncertainty Propagation in **High-Fidelity Physics-Based Models** of “High-Energy” Events for Complex Systems
Systemic Security

Presented By
Rick A. Jones
University of Virginia
5th Annual SERC Sponsor Research Review
February 25, 2014
Georgetown University
Hotel and Conference Center
Washington, DC

www.sercuarc.org

System Engineering for a New System

- Integrate Policy, Technology and Process (including human factors) to satisfy
- Objectives of diverse system stakeholders
- Subject to constraints (e.g., Cost, Schedule)
Cyber Security of Combat Systems

- Cyber security community has not addressed the cyber security of missions as opposed to the systems that together carry out a mission
- Cyber security community has focused on network and perimeter security, and has not addressed the protection of mission functions which reside within combat systems:
  - Weapon Systems
  - Sensor Systems
  - C2 Systems

SERC Cyber Program

- Addresses Policy, Process and Technology
  - Policy: Solution selection methodology that focuses on the cyber security of the combined set of systems that conduct a mission
  - Technology: Development of a technology architecture and specific solutions that protect critical functions within individual combat systems
  - Process: Human in the loop, simulation-based exploration and evaluation of candidate operational procedures for response to attack detections (be they false alarms or true detections)
- Integrating these diverse efforts through use of a UAV-based surveillance mission as the test case for prototypes in each area
- Working with SERC and the DOD SERC sponsor, we are gaining tangible outside support ($, simulation vehicle, UAV, hardware and software) to the SERC program from stakeholders interested in transitions of developed technology and system concepts

Broad Objective

Reversing cyber security asymmetry from favoring our adversaries (small investment in straight forward cyber exploits upsetting major system capabilities), to favoring the US (small investments for protecting the most critical system functions using System Aware cyber security solutions that require very complex and high cost exploits to defeat)
Broad Objective

Reversing cyber security asymmetry from favoring our adversaries (small investment in straightforward cyber exploits upsetting major system capabilities), to favoring the US (small investments for protecting the most critical system functions using System Aware cyber security solutions that require very complex and high cost exploits to defeat)

Focus on Defense Against Exploits that Impact System Performance (e.g., Data Corruption, Functional Degradation, System Latencies)

Selection Methodology

• Blue/Red/Green team analysis for individual combat systems to identify:
  — Most Critical Individual System Functions (Blue)
  — Identification of specific asymmetric attacks on these functions (Red)
  — Identification of technical solutions to counter asymmetric attacks
  — Assessment of costs and security benefits to select the most desirable integrated solution sets

• At the mission level, using individual system level inputs, the service Cyber Commands could integrate the individual system analyses on a mission security basis

• Utilize analytical tools to support decision-making
Status

• Refining decision-support techniques and tools based on our internal project first use of the methodology and prototype tools

• Preparing for an October Workshop with interested military planners
  — Recently had discussions with Navy 10th Fleet
  — With Mitre support, preparing for discussions with AF Cyber Command
  — Considering invitation to a representative(s) of the National Defense University

Technology: System Aware Cyber Security
High Level Architectural Overview

System to be Protected

Internal Controls

Sentinel Providing System-Aware Security

Sentinel Data Flow

System to be Protected

System Control Information

Sensors

Mass Storage

Data Conditioning

Data Integration

Decision Making

Data Analysis

Actions
- Forward Data
- Isolate Threat
- Restore System

Systems Communication Channels

Security Comm. Channel

SSRR 2014 February 25, 2014 11
Super Secure Sentinel

• Architecture is based upon development of Sentinels that can be more trusted than the systems that they monitor

• Characteristics of monitoring applications support potential for Super Secure Sentinel implementations

  Very small monitoring apps (< 500 SLOC)
  No requirement for high performance or tight synchronization
  No complex intertwining of applications
  Manageable number of hardware components
  Diverse low cost hardware is available, supporting diverse OS’s, diverse programming languages, diverse communications protocols, etc.

Technology Prototype: Autonomous Surveillance System On Board a UAV
GAUSS– GTRI AIRBORNE UNMANNED SENSOR SYSTEM

FOUR SENSOR OBJECTIVE BASELINE

- Multi-Channel Radar (8 channels)
  
  ESA Antenna: 8 phase centers, each 4 x 4 elements
  
  X-band, 600 MHz BW (design; 1 GHz max)
  
  Arbitrary Waveform Capable (1st design LFM)
  
  Acquisition Modes: DMTI, SAR, HRR, HRRD, CCD

- Multi-Channel SIGINT
  
  Two orthogonal dipole pairs: TDOA geo-location
  
  Ambient Complex-Baseband Spectrum Analysis
  
  Signal Copy Selected Sub-Bands

- Gimbaled, Stabilized EO/IR Camera Ball

- High Precision GPS & INS (eventual swarm capable inter-UAV coherent RF sensors)

CAPABILITIES

- Electronic Scanning; No Antenna Mechanical Gimbal

- Multi-TB On-Board Data Recording

- Reconfigurable for Other Sensors: LIDAR, HSI, Chem-Bio

- Multi-Platform Distributed Sensor Experiments (eg, MIMO)

- Autonomous & Collaborative Multi-Platform Control

- Space for Future GPU/FPGA On-Board Processing

Modified Griffon Aerospace
Outlaw (MQ-170) – Extended Range (ER)
Unmanned Aircraft System (UAS)

Current Project Exploits and Solutions

**Exploits**

- Waypoint Manipulation from ground or onboard the aircraft

- Meta Data manipulation on imagery

- GPS embedded data manipulation

- Pointing control of surveillance camera

**Solutions**

- Airborne and ground-based detection of attacker waypoint changes, classifying the nature of the attack, and restoration

- Airborne detection of meta data manipulation

- Airborne detection of embedded GPS attack

- Airborne detection of attacker control of camera pointing and correction
# Technology Status

- Developed a number of design patterns for cyber security solutions to protect system functions
- Implementing a live prototype with live flight evaluations scheduled for the end of this coming summer with GTRI (aircraft integration and flight testing) and SiCore (secure electronics board design and implementation, funded by AF) support
- Starting a new effort to develop a Sentinel on a private cloud to monitor imagery exploitation system in use by the AF and Army (with Leidos support)

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# Process: Team –Based Response to Detected Cyber Attacks
Operational Concept Development for Response to Cyber Attacks on Combat Systems

- Based on current AF UAV Surveillance operational procedures
- Add a Cyber Officer to a team of:
  - Pilot
  - Surveillance Officer
  - Intel Officer
  - Mission Commander
- Human in the loop, simulation-based exploration and evaluation of candidate operational procedures for response to detected attacks
  - Team Structure
  - Information needs and situation presentation mechanisms
  - Repeatability of responses
  - Robustness across different attacks
  - Influence of "context factors" on responses
  - Responses to false alarms
- Mitre team at Creech AFB is supporting this effort, including providing simulation vehicle to support the evaluation

Status of Process Effort

- Determined what the needed simulation capabilities are and Mitre will lead the development work
- By end of the summer we expect to have conducted some human-in-the-loop experiments and will start discussions with AF at Creech AFB (led by Mitre) to hopefully start experiments with AF operational people
Summary

- The set of policy/process/technology research efforts provides a holistic start to transitioning these concepts to military use

- AF, SiCore, Mitre, Leidos, GTRI, and UVA are all providing resources to advance the project
  - AF: Funding for SiCore
  - SiCore: Electronics and training to UVA and GTRI for use of their development kits (FPGA-based development, use of encryption on the board, etc.)
  - Leidos: Advanced Imagery Exploitation System (AIMES) SW currently licensed to the AF and Army
  - GTRI: Use of the Outlaw Aircraft
  - Mitre: Use of REACT Simulation Vehicle

System Aware Cyber Security Publications


- B. M. Horowitz and K. M. Pierce, The integration of diversely redundant designs, dynamic system models, and state estimation technology to the cyber security of physical systems, Systems Engineering, 2013.


Need for Multiple Interacting Sentinels for Integrated Attacks and Symptom Sharing

Aircraft Based System(s)
Ground-Based Pilot System
Mission Control System
Exploitation System(s)

Example:
Autonomous Surveillance Platform Protection
Example:

Autonomous Surveillance Platform Protection

Config. hopping
Diverse redundancy
Port Hopping
Dedicated voting processing
SW power utilization fingerprint
SW CPU and memory usage fingerprint

• For Security Control
  Only
• Spread Spectrum Waveform
• Low Data Rate
Systemic Assurance

Dr. Bill Scherlis, Carnegie Mellon University

5th Annual SERC Sponsor Research Review
February 25, 2014
Georgetown University
Hotel and Conference Center
Washington, DC

www.sercuarc.org

SERC – Systemic Assurance – outline

1. Software Assurance as an emerging major SE focus
2. Perspective on systems development and sustainment
3. Challenges for baseline software assurance practice
4. Evidence of the opportunity – practices and technology
5. ROI and the economic case
6. Conops for the systemic assurance project
1. Software assurance as an emerging major focus

- Attention and evidence
  - DSB foreign software: T&E
  - PCAST cybersecurity: Arch
  - Section 933 NDAA
  - The SysE role: Higher stakes
  - Toyota $1.1B, ECSS, Healthcare.gov, F-35, ...

- Driver – roles for software
  - Increasingly critical, broadly pervasive, expectedly nimble

2. Perspective on systems devt and sustainment

- U.S. Naval Institute
  - Payloads over Platforms: Charting a New Course
    - By Admiral Jonathan W. Greenert, U.S. Navy
    - We need to move from "luxury-car" platforms—with their built-in capabilities—toward dependable "trucks" that can handle a changing payload selection.
    - Navy platforms, particularly ships and aircraft, are large capital investments frequently designed to last for 20 to 50 years. To ensure our Navy stays relevant, these platforms have to adapt to the changing fiscal, security, and technological conditions they will encounter over their long service lives. It is unaffordable, however, to adapt a platform by replacing either it or its integral systems each time a new mission or need arises. We will instead need to change the modular weapon, sensor, and communication subassemblies (modules) that can be swapped in and out. In addition to being more affordable, this approach allows for greater adaptability. This is the key to a cost-effective approach to transform our fleet.
Platforms and payloads – aspirations and actuality

Platforms and payloads – structures and practices

- Structure of systems, supporting artifacts, and organizations
  - Framework+apps model
  - Rich supply chains and socio-technical ecosystems
  - Architectural commitment, ownership, evolution
  - Allied models, tests, analytics, and other data

- Processes, practices, and teams
  - Evolutionary methods – IID and "agile at scale"
  - Powerful tools – developers and teams
  - Data intensive – development and quality
  - Rapid deployment – “DevOps”
    - Shift of balance from development to sustainment/modernization

"SOSCOE is a tailorable software toolkit to support legacy and SOA applications for the Tactical Domain. Enables a loosely coupled system with "Plug and Play" of new hardware and software applications. Allows the user to establish an "Investment Strategy" evolutionarily and incrementally change."
NB: Software and systems engineering – the evolving role

- **Building material of choice**
  - Largest single asset class (NRC STEP) – pervasive and critical in systems
  - No plateau of capability anywhere in sight

- **Cybersecurity**
  - The *materiel* of defense and offense
  - The manifestation of the assets being protected

- **Diverse roles**
  - Manifesting capability and autonomy
  - Enabling interlinking of systems of systems
  - Affording nimble response to changes in mission and infrastructure
    - The locus of the changeable

- **Consequence**
  - Routine activity gives way to automation
  - Hence more of the engineering activity is “innovative”

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3. Challenges for baseline assurance practice

- **Realities of modern (non-specialist) evaluation/certification**
  - Growing need for higher levels of assurance – safety and security
  - Process compliance giving way to product evaluation – freezing issue
  - Snapshot – no dynamism
  - After the fact – information loss and reverse engineering reqts
  - Whole system – vs incremental re-certification
  - No verification (A1; EAL7) – no positive assurance
  - Technical difficulties – concurrency, autonomy, ...
  - IP difficulties – what can the evaluator see?
  - IP difficulties – what can the prime see?

- **Judgments regarding T&E**
  - Practices out of phase with modern devt reality
  - Not at pace with cybersecurity requirements
  - Not exploiting potential of current technology
Perspective – particular challenges of software

- **The technology**
  - Rapid continuing progress in technology and practice – *no plateau*
  - Quantitative ROI elusive – *measurement for critical attributes*

- **The ecology**
  - STE focus on selection/configuration – *not empty-page coding*

- **Influences on adoption of quality practices**
  - Measurement difficulty – *Debt? Cost to complete? Quality?*
  - Relating quality and capability and timeliness – *push out the curve*
  - Adoption criteria – *ROI vs. engineering judgment*
  - Diffuseness of system design and technical heritage – TRL++, 6.x++, ?
    - Non-appropriability and weak “attributability”

4. Evidence of opportunity – practices & technology

- **Process and team culture**
  - SDL (Howard, Lipner), BSIMM (McGraw et al.)
  - Systems processes and software processes – a convergence

- **Technical advances in the software domain**
  - **Semantics** intensive and **data** intensive
    - Models, analyses, tools, languages
  - Ubiquity of advanced **tooling** and **modeling** and **analytics**
    - Individual engineers, small teams, larger orgns, supply chains
    - Internal business case and broad adoption at leading vendors

- **Interplay of SysE and SwE**
  - **Actions and enactment**: process models, teams, organizations
    - Conflicting decision drivers
    - Risk, quality attributes, functional attributes, cost, schedule
    - Interplay/trade-offs of *ilities*
    - Architectural/interface/API choices
  - **Artifacts**: Data, models, tools, and process support
    - Interplay of diverse models and abstractions
5. ROI and the economic case

- **Challenges**
  - Arm’s length and alignment of incentives
    - Cf. Commercial best practice, particularly vendors
    - Arm’s length enhances the measurement challenge!
  - Acquisition culture and normative practices
  - Sustainment → modernization
    - Cf. Depot/organic capability and engagement models
    - Cf. DevOps process patterns
  - C&A and T&E standards and practices
  - Training and technical refresh

- **Opportunity**
  - There is a business case at successful adopters
    - Developer ROI; Team ROI; Organizational ROI
  - The cases combine measurement and judgment
  - Advancing the frontier of measurement
  - The accretion of assets supports incremental improvement
    - Assets include data, models, and evidence in support of claims
    - DIS premise: evidence

6. Conops for systemic assurance

**Summary**: Provide practices for systemic assurance of safety, reliability, availability, maintainability, evolvability, and adaptability

**Impact**: Advancement in modeling, analysis, tooling, and process in support of rapid and effective certification of systems in development and recertification of systems in sustainment/modernization.

**Validation**: Achieve this through a strategy that links technical advancement with validation effort including prototyping, case studies and field trials, development of measures, and engagement with assurance stakeholders.

**Status**: Project initiation in 2014. This effort builds on a long record of engagement on the challenges of assurance at scale for component-based complex systems, including architecture, resiliency, modeling, analysis, tooling, concurrency, and other areas.
Conops – the Seven Steps

1. Identify baseline and intervention models for a selection of current standards
2. Advance capability for traceability to support explicit modeling and chains of evidence.
3. Design and implement experiments to address the challenge of rapid recertification.
4. Develop a framework for assessment of architecture-derived quality attributes
5. Develop requirements elicitation and management approaches that better address quality and policy objectives.
6. Augment and collaborate with diverse existing efforts focused on technical means to address particular quality criteria.
7. Identify and advance areas to support increasing automation. The key hypothesis is that assurance-related interventions will increase productivity throughout the lifecycle, leading to a "positive benefit" model.
The Future of Networked Research and Education

Prof. Dave Olwell, NPS

5th Annual SERC Sponsor Research Review
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Collaborative Research

• Much technical research is already conducted in a team environment
  — Lead PI
  — Multiple researchers
  — Usually in one institution (financial, collegial, proximity issues)

• SERC expands the envelope by facilitating collaboration across institutions
  — Still with the lead PI concept
  — Infrastructure to deal with the financial issues
  — Teambuilding to deal with the collegial issues
  — Technology and F2F meetings to deal with proximity

• Good examples of both low capital and high capital projects
  — BKCAS and HADRON, e.g.
Collaborative Doctoral Education

- Degrees still awarded by one school
  - Awarding campus policies govern
  - Seeing more evidence of cross-university doctoral committees
  - Even local committees can have dysfunctional behavior; jury is out on the efficacy of cross-university committees.
  - Much external collaboration occurs in campuses with small tenured faculty
- While many campuses have large research lines that support multiple doctoral students, we have not seen that so much across institutions.
- Relationship between doctoral advisor and candidate is essentially one-to-one.
  - Dissertation is an individual product
  - Advisor plays key role
  - Still highly unusual for advisor to be from another institution

Conclusion

- Collaborative research is farther advanced than collaborative doctoral education.
- Technology is not the barrier; the nature of the advisor-candidate relationship is.
- Tipping point depends on new understanding of that relationship.
Networked Research and Education

Bill Scherlis
Professor and Director, Institute for Software Research
School of Computer Science

- Background – Ed tech
  - MOOC
  - Flip
  - Learning R&D
  - Curriculum

- Opportunity – Delivery
  - Hybrid curricular
  - Intensive executive

- Opportunity – SE Content
  - Well lopsided
  - Software domain

- Opportunity – Modalities
  - Bring to users
  - Networked