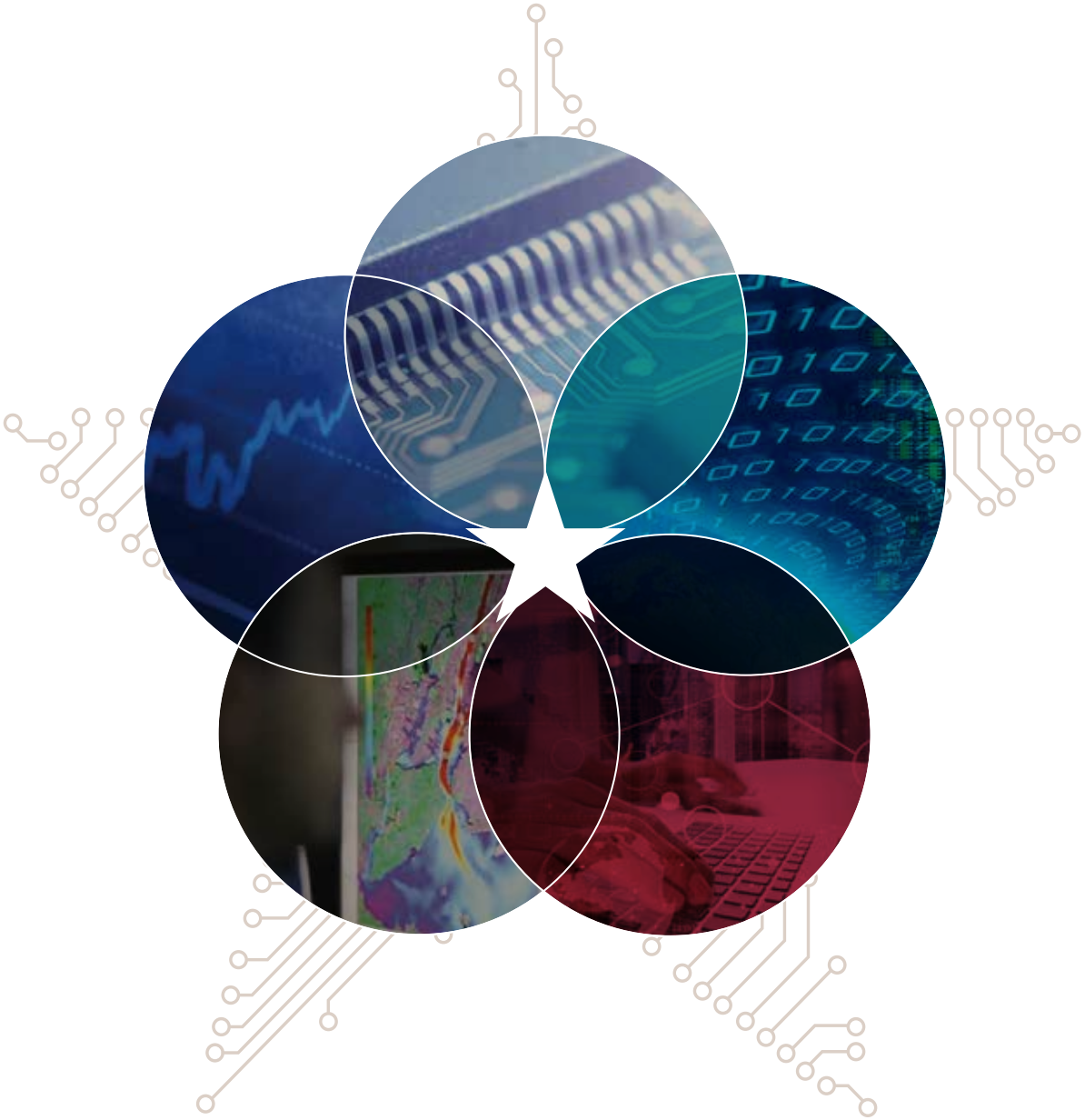


SYSTEMS ENGINEERING RESEARCH CENTER

A U.S. DEPARTMENT OF DEFENSE UNIVERSITY AFFILIATED RESEARCH CENTER

ANNUAL REPORT 2015

SYSTEMS ENGINEERING RESEARCH CENTER

CONTENTS

TECHNICAL EXCELLENCE

Technical excellence within the SERC is achieved in two critical areas: as a requirement of every individual and collective SERC research activity, and as a result of the research products delivered to the systems engineering community. Success in both areas is critical to achieving the SERC mission.

Excellence In How We Do What We Do

Achieving technical excellence in SERC research projects is dependent on a number of factors:

- Close relationship with our sponsors and customers assures continual alignment with their needs and expectations
- The SERC Chief Technology Officer, Research Council and Principal Investigators ensure high quality research, minimal overlap, and a high level of synergy across the research tasks
- Peer review of publications and participation in conferences, working groups and joint projects with the broader engineering community provide the feedback necessary for excellence
- SERC's collaborating universities provide a range of talented and thoughtful researchers with broad systems expertise and domain experience
- Creativity in both concepts and conduct leads to effective, efficient research

What We Do Improves The Excellence Of The Systems Engineering Community

SERC research projects are only successful if they deliver information, tools and understanding to improve the technical excellence of the SE community and increase the probability of success in evolving defense and commercial systems. The usefulness and availability of SERC research products build technical excellence by:

- Providing new ways (or evolving existing ways) to solve difficult systems engineering problems
- Focusing on the four research areas critical to our sponsors and customers
- Engaging with users in government and industry to gain feedback and build transition strategies from the beginning of every research task
- Scanning the horizon for potential problems, undiscovered solutions, and promising concepts as seeds for research
- Supporting the education and development of tomorrow's systems engineers

By seeking technical excellence in our research projects and targeting their results at improving technical excellence in the defense systems development and evolution community, the SERC provides a unique interconnection of customer needs, research capabilities, and broad user transition coalitions.

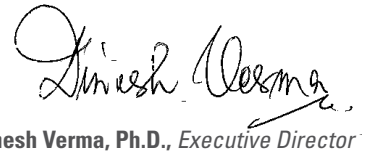
GREETINGS FROM THE EXECUTIVE DIRECTOR

It is with immense pride that I introduce the 2015 SERC Annual Report which marks the conclusion of our seventh year of operation. This year's Annual Report focuses on the critical theme of "Technical Excellence" – not just of the research itself, but the subsequent transition of this research into practice for impact. I am very proud of the manner in which both these elements of Technical Excellence within the SERC are evolving. Our Principal Investigators are increasingly conducting research of greater relevance, but a number of our research activities have reached the critical juncture of transition to practice.

Our four thematic areas pertaining to a) Enterprises and Systems of Systems; b) Trusted Systems; c) Systems Engineering and Management Transformation; and d) Human Capital Development, have remained steady for the past few years, due to continued validation by our sponsors. Increasingly within the scope of these thematic areas, we are encountering aspects that suggest current and future challenges — resulting from a focus on autonomy in systems, cyber-physical systems, and a greater need for adaptability in complex systems. We continue to collaborate with research partners such as the National Science Foundation (NSF) along with transition partners such as the International Council on Systems Engineering (INCOSE), the National Defense Industrial Association (NDIA), and the MITRE Corporation and others within the defense Industry.

This year's Annual Report focuses on the critical theme of "Technical Excellence" – not just of the research itself, but the subsequent transition of this research into practice for impact.

I would like to take this opportunity to thank members of the SERC Research Council for their dedication and hard work; and members of the SERC Advisory Board, chaired by Dr. Michael Griffin, for your counsel and insight. Finally, we are extremely grateful for the trust and support of our research sponsors within the Department of Defense and federal government; without this, we would not be in a position to have a substantial impact within the systems engineering community.



Dinesh Verma, Ph.D., *Executive Director*

"These tools force the engineers to dive deep into the interdependencies of systems in a SoS, and consequently provide meaningful analysis information that could be used to make smarter decisions early in the lifecycle of acquisition and modernization programs. Just going through the process of determining the interdependencies is a useful exercise in itself. However, the Purdue SoS Analytic workbench provides additional insight which based on this quick study may prove to be well worth the effort."

Purdue SoS Analytic Workbench Review Dec 2014
Joseph DeLuca & Javier Garcia, *MITRE Corporation*

SERC OVERVIEW

Since 2008, the SERC has received over $50 million in research awards involving nearly 500 faculty, staff and students from across the SERC Collaborators. That research spanned 51 projects and focused on the SERC's four strategic research areas. Those projects produced 177 journal and conference papers and 110 technical reports.

RESEARCH AREA	Projects	Conference & Journal Papers	Technical Reports
Enterprises and Systems of Systems	6	44	17
Trusted Systems	3	15	9
Systems Engineering and Management Transformation	30	67	52
Human Capital Development	11	51	32
TOTAL	**51***	**177**	**110**

** 1 project spans all four research areas*

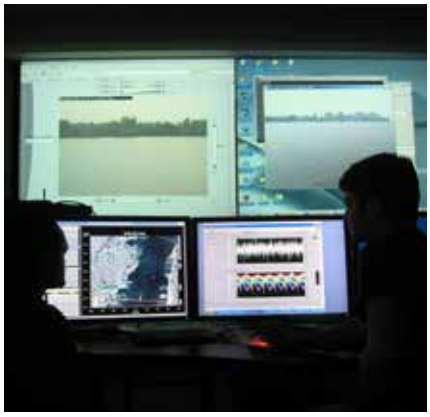
2015 SPONSOR AWARDS

SPONSOR	2015
DASD(SE)	53%
Army	29%
DAU	11%
Navy	5%
Other DoD	2%

TECHNICAL PLAN UPDATE

The first update to the SERC Technical Plan was developed in 2015 and describes progress since the Assistant Secretary of Defense for Research and Engineering approved the original SERC Technical Plan in October 2013 and annual Core funding was appropriated to match the Technical Plan. In this update, the Grand Challenges remain virtually unchanged, with the focus being updates to the research programs and other elements in the plan. In addition, this update includes much greater transition planning information than in the original version. The next Technical Plan update in two years will address changes to the Grand Challenges and research strategies, and will be used to support the DoD's 5-year comprehensive review of the SERC.

More than two-dozen projects have been executed since the original Technical Plan was published, some to completion, others still ongoing. These projects have been delivering methods, processes, and tools (MPTs) in each of the four research areas that define the SERC research portfolio. Transition has also been ongoing and growing, with many acquisition programs and defense organizations piloting and adopting SERC MPTs as those MPTs have matured. Since October 2013, when the SERC began executing this plan, SERC researchers have delivered more than 110 papers and technical reports, and prototype software implementations of their methods and processes. Equally important, SERC collaboration and infrastructure have grown significantly, as reflected in the new SERC Innovation and Demonstration Lab, where projects can demonstrate their research both individually and coordinated across projects.

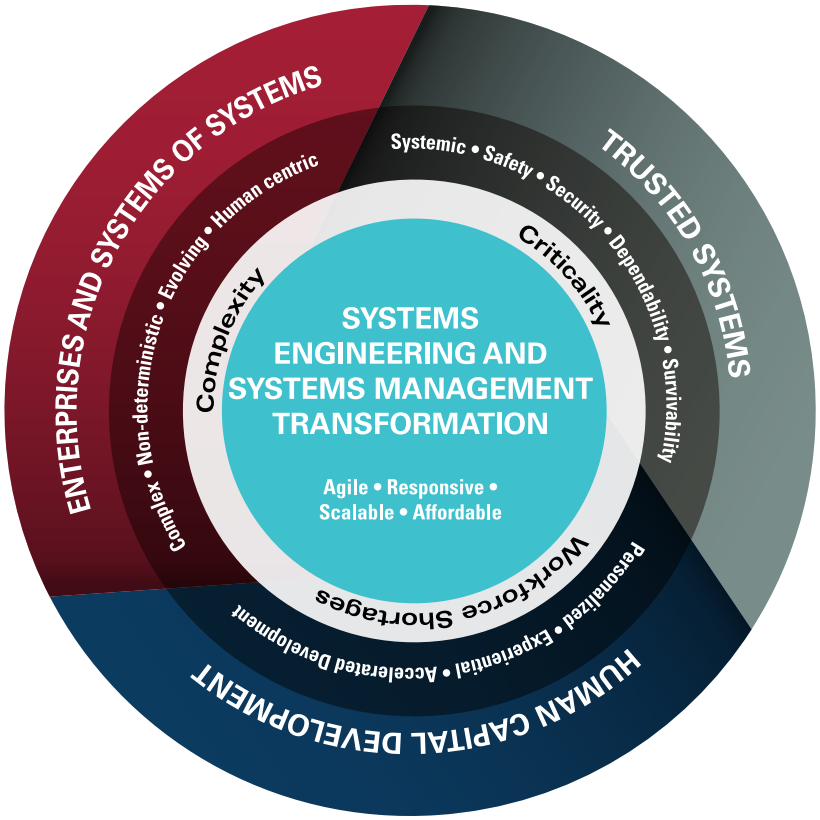


"The Helix project, particularly the Atlas model, has been extremely valuable to us as we undertake a more competency-based approach to engineering resource management. The data-driven approach to the research gives us great confidence that the Atlas model accurately represents the key components of systems engineering. We also anticipate that this model will be extensible to disciplines beyond systems engineering."

Michael Gries, Director, Avionics Certification Office
Rockwell Collins

RESEARCH FOCUS AREAS

The SERC research portfolio is structured into four thematic focus areas:



Enterprises and Systems of Systems

Trusted Systems

Systems Engineering and Systems Management Transformation

Human Capital Development

Enterprises and Systems of Systems—*the evolving need of very large scale systems composed of smaller systems, which may be technical, socio-technical, or even natural systems.* These are complex systems in which the human behavioral aspects are often critical, boundaries are often fuzzy, interdependencies are dynamic, and emergent behavior is the norm. Research must enable prediction, conception, design, integration, verification, evolution, and management of such complex systems.

Trusted Systems—*the need for ways to conceive, develop, deploy, and sustain systems that are safe, secure, dependable, and survivable.* Research must enable prediction, conception, design, integration, verification, evolution, and management of these emergent properties of the system as a whole, recognizing these are not just properties of the individual components and that it is essential that the human element be considered.

Systems Engineering and Systems Management Transformation—*the need for ways to acquire complex systems with rapidly changing requirements and technology that are being deployed into evolving legacy environments.* Decision-making capabilities to manage these systems are critical to determine how and when to apply different strategies and approaches. Research must leverage the capabilities of computation, visualization, and communication so that systems engineering and management can respond quickly and agilely to the characteristics of these new systems and their acquisitions.

Human Capital Development—*the need to respond to the retirement of the baby boomer generation, the reduced numbers of US citizens entering the technical workforce, and the new systems challenges facing technical staff.* Research must determine the critical systems engineering knowledge and skills that the Department of Defense (DoD) and Intelligence Community (IC) workforce require as well as the best means to continually impart that knowledge and skills.

In this section, we spotlight several research projects from each of the focus areas that were underway in 2015, and that illustrate the diversity of approaches, strategies, and outcomes of the SERC as a whole.

ENTERPRISES AND SYSTEMS OF SYSTEMS

Engineered Resilient Systems: Tradespace Tools

The Department of Defense's Community of Interest for Engineered Resilient Systems (ERS) calls for systems to be effective throughout their life cycle even when the mission context changes beyond its original intention. Tradespace analysis enables adaptable designs using diverse, easily modified and re-used systems models, and rapid iteration with a clear linkage to evolving mission needs. Georgia Tech's Systems Engineering Research Division is co-developing a web-based, collaborative tradespace environment along with the US Army Engineer Research and Development Center (ERDC) for the ERS Community of Interest that leverages Georgia Tech's expertise in collaborative, executable Model-Based Systems Engineering (MBSE) and ERDC's leadership of the DoD's High Performance Computer infrastructure.

PI: Tommer Ender, Ph.D. (Georgia Institute of Technology)

Sponsor: U.S. Army Engineer Research and Development Center Information Technology Laboratory (ERDC-ITL)

Link: http://www.sercuarc.org/projects/engineered-resilient-systems-tradespace-tools/

Enterprise Systems Analysis: Multi-level Socio-technical Modeling

Many of the challenges that confront the DoD are characterized by the intersection of complex social, political, economic, and technical phenomena where conventional modeling techniques are inadequate. Human and organizational effects can dominate technical outcomes. This task is creating systems-oriented modeling methodologies to study and assist policy formulation for such enterprise problems, along with case study demonstrations and validations.

In 2015, task activities included:

- Developing an enterprise-level simulation of counterfeit part intrusion into the defense supply chain. The model considers the interaction among policy choices of several government entities including the DoD, Department of Justice, and Customs and Border Protection.
- Analyzing a case study on the policy implications of behavioral and information economics for dynamic toll roads. This served as the impetus for a classification and decision making scheme for identifying and dealing with structural uncertainty and policy tipping points.
- Developing an interactive visualization test interface to analyze approaches to aid decision makers analyzing complex enterprise diagnostic problems.
- Refining an enterprise modeling methodology based on all of these activities.

PI: Michael Pennock, Ph.D. (Stevens Institute of Technology)

Sponsor: ODASD(SE)

Link: http://www.sercuarc.org/projects/multilevelsociotechmodel-enterprisesystemanalysis/

Assessing the Impact of Development Disruptions and Dependencies in Systems of Systems (SoS)

The SoS Analytic Workbench (AWB) is a suite of methods, processes and tools to assess operational and development disruptions and dependencies in SoS architectures. Results in 2015 included:

- Completed an initial, functional concept for the AWB that uses a suite of computational tools to facilitate better informed decision-making for SoS architecture evolution; the tools include: System Operational Dependency Analysis/System Development Dependency Analysis, Decentralized Decision Planning, System Importance Measures (SIMs), and Robust Portfolio Optimization.

PI: Daniel DeLaurentis, Ph.D. (Purdue University)

Sponsor: ODASD(SE)

Link: http://www.sercuarc.org/projects/assessing-the-impact-of-development-disruptions-and-dependencies-in-system-of-systems-sos/

- Developed an AWB use case demonstration problem involving a Naval Warfare Scenario. Each of the AWB tools is used in this common case study to illustrate the value in each tool performing various types of SoS-level architectural analysis.

SoS Analysis and Architecting using Agent-based Behavioral Modeling – FILA-SoS

FILA-SoS and the Wave Process address four of the most challenging aspects of SoS architecting: dealing with the uncertainty and variability of capabilities and availability of potential component systems; providing for evolution of SoS needs, resources and environment over time; accounting for differing approaches and motivations of autonomous component system managers; and optimizing SoS characteristics in an uncertain dynamic environment with fixed resources.

FILA-SoS models and simulates SoS systems with evolution for multiple waves. Models can be run independently or in conjunction with each other. Two model types represent SoS behavior and individual system behavior. The capability:

- Supports study of negotiation dynamics between SoS and individual systems and the dynamic behavior of different types of systems (selfish, opportunistic, cooperative)

PI: Cihan Dagli, Ph.D. (Missouri S&T)

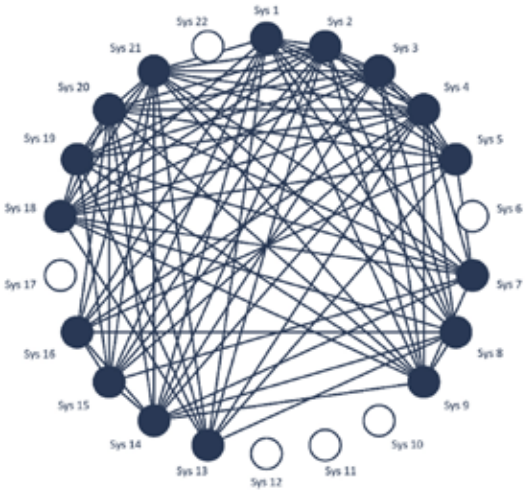
Sponsors: ODASD(SE), MITRE

Link: http://www.sercuarc.org/projects/flexible-intelligent-learning-architectures-for-systems-of-systems-fila-sos/

- Identifies intra- and interdependencies among SoS elements and the acquisition environment
- Reveals emergent behavior of systems in the acquisition environment and the impact on SoS architecture quality

Integrated Quantitative Decision Making Model with seven independent modules

- Meta-Architecture Generation Fuzzy Genetic model
- Meta-Architecture Generation Multi-Level model
- Architecture Assessment Model
- SoS Negotiation Model
- System Negotiation Model: Selfish
- System Negotiation Model: Cooperative
- System Negotiation Model: Opportunistic
- Architecture Executable Model
- Overall Negotiation Framework



OPTIMIZED META-ARCHITECTURE BY FILA-SoS	INTELLIGENCE SURVEILLANCE RECONNAISSANCE SoS
Assessment of the ISR SoS with 22 Systems	3.61
Key Attribute Values SoS *(Systems selected are represented with black circles)*	Range 0-4
Performance	2.28
Affordability	3.09
Flexibility	4
Robustness	3.77

Systemic Assurance

PI: Bill Scherlis, Ph.D. (Carnegie Mellon University)

Sponsor: ODASD(SE)

Link: http://www.sercuarc.org/projects/systemic-assurance/

Systems cannot be deployed until customer organizations judge them to be fit for use in the intended mission environment. Confident assurance judgments, whether regarding system function, security, quality, performance, resiliency, or maintainability, must be based on evidence of some kind. For complex software-reliant systems, confident judgments require a diversity of kinds of evidence. This may include models related to requirements and operating environment (hazards, security, safety, functional requirements, performance, resiliency and reliability), system structure (architecture, design, APIs and other interfaces, interconnections), materials (physical devices, software code), evaluation (tests, monitoring data, operation details), and many others. The results of using the models support reasoning about the interrelationships of the various systems engineering artifacts to draw conclusions and organize evidence. This reasoning is accomplished using diverse analytic methods (such as mathematical and sound analyses) and empirical methods (such as testing, inspection, simulation, and monitoring). By building dependency models that link these various parts together, we believe assurance judgments can be confident and swift, development productivity can be enhanced, and progress towards the aspiration of continuous recertification of systems through development, sustainment, and modernization achieved.

Engineering disciplines show strong signs of progress towards this framework of modeling, analysis, evidence, and dependency management. Systems and software engineering use numerous modeling formalisms, ranging from general-purpose modeling (SysML) to highly specialized models for particular technical quality attributes. Additionally, modern team software tools retain data regarding the lineage of every line of software code, including when, why, and by whom it was last changed. An extreme example is the Google code repository, with more than a billion lines of code and tens of thousands of transactions logged each day. The System Assurance project builds on these ideas with a four-part approach to evidence-based assurance: (1) A baseline analysis of codified existing best practices for a representative diverse set of assurance judgments in avionics, secure Defense IT, cybersecurity, and embedded devices; (2) An identification and validation of meta-criteria that support comparison and evaluation of existing and future best practices and standards; (3) Advancement of technical practice for engineering activities related to requirements, architecture, design, and code, with emphasis on models, reasoning, and evidence; (4) Concepts for improved standards that build on this understanding and can exploit the newly data-intensive character of engineering practice.

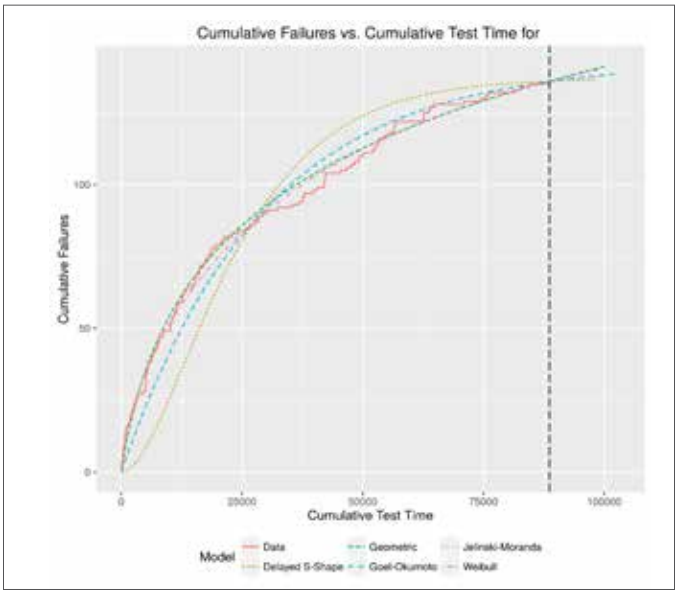
Software Reliability Modeling

PIs: Leon Osterweil, Ph.D. and Lance Fiondella, Ph.D. (University of Massachusetts)

Sponsor: NAVAIR

Link: http://www.sercuarc.org/projects/software-reliability-modeling/

The past decade has seen a sharp rise in the number of software intensive systems acquired by the DoD. While hardware has enjoyed significant gains in reliability, DoD attributes 50-90% of systems failures to software. Thus, software contributes disproportionately to system unreliability, severely slowing software delivery and detracting from mission effectiveness design targets. With support from the Naval Air Systems Command (NAVAIR), this project has developed an open source software reliability modeling tool to aid DoD organizations and their contractors to quantitatively measure and predict the reliability improvement of software. The use of such models can improve effectiveness and quality in software development organizations and support government oversight of software during the acquisition process. In addition to tool development, short courses are offered to organizations wishing to integrate the tool into their testing processes and those of the contractors they oversee. More than a dozen students were involved in the development and test of this tool, creating a pipeline of new talent trained in the theory and practical details of software reliability.



Security Engineering

PI: Barry Horowitz, Ph.D. (University of Virginia)
Sponsor: ODASD(SE)
Link: http://www.sercuarc.org/projects/security-engineering/

This research area has focused on employing secure monitors (referred to as Sentinels) to detect and respond to cyber attacks that impact physical system functions during system operation. The Sentinels are designed to recognize high-risk illogical behaviors that are likely to be the result of a cyber attack, and when possible, support operators in initiating appropriate system reconfiguration actions to permit operations to continue. Research efforts in this area, referred to as System-Aware Cybersecurity, have stimulated the start of technology transition activities. Based upon results that have been achieved through of a number of SERC prototype-based research efforts, the Army has started to work with the SERC to develop a secure Sentinel for a tank fire control system. The effort will involve design and evaluation of the Sentinel, while an Army software development team at Picatinny Arsenal implements the Sentinel and addresses the integration into the weapon system. In parallel, the Air Force Institute of Technology (AFIT) has been working with the project team on issues surrounding human involvement in real-time reconfiguration management for situations caused by a cyber attack. UAV-based surveillance systems have been the focus of these efforts. Experiments involving humans remotely controlling ground vehicles are scheduled to start in Spring 2016, with the objective being to learn how to best prepare and train pilots of unmanned vehicles to respond to detected attacks. A number of other organizations have initiated discussions with UVa regarding the start of transition projects derived from the Security Engineering research program, pointing to the growing interest in cybersecurity for physical systems.

The University of Virginia/ Georgia Tech project team during a Sentinel technology test and evaluation effort at Early County Airport in Blakely, Georgia.

"The collaboration between SERC and INCOSE over the last two years has had a tremendous impact on systems engineering: joint stewardship of BKCASE to advance both the body of knowledge and the reference curriculum, joint workshops ranging from identifying the theory of SE to closing the gap between systems and software, joint research to assess and improve SE proficiency, and much more. Perhaps even more impressive than the progress made is the foundation built and momentum established, promising even greater contributions in the years to come."

David Long, *2014-2015 INCOSE President*

Interactive Model-Centric Systems Engineering

Models are increasingly used to drive major acquisition and design decisions. While progress has been made on standards, methods and techniques for model-based systems engineering, there has been little attention to complexities of human-model interaction. IMCSE aims to develop transformative results through enabling intense human-model interaction to rapidly conceive of and interact with systems models. This supports rapid trade decisions given present knowledge and future uncertainties, as well as what is practical given resources and constraints.

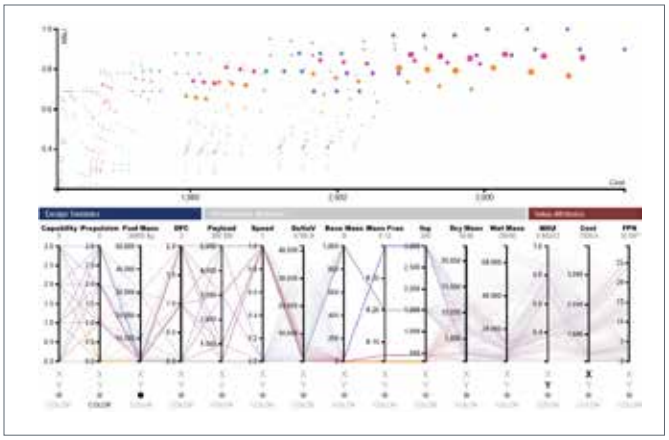
Interactive model-centric systems engineering requires new knowledge and ways of working, and innovation in constructs and technologies. Progress toward this goal in 2015 included:

- Events and activities developing a research roadmap for interactive model-centric systems engineering, with defined activities, targeted interim outcomes, and transition actions. Supporting studies included non-technical challenges and research needs related to digital system models and investigation of cognitive and perceptual considerations in human-model interaction.
- A framework was developed and tested for conducting value model trades and evaluative (performance, cost) model trades was developed and tested. A demonstration case for interactive model-trading, including value, performance, and cost models with inherited data was completed to demonstrate impact on system decision making.
- The Interactive Epoch-Era Analysis framework and supporting tools were applied to a defense-oriented demonstration case, focusing on opportunities to improve the uncertainty analysis, ease of use, data scaling, visualization techniques, and overall analysis approach. Demonstration prototypes were developed for single epoch analysis and multi-epoch analysis. The graphic shows an interactive filtering application that allows the decision-maker to interact with their data to identify designs and epochs of interest.

PIs: Donna Rhodes, Ph.D., and Adam Ross, Ph.D. (Massachusetts Institute of Technology)

Sponsor: ODASD(SE)

Link: http://www.sercuarc.org/projects/interactive-model-centric-systems-engineering-imcse-program/



Model-Centric UAV ISR Analysis

During the SERC Tradespace and Analysis Project (iTAP), AFIT developed a methodology to determine the influence of requirements change on system design. A new effort, built on prior work at AFIT and NPS, explores the use of executable architectures associated with Model Based Systems Engineering (MBSE) tools to guide early design decisions given requirements changes and System of System (SoS) architectural variations. Operational and system architectures of military scenarios are developed and represented in an MBSE environment. The models are then used to support the evaluation of system performance, higher-level qualities, and parametric software and system cost estimating approaches. Translation rules and constructs between MBSE methods, performance analysis and cost model inputs are being developed and demonstrations of tool interoperability and tailorability to DoD domains are being conducted.

This joint AFIT-NPS effort expanded to include heterogeneous teams of UASs performing ISR missions in increasingly complex environments. Architecture work has begun on a mobile missile search and engagement scenario, as well as the preliminary definition of an anti-terrorist scenario. These scenarios envision three tiers of UASs (small, medium, large) with varying sensor, communication, and decision-making capabilities. Ground station and other friendly element communication will also be considered within the SoS architecture. Measures of effectiveness will be established, uncertainty associated with the adversary and the environment will be characterized and modeled, and system parameters will be chosen to demonstrate the ability to perform meaningful trade space analysis that considers affordability. The project will also begin to create a library of UAS failure modes and corresponding failsafe behaviors for use in generating UAS and swarm level requirements. To better account for attrition, inventory requirements and total ownership cost, determining failure mode probabilities and factoring them into concept performance evaluation and associated life cycle cost estimates is needed.

PIs: David Jacques, Ph.D., Lt Col, USAF (AFIT); and Raymond Madachy, Ph.D., (Naval Postgraduate School); under Barry Boehm's Tradespace and Affordability project

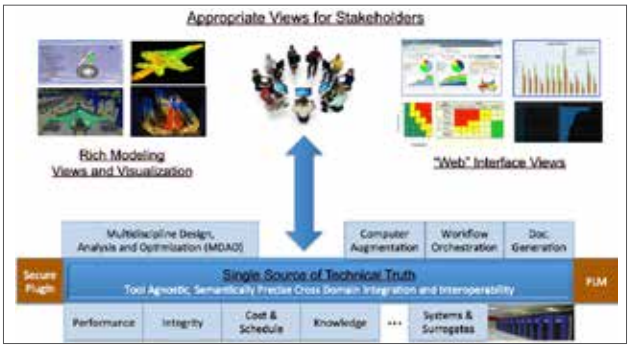
Sponsor: ODASD(SE)

Link: http://www.sercuarc.org/projects/tradespace-and-affordability/

Transforming Systems Engineering through Model-Centric Engineering

In 2013, Naval Air Systems Command (NAVAIR) initiated research into a vision held by NAVAIR's leadership to assess the technical feasibility of a radical transformation through a more holistic model-centric system engineering (MCSE) approach. The expected capability of such an approach would enable mission-based analysis and engineering that reduces the typical time by at least 25 percent from what is achieved today for large-scale air vehicle systems (e.g., Joint Strike Fighter) within a 10-year timeframe.

There has been considerable emphasis on understanding the state-of-the-art through discussions with industry, government and academia. The team comprised of both NAVAIR and SERC researchers conducted over 28 discussions, including 21 onsite. The message presented to



PI: Mark Blackburn, Ph.D. (Stevens Institute of Technology)

Sponsor: NAVAIR

Link: http://www.sercuarc.org/projects/transforming-systems-engineering-through-model-based-systems-engineering/

NAVAIR senior leadership suggests that model-centric engineering is in use and adoption seems to be accelerating. Organizations are progressing beyond model-based to model-centric where integration of computational capabilities, models, software, hardware, platforms, and humans-in-the-loop allows multi-disciplinary teams to assess system designs using dynamic models and surrogates to support continuous and often virtual verification and validation in the face of changing mission needs. The enabling digital technologies are changing how organizations are conceptualizing, architecting, designing, developing, producing, and sustaining systems and systems of systems. The final technical report provides evidence of traceability to different instances of use of these MCSE-relevant and cross-domain modeling technologies and their possible impacts/relationships on characteristics, such as: performance, integrity, affordability, risk, methodologies, and within a single source of technical truth, all enabled by continuous advancements in High Performance Computing.

PACK: Portfolio Analysis Kit - Development and Application of Standardized Portfolio Management Strategy

Efficient asset management is a critical function of the Department of Defense. Program Managers (PMs) and DoD leadership are tasked with managing their portfolios with some constraints, most often budget, while maintaining the same set of capabilities. Portfolio management addresses the following:

- What is the problem, challenge, or opportunity?
- What capabilities are required?
- What functions address these capabilities?
- Which assets provide the necessary functionality?
- How well does each asset provide its desired functionality?

Georgia Tech has supported Marine Corps PMs and War Rooms to analyze portfolios of counter-IED, logistics, ground vehicles, and IT systems. To standardize the approach to these challenges, Georgia Tech is developing the Portfolio Analysis Kit (PACK). PACK applies model-based systems engineering standards to answer these questions and facilitate portfolio research and development.

The figure represents the conceptual decomposition of PACK. The need is decomposed into a set of high-level goals and well-defined requirements. This process provides structure to the analysis. Citation touches all aspects of the analysis. What is the source of the data? Traceable, trustworthy data improve the overall quality of the analysis.

An asset is an element of a portfolio. An IT portfolio may contain hardware and software assets. These may be similar or disparate; the key is that each addresses a specified need of the research.

PIs: Daniel C. Browne, and Todd B. Shayler (Georgia Institute of Technology)

Sponsor: Marine Corps Systems Command - FACT PM (MARCORSYSCOM)

Link: http://www.sercuarc.org/projects/development-and-application-of-fact-portfolio-management-capability/

A strategy is a set of portfolios that all address the same need across some dimension, such as time. Strategies are analyzed and compared to determine which bests suites a situation. Context represents the importance of an asset's capabilities to the overall need. The utility of an asset depends both on its context and its value, where context may vary across stakeholders.

PACK provides a strict process for organizing a portfolio management analysis that automates the calculation and comparison of portfolio utility across time. Now, researchers can tackle the next challenges of portfolio management.

The conceptual decomposition of portfolio management and the foundation of PACK.

Foundations of System Qualities Tradespace Analysis

PI: Barry Boehm, Ph.D. (University of Southern California)
Sponsor: ODASD(SE)
Link: http://www.sercuarc.org/projects/tradespace-and-affordability/

The USC-MIT-UVa team made significant progress in bringing together the USC and MIT System Qualities (SQs) and UVa's formal analysis capabilities to create a much-needed capability in the area: an integrated framework with formal foundations for SQ tradespace analysis. Exploration of the relationships identified a particular SQ attribute, Maintainability, as being key to most of the SQs in the combined ontologies. It is clearly key to Changeability and to Life Cycle Affordability, but also influences Dependability through the equation defining Availability as a function of Reliability (Mean Time Between Failures) and Maintainability (Mean Time To Repair). It is also involved in which mission Effectiveness SQs (e.g., Range, Payload, Accuracy) the system stakeholders are depending on. Subsequent focused research on Maintainability included experiments on the predictive capability of Maintainability metrics, and the development of a much-needed Software-Intensive Systems Maintainability Readiness Level (SMRL) framework that has already attracted the interests of the Army Practical Systems Measurement Users Group and several Aerospace Corp. projects.

Agile SE – Enablers, Quantification, and Kanban Scheduling

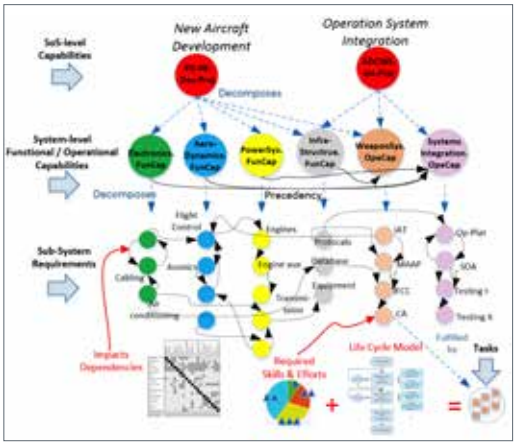
PI: Richard Turner, D.Sc. (Stevens Institute of Technology)
Sponsor: ODASD(SE)
Link: http://www.sercuarc.org/projects/agile-se-enablers-quantification-and-kanban-scheduling/

Successfully applying systems engineering to evolving complex systems and systems of systems is challenged by the ineffectiveness of many traditional management and governance approaches. The current systems development environment includes:

- Rapid change in threats, capability needs and priorities, and available technology/solution concepts
- Multiple powerful stakeholders with inconsistent win conditions
- Independently evolving legacy or component systems with heterogeneous governance systems
- Overall capability enhancement via continuous, interdependent software development

Scheduling and resourcing ongoing development and operation tasks in a high uncertainty environment is challenging. New ways of coordinating, valuing, and performing work across this complex development environment are needed. Beginning in 2011, research identified several agile and lean approaches that might provide better governance and address some of these issues. Organizational structures can have a significant impact on productivity; however, changing these structures can incur significant costs with uncertain benefits. This research provides a modeling environment to experiment with more effective application of SE and development resources to build different aspects of the system. The results will inform organizations contemplating changes to the system development organizations. Organizations will be able to identify, develop, investigate and validate new governance and management approaches with sufficient rigor to encourage adoption.

The initial delivery of the environment included a Domain Specific Language (DSL) developed to describe the organization, work flow, and governance properties of a system or system of systems. A compiler was developed for the language and implementation software was completed using an open source agent-based simulation environment. The current tool suite includes a standalone system that can be implemented as a virtual machine, a modifiable Eclipse-based system, and a version available via the web on servers at Auburn and USC. The tool suite will continue to be improved and the DSL refined during 2016.



"As part of your industry team for a few years I find the Agile SE work promising in both the governance concepts and the scope of the simulation capability. As this capability matures, integrating it with the Experience Accelerator could provide training on how different projects and environments can use different governance structures to enhance the probability of success."

Garry Roedler, *INCOSE President-Elect*

HUMAN CAPITAL DEVELOPMENT

Workforce Evolution (Helix) – What Makes Systems Engineers Effective

In 2012, the DoD began to sponsor Helix, a project that is creating Atlas, a theory of what makes systems engineers effective. Atlas identifies the key characteristics of systems engineers, explains what promotes and inhibits their effectiveness, and identifies how organizations are attempting to improve effectiveness of their systems engineering workforce.

In Atlas, a systems engineer is considered effective when he consistently delivers "value", which is defined by the organization and delivered through performing certain roles and responsibilities within a given position. In order to perform effectively, a system engineer must also have the right proficiencies – the knowledge, skills, abilities, behaviors, and cognition – to support his work. Atlas identifies 28 proficiencies which change over the career of an individual based on his experiences, mentoring, and education & training, all in the context of his personal characteristics and development initiatives as well as the characteristics and development initiatives of the organizations for which he works.

The current release of Atlas is based on interviews with 287 individuals from 20 organizations in the DoD, defense industrial base, and commercial industry, as well as analysis of more than 2500 applications to the INCOSE Certified Systems Engineering Professional program.

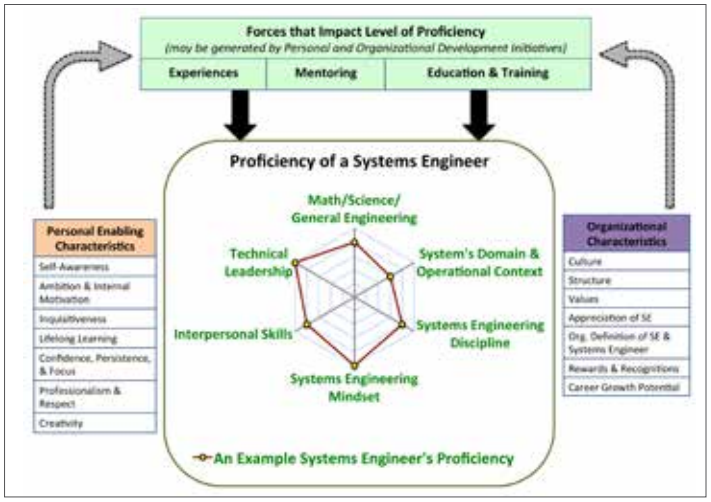
Early adopters from the government and industry are confirming the value of Helix. During 2016, Atlas will continue to mature and be adopted by a growing community of users.

Helix expects to release Atlas 1.0 at the end of 2016.

PI: Art Pyster, Ph.D. (Stevens Institute of Technology)

Sponsor: ODASD(SE)

Link: http://www.sercuarc.org/projects/helix/



Developing SE Technical Leadership

Research into how to accelerate the development of acquisition professionals to fill key leadership positions (KLPs) continued during 2015. Earlier work demonstrated the feasibility of accomplishing the objective through the development of three pilot workshops, and their delivery and refinement in a series of nine pilots. The three workshops were built on a model of three concentric lenses, a Systems Lens, a Business Lens and an Enterprise Lens, each with a wider field of view corresponding to the increasing scope required of technical leaders as they progress from leading technical development to leading integrated product teams to leading organizational and cultural change.

The Systems Lens was transitioned to the government by transferring the workshop content and delivery methodology to instructors from the Defense Acquisition University (DAU). A final SERC-led pilot of SYS 360A was conducted at DAU in January 2015, with the targeted DAU instructors participating. The DAU instructors then delivered a government-led pilot at DAU South in Huntsville, AL in May. The students rated the course very highly in both learning effectiveness and course relevance. Based on the success of the pilots, DAU has now integrated the Systems Lens into its standard curriculum as course TRL 350.

PI: Michael Pennotti, Ph.D. (Stevens Institute of Technology)

Sponsors: Defense Acquisition Univeristy and ODASD(SE)

Link: http://www.sercuarc.org/projects/developing-se-technical-leadership/

The Business Lens and the Enterprise Lens were transitioned with the Defense Systems Management College of DAU by integrating the courses into the 12-month Key Leadership Development Program (KLDP) jointly developed by DAU with and for the Missile Defense Agency. As part of that larger program, a SERC-led pilot of the Business Lens was conducted in Tucson, AZ in November 2015 as KLDP Segment 3. Hosted by Raytheon Missile Systems, the pilot demonstrated the need for modifications to the previously validated SYS 350B material to better integrate it into the overall KLDP. At year-end, corresponding modifications were being developed for SYS 350C to support its inclusion in a SERC-led pilot of the Enterprise Lens scheduled for March of 2016 as KLDP Segment 5.

Developing and Applying the Systems Engineering Experience Accelerator (SEEA)

PI: Jon Wade, Ph.D. (Stevens Institute of Technology)
Sponsors: Defense Acquisition Univeristy and ODASD(SE)
Link: http://www.sercuarc.org/projects/system-engineering-experience-accelerator/

During the past year, the capabilities of the Experience Accelerator were enhanced and refined, significant progress was made in the development of a tool suite capable of reducing the effort to develop new experiences, and interest in its use has greatly been expanded. Some of the enhanced capabilities included stable multi-player capability, improved feedback to the students explaining the outcomes of the team's decisions, enhanced dialog capability dependent on the state of the simulation and the student's actions, and significantly improved user interface to facilitate access to project information. Using Core funding, several new tools were developed that could greatly accelerate the creation of new virtual experiences and enable those outside the research team to create new experiences. The Sim Builder and Sim Tuner tools were developed to leverage and facilitate the development of systems dynamics models. A trio of experience development tools - the Phase Editor, Event Editor and Artifact Integrator - were completed and integrated into a single experience creation tool. Finally, experience data collection and prototype visualization tools have been developed to assist in the evaluation of student learning. An Experience Accelerator workshop and presentation was made to the Corporate Advisory Board at the 2015 INCOSE International Workshop. As a result, there has been a substantial increase in the amount of interest in using the EA including development of a new reliability engineering experience by the UK Ministry of Defence, the use of the EA in two doctoral dissertations to measure systems thinking and engineering capabilities, and industrial interest in the tailoring and development of new experiences.

Systems Engineering Expert Knowledge (SEEK)

PI: Jon Wade, Ph.D. (Stevens Institute of Technology)
Sponsors: Defense Acquisition Univeristy and ODASD(SE)
Link: http://www.sercuarc.org/projects/seek/

Much of the Systems Engineering and technical role documentation provides a description of the "who", "what" and "when." However, there is very little guidance on the "how." Case studies are a tool that can be used to provide realism and bring systems engineering practice into the classroom. They can be a valuable source of lessons learned and underscore the effect of decision making. It is especially important to capture such lessons learned today given the high percentage of the senior defense acquisition workforce eligible for retirement soon, and the lack of organized processes for capturing and disseminating their knowledge. Moreover, such case studies can be an important complement to other educational resources such as the SEBoK.

The Systems Engineering Expert Knowledge (SEEK) project was a collaboration among researchers at Stevens, Carnegie Mellon University, and the Naval Postgraduate School to develop such case studies. The team followed a data-driven approach in which the case study narrative is supported to the extent possible by collected acquisition data (especially cost and schedule performance), demonstrated program performance against KPPs, and actual program documentation which describes the planned and actual Systems Engineering processes. These sources were complemented by discussions or publications from key program stakeholders. The resulting description of the program's System Engineering practices and results were augmented with discussion questions that were designed to support new course needs at Defense Acquisition University (DAU) in the realm of Reliability and Maintainability, but can also fit into more general Systems Engineering courses at DAU and elsewhere. Two versions (unrestricted and FOUO) of each case study were created in order to share appropriate data with different audiences.

Two case studies have been completed: One on the Expeditionary Fighting Vehicle, a technically ambitious program to develop an armored, fully tracked infantry combat vehicle able to carry 17 combat-equipped Marines. A second case study on the Trident MARK 6 MOD 1 Guidance System examined an acquisition program with a consistent ability to hit or exceed key reliability milestones.

"Systems Engineering Transformation to model-centric is a key enabler for future development and deployment of modern naval air weapon systems. The model-centric methodology will result in the development and deployment of highly capable weapon systems at significant reduced acquisition cycle-time. The modeling research accomplished by the SERC was critical in the determination of SE Transformation feasibility at NAVAIR and helped establish confidence in the cost-effectiveness and practicality of its implementation."

Jaime Guerrero, ***Director, SEDIC - AIR 4.1, NAVAIR***

IMPACT AND TRANSITIONS

SERC PROJECT INCUBATOR

The first instance of the SERC Project Incubator was completed this past year. Of the 29 proposed Incubator projects, 5 were given small grants to propose specific research plans, which were reviewed at a July 2015 workshop. Two projects, Foundations of Systems Engineering (U.Virginia) and Model-Centric Collaborative Environments (Wayne State) were recommended for follow-on workshops for further definition. Three proposed projects were identified for funding and scheduled to begin in 2016. Each has synergies with ongoing SERC projects. System Safety (TAMU) has strong connections with the CMU Systems Assurance project and with the multi-university System Qualities Ontology, Tradespace and Affordability (SQOTA) project. Technical Debt (SMU) has strong connections with the Maintainability focus of the SQOTA project. The focus of Formal Methods of Resilient Systems Design (USC) on Unmanned Air Vehicles (UAVs) adaptive control has strong connections with the UAV-oriented Systems Security (UVa) project and the AFIT-NPS tradespace modeling of Intelligence, Surveillance, and Reconnaissance (ISR) UAV missions.

SERC INNOVATION AND DEMONSTRATION LAB (SIDL)

The IDL virtual facility is intended to be the first stop for a systems engineering researcher. The virtual face of the facility will be integrated within the SERC website, containing the source code and data files for research that is conducted at the SERC. In addition, the site will contain a description of System Engineering (SE) methods, processes, and tools (MPTs) along with online demonstrations, videos, instructions, and downloads for SERC developed tools, open source tools, and URLs for often used commercial tools. This material will all be linked to the reports, papers, and other documentation relating to SERC sponsored research. At a future date, this may be linked to non-SERC sponsored SE research as well. Wikis and chat rooms will provide the means by which SE researchers can share their experiences with these tool sets. One possibility is that a distribution, packaged with all of the available open source SE tools that can run in that environment, can be made available as a downloadable SE research starter kit. The SERC will provide expertise and assistance to SERC collaborating researchers to ensure that their research tools, data, and results are shareable on the IDL.

The central physical facility is currently instantiated at Stevens Institute of Technology in Hoboken, NJ as an immersive environment consisting of multiple vertically-mounted touchscreen displays along with the necessary computer hardware to run simulations and drive the graphical environment. There is also a touchscreen Video Wall, a touchscreen Smartboard and a touchscreen Portrait display which hosts popular and interactive research. Beyond the hardware and software, this lab is designed to provide multiple benefits to the SERC researchers and staff. Additional physical facilities of various capabilities will be supported at other SERC collaborating institutions. These facilities will be supported by their host collaborating institutions but will provide an environment to demonstrate SERC research to interested parties near those sites.

SERC MOBILE IMMERSION LAB (SMIL)

The SERC Mobile Immersion Lab was designed to be a mobile implementation of the SERC Innovation and Demonstration Lab having the same capabilities and functions in a slightly smaller and mobile package. This mobile implementation is currently instantiated at Stevens Institute of Technology in Washington, DC as an immersive environment consisting of five vertically-mounted touchscreen displays along with the necessary computer hardware to run simulations and drive the graphical environment. Beyond the hardware and software, this lab is designed to provide multiple benefits to the SERC researchers and staff. Additional physical facilities of various capabilities will be supported at other SERC collaborating institutions. These facilities will be supported by their host collaborating institutions but will provide an environment to demonstrate SERC research to interested parties near those sites. This Mobile Immersion Lab can also be used in conjunction with other Mobile Immersion Labs to collaborate in networked demonstrations and research. The SERC Mobile Immersion Lab made its debut at the SSRR in Washington DC in December 2015.

ANNUAL EVENTS

Each year, the SERC holds annual events and reviews to showcase the research conducted by its Collaborators, Doctoral Fellows, and graduate students. These annual events present the opportunity to learn first-hand about current and planned SERC projects, about the many research interests of the SERC collaborators and Doctoral Fellows, and to meet dozens of faculty and students who are conducting SERC-funded research. Through such interaction, we hope to better understand the sponsor needs and to strengthen and focus the community of systems engineering researchers on projects and research that provide the highest practical value and can easily transition into active use within the sponsor's operational communities.

SERC SPONSOR RESEARCH REVIEW

The SERC Sponsor Research Review is a one-day, sponsor-focused event held in Washington, DC. This event unites the government, industry, and university systems engineering research community in order to share research progress and discuss the most challenging systems engineering issues facing the Department of Defense. Since its inception as a University Affiliated Research Center, the SERC research strategy has evolved to incorporate four key areas: Enterprises and Systems of Systems, Trusted Systems, Systems Engineering and Management Transformation, and Human Capital Development. The SSRR program and sessions focus on the research results that we have achieved in each of these key areas.

SERC TECHNICAL REVIEWS

SERC Technical reviews were conducted in several different forums in 2015. At the Conference of Systems Engineering Research (CSER) held at Stevens on March 17-19, many papers based on SERC sponsored research were presented and reviewed. In addition, a separate research track was established focused specifically on SERC research that did not have publications in the main research track. The SSRR, conducted on December 3, 2015, reviewed the research of 20 projects with sponsors, academics, FFRDC and industrial partners' publications in the main research track. Finally, internal research reviews were conducted in each research project with the sponsors, researchers and other parties.

"Our involvement with the SERC Helix research provides an external assessment of our workforce; this external assessment confirmed some of our understanding of the workforce and highlighted some areas where we could focus improvements. We have also compared the ATLAS model against our internal assessment model and find it to be compatible."

Al Stanbury, ***Associate, Systems Engineering Directorate***
Malcolm Baldrige National Quality Award - 2007 Recipient

STUDENT ENGAGEMENT

SERC DOCTORAL FELLOWS PROGRAM DESCRIPTION

Leveraging an exceptional foundation of education and training, the SERC Doctoral Fellows Program consists of selected SERC Collaborator Universities and participating U.S.-based organizations that nominate and select employees to become Ph.D. students concentrating on systems-related research that is consistent with the SERC's charter. The SERC Doctoral Fellows Program is not a scholarship program. Rather, participating organizations sponsor a specific number of Doctoral Fellows each year based upon their size and annual revenue. Fellows receive tuition reimbursement from their sponsoring organizations and are allocated one work day per week to dedicate toward their doctoral studies and research. If your organization desires to participate in this unique program, please contact the SERC at your earliest convenience.

SERC DOCTORAL STUDENTS FORUM

The SERC Doctoral Students Forum provides an opportunity for doctoral students conducting highly relevant, systems engineering-related research at any of the SERC collaborating universities to present their research in an open forum, regardless of whether or not the research was conducted through a SERC research task. This half-day event drives high impact by exposing the attendees to research that they may not have otherwise encountered. Attendance at the SERC Doctoral Students Forum is open to government, industry, and academic institutions.

For more information about these annual events, please see the SERC website (**www.sercuarc.org**) or contact a member of the SERC Leadership Team.

BEST STUDENT PAPER/DOCTORAL STUDENT PROFILE

Mr. Paul Beery, of the Naval Postgraduate School, was selected as the winner of the 2015 SERC Student Systems Engineering Research Paper Award for his paper, "A Systems Design Exploration Approach That Illuminates Tradespaces Using Simulation Metamodeling." The submitted papers were judged by the SERC Research Council on the basis of potential impact, advancement to Systems Engineering, originality, technical content and clarity of presentation. Mr. Beery presented his research at the SERC Doctoral Students Forum and the SSRR 2015. Congratulations to Paul for his outstanding research efforts.

CAPSTONE MARKETPLACE

Capstone Marketplace addresses the critical challenge of developing the next generation of systems engineering talent for future Department of Defense and industry needs. The complexity of today's defense systems drives a demand for systems engineering talent, and today's systems engineers must design systems that are resilient to unknown missions and creative adversaries. Great engineers require technical depth, breadth, and leadership skills to deal with today's complex systems. Most engineers, however, graduate with depth in one discipline, but with limited breadth and leadership skills. The lack of breadth and leadership skills impact the student as they are immersed in industry, hindering systems engineering, systems thinking, and design. Creating multidisciplinary student teams and pairing them with challenging engineering projects from industry helps students gain better insight into systems engineering, systems thinking, leadership qualities, and gain a better appreciation of the differences in methods and tools of different engineering disciplines. The project sponsors provide domain expertise and advise, while faculty supervisors help guide the teams and grade their work. The Capstone Marketplace website (**www.capstonemarketplace.org**) makes it easy for sponsors to reach out to potential students, and it helps the students find projects best matched to their interests.

SERC LEADERSHIP

For full bios visit ***http://www.sercuarc.org/serc-leadership/***

Barry Boehm
Chief Scientist, SERC

Megan Clifford
Manager of Program Operations, SERC

Mitchell Kerman
Director of Program Development and Transition, SERC

Art Pyster
Chief Operating Officer, SERC

Monica Ruiz
Manager of Financial Operations, SERC

Dinesh Verma
Executive Director, SERC

Jon Wade
Chief Technology Officer, SERC

SERC ADVISORY BOARD

For full bios visit ***http://www.sercuarc.org/serc-advisory-board/***

Major General Curtis M. Bedke
US Air Force (Retired)

Lieutenant General Ted Bowlds
US Air Force (Retired)

Victoria Cox
Assistant Administrator for NextGen at the Federal Aviation Administration (Retired)

Dr. Ruth David
President and CEO of Analytic Services Inc. (Retired)

Alfred Grasso
President and CEO, The MITRE Corporation

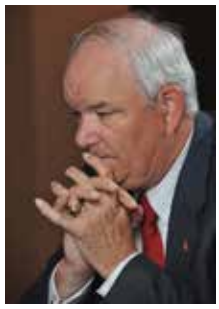
Dr. Michael D. Griffin
Chairman and CEO of Schafer Corporation; Chairman, SERC Advisory Board

Major General Nick Justice
US Army (Retired) Executive Director of PowerAmerica

David Long
President, INCOSE

Dr. Steve Rottler
Vice President, California Laboratory & Energy, Climate and Infrastructure Security Sandia National Laboratories

CAPT William M. Shepherd
US Navy (Retired), NASA Astronaut (Retired), Science Advisor, US Special Operations Command (Former)



The Honorable Michael Wynne
21st Secretary of the Air Force (Retired), Emeritus member and former Chairman of the SERC Advisory Board

SERC RESEARCH COUNCIL

For full bios visit ***http://www.sercuarc.org/serc-research-council/***

ENTERPRISES AND SYSTEMS OF SYSTEMS

William B. Rouse

Alexander Crombie Humphreys Chair in Economics of Engineering, Stevens Institute of Technology

Daniel A. DeLaurentis

Associate Professor, School of Aeronautics & Astronautics, Purdue University

Jo Ann Lane

Co-Director of the Center for Systems and Software Engineering at the University of Southern California

TRUSTED SYSTEMS

Barry Horowitz

Munster Professor of Systems and Information Engineering and Chair, University of Virginia

William Scherlis

Professor and Director, Institute for Software Research, Carnegie Mellon University

HUMAN CAPITAL DEVELOPMENT

Tom McDermott

Director of Technology Policy Initiative. Sam Nunn School of International Affairs, Georgia Institute of Technology

Jon Wade

Distinguished Research Professor, Stevens Institute of Technology

SE AND SM TRANSFORMATION

Barry Boehm

Distinguished Professor of Computer Sciences, Industrial and Systems Engineering, and Astronautics, and Director of the Center for Systems and Software Engineering, University of Southern California.

Paul Collopy

Chair, Industrial and Systems Engineering and Engineering Management,University of Alabama in Huntsville

ABOUT THE SERC

The Systems Engineering Research Center (SERC), a University-Affiliated Research Center of the US Department of Defense, leverages the research and expertise of senior lead researchers from 22 collaborator universities throughout the United States. The SERC is unprecedented in the depth and breadth of its reach, leadership, and citizenship in systems engineering through its conduct of vitally important research and the education of future systems engineering leaders, including through the SERC Doctoral Fellows Program (see page 15).

Begun in 2008 and led by Stevens Institute of Technology and principal collaborator, the University of Southern California (USC), the SERC is a national resource providing a critical mass of systems engineering researchers—a community of broad experience, deep knowledge, and diverse interests. SERC researchers have worked across a wide variety of domains and industries, and bring that wide-ranging wealth of experience and expertise to their research. Establishing such a community of focused SE researchers, while difficult, delivers impact well beyond what any one university could accomplish.

BECOMING A SPONSOR

Since 2008, SERC research sponsors have benefited from research performed by nearly 500 faculty, staff, and students across the SERC Collaborator universities. Any US Government organization can benefit from the SERC by sponsoring systems research or by adopting the results of research sponsored by others.

Interested government organizations should contact the SERC's primary sponsor, the Deputy Assistant Secretary of Defense for Systems Engineering, to discuss their needs and determine if addressing them is within the scope of the SERC's mission. If it is, the organization will refine those needs and the SERC will respond with its technical approach, cost estimate, and deliverables. The SERC will then select a principal investigator and a team of researchers to perform the work and deliver results and value to the funding organization. Unless specifically limited, results are published and available for inclusion in education and transition activities across the systems engineering community.

University or Research Organization

1. Stevens Institute of Technology
2. University of Southern California
3. Air Force Institute of Technology
4. Auburn University
5. Carnegie Mellon University
6. Georgetown University
7. Georgia Institute of Technology
8. Massachusetts Institute of Technology
9. Missouri University of Science and Technology
10. Naval Postgraduate School
11. North Carolina Agricultural & Technical State University
12. Pennsylvania State University
13. Purdue University
14. Southern Methodist University
15. Texas A&M University
16. Texas Tech University
17. University of Alabama in Huntsville
18. University of California - San Diego
19. University of Maryland
20. University of Massachusetts Amherst
21. University of Virginia
22. Wayne State University

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