SYSTEMS ENGINEERING RESEARCH CENTER

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

2016 ANNUAL REPORT

STRENGTHENING THE SYSTEMS RESEARCH NETWORK IN THE U.S.

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GREETINGS FROM THE EXECUTIVE DIRECTOR

The SERC research network of today is strengthened by the thought leadership of our Principal Investigators, exceptional contributions of our university and research collaborators, unwavering support of our sponsors, the dedication of our SERC Research Council, and the counsel of our SERC Advisory Board.

It is in this context that I am pleased to present this year's annual report which focuses on the critical theme of "Strengthening the Systems Research Network in the U.S." The theme reflects on the achievements of 2016 and the trajectory of the SERC network going forward.

The SERC provides a unique interconnection of customer needs, research capabilities, and broad user transition coalitions. We now have a strong platform of 22 university and research organizations distributed across the country. We are connected in taking important steps towards responding to the global challenges of our customers. This, we achieve, by leveraging and applying world-class research and providing measurable impact for our customers, as well as people around the world.

The continued strength of our research network is wholly reliant upon a number of factors:

- Deep-rooted, trust-based relationships with our sponsors and customers enable the systems research network to align our efforts with their needs and expectations.
- Collaborating 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), the MITRE Corporation, the Applied Physics Laboratory, and others within the defense Industry.
- Talented and thoughtful researchers from our collaborating universities, each bringing broad systems expertise across multiple domains.
- High quality research outputs and effective synergies across research tasks taking place across the SERC network nationwide.
- Broad engineering community collaborating on peer review of publications and participating in conferences, working groups and joint projects.

In 2015, our theme was "Technical Excellence." Whether it is working shoulder-to-shoulder with our customers to help them meet their critical challenges or empower them to capitalize on big opportunities with increasingly relevant systems research, our commitment to delivering technical excellence remains unwavering.

Building upon that objective, we aim to strengthen the systems research network through our strategic alliances with thought leaders, as well as new initiatives to help address the disruptive challenges topping the agenda of the SERC Leadership Council, SERC Advisory Board and SERC Research Council.

"Strengthening the Systems Research Network in the U.S." requires that our research results are useful and available to our customers through multiple avenues, including new programs that we launched last year such as SERC Talks. This year's theme necessitates continued focus on solving difficult systems engineering problems across the four research areas critical to our sponsors and customers. What's more, we continue to scan the horizon for undiscovered solutions, as well as support the education and development of tomorrow's systems engineers.

In this report, we present you snippets of the work the SERC network is undertaking. It highlights some of our current research – by no means an exhaustive list – but it should give great insight as to the strength of our network and provide a preview of where we are headed. And we invite you to learn more by visiting the SERC website to get more concrete details of the work of our systems research network.

Customers are increasingly looking for us to help solve systems challenges in an age where accelerated pace of change and technology disruption are the norm. The SERC has never been more prepared to help customers transform, adapt, and take advantage of new systems opportunities. I am very excited about the SERC community, and how together, we can strengthen the systems network in 2017 and beyond.

Dinesh Verma

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

SERC TALKS

Launched on June 1, 2016 SERC Talks is a bi-monthly, research webinar series featuring researchers from our systems engineering community sharing their insight on critical future systems engineering challenge areas. Dr. Barry Boehm, our Editor-in-Chief of the Series curated the Talks to focus on following themes through 2017:

- **Model-Centric Systems Engineering**
- **Cyber-Physical-Human Learning Systems**
- **Cyber Security Systems Engineering**

SERC Talks originated from the technical presentations which took place periodically during our SERC Collaborator WebEx meetings, and by popular demand, became a public forum that will continue to grow and explore the evolution of systems engineering. Aspiring to create an ongoing and more collaborative dialogue between academia, government, and industry sectors, SERC continues to serve as a vehicle to grow systems engineering research into areas which can transition into impact. This series' impact extends beyond the individual participants, as many sites incorporate SERC Talks into working groups and classrooms. The sessions are recorded and available for viewing on the SERC website and SERC YouTube channel.

Participation: The attendance ratio for those attending the live event reach 46% (industry standard marks optimal attendance between 40-50%). Participants were about evenly spread among industry, academia, government, and FFRDCs. An archive of each recorded session is hosted on YouTube for asynchronous participation.

Engagement: SERC Talk participants stay engaged through 52 minutes of the 60 minute talk, leaving some time for questions and answers, with an 86% attention rate throughout the series.

2016 SERC TALKS

TITLE, PRESENTER	DATE
We Need a New Design Perspective for Socio-Technical Systems. Can Complex Network Perspective Be a Viable Candidate? Dr. Babak Heydari, Stevens Institute of Technology	June 1, 2016
What Were the Top Issues and Opportunities from the SERC Model-Centric Design and Acquisition Forum? Dr. Dinesh Verma, Dr. Mark Blackburn and Megan Clifford, Stevens Institute of Technology	Aug. 3, 2016
What Lives at the Intersection of MOSA and Set-Based Design? Dr. Gary Witus, Wayne State University	Oct. 19, 2016
Why is Human-Model Interactivity Important to the Future of Model-Centric Systems Engineering? Dr. Donna Rhodes & Dr. Adam Ross, MIT	Dec. 7, 2016

Dates for future SERC Talks are available at http://www.sercuarc.org/serc-talks

"The International Council on Systems Engineering (INCOSE) partnership with SERC is a key enabler for the global advancement of systems engineering. The BKCASE Project that created both the Guide to the SE Body of Knowledge (SEBoK) and the Graduate Reference Curriculum for SE (GRCSE) has contributed to the whole systems engineering community, and in doing so strengthened international collaboration. SERC work on Helix, supported by INCOSE, is helping us understand how to develop even more effective systems engineers. And looking to the future we are working together to understand the right systems research vision that will help the global SE community address the complexities and challenges of the future. This is a valuable partnership which continues to innovate and deliver excellent outcomes that are enabling, promoting, and advancing Systems Engineering and systems approaches."

Alan Harding, ***CEng FIET***
INCOSE President 2016-2018

CONTENTS

SERC NAV INTRODUCTION

The SERC NAV, short for Network Analysis and Visualization, is a software tool that was initially developed to capture and allow users to visually interact with data and relationships that exist in the SERC ecosystem. Those data and relationships include professors, universities, research projects, publications, and metadata about the persons involved. The idea is that users would interact with the SERC NAV Interface which would visualize the data and relationships within the SERC NAV. Users would be able to click the visualized data on the screen and navigate between data that is related to each other. In this way, users would be able to visually traverse the database and discover the composition of the SERC with regard to research being performed, persons related to the research, universities who collaborate with the SERC, publications related to the research and many other data that exists. An example of the SERC NAV when looking at the relationship between the SERC and the SERC's Collaborating Universities is illustrated below:

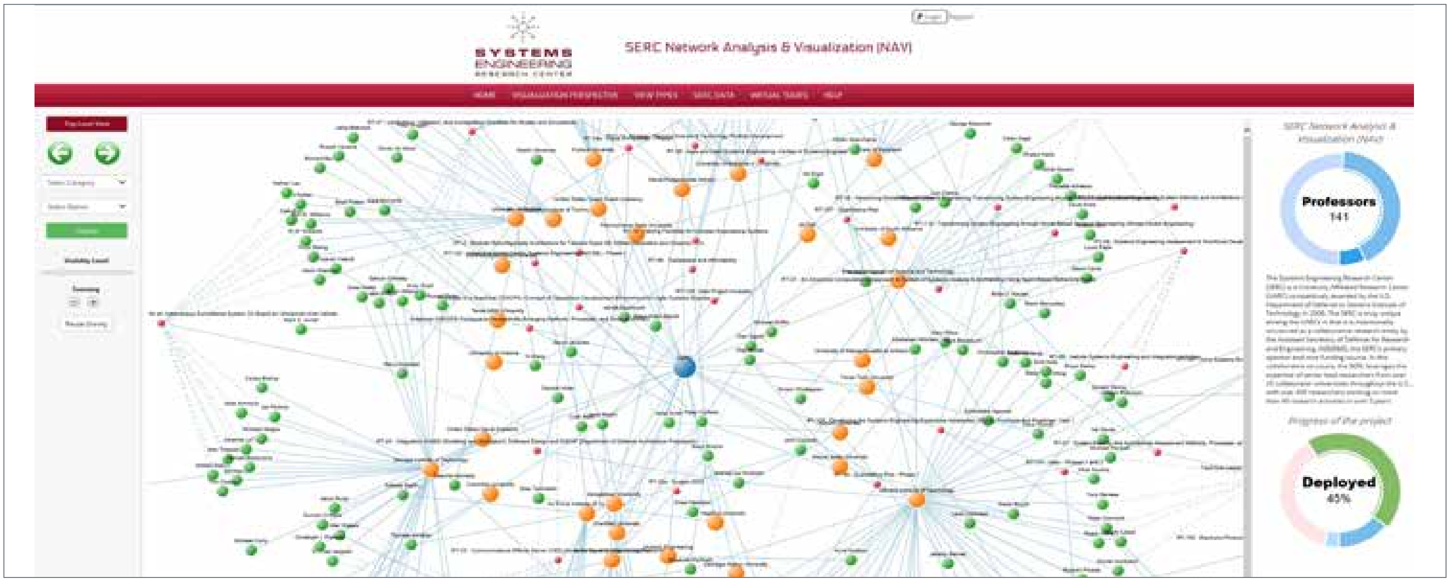

Figure 1

Visualization Perspectives

Since the data that is contained in the SERC NAV database is vast, trying to visualize all the data at one time would not be comprehensible. The SERC NAV uses what we call Perspectives to define a subset of data that we use to visualize. Each Perspective has a unique characteristic. For instance one is named the University-PI Perspective. This Perspective encapsulates data such as the SERC itself, all SERC collaborating Universities, all the Principal Investigators and Co-Principal Investigators that are related to each University, all Research Tasks that are related to each Principal Investigator and Publications that are connected to each Principal Investigator. Other Perspectives also exist. For instance we can look at the relationships of the same data, but instead of how the Research is related to the Principal Investigators, it is organized by SERC Thrust Categories. We call this the Thrust-Category Perspective. These Perspectives will be able to be defined and created by the SERC NAV Administrator.

As a user traverses the data in SERC NAV, they will discover the successive relationships to other data. An example of this is shown below where the Green Sphere represents a Principal Investigator, Dr. Jon Wade and the Research Projects (Red Spheres) that Dr. Wade is connected to. The solid lines indicate Dr. Wade is a Principal Investigator to the Research Projects and the dotted lines indicate that Dr. Wade is a Co- Principal Investigator to the Research Projects. You can also see that Dr. Jon Wade is connected to the Stevens Institute of Technology. In this image we also see one degree of connectivity between the centroid (Dr. Jon Wade) and the data that Dr. Wade is connected to. We intend to allow the user to change the degree on connectivity as desired.

Research Project Web Pages

All SERC Research Projects will have their own Web Page on the SERC NAV. Each Research Web Page will contain information about each Research Project, artifacts from that Research Project, Simulations, White Papers and Technical Reports will also be available on the Research Web Page. Each Research Web Page will be managed by both the SERC NAV Administrator and the actual Principal Investigator for that Research Project.

User Registration and Logins

Users of the SERC NAV will be able to Register and Login to the system. Depending on the user's Login type, that user will have different privileges. For instance, a Principal Investigator will be able to Register / Login and have access to edit their own Research Web Page. All SERC NAV Registered Users will have the opportunity to complete their own profile data. Parts of this data, once entered and approved by the SERC NAV Administrator, will be available for SERC NAV Visualization.

SERC NAV Future

The SERC NAV Engine was designed in a way such that future enhancements can be added without major architectural changes. We envision that once the SERC NAV is deployed, Report type algorithms and interfaces will then be created and added to the SERC NAV so that daily SERC operations will be made easier and more efficient.

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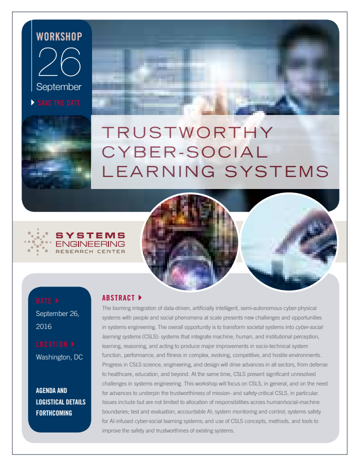
FORUMS

MODEL-CENTRIC ENGINEERING FORUM: The intent of the *Model-Centric Engineering Forum* was to enable discussions between key stakeholders and thought leaders on challenges, issues, concerns, and enablers for a transformation towards model-centric engineering. The forum served as a platform for members in industry, government, and academia to share ideas on how we could collectively operate in a transformed world of model-centric engineering in acquisition. Presentations, panels, and breakout sessions reflected on enabling tools, technologies and concepts for new business models within such an ecosystem that facilitates coordination and collaboration, and can be addressed through focused research and policy. As the three contextual talks addressed practice, acquisition, and research, the two panel sessions explored how government and industry can collaborate more effectively. The breakout sessions explored an industry and government collaboration operational model and the capabilities for a new operational paradigm. Capabilities, opportunities, barriers, and breakthroughs were identified and condensed in both sessions and can be found in the workshop report. During the course of the day, recurrent themes clustered into four perceived areas of benefit: 1-Improved acquisition, 2-Improved efficiency and effectiveness, 3-Improved communication: better trade space exploration; reduced risk, 4-Improved designs and resulting systems and solutions.

MODULAR OPEN SYSTEMS APPROACH (MOSA): TOWARDS COST EFFECTIVE ACQUISITION STRATEGY
As part of SERC project RT-163, a workshop was held October 5th, 2016 on *Modular Open Systems Approach (MOSA): Towards Cost Effective Acquisition Strategy*. 31 attendees [13 Government, 6 Industry, 12 Academia] addressed questions on how to: 1) define modularity and openness perspectives (technical and programmatic) in an ecosystem concept; 2) quantify costs, benefits, and risks of modularization across multiple stakeholder dimensions; and 3) identify compatible policies to capitalize on positive aspects of modularization. Workshop findings included:

- A need for long-term business strategies, drivers and objective measures of benefit from MOSA for each stakeholder
- Modularity is not a useful output measure; instead measures and tools are needed to assess consequences of modularization choices, especially under multiple uncertainties
- Need for feedback mechanisms to help stakeholders understand localized and collective impact from strategies in a MOSA ecosystem
- Need for a case study repository containing best practices, tacit knowledge and anecdotes mapped to appropriate stages of the acquisition process

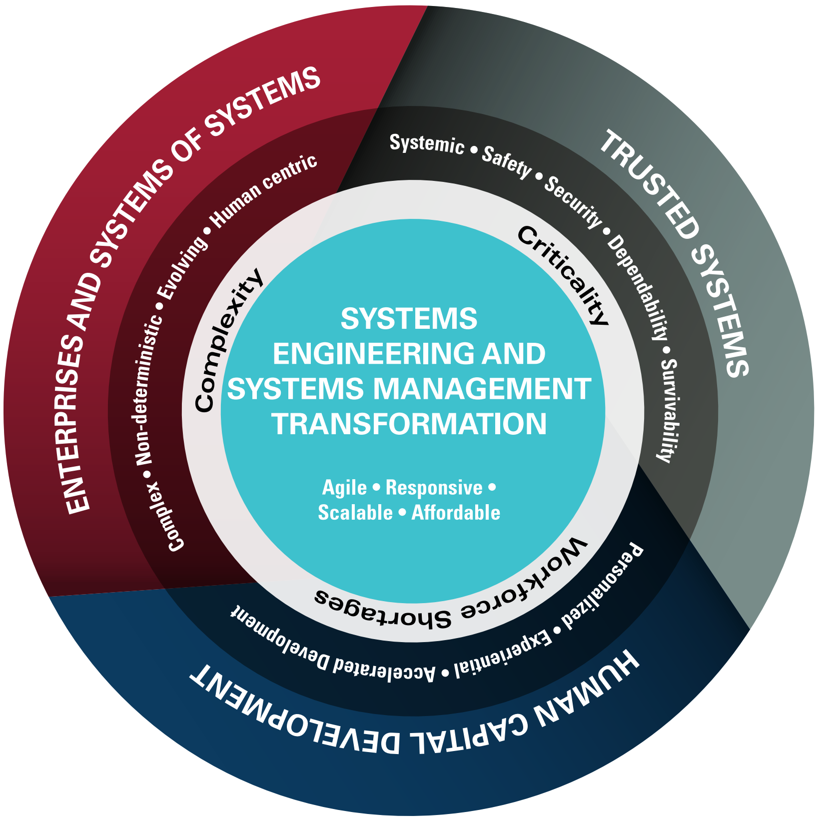


CYBER SOCIAL LEARNING SYSTEMS: On September 26, 2016, Kevin Sullivan ran the *SERC Workshop on Trusted and Trustworthy Cyber-Social Learning Systems*. The workshop brought together 13 international experts in dependable cyber-physical systems, system safety, human-in-the-loop cyber-physical systems, artificial intelligence, and cyber-enabled, human-intensive, and learning systems (with acute healthcare delivery systems, supported by advanced predictive analytics as a form of autonomy at rest, as a case study in cyber-physical-human learning systems).

The problem this workshop addressed was our lack of systems engineering concepts, models, methods, and tools for rigorous safety/dependability engineering in the development, operation, and evolution of human-intensive, CPS- and AI-enabled, learning systems. By learning systems, we mean systems that learn at all levels, across the systems lifecycle, including machine learning, individual human learning, organizational learning, and cross-organizational learning at scale.

At the heart of the matter was the idea that continual learning poses major opportunities for defense, but also major challenges to the field of systems engineering. Key issues addressed included: (1) the need for far more nuanced and dynamic models of trust and trustworthiness, including methods for machine-human calibration and communication of trust and trustworthiness; (2) the inability of, and need for, autonomous systems based on machine-learning to determine when they are operating outside of their envelopes of competence; (3) the difficulties involved in setting and communicating objective functions for human-machine systems to optimize; (4) challenges in integrating machine learning systems with human and social components of complex systems; (5) the need for concepts, models, methods, and tools to integrate ethical considerations into the development, operation, and evolution of learning systems; (6) how and for what kinds of systems a variety of methods, from testing to proof engineering, can be used for dependability assurance of cyber-physical-human learning systems across the lifecycle, including during the post-deployment operational stages; (7) challenges posed by advances in these area for systems acquisition, workforce development, and software engineering quality and competency.

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: *Providing ways to develop, characterize and evolve 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: *Providing 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: *Providing ways to acquire complex systems with rapidly changing requirements and technology, which are being deployed into evolving legacy environments.* Decision-making capabilities to manage these systems are critical in order to determine how and when to apply different strategies and approaches, and how enduring architectures may be used to allow an agile response. 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: *Providing ways to ensure that the quality and quantity of systems engineers and technical leaders provide a competitive advantage for the DoD and defense industrial base.* Research must determine the critical knowledge and skills that the DoD and IC workforce require as well as determine the best means to continually impart that knowledge and skills.

The first update to the SERC Technical Plan 2013 – 2018 was completed in December 2015 and describes progress since the Assistant Secretary of Defense for Research and Engineering approved the original SERC Technical Plan in October 2013. 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. Preparation has already been initiated on the development of the next Technical Plan for 2018-2023. The current Technical Plan has been quite successful in bringing synergy and cohesion to projects within each program, as shown in the Systemigram below.

Moving forward, the objective of the future Technical Plan will be to extend this more broadly within and across the research focus areas addressing more specific, higher-level grand challenges. Work has taken place in conjunction with the International Council of Systems Engineering (INCOSE) in a series of workshops that have identified a number of systems-related society grand challenges, and will define the systems engineering gaps and areas of research focus to address these.

Between October 1, 2013 and December 31, 2016 research on the eleven programs in the Technical Plan has been packaged into 59 projects which have been awarded more than $16M in Core funds plus more than $9M from other DoD organizations, including all the Services, Defense Acquisition University, and elements of the Intelligence Community. In several cases, those non-Core funds augmented existing projects. These projects have been delivering methods, processes, and tools (MPTs) in each of the four research areas that define the SERC research portfolio, contributing towards achieving the Grand Challenges. Transition has also been ongoing and growing, with many acquisition programs and defense organizations piloting and adopting SERC MPTs as they have matured. Since October 2013, when the SERC began executing this plan, SERC researchers have delivered more than 300 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 research projects can be demonstrated, either individually or in coordinated groups.

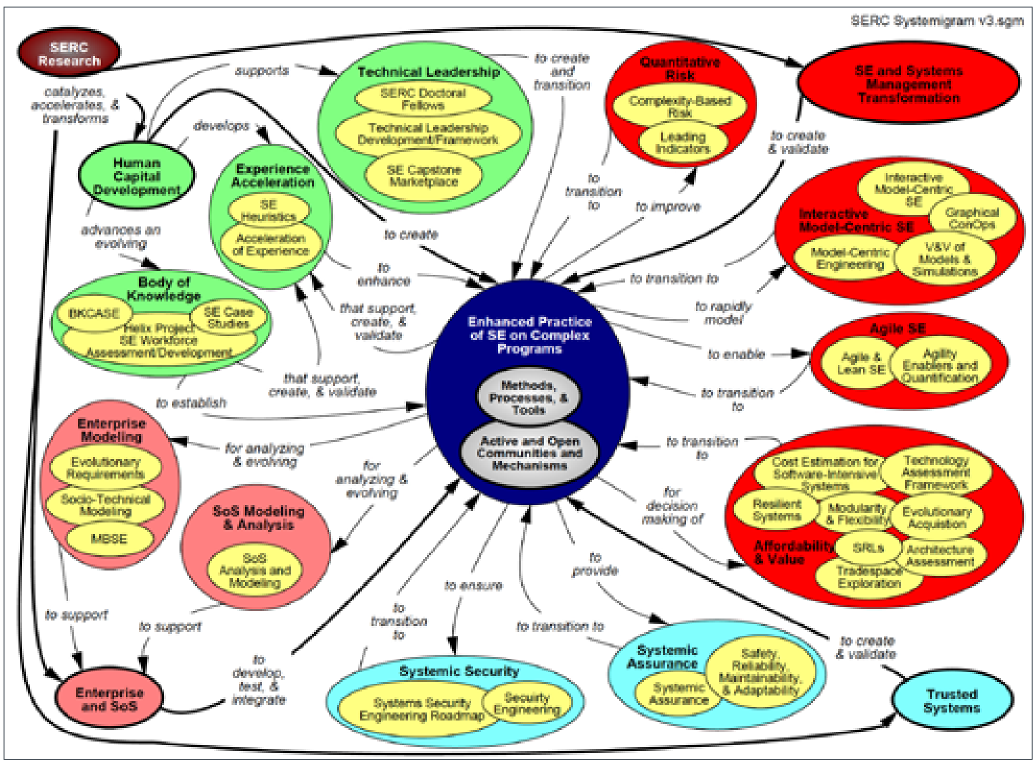


Figure 1

ANNUAL EVENTS

SERC SPONSOR RESEARCH REVIEW

This one-day, sponsor-focused event is held in Washington, DC. The SSRR unites the government, industry, and academic systems engineering research community in order to share research progress and discuss the most challenging systems engineering issues facing the Department of Defense. The SSRR program and sessions focus on the research results achieved in each of four thematic areas. The platform provides exposure to find further potential collaboration and refinement of the work being done. The 2016 SSRR saw increased participation, while the research showed maturity and readiness for transition. The next SSRR will be on Nov. 8th, 2017 at FHI360 located on the 8th floor at 1825 Connecticut Ave., Washington, DC 20009.

	2009	SSRR 2015	SSRR 2016
Academia	47	56	77
Government	19	44	52
Industry	4	20	7
Total	**70**	**120**	**136**

In this section, we spotlight several research projects from each of the focus areas that were underway in 2016, and that illustrate the diversity of approaches, strategies, and outcomes of the SERC as a whole.

ENTERPRISES AND SYSTEMS OF SYSTEMS

Enterprise Analysis

PI: Dr. Michael Pennock (Stevens Institute of Technology)

Sponsor: ODASD(SE)

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

Many of the challenges that confront the Department of Defense (DoD) are characterized by the intersection of complex social, political, economic, and technical phenomena where conventional modeling techniques are inadequate. Examples include:

- Managing joint and international acquisition programs
- Coordinating disaster and humanitarian responses involving governments, NGOs, and US agencies
- Sustaining the defense supplier base in the face of declining acquisition quantities
- Providing healthcare to service members and their families

Each of these situations involves the interaction of independent organizations with differing objectives with direct impacts on the performance, operation, and sustainment of technical systems. Human and organizational effects can dominate technical outcomes. Such effects have been difficult to capture in traditional engineering modeling and analysis approaches.

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. The goal is to better enable policy makers and decision makers to:

- Explore the salient features of the enterprise system
    - Identify the key drivers of system behavior and resulting outcomes
- Perform "what if" analyses
    - Evaluate the efficacy of policy options to alter system behavior and outcomes
- "Test drive" the future
    - Allow key stakeholders to experience the behavior of the "to be" system

Results in 2016:

- Completed the development and review of 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 include the DoD, DoJ, and CBP. (See Figure 1).
- The outcome of the counterfeit parts case study was that the simulation could be a useful mechanism for integrating the knowledge of a diverse group of subject matter experts about the potential impact of a policy and conveying that knowledge to non-experts.
- Identified the need for a capability to systematically identify counterintuitive policy impacts that subject matter experts may miss.

Activities in 2016:

- Extend the modeling approach to detect unintended or counterintuitive impacts of a policy that result from interactions among phenomena at different scales.
- Develop a case study on critical infrastructure protection to test new updates to the modeling methodology
- Refine the modeling methodology based on the results of the case study

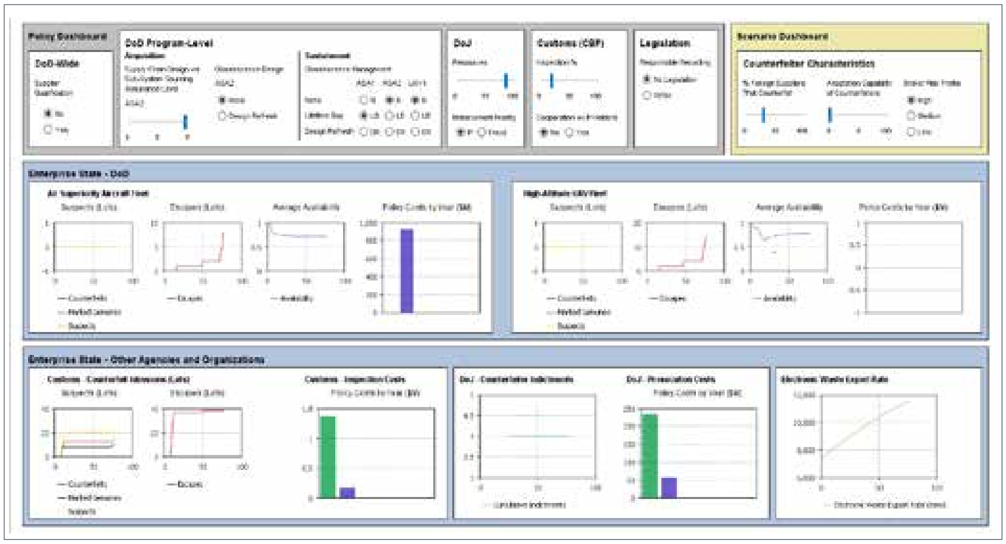


Figure 1 - User Interface for the Counterfeit Parts Enterprise Model

Analytic Workbench

The development of a large group of interdependently operating systems, or ‘System of Systems (SoS)’, presents significant challenges across technical, operational and programmatic dimensions. Trades between cost, schedule, performance, and various risks, are essential during analysis of alternatives for both individual systems and the SoS architecture. Often, decisions are made at the systems level with little consideration for cascading effects on the bigger SoS. The large number of decision variables involved, ubiquitous uncertainty, and complex interactions that exist between systems create analysis problems that go well beyond the immediate mental faculties of decision-makers.

The Department of Defense (DoD) has developed guidance on managing the development of SoS architectures. However, to enable effective SoS SE management and support, this high-level guidance must be complemented by an appropriate collection of methods, processes and tools to support SoS architectural decision-making. Our research is part of a multi-year effort that seeks to establish an ‘System of Systems Analytic Workbench’ of computational tools that can aid SoS practitioners in making better-informed decisions on evolving SoS architectures.

Typical architectural questions asked by SoS practitioners, across the spectrum of relevant interdependent domains, have several commonalities. Through this research task, “Assessing the Impact of Development Disruptions and Dependencies in Analysis of Alternative of System of Systems,” we map these archetypal queries to a small collection of relevant methods, processes and tools that can provide useful analytical outputs, based on the nature of the query, to directly

PI: Dr. Daniel DeLaurentis (Purdue University)
Co-PI: Dr. Karen Marais (Purdue University)
Sponsor: ODASD(SE)
Link: http://www.sercuarc.org/projects/assessing-the-impact-of-development-disruptions-and-dependencies-in-system-of-systems-sos/

support SoS acquisition and architectural decisions (See Fig. 1). The key focus is to relegate the cognitive complexities of dealing with issues related to highly interconnected systems to the methods, while delegating the decision-making and tradespace exploration aspects to the practitioner.

Our research has focused on a multi-pronged quantitative approach that leverages currently available computational methods, tailored specifically towards addressing the complex technical dimensions that practitioners may face in performing SoS evolutionary actions. These technical complexities span both the operational domain – where systems interact to provide key SoS level capabilities, and the development domain – where schedules of developing yet-to-be introduced systems can have critical impacts on cost and capability.

An initial prototype SoS Analytic Workbench has been shared with our collaborator entities; this prototype includes an online implementation with over 55+ registered users who have accessed or used the toolset. We have also engaged in transitional activities with our core collaborators at MITRE Corporation, Naval Surface Warfare Center Dahlgren Division (NSWCDD), and John Hopkins University Applied Physics Laboratory (JHUAPL), on refinement and use of the tool in their respective environments.

Our continued efforts with collaborators will serve to further refine these tools towards providing greater utility to a range of practitioners while still retaining the domain independence of the tools.

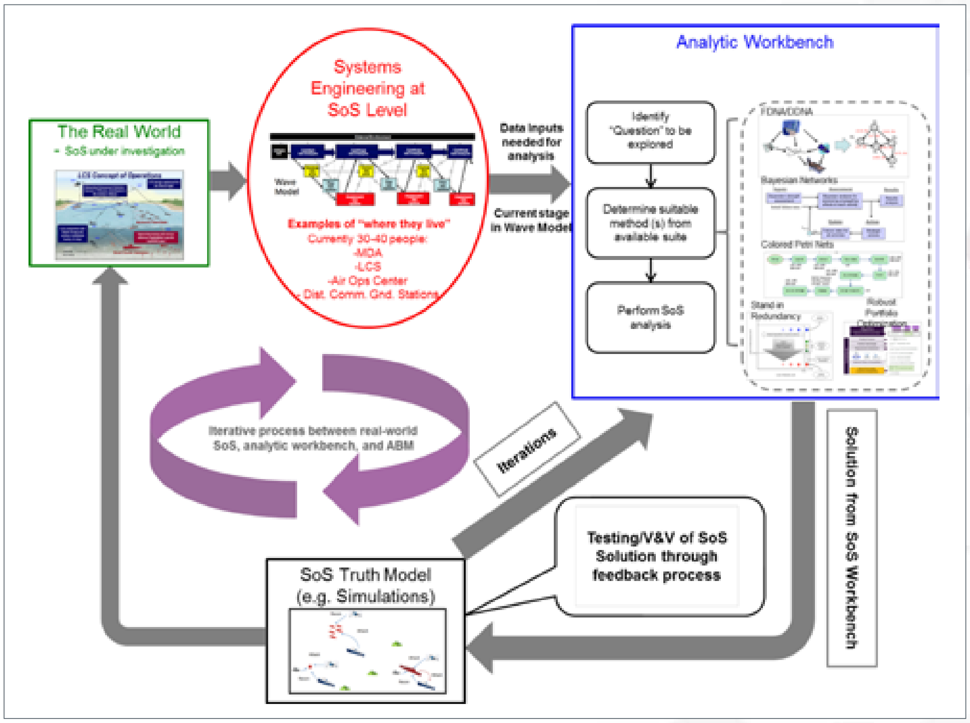


Figure 1 - Mapping Methods to SoS Archetypal Questions

System Aware Cybersecurity

PI: Dr. Barry M. Horowitz (University of Virginia)
Co-PIs: Dr. Peter Beling (University of Virginia); Dr. Cody Fleming (University of Virginia)
Sponsor: ODASD(SE)
Link: http://www.sercuarc.org/projects/security-engineering/

In 2011, the SERC initiated one of the earliest research programs focused on physical system cyber-attack risks to address military concerns regarding potential attacks against physical systems (unmanned aerial vehicles (UAV) and military weapon control systems). The hypothesis was that, based upon design knowledge of the protected system, successful attacks could be detected and corrected by employment of monitoring systems (Sentinels) integrated with the protected physical system. It was hypothesized that the Sentinels could detect inappropriate system behaviors that could be diagnosed as being most likely caused by a cyber-attack. Furthermore, the hypothesis assumed that there would be a significant set of attacks that, even though they were successful, detection and corrections through system reconfigurations could occur rapidly enough so as to eliminate significant consequences and permit continued operation.

It was recognized that in order to provide viable solutions, the Sentinel implementations would need to be highly trusted, and that engineering efforts to develop Sentinel solutions would need to be directed toward meeting the most stringent security requirements. An implicit, but very important additional assumption related to the Sentinel concept, was that Sentinel designs could be of much lower scale and less complexity than the systems they protect. It allowed the employment of an important set of cybersecurity techniques that have been constrained by system scale, complexity and cost when considered for use as part of the system being protected.

The largest fraction of the System Aware Cybersecurity effort to-date has been focused on prototype development and experimentation related to the Sentinel concept described above. Results derived from several prototype development projects (UAV, Virginia State Police automobiles, 3D printers, radar, weapon fire control system, video exploitation ground site) have served to support the original research hypotheses. The learning derived from prototyping projects is resulting in advancing toward initial implementations, as well as exploring new system applications that include important differences in their operational characteristics as related to cyber-attacks.

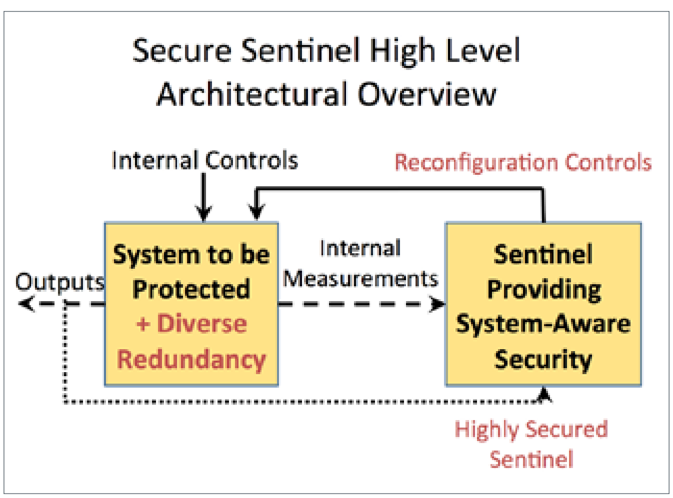


Figure 1 - Secure sentinel high level architectural overview

In the process of conducting operational experiments an unanticipated set of important issues emerged, such as questions as to whether or not to permit automated reconfigurations by the Sentinels. Early results of simulation and live experimental projects have indicated that criteria related to human attributes such as suspicious nature could serve to help identify operators who would be more or less effective in being part of a semi-automated Sentinel-based defense system.

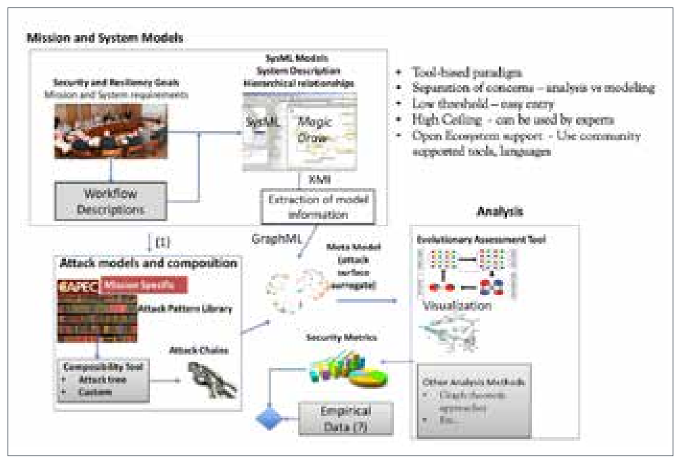


Figure 2 - Model-based decision Support Tools

Another important emergent outcome highlighted the critical need for decision support processes and support tools for deciding on the specific monitoring and control features to include in Sentinel designs. SERC research activities are currently engaged in development of prototype analysis tools to address this mission-focused need, and the Army has been working with the SERC to engage in exploration of the design and employment of needed decision support tools.

The progress and issues discussed above point to the importance of this research activity. The rapid rate of advancements related to cyber-physical systems create a need that requires new cybersecurity solutions at the same pace as the automation advancements that are being made. Based on its results to-date, the SERC is in a very strong position to play a leadership role in supporting the cybersecurity needs of the DoD and other government organizations.

Quantitative Risk

PI: Dr. Gary Witus (Wayne State University)

Sponsor: ODASD(SE)

Link: http://www.sercuarc.org/projects/quantitative-technical-risk/

This project was conducted in collaboration with US Army TARDEC. We developed methods, procedures and tools (MPT) to provide quantitative, evidence-based information regarding sources and magnitude of schedule risk in Engineering and Manufacturing Development (EMD) programs. Some of the risk indicator metrics were derived from the INCOSE System Development Leading Indicators. Others were new risk indicators aligned with “best practices” in program planning and scheduling, employing generally available contractor reporting data.

We tested and demonstrated the methods on an ACAT I Major Defense Acquisition Program, working with the Government’s Risk Management team. The Risk Management team provided feedback on their views of the relevance of the risk indicators, reliability and availability of the input data, and risk perspectives for they would like to have quantitative risk evidence metrics. They had independently come up with some analysis methods that were similar to some of our risk indicators we proposed. Other of our quantitative risk MPT provided them with new and useful analysis, diagnosis and insight. One of the highly-valued MPT is illustrated in figure 1.

Inaccurate and unreliable scheduling estimates are a source of program risk. Biased and inaccurate estimates of task durations are a direct source of risk of schedule overrun relative to the plan. They are also evidence that the management team did not have sufficient understanding of the program difficulty, another source of risk.

We used change in task durations in the quarterly Integrated Master Schedule (IMS) updates, for tasks at level 5 of the Work Breakdown Structure (WBS), limited to tasks that had been begun but not yet completed, to estimate bias and dispersion and to identify tasks with significant duration increases. We found similar results when we took the complementary view comparing the “percent physically complete” as reported in the Earned Value Management (EVM) system to the “percent schedule complete” as reported in the IMS.

Program Schedule Risk Assessments (PSRA) is widely recommended to assess the impact of task duration uncertainty on the likelihood and magnitude of schedule overrun. PSRA uses Monte-Carlo simulation to estimate likelihood and expected magnitude of schedule overrun, based on random draws from the probability distributions of task duration. It accounts for the precedence relationships among the tasks in the IMS PERT network.

We extended PSRA with MPT to identify tasks likely to have a significant impact on program delay, at varying levels of assumed uncertainty in task duration as a percentage of the expected duration. The Risk Management team was especially interested in which tasks were likely to have a significant impact on delay at the measured uncertainty factor that were not on the traditional deterministic critical path, and which tasks became significant risk factors when the uncertainty factor was further increased.

PSRA is not often employed on large-scale programs, or is applied only to a subset of the tasks. There is a significant cost to collect these estimates in an MDAP program such as this with over 5,000 tasks (The contract for the subject EMD program only required PSRA for those tasks that were on the critical path for deterministic times, and the impact of uncertainty in tasks not on the deterministic critical path was not addressed.). It is difficult to obtain estimates on the probability distributions of task times from the engineering leads. Our evidence based approach solves this problem using program data.

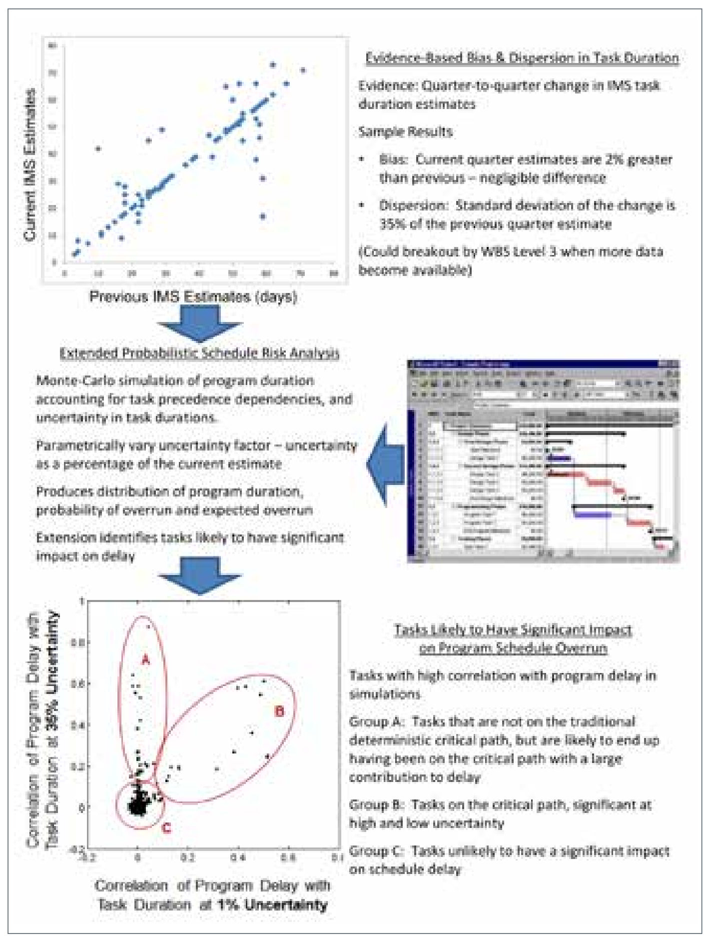


Figure 1 - Evidence-Based Schedule Risk, Sensitivity to Uncertainty Assumptions, and Diagnosis

Interactive Model-Centric Systems Engineering

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

Sponsor: ODASD(SE)

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

The Interactive Model-Centric Systems Engineering (IMCSE) research program arises from the unique opportunity to investigate the various aspects of humans interacting with models and model-generated data, in the context of systems engineering practice. IMCSE research 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 available resources and constraints. While model-based engineering initiatives are advancing technical aspects of models in the engineering of systems, this research advances knowledge relevant to human interaction with models and model-generated information. During the past year IMCSE researchers at MIT continued investigating various aspects of humans interacting with models and model-generated data.

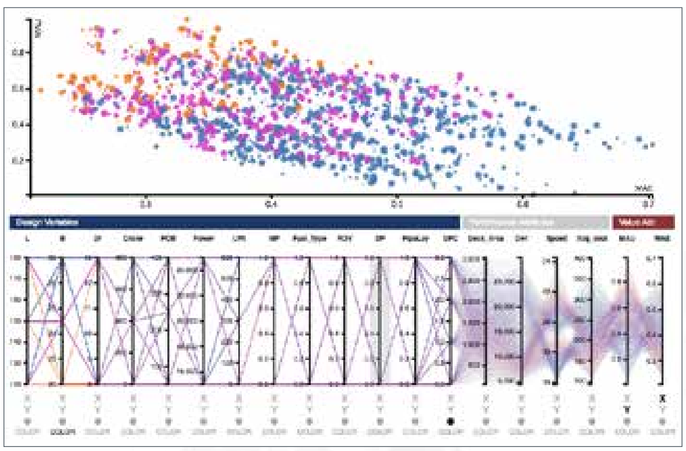


Figure 1 - Interactive Filtering Application for tradespace exploration for the offshore ship design base case

Interactive Epoch-Era Analysis. Continued research was performed on an innovative method for evaluating systems under dynamic uncertainty using epoch-era analysis with focus on enhanced interactive capability and allowing for scaling for big data analysis. The Interactive Epoch-Era Analysis framework and supporting tools were applied to a multi-mission on-orbit servicing vehicle, demonstrating key concepts and prototype interactive visualizations, focusing on opportunities to improve the uncertainty analysis, ease of use, data scaling, visualization techniques, and overall analysis approach.

Model Trading. A framework for conducting value model trades and evaluative (performance, cost) model trades was further developed and tested. One of the key means of leveraging a model-centric environment is the trading of models, which can reveal insights about the system that are difficult or impossible to see when considering only a single model. Prior work has demonstrated this technique on the value models used to determine the "goodness" of alternatives based on their performance and cost attributes. During the past year, the research extended the model trading paradigm to evaluative models: those that calculate the attributes themselves. 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.

Model-Centric Decision Making. A study was initiated to generate empirical insight into how human actors and decision-makers trust, perceive, and interact with models. An interview-based approach is used to identify important considerations surrounding human-model interaction and trust that experts deem important for effective decision-making. These considerations include practices that interviewed experts implement to aid in their decision-making, along with identified challenges and potential mitigations to challenges that can degrade effective model-centric decision-making. The descriptive insights gained through empirical research, along with research on decision-making and biases, aims to identify heuristics and design principles to inform policy, design, implementation, and use of model-centric engineering.

Curation of Model-Centric Environments. As the model-centric environments become increasingly complex and critically important, there is a need to more strategically lead and manage them. Under the premise that model-centric environments of the future will necessitate specialized leadership and competencies, a new leadership role for curation has been investigated. The curation function would set and administer model-related policies and practices, and ensure models and related documents are authenticated, preserved, classified and organized accordingly with model metadata standards. The curator may own the data management for models and related information, or oversee the ownership by other individuals or organization. As needed, a curator would meet with individuals and teams, who will create, use and re-use digital assets, helping to determine a useful classification of both individual models and sets of models. At the organization level, the curator may organize training and special projects. Empirical knowledge gathering has investigated the challenges and needs, and investigated the potential roles and responsibilities for this curation role.

IMCSE research has been presented and discussed with practitioners and sponsors in numerous research meetings and workshops, as well as with other researchers in the systems community. A SERC Talks webinar highlighted various research efforts under the project. These activities have raised the awareness of challenges and needs surrounding human-model interactivity, and there is a growing community of interest with the SERC and the larger systems community.

System Qualities Ontology, Tradespace and Affordability

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

2016 was the third year of a 5-year, 8-university project called System Qualities Ontology, Tradespace and Affordability (SQOTA), originally called ilities Tradespace and Affordability Project (iTAP). Its main objective is to provide DoD-community systems engineers with stronger foundations and methods, models, processes, and tools (MMPTs) for dealing with the complex and system-critical interactions among a system's quality attributes (SQs), also called ilities or non-functional requirements (NFRs). The SQs are often weakly and inconsistently defined and underemphasized in DoD acquisition reviews and guidance, resulting in a major source of shortfalls and overruns in system acquisition and support.

SQ Ontology A major development in 2016 was the publication of a workable ontology of the nature and relations of the SQs. It built upon partial ontologies by David Jacques and Erin Ryan at AFIT; by Adam Ross and Donna Rhodes at MIT; and Barry Boehm and Jo Ann Lane at USC, along with an initial formal definition of the relations among the SQs by Kevin Sullivan at U. Virginia. One part of the ontology organizes the SQs into a class hierarchy reflecting system stakeholders' value propositions (Mission Effectiveness, Life Cycle Efficiency, Dependability, Changeability), and the means for satisfying them. Other parts of the ontology identify the sources of variation in an SQ's numerical value with respect to stakeholder priorities; internal and external system states and processes; and synergy and conflict relations among the SQs.

SQ Methods, Models, Processes, and Tools (MMPTs) Other universities, such as Wayne State University, Georgia Tech, AFIT, and NPS, on the SQOTA team are focusing on MMPTs for strengthening the SQ aspects of systems engineering in the context of the ontology and recent DoD emphasis areas such as Model-Based Systems Engineering (MBSE), Modular Open Systems Architecture (MOSA), and Set-Based Design (SBD). Online is a summary of the work being done by Gary Witus at Wayne State U. with TARDEC and also similar work that is being done by Michael Yukish at Penn State U. on Navy applications.

AFIT and NPS MMPTs. AFIT and NPS have been developing and demonstrating methods for integrating MBSE approaches for early architectural definition, effectiveness analysis, and cost estimation. Our shared case studies and models are for ISR missions of increasing complexity with multi-tiered collections of heterogeneous UAS. AFIT has been defining architectures using SysML compliant modeling packages, with the intent being direct simulation and evaluation of the underlying concepts, and the population of early cost estimation tools to provide useful relative cost estimates associated with possible variations of the architecture. NPS has demonstrated the viability of using the SysML model for direct inputs to cost models.

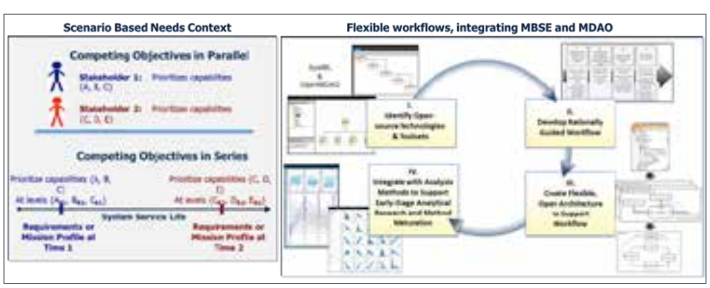


Figure 1 - Transitioning SQOTA - Successfully transitioned methods and approaches developed under SQOTA to other DoD Army, Marine Corps, and Navy programs

Georgia Tech Research Institute (GTRI) In support of the SQOTA effort, GTRI has investigated new methods and constructs for design exploration. GTRI's objectives focus on methods, processes, and tools to support analytical foundations through flexible and rationally guided workflows. There are two primary thrusts to the research: 1) methods and constructs to analytically execute formalisms, and 2) processes and tools that help operationalize these constructs in a scalable and traceable manner.

GTRI Transition Example: Engineered Resilient Systems (ERS) is one of seventeen DoD Communities of Interest led by the US Army Corps of Engineers. One of its primary goals is to develop an integrated, trusted, computational environment supporting all phases of the DoD's acquisition and operational analysis, to result in a series of government owned and hosted tools to support. One of these tools, the "ERS TradeBuilder" is built by GTRI to conduct executable, model based systems engineering and support trade studies, as illustrated in Figure 1.

Next-Generation Cost Models Trends affecting system and software engineering practices such as internets of things, 3D printing, cloud services, big-data analytics, autonomic and learning systems, agile methods, and asymmetric threats, such as for cyber security, present challenges for DoD systems and software engineering practices, and also for estimating their costs and their impact on Affordability. The SQOTA Next-Generation Cost Models effort, with co-PIs Barry Boehm and Jo Ann Lane at USC and Ray Madachy at NPS, has made significant progress in defining next-generation versions of the COCOMO II software cost model (COCOMO III, led by Brad Clark at USC), and the COSYSMO 2.0 systems engineering cost model (COSYSMO 3.0, led by Jim Alstad at USC). For COCOMO III, we have concluded that there will be no single model that is good for estimating all of the challenge areas above, and are prioritizing to create an initial version that best fits most of DoD's major project types.

For COSYSMO 3.0, in 2016 we achieved a major milestone in completing an Expert-Based Model. The remaining step is to gather actual project data and combine that with the expert opinions to yield the final model. The 2016 events at which we had half-day working group sessions for COSYSMO 3.0 and often COCOMO III were the Army- and Navy-sponsored Practical Systems Measurement User Group (February), the Ground Systems Architecture Workshop (March), USC CSSE's Annual Research Review (March), the Navy and NGA-sponsored Software and IT Cost Analysis Solutions Team meeting (August), and USC CSSE's COCOMO Forum (October).

Helix

Helix has been examining what makes systems engineers effective for over four years. The primary product of Helix is Atlas: The Theory of Effective Systems Engineers. Atlas 1.0, released in December 2016, is the culmination of over four years of research into what makes systems engineers effective. The key elements that play a role in effectiveness are identified in Figure 1 below. The specifics defined for each of these variables are the result of in-depth research on systems engineers.

PI: Dr. Nicole Hutchison (Stevens Institute of Technology)
Co-PI: Dr. Dinesh Verma (Stevens Institute of Technology)
Sponsor: ODASD(SE)
Link: http://www.sercuarc.org/projects/helix/

The main theme of Atlas is an Individual Systems Engineer who provides Consistent Delivery of Value is an Effective Systems Engineer. This definition hinges on Value, which is defined by the Organization in which a systems engineer is working. Value is created by working in defined positions and roles. The organization must establish the position of the systems engineer in terms of roles and responsibilities and this should align with specific levels of Proficiency – knowledge, skills, abilities – that enable a systems engineer to perform in a given position.

Atlas is expected to be used in several ways: first, by individuals who wish to better understand their own proficiencies and effectiveness in the context of their organization; second, by organizations that wish to understand the current state of the effectiveness of their systems engineers; and third, by either individuals or organizations for future career planning. To date, at least five organizations have used Atlas to better understand their systems engineering workforce. The proficiency model of Atlas, shown below, has been used to:

- Gain a baseline understanding of the knowledge, skills, abilities, behaviors, and cognitions of individual systems engineers in an organization;
- Identify critical proficiency levels for specific critical positions in the organization (e.g. chief systems engineer, system architect, or system analyst);
- Help individuals plan for their future careers, in terms of proficiencies they need to grow for desired future positions or to foster desired skills; or
- Guide conversations among systems engineers and their leaders to guide decisions about career paths – target experiences, mentoring relationships, educational or training programs.

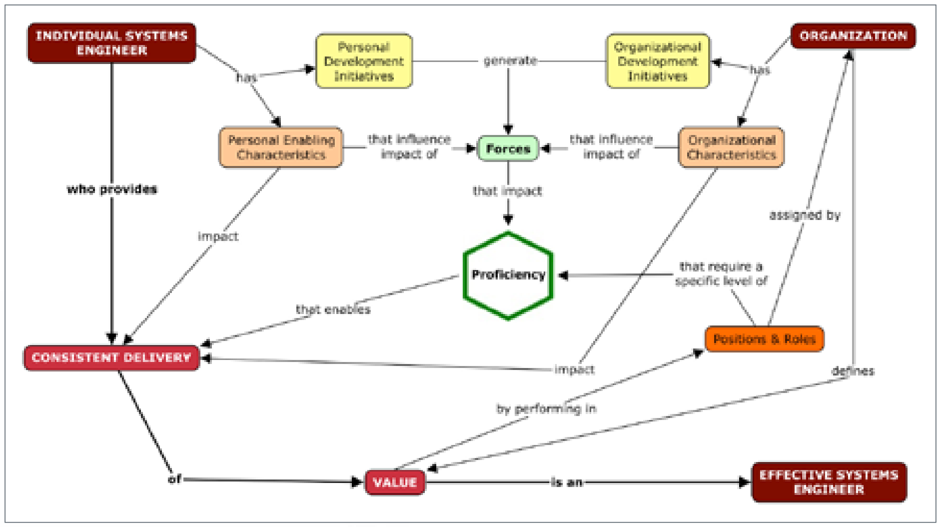


Figure 1 - Atlas 1.0 Overview

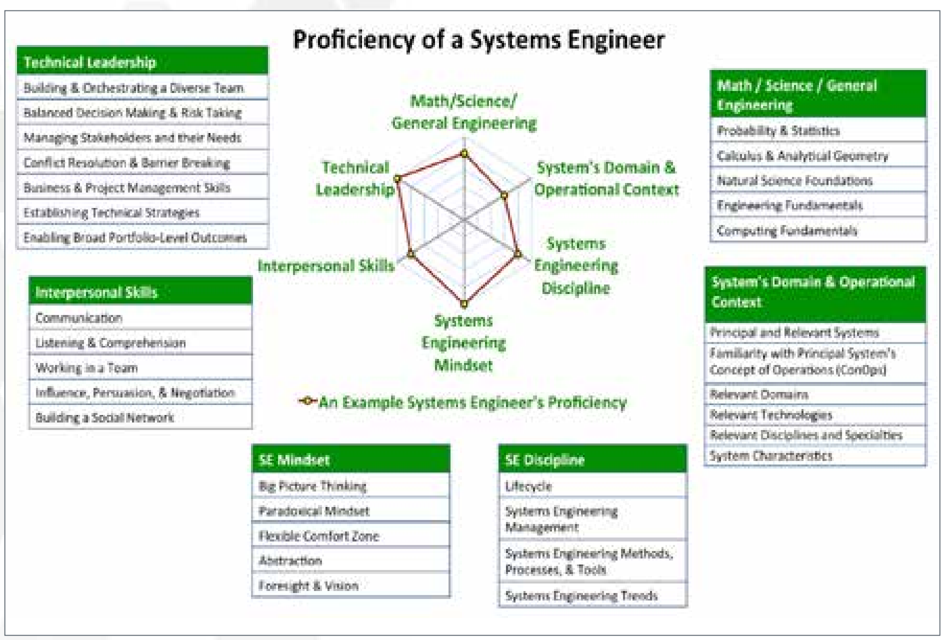


Figure 2 - Critical Proficiencies for Systems Engineers

Developing and Applying the Systems Engineering Experience Accelerator (SEEA)

PI: Dr. Jon Wade (Stevens Institute of Technology)

Co-PIs: Dr. Douglas Bodner (Georgia Institute of Technology), Dr. Richard Turner (Stevens Institute of Technology)

Sponsors: Defense Acquisition Univeristy and ODASD(SE)

Link: http://www.sercuarc.org/projects/system-engineering-experience-accelerator/

This past year, significant efforts have been undertaken to enhance, refine and transition the Experience Accelerator into broad usage. In particular, the SERC will complete research in the following areas:

1. Develop new content for the DAU unmanned aerial system (UAS) experience. SERC researchers are developing content focused on using trade studies to make technical decisions, as well as making reliability decisions.
2. Improve the current DAU UAS experience. SERC researchers are improving content for non-player characters and update student lecturer materials.
3. Improve the user interface to accommodate learners with disabilities. As part of this process, the SERC are migrating the EA infrastructure from Adobe Flash to HTML5.
4. Validate the research hypothesis. SERC researchers are capturing and analyzing student learning results.
5. Support Deployment at DAU and Transition to Open Source Sustainment.

For Task 1, the current DAU experience is primarily programmatic in its focus. However, systems engineers also need the capability to perform trade studies and make technical decisions. As such, these capabilities need to be added to enhance the current DAU experience to test the hypothesis in these areas. In addition to the new capabilities, Task 2 will have a series of improvements in the current experience which needs to be made to ensure that the user of the EA has the opportunity to effectively learn the desired lessons. The current DAU experience can be extended in both scope and new capabilities. The experience was designed to support the UAV project from PDR to limited production. Four additional phases have been prototyped. However, these additional four phases have not kept up with the PDR to CDR development phase which became the focus of the DAU experience. For Task 3, the objective is to determine the requirements for simulated learning technologies, specifically the EA, Section 508 Compliance, based on these requirements determine a compliance strategy for design, implementation and validation, and then provide an estimate for this work. The objective for Implementation part is to implement these changes to ensure that the EA is Section 508 compliant, which enables the EA to be accessible to those with disabilities.

For Task 4, the validation of the research hypothesis through the learning evaluation process will require support for classroom instructors, students, and the active capture and analysis of learning results. These evaluations will take place for the DAU experience at DAU and potentially other institutions. Learning evaluation is a critical element to validating the research hypothesis. In addition to the research in Increment 4, research in learning efficacy is taking place through a doctoral dissertation funded by ARDEC, educational research at Stevens, and tools development funded by SERC core funds. However, research will need to be done to determine specifically how learning will be evaluated for the DAU experience. Additional work is necessary to create a plan that is specific to DAU needs for Task 5.

Synergistically with this research, SERC core funds are being used to enhance and refine tools to develop and tailor learning experiences, and evaluate the results. While significant progress has been made in their development, additional work is required before these tools can be released to an open source community. In particular, the following capabilities are being developed:

1. Simulation Tools: Further refinement of Sim Builder and Sim Tuner functionality to include the following efforts: Development of a base library of simulation modules based on the UAV experience. Enhanced functionality for use of submodels. Enhanced displays to understand the impact of variable changes. Improved chart design interface.
2. Experience Builder: Updated user guidance. Identification of potential HTML5 support tools.
3. Learning Assessor: Functionality updates to support pilot application, which will identify opportunities to improve performance. Analysis of calculated scores vs. assessed learner performance.
4. EA Infrastructure: Update of learner interface technology from Flash to HTML5, which is critical for Section 508 compliance, and is a requirement for U.S. Government use.

The SERC shall conduct a user evaluation at the end of the project, demonstrating the utility of the tools to support modifications to SEEA experiences, providing assurance that the tools are ready for full release to the open source sustainment community.

There has been a substantial increase on the amount of interest by SERC Collaborators in the use of the EA. The SEEA was successfully utilized by Dr. Dale Thomas in a graduate Introduction to Systems Engineering course at UAH in the Fall 2016 semester and will be used again the same course and in Management Systems Analysis course in the Spring 2017 semester. Drs. John Colombi and David Long of AFIT are investigating the use of the EA in their courses. Two new SE Masters Projects at Stevens will be conducted during the Spring of 2017 that will develop new EA experiences. In addition, two Stevens doctoral programs will be investigating the evaluation of SE and Systems Thinking capabilities using the EA. Finally, outside of the SERC Collaborators, a reliability SE experience was developed by Dr. Duncan Kemp and team from the UK Ministry of Defence, which will be refined and targeted for deployment in 2017.

Success in 2017 will result in proving the hypothesis that the EA technology is effective in evaluating and teaching systems engineering, and providing the capabilities to scale to support a community of developers engaged in creating modules for their organizations that allow educators and other non-programmers to create, maintain, and evolve experiential learning modules.

SUMMARY OF NEW RESEARCH TASKS AWARDED IN 2016

Some of the Researching Projects specifically pursuing the Grand Challenges according to the Technical Plan continued in 2016. Among those are *Helix* (Nicole Hutchison), *Security Engineering* (Barry Horowitz), *Transforming Systems Engineering through Model-Centric Engineering* (Mark Blackburn), *Agile Systems Engineering* (Rich Turner), *Systems Qualities Tradepace and Affordability* (Barry Boehm), *Interactive Model-Centric Systems Engineering* (Donna Rhodes), *Enterprise Analysis* (Michael Pennock), and the *Experience Accelerator* (Jon Wade). However, several new projects were funded in 2016. A few to highlight are:

Investigated Approaches to Achieve Modularity Benefits in the Acquisition Ecosystem is a task lead by Dan DeLaurentis at Purdue University. The researchers are investigating how DoD can develop systems to exploit modularity to enhance their effectiveness, as well as to work more effectively with other systems (in a system-of-systems context) in a variety of missions.

Formal Methods in Resilient Systems Design using a Flexible Contract Approach is led by Azad Madni. The researchers shall investigate use of formal methods to engineer resilient systems using a combination of flexible Contract-Based Design (CBD) and Partially Observable Markov Decision Processes (POMDP) to formally characterize complex systems and improve methods for developing resilient behaviors. Specifically, the SERC shall develop and investigate using rigorous resilience contract methods based on the use of POMDPs; evaluate the impact of flexibility on formal checking methods; and develop practical constraints and methods for applying resilience contracts.

In November 2015, the United States (US) Army RDECOM-ARDEC in Picatinny, NJ held a working session to discuss the needs and scenarios for an SE transformation enabled by evolving model-centric engineering (MCE) technologies and methods. The meeting also covered other SERC-related MCE research finding, discussing both the benefits as well as the realistic perspectives on the timeframe for such a transformation that not only involves technologies, but also new methods, competencies, partnerships and governance. This meeting provided a catalyst for ARDEC to organize a follow-on meeting in 2016 to discuss its prioritization of key areas to initiate such a transformation. ARDEC leadership discussed five key areas to initiate research into a transformation that when realized is expected to results in capabilities to enable mission/system-based analysis and engineering achieving a 50 percent reduction in life cycle cost/schedule. The SERC and ARDEC are now working through a researching task of the five key areas.

TRANSITION PARTNERSHIPS WITH MITRE AND THE JHU APPLIED PHYSICS LABORATORY

MITRE: SERC has been partnering with MITRE as an FFRDC for transition, scouting, connecting, collaborating, evaluating, and educating federal agencies to enable greater impact from the developed research. The objective is to make broadly available the best systems engineering methods, processes, and tools and improve government program success by teaming MITRE engineers with SERC researchers in the application of the latest SERC research. Having the transition aspect in mind early shapes and refines deliverables to be the best for the sponsor and greater Intelligence Community. To facilitate this process, SERC research faculty regularly provide presentations on on-going research to MITRE experts. A broad range of potential transition opportunities within and beyond the Department of Defense are being identified.

JHU Applied Physics Laboratory: One major transition of SERC research was the Analytic Workbench Technology (RT-108, 134, 155) into government service through the Johns Hopkins University Applied Physics Lab (JHUAPL). JHUAPL is working with a government sponsor in one domain to identify technology transition opportunities from research projects being conducted by the SERC. As mature SERC technology and appropriate government programs are identified, JHUAPL works as a trusted technology transfer agent of the government, incorporating the technology into service and ensuring its benefits are realized in areas where the SERC has limited access to government programs and information.

RESEARCH TRANSITIONS

The table (right) highlights selected projects that have been or are in the process of being transitioned into practice and education across the SERC university network.

Aside from these transitions, in 2016 there were 70 publications and Technical Reports from the SERC. Systems Engineering and Systems Management Transformation had 49; Enterprises and Systems of Systems totaled 11; Trusted Systems published 2; and Human Capital Development had 8.

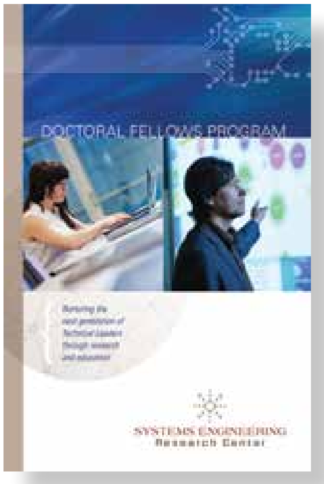
RESEARCH PROJECT	RECOGNIZED IMPACT
Next-Generation Cost Estimation & Metrics for Software-Intensive Systems *SE and SM Transformation*	Results have been used by the Air Force Cost Analysis Agency (AFCAA) research sponsor and other organizations in the independent cost analysis of major software-intensive systems, and in the preparation of a guidebook for general costing use.
Enterprise Systems Analysis *Enterprises and Systems of Systems*	The methodology of enterprise modeling and lessons learned through SERC supported research was adopted by the Robert Wood Johnson Foundation for a health enterprise decision analysis project to examine the enterprise issues that impact the adoption of evidence based care.
Engineered Resilient Systems: Tradespace Tools Research *SE and SM Transformation*	US Army ERDC deployed the ERS toolset on ERDC servers, enabling ERDC to conduct tradestudies of interest. Also support was the application of the ERS TradeBuilder tools and methods to systems of interest to the DoD acquisition community; these specifically include enabling US Army ARDEC to conduct a mortar design study, and US Army Edgewood ChemBio Center to conduct a chemical biology defense assessment.
Leadership Development Framework for the Technical Acquisition Workforce *Human Capital Development*	The study documented for the first time a comprehensive analysis of the relevant scholarly literature on the subject of technical leadership development, while the survey represents solid examination of our current understanding about how technical leaders have been, and are best, developed, and serves as a strong foundation for future work. The Technical Leadership Guide will be used to help update the Individual Development Plans for the civilian workforce in ASD(R&E) in the near future.

BEST STUDENT PAPER

Mr. Eren Sakinc, of Auburn University, was selected as the winner of the 2016 SERC Student Systems Engineering Research Paper Award for his paper, "Manufacturing Cost Prediction in the Presence of Categorical and Numeric Design Attributes." 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. Sakinc presented his research at the SERC Doctoral Students Forum and the SSRR 2016.
Congratulations to Eren for his outstanding research efforts.

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 even drives high impact by exposing the attendees to the research students are conducting, and the students to experts outside of academia. Attendance at the SERC Doctoral Students Forum is open to government, industry, and academic institutions. In 2016, there were stellar presentations by ten different students, which is a 66.7% increase in student participation.



SERC DOCTORAL FELLOWS PROGRAM DESCRIPTION

Leveraging an exceptional foundation of education, 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 and in alignment with its research priorities. The SERC Doctoral Fellows Program is not a scholarship program. Rather, participating organizations sponsor a specific number of Doctoral Fellows each year. 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. Currently the following organizations are sponsors of the SERC Doctoral Fellows Program: The MITRE Corporation; ARDEC-Picatinny Arsenal; The Boeing Company; and Raytheon Company - Missile Systems.

For more information about the SERC Doctoral Fellows Program and Students Forum, please see the webpage (http://www.sercuarc.org/doctoral-fellows-program/) or contact Megan M. Clifford.

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. 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, while enabling 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. Faculty and students are also able to propose projects that may be of interest to the sponsors. Please contact Megan M. Clifford (megan.clifford@stevens.edu) for more information, or to see some of the great ingenuity that has come from engagement with the Capstone Marketplace.

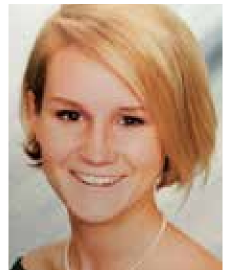
LEADERSHIP TEAM

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

Dinesh Verma
Executive Director, SERC

Jon Wade
Chief Technology Officer, SERC

Barry Boehm
Chief Scientist, Chair of the SERC Research Council, SERC

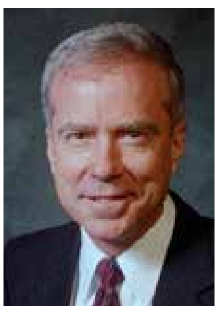


Megan M. Clifford
Chief of Staff to Executive Director/ Manager Program Operations, SERC

Roger Blake
Chief Software Engineer, SERC

SERC ADVISORY BOARD

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

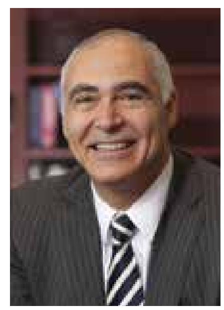


Major General Curtis M. Bedke
US Air Force (Retired)

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

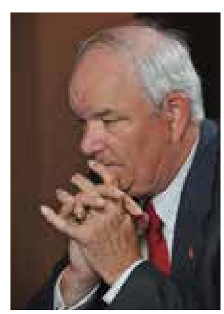
Dr. Michael D. Griffin
Chairman and CEO of Schafer Corporation; Chairman, SERC Advisory Board

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

RESEARCH COUNCIL

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

SE AND SM TRANSFORMATION

Barry Boehm

Chair of the SERC Research Council

See previous page in SERC Leadership team; SERC Chief Scientist

The SERC's research strategy has steadily matured since the first contract, and as a result, the SERC 5-year Technical Plan for FY14-FY18 strengthened each research area, creating a funding framework and synergy between projects within a research focus area. As a result, the Research Council formed and designated leaders to oversee each research area and program. The individuals were selected for their stature, vision, and dedication to successfully delivering research that addresses the sponsor needs and grand challenges formed with 3-year term agreements. Two members of our Research Council have stepped down after completion of their 3-year terms in 2016, and had dedicatedly served SERC through this position since 2013.

***Jo Ann Lane**, who was the Co-Director of the Center for Systems and Software Engineering at USC.*

***William Scherlis**, who is a Professor and Director at the Institute for Software Research within Carnegie Mellon University.*

*We do welcome **Kevin Sullivan** from University of Virginia and **Mark Blackburn** from Stevens as new members in the RC serving in the Trusted Systems and SE and SM Transformation respectively.*

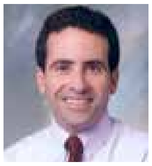
Mark R. Blackburn

Associate Professor, Stevens Institute of Technology

Paul Collopy

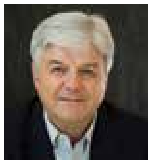
Chair, Industrial and Systems Engineering and Engineering Management,University of Alabama in Huntsville

ENTERPRISES AND SYSTEMS OF SYSTEMS



Daniel A. DeLaurentis

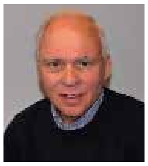
Associate Professor, School of Aeronautics & Astronautics, Purdue University



William B. Rouse

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

TRUSTED SYSTEMS



Barry Horowitz

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

Kevin Sullivan

Associate Professor in Computer Science, University of Virginia

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

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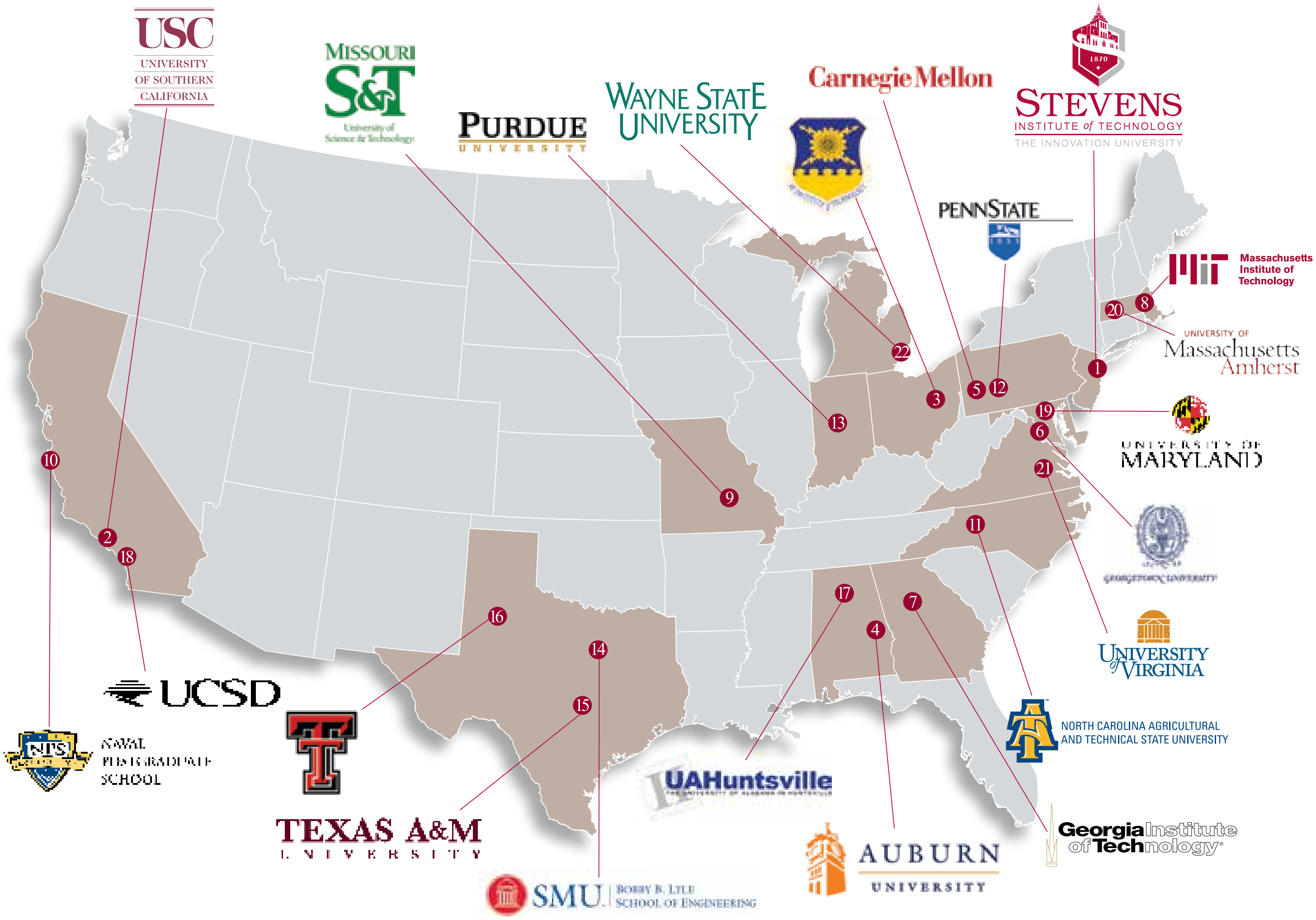

University or Research Organization

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12. Pennsylvania State University
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