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SERC 2014–2018 Technical Plan

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EXECUTIVE SUMMARY

This SERC 2014-2018 Technical Plan is intended to provide the vehicle by which to align the SERC Vision and Research Strategy with the Sponsor's Core funding priorities. It describes the SERC Vision, the Sponsor's needs, and the SERC's response to these needs, supported by research thrusts in the four areas of *Enterprises and Systems of Systems* (ESOS), *Trusted Systems* (TS), *Systems Engineering and Systems Management Transformation* (SEMT) and *Human Capital Development* (HCD). A Grand Challenge statement is presented for each research thrust area, along with a strategy to address it. Eleven research programs have been identified to support this strategy. Research projects are then presented which support each of these programs, consisting of existing and future projects.

The stated grand challenges are as follows:

ESOS - Create the foundational SE principles and develop the appropriate MPTs to enable the DoD to architect, design, analyze, monitor and evolve complex enterprises and systems of systems to provide the DoD with an overwhelming competitive advantage over its current and future adversaries.

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

SEMT - Transform the DoD community's systems engineering and management methods, processes, tools and practices to enable much more rapid, concurrent, flexible, scalable definition and analysis of the increasingly complex, dynamic, multi-stakeholder, cyber-physical-human DoD systems and systems of systems of the future.

HCD - Discover how to dramatically accelerate the professional development of highly capable systems engineers and technical leaders in DoD and the defense industrial base and determine how to sustainably implement those findings.

The SERC 2014 - 2018 Technical Plan will deliver the greatest impact for DoD and the intelligence community (IC) by

1. *Conducting* long-term research that makes significant progress on the grand challenges

2. *Transitioning* that research into practice within DoD, the IC, defense industrial base, and other federal agencies; and by developing more powerful ways to facilitate such transition
3. *Amplifying* sponsor resources by forging relationships with other organizations that become partners, contributing their resources and energy to the SERC and adopting SERC research
4. *Strengthening* the existing SERC culture, mechanisms and focus on collaboration
5. *Instituting* new approaches to educate future systems engineers and engineers that leverage the full strength and diversity of the collaboration

1 SERC VISION

At the end of 2018, after executing this Plan, the SERC will have the following characteristics:

- The SERC has indeed become the go-to place for high-quality SE research and exploratory development. Its research is widely applied in DoD and the defense industrial base with tangible impact affecting billions of dollars of acquisitions; its research results are woven into the curricula of dozens of university programs (including many outside the set of SERC Collaborators) that are educating thousands of students.
- The SERC has stabilized at 25 high-capability, collaborative universities. It includes ten of the US News and World Report top-25 industrial/manufacturing/systems engineering departments.
- SERC Collaborators graduate over half of the US MS-SE and PhD-SE graduates per year. Many PhD graduates join other SERC universities as faculty or staff, significantly increasing the breadth and depth of research collaborations. Collaborators attract and educate the best students, drawn from current DoD and defense industrial base employees and from those who are attracted to systems engineering by the vigor and quality of Collaborator educational programs.
- The SERC provides much of the leadership in SE-related professional societies, increasing collaboration among them. It continues to operate and grow the Conference on Systems Engineering Research as the premier SE research conference, along with feeding its papers into the leading SE-related journals.
- The SERC operates the world's largest and most-visited SE research website, including the largest and best-organized SE research experience base. It continues to provide leadership in evolving the SE Body of Knowledge. It runs the most widely-attended and highest-rated SE webcast series.

Implications: This vision requires significant investment in high-quality infrastructure, operations, and outreach. Such investment will require time to develop and mature.

2 SPONSOR NEEDS

The DoD and the IC have a continuing need for SE research. They face major challenges with respect to available SE methods, processes, and tools (MPTs), which have repeatedly been found wanting as described in more detail later in this section. Increasing system complexity, scale, and dynamism are driven by DoD's need to keep up with increasingly capable adversaries with widespread access to new technologies, along with challenges of legacy system interoperability and asymmetric warfare. In order to see-first, understand-first, act-first, and finish decisively, DoD needs its evolving systems to continue to interoperate readily and dependably. New technologies, such as smart systems, cloud services, powerful search engines, nanotechnology, and Internet-of-things, present new challenges to the SE discipline. New MPTs are needed in order to develop complex systems that are sustainable, affordable, and adaptive, while leveraging DoD's capital-intensive legacy. At the same time, these technologies may be commercially available to adversaries who can use them to improvise new threats.

The National Research Council's "Human-System Integration in the System Development Process," (NRC, 2007), "Pre-Milestone A and Early-Phase SE," (NRC, 2008), and "Critical Code," (NRC, 2010) studies consistently found that the SE MPTs for integrating hardware engineering, human factors engineering, and software engineering into a scalable, unified approach were not up to the challenges of the complexity, scale, and dynamism characterizing DoD's large-scale systems and systems of systems. SE must enable rapid, affordable, trusted, and agile development of systems that are themselves rapidly fielded, affordable, trusted, and agile. The frequently ossified MPTs and inadequately prepared workforce common to today's acquisitions cannot meet those challenges. SE research is required to develop responsive MPTs and a fully qualified workforce.

The 2009 Weapons System Acquisition Reform Act (WSARA, 2009) responded to the chronic shortfall in capabilities of the SE acquisition workforce. Among other steps, it demands innovative research to successfully address the increasing complexity and scale of both the systems DoD acquires and the dynamic and highly budget constrained environment in which those acquisitions occur. Related DoD directives such as DoD Instruction 5000.02, "Operation of the Defense Acquisition System," (DoD, 2008), the USD(AT&L) Ashton Carter memorandum, "Better Buying Power: Mandate for Restoring Affordability and Productivity in Defense Spending," (Carter, 2010), "Better Buying Power 2.0: Continuing the Pursuit for Greater Efficiency and Productivity in Defense

Spending” (Carter, 2012), and the Defense Business Board study “Linking and Streamlining the Defense Requirements, Acquisition, and Budget Processes,” (DBB 2012) also emphasize the need to more strongly integrate the SE function and the system cost and schedule analysis functions. This involves not only organizational and procedural improvements but also research into tradeoffs between system cost, schedule, and performance attributes; techniques for determining the ROI for investments in system flexibility and resilience; techniques for expediting the SE function; and improved capabilities for estimating and managing the cost and schedule of DoD software-intensive systems.

Another highlighted critical area (DoD, 2008a; DoD, 2009; and DSB, 2007) is the need for more effective cyber-security of DoD information assets. This involves complementing the existing network and perimeter protections, which are primarily reactive, with more pro-active and system-aware protections. These include the ability to (a) combine techniques developed for the design of resilient systems with advanced cyber security techniques for achieving protection at the application layer of a system, including diverse redundancy and configuration hopping; (b) utilize system of systems design opportunities as a more resilient base for responding to cyber-attacks; and (c) combine techniques developed for automatic control systems in a manner that will both enable defense systems to determine if operator displays are being manipulated and serve as a basis for making rapid forensic analyses after a cyber-attack has possibly occurred.

The 2010 DoD Science and Technology (S&T) priorities, presented by the Honorable Zachary J. Lemnios in his testimony to the House Committee on Armed Services on the FY13 budget request (Lemnios, 2012), respond to the complexity, scale, and dynamism of future DoD systems, which will continue to accelerate, making even stronger demands on DoD SE technology. Five of the seven DoD S&T priorities identified in his testimony -- Engineered Resilient Systems, Cyber Science and Technology, Autonomy, Data to Decisions, Human Systems – are SE-intensive. All demand extensive SE research.

3 SERC RESPONSE

The SERC actively manages its research portfolio, looking for and nurturing synergies between projects. Additionally, the SERC works with its sponsor to identify opportunities where increased funding and project duration can produce higher positive impact on DoD’s strategic SE research needs. This has been especially evident during 2012 and 2013, in which a majority of new funding has extended existing projects rather than begin new ones. Most projects are now being conceived and proposed as multi-phase, multi-year efforts; for example, the Experience Accelerator Project, which is attempting to develop ways to greatly reduce the time needed to develop a mature systems engineer, is being executed as a 3-year project to deliver a strong foundational

capability. Additional sponsors and funding are being sought to continue growing that capability and to deliver greater value after those first three years.

In coordination with its sponsors, the SERC has structured its research portfolio into the following four thematic research areas, also depicted in Figure 3-1.

- **Enterprise Systems 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, 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. 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 knowledge and skills that the DoD and IC workforce require as well as determine the best means to continually impart that knowledge and skills.

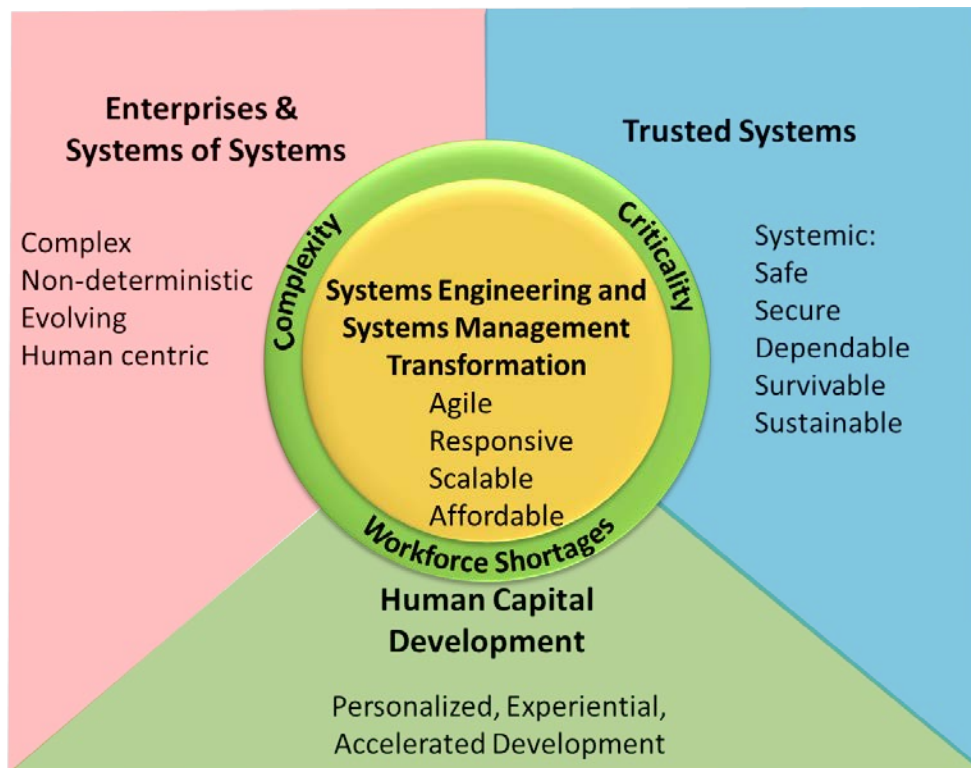


Figure 3-1. The four thematic areas being addressed by SERC research tasks and priorities

These thematic areas have been further divided into eleven programs, shown below, that have the potential to make a transformative impact on DoD and the IC. The SERC Research Council, which includes some of the most capable researchers in the field, helped shape this portfolio.

- **Enterprise Systems and Systems of Systems**
 - *Enterprise Modeling*: Model the socio-technical aspects of complex systems of system and enterprise systems, including developing and populating a framework to integrate models created using diverse methods and tools
 - *System of Systems Modeling and Analysis*: Develop and test MPTs for analyzing and evolving systems of systems and provide support for their technical assessment in an Analytic Workbench construct
- **Trusted Systems**
 - *Systemic Security*: Create, validate, and transition MPTs to ensure systemic security using knowledge of system objectives and operation
 - *Systemic Assurance*: Provide systemic assurance of safety, reliability, availability, maintainability, evolvability, and adaptability

- **Systems Engineering and Systems Management Transformation**
 - *Affordability and Value in Systems*: Create, validate, and transition MPTs to make better decisions on affordability and value in systems
 - *Quantitative Risk*: Create, validate, and transition MPTs to improve risk identification, analysis tracking and management in acquisition and sustainment programs
 - *Interactive Model-Centric Systems Engineering (IMCSE)*: Create, validate, and transition MPTs to rapidly model the critical aspects of systems, especially those that facilitate collaborative system development
 - *Agile Systems Engineering*: Create, validate, and transition MPTs that enable rapid and flexible SE that can be applied for many kinds of systems in many types of development contexts
- **Human Capital Development**
 - *Evolving Body of Knowledge*: Establish active communities and mechanisms that create and support living bodies of SE knowledge
 - *Experience Acceleration*: Develop an open source community that creates, validates, and transitions technology and content for the use of experiential technology to educate systems engineers and technical leaders
 - *SE and Technical Leadership Education*: Create, validate, and transition curricula and practices to support the instruction and learning of systems and technical leadership for inexperienced students in college and experienced professionals

Each of these eleven programs conducts research, to varying degrees, in the following synergistic areas:

1. *Principles, Methods, and Techniques*: Develop improved ways to perform some aspect of SE and provide the underlying evidence for the expected results
2. *Analysis Tools*: Research means to create better analysis tools; automate methods and techniques to enable their application by practitioners
3. *Simulation*: Develop simulation technology to deepen system understanding and facilitate the effective application of SE MPTs
4. *Knowledge Transfer*: Determine how practitioners, researchers, and students can more easily and rapidly translate SE research findings into practice

4 OBJECTIVES, APPROACH AND PROCESS

4.1 OBJECTIVES

The SERC will have the greatest impact on DoD and the IC by:

1. Conducting long-term research that makes significant progress on the grand challenges
2. Transitioning that research into practice within DoD, the IC, defense industrial base, and other federal agencies; and by developing more powerful ways to facilitate such transition
3. Amplifying sponsor resources by forging relationships with other organizations that become partners, contributing their resources and energy to the SERC and adopting SERC research
4. Strengthening the existing SERC culture, mechanisms and focus on collaboration
5. Instituting new approaches to educate future systems engineers and engineers that leverage the full strength and diversity of the collaboration

These objectives align with the SERC's four Operational Principles:

1. Conduct innovative, high-impact research
 - a. Only perform tasks which are research oriented (usually publishable when not classified)
 - b. Focus research efforts on systems which can be generalized beyond a given domain and transform the discipline
 - c. Focus on research efforts that have the potential of increasing the security and prosperity of the nation
 - d. Focus on research which addresses future systems needs
2. Translate proof-of-principle prototypes to impactful applications
 - a. Work to ensure that there is a path from research results to impact
3. Strengthen and leverage the research network
 - a. Ensure that the research is conducted by the best available resources
 - b. Bring in new Collaborators who provide long-term strategic benefit
 - c. Focus on creating a network of academics, industry and government that is sustainable
4. Prepare the next generation
 - a. Provide a focus on education and training research, both in research (graduate students) and practitioners

4.2 APPROACH

The general approach to creating the SERC 2014-2018 Technical Plan was first to identify Grand Challenge problems in each of the four SERC thematic research areas shown in Figure 3-1. These Grand Challenges were formulated to provide a point of integration between existing programs in each research focus area, and also provide opportunities to generate new, related research areas. These Grand Challenges also provide inspiration and an integration point for non-SERC universities, federally funded research and development centers (FFRDCs), and industrial researchers to perform collaborative research and provide natural transition into use.

Additionally, the Plan assumes:

1. Incentives will be established so that future funding is dependent on principal investigators (PIs) and researchers finding funding for their programs outside the sponsorship. This could come in the form of matching funds or other incentives.
2. Incentives will be established for PIs to transition their research into practice. Each project will have a transition plan in place when the project begins with the opportunity for additional downstream funding to facilitate transition to practice and to develop educational materials and courses based on research results that will be shared by all SERC collaborating institutions.
3. Seed funding will be available to explore novel and promising ideas that may be the sources of future breakthroughs. These ideas will be selected by the sponsors, SERC Research Council and SERC leadership through an open solicitation process with all of the SERC Collaborators.
4. Shared IT infrastructure will be available for use by every research program.

4.3 PROCESS

SERC management and the SERC sponsor set the overall objectives and framework for this Plan. SERC management then worked with the Research Council, Program Leads and others to craft the Grand Challenges, objectives, and strategy for each of the four research focus areas, and to lay out program descriptions, timelines, anticipated results, and resources required.

5 FOCUS AREAS, PROGRAMS, AND PROJECTS

Programs in each of the four research focus areas and in supporting activities are described in the five subsections below.

5.1 ENTERPRISE AND SYSTEMS OF SYSTEMS (ESOS)

Each DoD/IC Service and Agency, and the DoD itself, is an example of “enterprises as systems”. Such organizations have the challenge of integrating and evolving multiple portfolios of systems with often-conflicting sets of objectives, constraints, stakeholders, and demands for resources. Systems of systems generally involve integrating multiple independently managed systems to achieve a unique capability, therefore involving needs for negotiation as well as control. Thus, in some contexts, systems of systems are enterprise challenges as well. Indeed, both “enterprises as systems” and systems of systems increasingly face situations in which the classical systems approach of deterministically engineering the system based on relatively static requirements and specified human interactions are insufficient. In such complex systems, human behavioral and social phenomena are critical as are cascading impacts from interdependencies; altogether emergent outcomes are the norm. Research is necessary to determine the foundational SE principles for such systems. Those principles can then be used to develop associated SE MPTs applicable to such complex systems.

Goal: Improved engineering to develop and deliver end-to-end defense capability to the warfighter for operation in complex organizational and operational environments, with fewer unintended negative consequences and greater resilience

5.1.1 ESOS GRAND CHALLENGE

The ESOS grand challenge to achieve the ESOS goal is to:

Create the foundational SE principles and develop the associated MPTs to enable the DoD and its partners to model (architect, design, analyze), acquire, evolve (operate, maintain, monitor) and verify complex enterprises and systems of systems to provide the DoD with an affordable and overwhelming competitive advantage over its current and future adversaries.

5.1.2 STRATEGIES TO ADDRESS THE ESOS GRAND CHALLENGE

Successfully executing the following strategies will make significant progress towards addressing the ESOS Grand Challenge:

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

2. *Acquire*: Develop MPTs that allow insight into enterprise/SoS acquisition approaches in the face of significant uncertainty and change to minimize unintended consequences and unforeseen risks
3. *Evolve*: Develop MPTs that facilitate evolving and growing an enterprise/SoS, including insight into different architectural and integration approaches that facilitate evolution in the face of uncertainty and change in how an enterprise/SoS is employed, the technologies available to realize it, and the environment in which it exists
4. *Verify*: Develop MPTs that allow the properties of an enterprise/SoS to be anticipated, monitored and confirmed during development and evolution, including an enterprise/SoS which includes legacy systems that are in operation while development and evolution are underway

Two research programs, described below, directly implement the strategy, *Enterprise SE and Modeling* and *Systems of Systems (SoS) Analysis*. Possible future projects were defined at the ESOS Summit held in on May 7-8th 2013 in Washington DC and are discussed after the ongoing projects.

5.1.3 ENTERPRISE SE AND MODELING PROGRAM

2012 and 2013 have been focused on developing a rigorous systems science and engineering foundation for ESOS, and building a community of researchers who collectively will advance ESOS research. In addition, ESOS researchers have been developing domain-specific multi-level or multi-scale models in areas such as counterfeit parts, healthcare delivery, and urban resilience with support from a variety of sponsors.

This foundation and experiences have provided the basis to take on the broader goal of providing enterprise level process mapping, monitoring and control for the grand challenge of Enterprise and Systems of Systems. As shown in Figure 5.1-1, data, forecasts and reports (including text) flow from the context of an enterprise's ongoing transformation; data and text mining are used to make sense of this flow of information; the insights gained enable computational modeling; the results of which are used to drive interactive visualizations that enable process mapping, monitoring and control.

Pursuit of this grand challenge represents a transition from focusing solely on the design of enterprises and systems of systems to the design and operation of enterprises and systems of systems. In other words, the computational models and interactive visualizations would be run in parallel with actual operations and provide a means for monitoring and the control of operations. This would enable the operators of complex

systems to detect, diagnose, and compensate for deviations of operations from expectations. The complex enterprise systems of interest could range from military operations and acquisition programs, to urban infrastructures and healthcare delivery organizations.

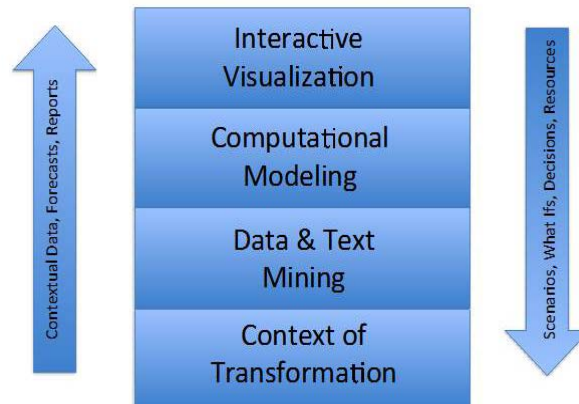


Figure 5.1-1. Enterprise Process Mapping, Monitoring and Control Communication Flows

This research program implements ESOS strategies 1, 2 and 3, currently, and will be extended to 4 as well. It includes one project already underway: Multi-Level Modeling of Socio-Technical Systems.

Table 5.1-1 offers a description of this project and which strategy it primarily supports.

Table 5.1-1. Enterprise SE and Modeling Projects

Projects	Started	Purpose	Primary ESOS Supported Strategies
Multi-Level Modeling of Socio-Technical Systems	2012	Develop an integrating framework to support multi-level modeling of socio-technical SoS systems	1

5.1.3.1 Multi-Level Modeling of Socio-Technical Systems Project

Over several decades, the Department of Defense has invested \$100B developing computational models and simulations of complex military systems. These estimated 8,000 software artifacts include 100 million lines of code and model everything from weapon platforms to operational military organizations. Unfortunately, they rarely interact with each other. Existing capabilities must be enhanced to allow models of different levels of fidelity to interoperate in a dynamic fashion.

This research shall perform an architectural assessment to determine the technical challenges, options and recommended architectural approaches involved in developing a modeling and simulation (M&S) framework to support the desired capabilities. The goal of the research is to review existing data structures, models, approaches, and technology to define an architecture that is as close to a complete solution to the problem as possible. The SERC will develop scenarios to test the completeness of the proposed architectures. These scenarios will, at a minimum, explore the impacts of the envisioned M&S framework on technology, military methods and organizational interactions. The SERC will explicitly identify critical technological, organizational, and other challenges to the development or use of the framework. The SERC will also provide an unambiguous statement regarding the common limitations of the elemental models and their aggregations within the framework. Future research will attempt to develop an integrating framework. It will formulate a multi-level model platform, (including alternative representations and approaches) and design a human-computer interface with rich visualizations and scenario building controls.

Table 5.1-2 shows the focus, deliverables, and investment in Multi-Level Modeling of Socio-Technical Systems through 2018.

Table 5.1-2. Multi-Level Modeling of Socio-Technical Systems Project Timeline

Year	Focus	Key Deliverables
Pre-2014	Architectural Assessment of existing commercial practices	Technical report, summary of interviews and observations
2014-15	Develop Integrating Framework	Technical Report
2016-18	Develop Modeling Prototype	Demonstration of prototype, code base, technical reports

5.1.4 SYSTEMS OF SYSTEMS (SoS) ANALYSIS PROGRAM

Developing a system of systems remains a highly challenging endeavor. The complex interdependencies among systems often exhibit managerial and operational independence, yet must work cohesively to achieve an overarching set of capabilities. Trades between capability and risk are essential decisions that must be addressed for SoS capability planning. Existing tools for such trades are of limited value when size and/or interdependency complexity is high.

This research program addresses the need to create and mature decision-support tools specifically for evolving SoS architectures; in particular, those technical architectures that support assessing the impact of potential disruptions during development or operation. The initial research explores analytical methods to quantify the impact of system interdependencies in the context of SoS capability development as well as broader agent models that address the often fuzzy influence of stakeholder perspectives in the technical development activities.

Additional research will focus on identifying innovative approaches to support SE in architecting, engineering, and evolving complex SoS.

This research program implements ESOS strategies 1, 2 and 3, currently, and will be extended to 4 as well. It includes one project already underway: Systems of Systems (SOS) Analysis. Table 5.1-3 offers a description of this project and which strategies it primarily supports.

Table 5.1-3. System of Systems Analysis Projects

Project	Started	Purpose	Primary ESOS Supported Strategies
Systems of Systems (SOS) Analysis	2011	Develop MPTs and an Analytic Workbench construct to house them for the purpose of SoS architecture evaluation, selection and evolution.	1, 2, 3

5.1.4.1 MPTs for a Systems of Systems Analytic Workbench Project

The objective is to develop a framework for an Analytic Workbench that presents practitioners with appropriate methods and tools that can characterize complex SoSs, dynamically analyze and assess SoS performance under changing conditions and scenarios, develop SoS architectures that effectively address the independent nature of constituent systems and their unanticipated change, and improve user capabilities given SoS complexities and risks.

Table 5.1-4 shows the focus, deliverables, and investment in Systems of Systems (SoS) Analysis through 2018.

Table 5.1-4. MPTs for a SoS Analytic Workbench Project Timeline

Year	Focus	Key Deliverables
Pre-2014	Evaluate architectures and Develop Proof of Concept simulation	Technical reports, agent based model for selected application domain
2014-15	Develop prototype tools	Technical reports, demonstration of prototype
2016-18	Refine and extend prototype tools	Technical reports, demonstration of prototype application

5.2 TRUSTED SYSTEMS (TS)

The organization of its assets into net-centric systems of systems (NCSOS) has enabled DoD to much more rapidly and effectively see-first, understand-first, act-first, and finish decisively in its operations. However, this implies that each of its assets needs to achieve higher levels of trust as part of the NCSOS, as compared to its previous role as a standalone platform, while retaining or improving its previous speed and effectiveness.

The SERC Trusted Systems research area addresses this challenge by balancing traditional reactive cyber-security defenses with pro-active mechanisms, making attacks more risky and expensive. It combines this approach with increased and continuous application of advanced assurance capabilities that concurrently address not only security but also safety, reliability, availability, maintainability, usability, interoperability, and resilience.

Goal: Transform system assurance from a late, reactive activity to an early and continuous, pro-active orchestration of advanced assurance MPTs, in ways that balance the simultaneous achievement of cyber-security trust and assurance with complementary MPTs for assuring safe, reliable, available, usable, interoperable, and resilient mission cost-effectiveness.

5.2.1 TS GRAND CHALLENGE

The TS grand challenge to achieve the TS goal is to:

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

5.2.2 STRATEGIES TO ADDRESS THE TRUSTED SYSTEM GRAND CHALLENGE

Successfully executing the following strategies will make significant progress towards addressing the TS Grand Challenge:

1. *Design for System Assurance and Trust:* Develop design patterns and systems architectures, with corresponding systems engineering principles guiding application, and associated design analysis MPTs for early assurance of needed properties
2. *Understand the Cost of Assurance and Ensure Cost-Effective Assurance:* Develop MPTs that enable understanding, predicting, and ensuring the cost-effectiveness of implementing high-assurance policies and requirements, especially on complex systems and complex systems of systems
3. *Understand and Ensure Balanced Tradeoffs Between Assurance “ilities” and Other “ilities”:* Develop MPTs that enable understanding, predicting, and ensuring cost-effective relationships among assurance policies/requirements and other “ilities”, such as usability, interoperability, and maintainability
4. *Measure System Assurance:* Develop MPTs that allow measuring “how much” assurance of needed properties a system has, and that permit comparison of the relative assurance and trust provided by alternative systems

Two SERC research programs directly implement the strategies:

- *Systemic Security.* The most compelling need for assurance of trust is in the area of system security. Given the numerous sources of security breaches available at low cost to attackers, a major concern is to make DoD systems, systems of systems, and enterprises harder and harder to attack, while simultaneously making them more risky and expensive to penetrate and damage.
- *Systemic Assurance.* Besides security attacks, there are numerous sources of system disruption such as natural disasters, system misuse, system overload, system component wear out, and defects in a system's requirements, design, or construction that cause loss of stakeholders' lives, health, capability, property, or financial assets that need significant improvements in trust not only for current systems, but for the more complex and dynamic DoD systems, systems of systems, and enterprises of the future.

In addition, improvements in system trust have been and are being addressed in the other research areas, particularly in SE and Management Transformation and its current projects inilities Tradespace and Affordability, Interactive Model-Centric SE, and Quantitative Risk. Example contributions from these and earlier SEMT projects include SERC insights such as those from the RTs addressing technical, integration and manufacturing maturity level assessment, the 35 Risk Management Precepts, the RT-EM approach to quantifying early-SE risks, the MIT epoch-era approach to assurance under uncertainty, and the set-based vs. point-design approach to assurance of systems undergoing continuing and extensive change. The synergies among these research projects will be addressed and enhanced by periodic cross-research-area workshops.

5.2.3 SYSTEMIC SECURITY PROGRAM

Goal: Develop safe, secure, dependable defense systems that are resilient to cyber and other threats through systemic security approaches that complement current, incomplete perimeter/network.

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

Strategy:

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

2. Understand the Cost of Security and Ensure Cost-Effective Security: Develop MPTs that enable understanding, predicting, and ensuring the cost-effectiveness of implementing specific security policies and requirements, especially on complex systems and complex systems of systems
3. Understand and Ensure Balanced Tradeoffs Between Security “ilities” and Other “Ilities”: Develop MPTs that enable understanding, predicting, and ensuring cost-effective relationships between specific security policies/requirements and other “ilities”, such as reliability, safety, and maintainability
4. Measure System Security: Develop MPTs that allow measuring “how much” security a system has and that permit comparison of the relative security between two alternative systems

This research program implements all four TS strategies above. It includes one project already underway which two Research Topics have supported. Table 5.2-1 offers a description of this project and which strategies it primarily supports.

Table 5.2-1. Systemic Security Projects

Projects	Started	Purpose	Primary TS Supported Strategies
Piloting and Extensions of Systems-Aware Security	2011	Refine systems-aware MPTs developed earlier and pilot them in multiple application areas	1, 2, 3, 4

5.2.3.1 Piloting and Extensions of Systems-Aware Security Project

In 2011, SERC RT-28: *Systems-Aware Security* developed a rapid prototype security capability that includes 1) data continuity checking within the application, 2) real-time virtual configuration hopping of selected C2 functions across multiple operating systems to provide defense through diversity, 3) real-time physical configuration hopping to both provide defense through diversity and resilience in the face of successful attacks, and 4) a closed loop control system for automatic restoration from a successful attack.

In 2012-2013, SERC RT-42: *Security Engineering Pilot* developed a prototype flight-capable security capability directed toward an unmanned air vehicle (outlaw aircraft containing an embedded Cloud Cap Piccolo flight control system) carrying an already selected set of surveillance equipment (video/IR cameras, radar, and a SIGINT package).

The continuation of this project will initially refine the Systems Engineering Pilot capability based on the preliminary evaluations. It will then conduct more thorough and realistic evaluations, further refine the capabilities, and package them to be tailorable to other domains.

Subsequent activities will involve the tailoring of the capabilities to other domains, and associated evaluation and refinement, along with monitoring and refinement of existing fielded capabilities.

Table 5.2-2 shows the focus, deliverables, and investment in the project through 2016. Continuing extensions and upgrades will be pursued in 2017 and 2018.

Table 5.2-2. Piloting and Extensions of Systems-Aware Security Project Timeline

Year	Focus	Key Deliverables
Pre-2014	Concept definition, prototyping, piloting	Initial Systems-Aware Security capability
2014	Extended evaluation, refinement, and Packaging	Tailorable Systems-Aware Security capability
2015	Initial new-domain tailoring, evaluation, and refinement	New-domain Systems-Aware Security capability
2016	Two new-domain tailoring, evaluation, and refinements	Two New-domain Systems-Aware Security capabilities

5.2.4 SYSTEMIC ASSURANCE PROGRAM

Besides security, the engineering of resilient DoD systems requires assurance of safety, reliability, availability, durability, survivability, maintainability, evolvability, adaptability, and sustainability. All of this assurance needs to be achieved for increasingly complex, dynamic, cyber-physical-human net-centric systems, systems of systems and enterprises with needs for rapid response incompatible with most heavyweight assurance MPTs. Carnegie Mellon University has been a leader in developing assurance MPTs in such areas as model checking, architectural style analysis, race and deadlock detection for multicore and other concurrent systems, appropriate test case generation, and assurance-case analysis that are not only more powerful in anomaly detection, but also leading to stronger possibilities for positive assurance and to greater scalability to large systems and to more rapid execution. These have been successfully applied in such areas as the High Level Architecture analysis for networked DoD models and simulations, cyber-physical robotic systems, and extremely large commercial Java programs.

The Systemic Assurance project builds on these capabilities and data sources to address their integration to develop incrementally composable combinations of MPTs and data-based composition guidance for obtaining the most cost and schedule-effective combinations for the assurance of necessary system properties. Particular areas of emphasis will be exploiting analogies with successful techniques in other domains, such as building codes; better management of chains of evidence to support ongoing re-evaluation for rapidly evolving systems both in development and in sustainment/modernization; enhancing MPTs with

language extensions for assurance assertions or context metadata; support for dynamic adaptiveness and resiliency in architectural design; and data management and metrics for more evidence-based design, development, and decision support.

Reflecting strong natural ties between the Systemic Assurance Project, the Piloting and Extensions of Systems-Aware Security Project, and the *ilities* Tradespace and Affordability Project (iTAP) described in 5.3.3.1, extensive coordination will be pursued among the three projects.

This research program implements all four Trusted Systems strategies above. It includes seven research and technology subprojects led by senior CMU researchers, with extensive internal coordination mechanisms to exploit the synergies among the various technical approaches. The CMU team members have an extensive network of collaborations and partnerships with DoD activities, other government agencies, the Software Engineering Institute, other SERC universities, and numerous industrial firms. The team will build on these to acquire access to data and technical partners. The seven subprojects are:

1. Develop baseline and intervention models for a selection of current standards and practices (identified in collaboration with DoD stakeholders), refining technical understanding of gaps and limitations. This baselining effort is essential to support a measurement-based approach to documenting the impact of the proposed new technologies and process interventions. This includes identifying the key criteria and dimensions of measurement.
2. Undertake engineering design effort focused on integrating improved capability for traceability and other features required to support explicit modeling and management of chains of evidence. A key focus is to demonstrate that it is possible to enhance existing tools and environments, including both integrated development environments (IDEs) and team tools, with relatively little disruption to established team practices and metrics.
3. Design and implement experiments to address the challenge of rapid recertification. These include capturing evidence and assurance-related reasoning (assurance cases, models, analyses, configuration management, etc.). This area of rapid recertification is critical to iterative, incremental, and staged development practices. It is also critical to systems with supply chains that include externally developed components and infrastructure such as commercial and open-sourced databases, operating systems, frameworks, and libraries. (Almost all larger-scale software-reliant systems have this characteristic.)
4. Develop a framework for assessment of architecture-derived quality attributes, focusing on architectural modeling and the relationship of architectural and compositional models with quality outcomes. This is essential in order to ensure that key decisions made at early lifecycle phases will have intended quality outcomes.

5. Develop requirements elicitation and management approaches that better address quality and policy objectives. Requirements elicitation and management is one of the earliest areas of focus in an engineering process, and decisions at this point can have tremendous leverage on quality outcomes. This work is directed at providing more immediate assessments of the potential outcomes of early requirements-related decisions. By improving models, it becomes possible to better manage the linkage of requirements and architectural decisions.
6. Augment and collaborate with diverse existing efforts focused on technical means to address particular quality criteria. Many of these quality criteria are emerging as significant challenges because they tend to defy conventional testing and inspection techniques. These include, for example, a number of attributes related to safe concurrency, compliance with application program interface rules-of-the-road, cyber-physical architectural compliance, state and access management for shared objects, taint and flow and other security-related attributes, and others.
7. Identify and advance areas in support of increasing automation, in order to reduce workload of developers and evaluators and to advance existing workload forward in the process, with immediate rewards. The purpose of this is to frame an ultimately more quantitative business case for adoption based on increased return on investment for assurance-related effort and reduced uncertainty (lesser variance in estimate “cones”). This is supportive of the longer-term goal of a “positive benefit” model for the adoption of assurance-related practices. It also supports a stakeholder-engaged process model analogous to building codes.

There are important synergies and interactions among these seven subprojects, with the principal features outlined in Figure 5.2-1 below (subproject numbers are in brackets).

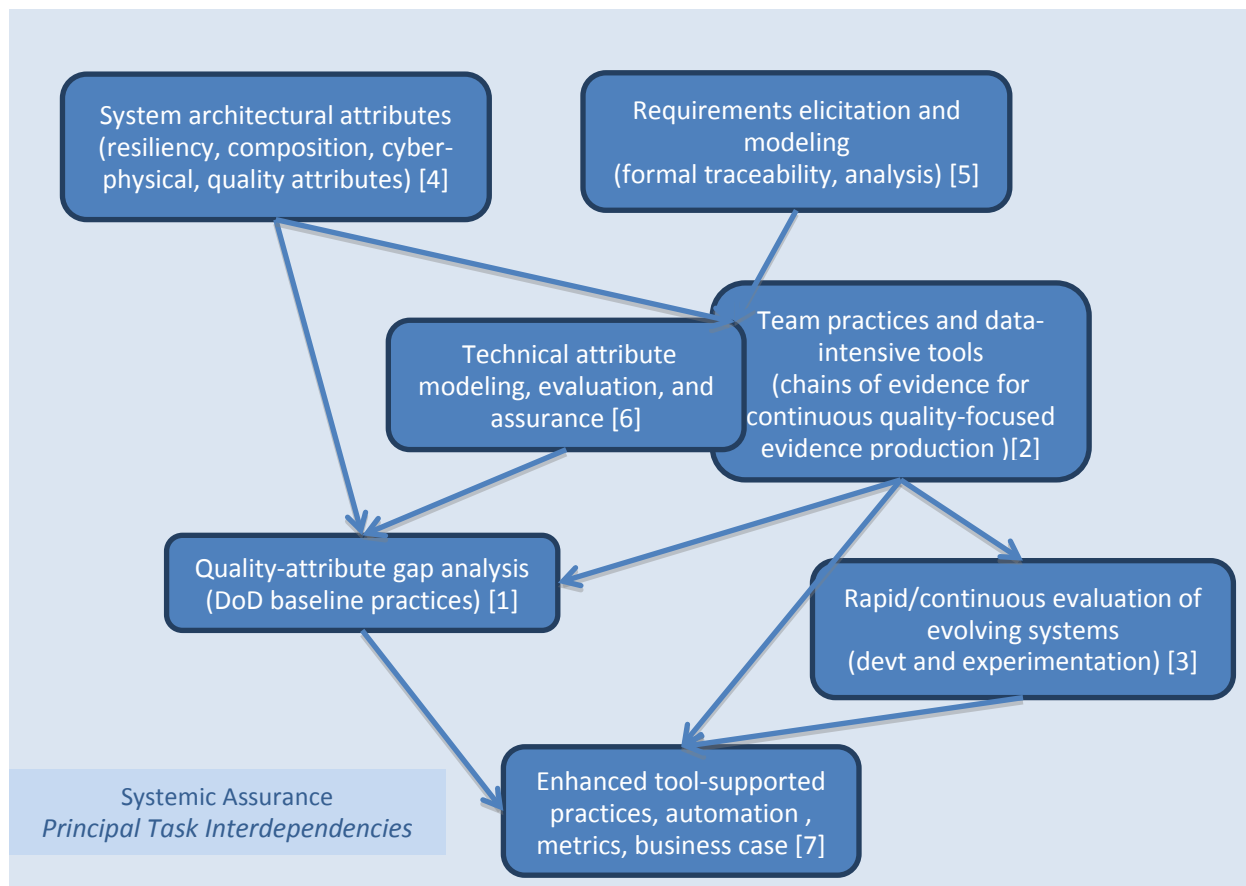


Figure 5.2-1. Systemic Assurance Principal Task Interdependencies

Table 5.2-3 below offers a description of this project timeline.

Table 5.2-3. Systemic Assurance Projects

Projects	Started	Purpose	Primary TS Supported Strategies
Systemic Assurance	2013	Inputs from previous and ongoing SERC areas, programs and projects, including Systemic Security, Systems Engineering and Management Transformation, and Systems of Systems and Enterprises programs	1, 2, 3, 4

5.2.4.1 Systemic Assurance

Table 5.2-4 shows the focus, deliverables, and investment in Systemic Assurance through 2016. Continuing extensions and upgrades will be pursued in 2017 and 2018.

Table 5.2-4. Systemic Assurance Project Timeline

Year	Focus	Key Deliverables
Pre-2014	Startup	Prepare for and hold kickoff meeting with sponsor, Systemic Security, and iTAP representatives
2014	Initiate efforts in all seven thrusts.	Identify principal candidate software code bases and cyber-physical systems for empirical studies. Candidates include commercial and government partner systems (depending on access) as well as significant open source systems of government interest such as Hadoop, SE Linux, Android SE, and others. Begin empirical studies and solution explorations.
2015	Identify most promising solution options, begin solution research and development	In thrust 1, complete baseline analysis and identify feature points to address in framing potential revised practices. Identify technical blockers and potential remediations. Initiate work on tool design, building on capabilities of established IDE and team tools. Develop a “minimal perturbation” model that developers will find familiar but that augments the tooling in specific ways to address the traceability, modeling, and analysis challenges of thrusts 2, 3, and 7. Continue work on specific technical attributes, focusing on the challenges of attributes that tend to defy conventional testing and inspection (thrusts 4 and 6). Develop assessment techniques to address the requirements elicitation goals of thrust 5.
2016	Elaborate and mature solutions; engage with stakeholders; conduct trial deployments. Identify and explore new areas of high-potential research	Engage with stakeholders (potentially in collaboration with SEI) to continue the baselining and criteria definition of thrust 1, leading to a preliminary formulation of an alternative model based on building code ideas (thrusts 2, 3, and 7). Advance efforts in technical and tooling thrusts, producing exemplar evidence-based assurance data for existing major components. Conduct trial deployments of advanced tooling and metrics capabilities with professional development teams in partner organizations. Advance requirements and architecture efforts, identifying candidate “emerging best practices” to support architecture-led iterative development efforts.

Year	Focus	Key Deliverables
2017	Demonstrate and interact with baseline capability users; extend and apply additional solutions. Mature new areas of high-potential research	Demonstrate rapid recertification for one or more of the exemplar systems for which evidence is created in year 3. Develop evidence-based approaches for dynamic and resilient systems potentially with shape-shifting architectures. Engage with stakeholders to advance experimental concepts for new evidence-based approaches to “designed-in assurance support” for larger-scale component-based systems.
2018	Based on experience with existing results, identify and pursue further baseline extensions and new-idea projects	Advance the traceability capabilities in tooling to support a concept of continuous re-evaluation and reconstruction of evidence to support a model of “continuous re-certification.” Enhance tool prototypes to include broader ranges of critical technical quality attributes (thrust 6). Identify advances in modeling, language, and analysis to enable broad adoption of evidence-based approaches.

5.3 SYSTEMS ENGINEERING AND SYSTEMS MANAGEMENT TRANSFORMATION (SEMT)

Traditional DoD systems engineering and management (SE&M) practices have been focused on the definition and acquisition of individual standalone platforms within a relatively stable environment. They have generally used slow, sequential processes that often commit to requirements before their development implications are fully understood. This has caused much late and expensive rework, along with brittle, hard-to-modify architectures.

However, DoD’s current and future environment requires that such platforms and their human and software elements be defined, integrated, and evolved within highly complex and dynamic net-centric systems of systems and enterprises. This requires research focused on transforming traditional SE&M MPTs to meet these current and future DoD mission needs.

Goal: Transform systems engineering and its associated management approaches away from systems designed for optimal performance against a static, pre-specified set of requirements over long procurement cycles to approaches that enhance the productivity of engineers to rapidly and concurrently develop cost effective, flexible, agile systems that can respond to evolving threats and mission needs. “Systems” covers the full range of DoD systems of interest from components such as sensors and effectors to DoD-wide net-centric systems of systems and enterprises. “Effectiveness” covers the full range of needed system quality attributes or ilities, such as reliability, availability, maintainability, safety, security, performance, usability,

scalability, interoperability, speed, versatility, flexibility, and adaptability, along with composite attributes such as resilience, suitability, and sustainability to support the desired mission performance. “Cost” covers the full range of needed resources, including present and future dollars, calendar time, critical skills, and critical material resources.

5.3.1 SEMT GRAND CHALLENGE

The SEMT grand challenge to achieve the SEMT goal is to:

Move the DoD community’s current systems engineering and management MPTs and practices away from sequential, single stovepipe system, hardware-first, outside-in, document-driven, point-solution, acquisition-oriented approaches; toward concurrent, portfolio and enterprise-oriented, hardware-software-human engineered, balanced outside-in and inside-out, model-driven, set-based, full life cycle approaches. These will enable much more rapid, concurrent, flexible, scalable definition and analysis of the increasingly complex, dynamic, multi-stakeholder, cyber-physical-human DoD systems, systems of systems, portfolios of systems, and enterprises of the future.

5.3.2 STRATEGY TO ADDRESS THE SEMT GRAND CHALLENGE

Successfully executing the following strategies will make significant progress towards addressing the SEMT Grand Challenge:

1. *Make Smart Trades Quickly:* Develop MPTs to enable stakeholders to be able to understand and visualize the tradespace and make smart decisions quickly that take into account how the many characteristics and functions of systems impact each other
2. *Rapidly Conceive of Systems:* Develop MPTs that allow multi-discipline stakeholders to quickly develop alternative system concepts and evaluate them for their effectiveness and practicality
3. *Balance Agility and Assurance:* Develop SE MPTs that work with high assurance in the face of high uncertainty and rapid change in mission, requirements, technology, and other factors to allow a system to be rapidly acquired and responsive to both anticipated and unanticipated changes in the field
4. *Align with Engineered Resilient Systems:* Align research to both leverage the research and technology results of the Engineered Resilient Systems (ERS) program, and contribute to it; e.g., ERS efforts to define new approaches to tradespace.

Four SERC research programs directly implement the strategies:

- Affordability and Value in Systems
- Quantitative Risk
- Interactive Model-Centric Systems Engineering (IMCSE)
- Agile Systems Engineering

5.3.3 AFFORDABILITY AND VALUE IN SYSTEMS PROGRAM

The Affordability and Value in Systems Program will use the full range of DoD stakeholder value propositions to structure and pursue a value-based ilities hierarchy. Its initial form includes the stakeholder values of having current-system Mission Effectiveness (Speed, Delivery Capability, Accuracy, Usability, Scalability, Versatility); current-system Resource Utilization Efficiency (Cost, Duration, Personnel, Scarce Quantities (size, weight, energy, ...), Producibility, Supportability); current-system Protection (Safety, Security, Privacy); current-system Robustness: (Reliability, Availability, Maintainability); along with future-system Flexibility (Modifiability, Tailorability/Extendibility, Adaptability); and future-system Composability (Interoperability/Portability, Openness/Standards Compliance, Service-Orientation) to address evolving field needs.

This program will pursue the Grand Challenge of performing ilities tradespace and affordability analysis for cyber-physical-human systems and systems of systems in a portfolio and enterprise context. It will integrate current strengths in physical-systems tradespace analysis and information-systems tradespace analysis. It will pursue both basic research on the foundational relationships among ilities, and applied research on the pilot application and evolution of ilities tradespace and affordability MPTs within key DoD application domains, including full-coverage cyber-physical-human total ownership cost estimation models addressing the new characteristics of future DoD systems, systems of systems, portfolios, and enterprises.

This research program primarily implements SEMT strategy one above. Table 5.3-1 offers a description of the ilities Tradespace and Affordability Project (iTAP), the one current project in the Affordability and Value in Systems Program.

Table 5.3-1. Affordability and Value in Systems Projects

Project	Started	Purpose	Primary SEMT Supported Strategies
iTAP	2012	Pursue the Grand Challenge of performing ilities tradespace and affordability analysis for cyber-physical-human systems	1

5.3.3.1 iTAP Project

Table 5.3-2 shows the focus, deliverables, and investment in iTAP through 2016. The timeline beyond 2016 has not yet been established. The iTAP program has two primary initial foci, and a third educational focus once a critical mass of iTAP capabilities have been developed.

The first initial focus is on researching and developing the foundations ofilities Tradespace and Affordability (IT&A) analysis via a framework of IT&A views that aid in organizing and applying IT&A analysis to address the systems engineering of cyber-physical-human systems, systems of systems, portfolios, and enterprises. The views include DoD stakeholder value-based ility definitions, relationships, and priorities; means-ends views for achieving individual ilities; architectural strategies for achieving individual ilities and their second-order impacts on other ilities; process strategies for incrementally addressing uncertainties in ility tradespace situations, and for concurrently balancing a cyber-physical-human system's ility aspects; domain-specific ility tradespace views; and system of systems and enterprise views, including challenges in scalability and in reconciling the incompatible assumptions of component-system domain-specific architectures.

The second initial focus is on extending and integrating existing IT&A MPTs to better support DoD cyber-physical-human system ility analysis. This will include developing more service-oriented and interoperable versions of current SERC ility MPTs; developing approaches for better integrating MPTs primarily focused on physical, cyber, or human system IT&A analysis; efforts to modify and compose existing SERC ility IT&A MPTs to better interoperate with each other and with counterpart MPTs in the ERS community and elsewhere; and efforts to apply the MPTs to the IT&A analysis of increasingly challenging DoD systems. In the affordability area, a particularly promising prospect is a collaborative SERC-Aerospace Corporation-USAF/SMC-NRO effort to develop an integrated lifecycle cyber-physical-human system cost model for satellite systems, including the flight, ground, and launch systems, which could be subsequently extended to other DoD domains, along with cost estimation at the portfolio and enterprise levels.

Table 5.3-2. iTAP Project Timeline

Year	Focus	Key Deliverables
Pre-2014	Research and develop basic iTAP concepts and framework. Explore early MPT applications and interoperability, including with ERS counterparts.	Basic iTAP concepts and framework. Results of early MPT applications and interoperability improvements. Prototype integrated lifecycle cyber-physical-human system cost model. Multi-view IT&A analysis guidance papers.
2014	Elaborate iTAP concepts and framework in key areas e.g., systems of systems. MPT extensions; broader and deeper applications and interoperability. iTAP new-idea explorations.	Elaborated iTAP concepts and framework. Results of broader and deeper MPT applications. Integrated lifecycle cyber-physical-human system cost model domain-specific IOC. Multi-view IT&A Analysis Guidebook v 0.5; associated papers.

Year	Focus	Key Deliverables
2015	Mature iTAP concepts, framework, Guidebook. Increasingly scalable and interoperable MPTs. Extensions of iTAP new-idea explorations. Guidebook-based outreach and educational initiatives	Mature iTAP concepts and framework. Results of increasingly scalable and interoperable MPT applications. Extended domain-specific lifecycle cyber-physical-human system cost model; prototypes in other domains, and for portfolio and enterprise extensions. Multi-view IT&A Analysis Guidebook v 1.0; Guidebook-oriented courseware, early usage at AFIT, NPS, DAU, SERC universities.
2016	Integration of new-idea explorations into iTAP concepts, framework, Guidebook. Increasingly scalable and interoperable MPTs. Further iTAP new-idea explorations. Guidebook-based outreach and educational initiatives	New-idea-extended iTAP concepts and framework. Results of increasingly scalable and interoperable MPT applications. Extended multi-domain lifecycle cyber-physical-human system cost model, including portfolio and enterprise extensions; Multi-view IT&A Analysis Guidebook v 1.1; Guidebook-oriented courseware, broad usage at AFIT, NPS, DAU, SERC, and other universities.

5.3.4 QUANTITATIVE RISK PROGRAM

The Quantitative Risk Program, which currently has one project, primarily implements SEMT strategy 1 above. Table 5.3-3 describes the Quantitative Technical Risk (QTR) Project.

Table 5.3-3. Quantitative Risk Projects

Projects	Started	Purpose	Primary SEMT Supported Strategies
Quantitative Technical Risk	2012	Develop a mix of near-term and long-term MPTs that quantify the technical risk programs face to support improved decision making about how to address those risks	1

5.3.4.1 Quantitative Technical Risk (QTR) Project

Table 5.3-4 shows the focus, deliverables, and investment in the QTR Project through 2014. The timeline beyond 2014 has not yet been established, and will be structured to build on progress in 2013 and 2014. Technical risk refers to risks that originate in, have effects on, or involve in risk mitigation including system configuration, architecture, baseline, technologies, design, manufacturing and/or integration. The QTR Project has two primary foci, to be addressed in parallel.

The first focus is incremental development of QTR MPTs addressing needs and gaps within the DoD acquisition Risk Management process, starting with “low-hanging fruit” then progressing to more challenging issues. The approach is to involve end-users in the services as co-developers and transition partners in order to ensure that the QTR are relevant to program risk issues; practical within the acquisition decision and information structures, processes, and temporal sequences; and can be effectively transitioned to end-users. The intent is to employ evidence-based methods to identify high-impact and high-contribution MPTs.

The second focus is fundamental research needed to develop QTR MPTs addressing challenging DoD Risk Management needs and issues. The approach is to adapt and expand promising theoretical frameworks and MPT approaches from areas outside of traditional DoD Risk Management, such as insurance underwriting for large-scale engineering and construction projects, real options in product design and development, and predictive analytics in insurance and business development. The scope includes risks over the entire system life cycle, peculiarities by type of system, type of acquisition, type of cause, type of causal chain, and types of mitigation strategies.

Table 5.3-4. Quantitative Technical Risk Project Timeline

Year	Focus	Key Deliverables
Pre-2014	Framing the issues, opportunities and technical approaches for relevant, practical QTR MPT near- and long-term research, development, validation and transition	Research framework of near- and long-term risk issues & potential QTR MPT for DoD acquisition. Findings from investigation of complexity theory for acquisition program risk management. List of approaches from outside traditional DoD acquisition. Plan for incremental development, validation and transition. Identification of potential case study systems and data sources. Outlines of strategies toward developing an adaptable integrated risk management framework, and transitioning MPT to end-user systems.

Year	Focus	Key Deliverables
2014	Incremental development, validation and transition of QTR MPT in parallel with longer-term research for additional QTR MPT.	Data for one or more historical systems and acquisition programs for use in case studies. Documentation of one or more initial QTR MPT harvesting “low-hanging-fruit”, with case studies applying the initial QTR MPT to a historical acquisition program. Letters of agreement with end-user co-development and transition partners in one or more services. Technical interface specifications and coordination milestones toward transition initial QTR MPT to a service SE and risk management system. Identification and assessment of “flexibility and adaptability” strategies and risk-hedges (real option) in DoD acquisition. Identification and assessment of Risk Breakdown Structures, Risk Factor Analysis and Risk Estimating Relationships (for predictive analytics) for DoD programs. Assessment of insurance industry approaches to advanced engineering projects for DoD acquisition programs.
2015-2018	Incremental development, validation and transition of QTR MPT in parallel with longer-term research for additional QTR MPT.	Documentation of incremental QTR MPT, case study validation, and transition to end-users SE and risk management systems. Further research on underlying methods and theory. Specific topics to be determined.

5.3.5 INTERACTIVE MODEL-CENTRIC SYSTEMS ENGINEERING (IMCSE) PROGRAM

The IMCSE Program will include and significantly extend the traditional focus on the modeling of system products and the use of the models to performilities tradespace and affordability analyses as described above, and increasingly use the models to generate software and hardware products. The IMCSE Program extensions will address the modeling of system execution processes, such as operational concept formulation, and system development processes, which can also be executed to aid in the generation of system products. Further, as was emphasized in the IMCSE section of the SERC Systems 2020 Report, an additional focus on modeling the system’s environment will be pursued, which is needed for performing many of the ilities tradespace and affordability analyses. Models can also improve affordability by automatically generating needed documentation, or even better by serving as the documentation itself. Further, models can reduce or avoid system overruns and performance shortfalls by enabling more thorough Analyses of Alternatives and evidence-based decision reviews.

This research program primarily implements all four of the SEMT strategies noted above. It builds on a recently completed set of projects (RT-30: *Graphical Concept of Operations*), and the

first IMCSE project currently under definition that will begin in late 2013. Table 5.3-5 offers a description of the active project and the strategies it primarily supports.

Table 5.3-5. IMCSE Projects

Projects	Started	Purpose	Primary SEMT Supported Strategies
Interactive Model-Centric Systems Engineering	Late 2013	Using models to drive systems engineering, development, production, and evolution	1, 2, 3, 4

5.3.5.1 Interactive Model-Centric Systems Engineering Project

Models have significantly changed SE practice over the past decade. Most notably, model-based systems engineering (MBSE) methods and tools are increasingly used throughout the entire system lifecycle to generate systems, software and hardware products, replacing labor-intensive and error-prone documentation-based processes with model-based ones. While substantial benefits have been achieved, the most impactful application of models in SE has yet to be realized. Truly transformative results will only come through intense human-model interaction, to rapidly conceive of systems and interact with models in order to make rapid trades to decide on what is most effective given present knowledge and future uncertainties, as well as what is practical given resources and constraints. The Interactive Model-Centric Systems Engineering (IMCSE) research program seeks to achieve this transformation.

The complexity and socio-technical nature of contemporary systems/SoSs drives an urgent need for a more powerful integration of humans and technologies. Early concept decisions have always been critically important, and with continuously evolving SoSs having long life spans, such decisions are now made throughout the entire life cycle. Soft factors become increasingly influential. For example, trust in model-based data sets and decisions are in part determined by the chosen model itself as perceived by specific decision makers. The timescale of making early architectural decisions is out of sync with the current model-based systems engineering capabilities and decision environments. New algorithms and novel modeling approaches must be discovered to accelerate technical and programmatic decision support from months to minutes; in order to effectively leverage and incorporate human knowledge and judgment, this requires an interactive capability. Much potential exists in maturing emerging novel methods for evaluating system responsiveness under complex uncertainties, to enable engineering of resilient systems. Further, as was emphasized in the SERC Systems 2020 Report, modeling the system's dynamic operational environment remains an open area of research. Forward research is informed by a recently completed set of SERC projects on Graphical Concept of Operations.

The IMCSE research program will involve three projects initiated in 2014, followed by additional projects in out-years as determined by the 2014 investigation of current state of art/practice. The three projects are:

1. **Pathfinder Project.** The project will investigate the current state of the art/practice in interactive model-centric systems engineering. Surveys and literature review will be used to establish a preliminary picture of what is being done in practice, current MPTs, and what research has/is being performed. This will inform the planning and conduct of an invited workshop to identify research opportunities, gaps and issues. A report will be developed from the workshop, including priorities for expanded and additional research in out-years of the project.
2. **Interactive Schedule Reduction Model.** This project will build on an existing prototype model (prior DARPA-support) for interactively exploring alternatives in the systems development process and application of resources. The model enables rapid sensitivity analysis of various factors to determine their potential impact on program schedule. Exploratory extensions of the model will be developed and evaluated, resulting in a new prototype for pilot application. A report will be developed on the findings and plans for pilot testing.
3. **Interactive Epoch-Era Analysis.** This project will involve research to extend a current approach for evaluating systems under uncertainty, Epoch-Era Analysis (EEA), through the development of an interactive capability. The resulting prototype method and supporting tools will be applied to a case on uncertainties in mission planning and deployment support, of particular interest to the ERS program. This case application will serve as a pathfinder for identifying key considerations for applicability and deployability of the method for eventual DoD use. A report will be developed on the findings for the research and case application, along with plans for further development and case applications.

Table 5.3-6 shows the focus, deliverables and investment in IMCSE through 2018 aimed at addressing the three projects above, as well as new projects in out-years. In 2014, the “pathfinder” project investigation will identify synergistic research opportunities. Beginning with the initial 2014 workshop, periodic targeted workshops will be convened with the intent of examining ongoing research that can be leveraged in the SERC research efforts, and involving the broader community in creating - and realizing - the vision and research agenda for the IMCSE program.

Table 5.3-6. IMCSE Project Timeline

Year	Focus	Key Deliverables
Pre-2014	New start	
2014	Pathfinder project with collaborative research discovery; exploratory extensions to an existing development schedule reduction model; exploratory piloting and interactive extensions to Epoch-Era method	<i>Pathfinder Project:</i> Investigation of current state of art/practice. Workshop to explore issues and opportunities, with report on workshop results. Pathfinder project report, with findings of research opportunities, gaps, and issues. Out-year research plans based on pathfinder results. <i>Interactive Schedule Reduction Model:</i> Exploratory extensions implemented and evaluated. Report on exploratory schedule model. Prototype model for pilot application. <i>Interactive Epoch-Era Analysis:</i> Exploratory research to develop interactive capability, with demonstration via a mission planning support application case. Report on exploratory research and case application.
2015	Initiate multi-year research plans based on pathfinder results, including 2014 project follow-on for one or both of the exploratory research projects. Assess results individually and comparatively.	<i>IMCSE Project Applications:</i> Based on pathfinder project results, select and initiate one or more additional projects, and increase SERC member collaboration in projects. Report to document the maturation of the MPTs for each of these projects, with comparative results.
2016	Increasing maturation of IMCSE MPTs and enabling environments, leading to adoption by user community and assessment of real-world impact; extend IMCSE scope via increased collaboration of additional universities and broader user community. Exploration of further new-idea projects.	<i>IMCSE MPT Implementations and Impact Assessments:</i> Continued maturation and implementation of IMCSE MPTs, with enabling environments. Ongoing study of impacts resulting in a comprehensive report of progress, results, and opportunities.
2017-2018	Increasing maturation and synthesis of IMCSE MPTs and enabling environments, leading to adoption by user community and demonstration of real-world impact; sustain and increase collaboration of additional universities and broader user community. Step-ups of new-idea projects.	<i>IMCSE MPT Synthesis Impact and Effective Practice Assessments:</i> Continued maturation, synthesis and implementation of IMCSE MPTs, with enabling environments. Ongoing study of real-world impacts to identify successful practices. A comprehensive report of impacts and insights, with guidance on practice.

5.3.6 AGILE SYSTEMS ENGINEERING PROGRAM

Agility can be defined as the ability to respond quickly and effectively to changes. In SE, there are two general areas where agility is a primary characteristic – process and product. Product agility through better architecting has been addressed extensively in SERC RT-18 on Valuing Flexibility, and in earlier work such as the Rechtin-Maier series of Systems Architecting books, the CMU-SEI Architecture Tradeoff Analysis Method book and reports, and the DARPA F6 and META projects. This effort will primarily focus on agile and lean process approaches.

Process agility provides systems engineers with methods, processes and tools to operate more effectively in development environments driven by change: the rapid pace of technology, the increasing need for interoperability between legacy and new capabilities, evolving requirements throughout the development lifecycle, and the changing economic and political factors that undergird and enable system development.

A key consideration in both process and product agility is the reconciliation and integration of systems and software engineering activities. Software by its nature is malleable and able to rapidly achieve modified or new capabilities while maintaining system operational capability. Currently, software development processes do not operate seamlessly with systems engineering processes. The ability for software to provide incremental capability requires adaptation of SE MPTs to enable modularity, flexibility and continuous integration and verification and validation (V&V).

The Agile SE Program currently has two projects:

1. Kanban in SE
2. Agile SE Enablers and Quantification

Table 5.3-7 offers a description of the two active projects and the strategies they primarily support.

Table 5.3-7. Agile SE Projects

Project	Started	Purpose	Primary SEMT Supported Strategies
Kanban in SE	2010	Exploration of applicability of Kanban methods to complex system evolution where development is primarily through capability enhancement and new features added to an existing system and infrastructure	2,3,4
Agile SE Enablers and Quantification	2008, 2012	Identifying and employing research that can inform and improve agile SE, drawing on the SERC RT-34 Expediting SE study and its initial model quantifying agile schedule compression	1,2,3,4

5.3.6.1 Kanban in SE Project

Kanban in SE explores the use of lean scheduling methods that have been successful in manufacturing. “Pull” or “on demand” scheduling methods smooth workflow by limiting scheduled work to current resource capacity and constantly reprioritizing the work to be performed according to real-time status information. This promotes earlier delivery of work and higher value to the downstream customer, improves the efficiency of scarce resources, prevents overloading of resources, and limits the overhead of maintaining constantly changing schedules.

This research was initially motivated by the ineffectiveness of integrated master schedules in rapidly changing operational environments and the success of Kanban approaches for the knowledge work of software development. Research to date has shown that Kanban approaches can be successful in the development and evolution of individual systems. Further research is necessary to determine the extent to which Kanban methods can be successfully applied in the initial definition of highly complex systems, or in the creation, operation, and management of systems of large, independently evolving systems.

The proposed research builds on the initial Kanban scheduling system (KSS) networks described in SERC RT-35. The KSS network seeks to prioritize engineering tasks based on SoS or complex system capability priorities and task interdependencies. This leads to implementation of the most value-adding features first, reduces wait time for scarce engineering specialties, and minimizes time wasted on context switching by overloaded resources. In achieving this goal, a KSS network provides two valuable side effects. First, the implementation of the network supports critical conversations about schedule and value decisions by the appropriate people at the right time and nearest the actual implementation. Second, the network significantly improves executive and systems engineering visibility into the status of multiple independent development organizations.

The proposed next steps in this research are to improve the simulation and analysis infrastructure and conduct industry pilots of the KSS network concepts to evaluate and calibrate the infrastructure.

The research infrastructure developed in RT-35 is insufficient for further research on the practicality and implementation of KSS networks. Current simulation capabilities need to be expanded to go beyond the comparison with traditional scheduling systems and provide the capability to model different organizational structures and to provide sensitivity analysis of the various flow control methods. The proposed Lean Kanban work will expand the basic model to include a fuller set of simulation features and reports. Several software and SE infrastructure tool manufacturers have confirmed interest in supporting this work using their own tool infrastructure.

As the analysis instrumentation evolves, in vivo piloting of the concept in industry will evaluate and calibrate the models. Several aerospace companies have agreed to support the piloting effort. By simulating the KSS network and comparing the results to actual pilots, actual schedule and effort savings can be captured and then extended through further modeling and simulation to various types of complex system developments. In addition, the results will provide the information necessary to justify an expected return on investment for these types of process changes. Finally, the results from simulation scenarios and actual pilots can be used as feasibility evidence for new system/system capability cost and schedule estimates, identify those estimates that are overly optimistic or overly conservative, and provide insights on the general range of applicability of Kanban approaches.

This work will take advantage of a large, skilled volunteer working group of industry professionals created during the RT-35 task. Members of the group represent the companies interested in both the infrastructure and piloting support. Table 5.3-8 shows the focus, deliverables, and investment in Kanban through 2018.

Table 5.3-8. Kanban in SE Project Timeline

Year	Focus	Key Deliverables
Pre-2014	Studying on-demand scheduling systems and adapting the concept to SE	Kanban-based Scheduling System (KSS) concepts; RT-35 Kanban in SE reports and papers; Kanban in SE industry working group
2014-2015	Simulating, and piloting KSS networks	Demonstration, deployment and evaluation materials; piloting plans; piloting results
2016	Enhancing KSS Concept	Continued piloting; Adding economic factors; adding Bayesian Belief Network supported estimation based on Kanban system information and flow data to support capability selection and staffing decisions
2017-2018	Extending KSS concept	Adapt the KSS concept to additional SE environments

5.3.6.2 Agile SE Enablers and Quantification Project

Candidate Agile SE enablers include the product, process, people, project, and risk factors identified in the SERC RT-34 Expediting SE study, and the candidate enablers identified in RT-35: Life cycle process selection (ICSM, mixed-mode); Human cognition, negotiation and communications; Governance of evolving system development; and Organizational and system goal alignment.

This task draws on the extensive interviews, site visits, and analyses of expedited SE experience, and the associated SE acceleration estimation model developed in the SERC RT-34 Expedited SE study. It can also take advantage of a number of activities external to SERC, including the INCOSE Agile SE Working Group, the Lean Systems Society and its projects, and the programmatic information from MITRE and other FFRDCs.

Table 5.3-9 shows the focus, deliverables, and investment in Agile SE Enablers through 2018.

Table 5.3-9. Agile SE Enablers Project Timeline

Year	Focus	Key Deliverables
Pre-2014	MPTs in software	MPT reports and papers; RT-35 phase 1 work; RT-34 work; support of INCOSE Agile SE WG
2014	Fundamentals of agility	White papers on topics such as: SE as a service concept; Complexity and sense-making in SE decisions; Governance, organizational and contracting requirements for implementing agile SE. Quantitative schedule acceleration model extensions, calibration, behavioral analysis. Experimental applications and resulting formulation of further high-impact Agile SE research.
2015-2018		Performance, evaluation, and refinement of further high-impact Agile SE research project results

5.4 HUMAN CAPITAL DEVELOPMENT (HCD)

Over the last decade, DoD and the defense industrial base (DIB) have often cited a shortfall in the quantity of systems engineers and in the knowledge, skills, and abilities (KSAs) of those systems engineers (NDIA 2006, WSARA 2009, NDIA 2010). The Human Capital Development (HCD) research area directly targets that shortfall.

Goal: Ensure a competitive advantage through the availability to the DoD and the defense industrial base of highly capable systems engineers and technical leaders

5.4.1 HCD GRAND CHALLENGE

The HCD grand challenge to achieve the HCD goal is to:

Discover how to dramatically accelerate the professional development of highly capable systems engineers and technical leaders in DoD and the defense industrial base and determine how to sustainably implement those findings

5.4.2 STRATEGY TO ADDRESS THE HCD GRAND CHALLENGE

Successfully executing the following strategies will make significant progress towards addressing the HCD Grand Challenge:

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

2. *Educate and Train Faster:* Develop innovative approaches and technology to educate and train systems engineers and systems teams at all levels, engineers, and STEM students much more rapidly, effectively and efficiently than with classical means
3. *Develop Effective Technical Leaders:* Develop innovative approaches to educate DoD technical leaders with the right mix of technical, business, and enterprise skills
4. *Improve SE and STEM Education:* Develop recommendations and systems curricula for the next generation of systems engineers, engineers and STEM students
5. *Track Progress:* Track the changes in SE workforce demographics and performance over time to understand how the workforce is improving and how improvement programs are working

Three HCD research programs directly implement the strategy:

- Evolving Body of Knowledge
- Experience Acceleration
- Systems Engineering and Technical Leadership Education

The synergy and interaction of the HCD programs and projects is shown in Figure 5.4-1 below.

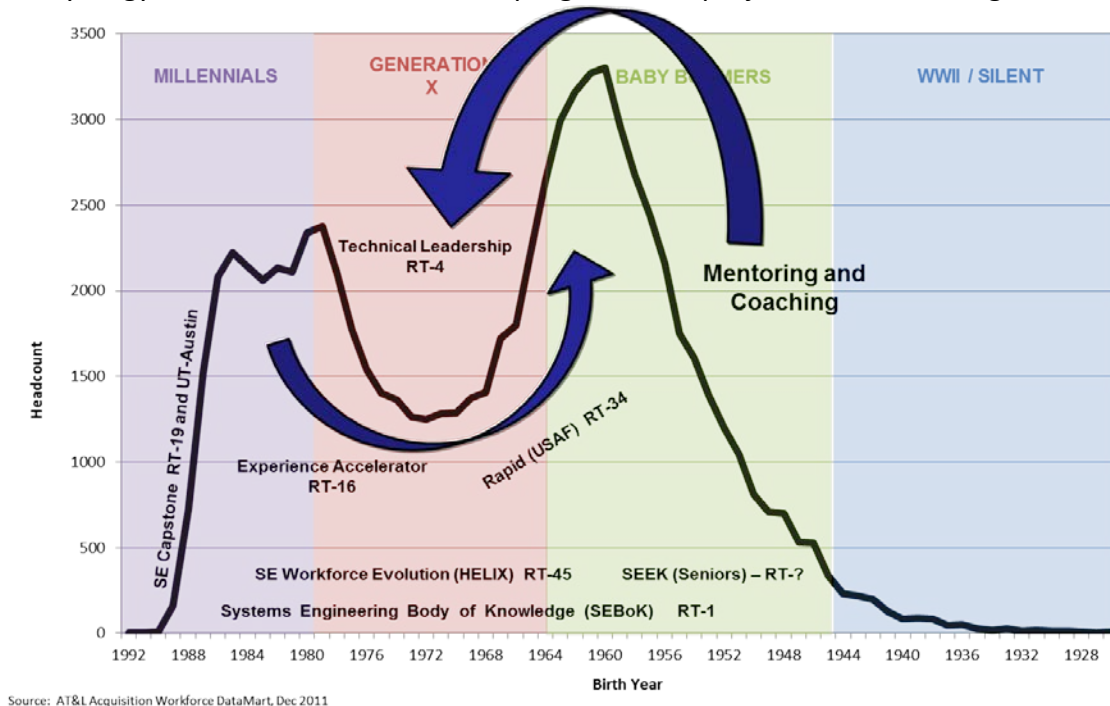


Figure 5.4-1. HCD Program and Project Synergy to Meet Grand Challenge

5.4.3 EVOLVING BODY OF KNOWLEDGE PROGRAM

This research program primarily implements HCD strategies 1, 4 and 5 above – *Create and Provide Easy Knowledge Access, Improve SE and STEM Education, and Track Progress*. It includes two projects already underway (BKCASE and Helix) and a third project (SEEK) that will begin in late 2013. Table 5.4-1 offers a description of these three projects and which strategies they primarily support.

Table 5.4-1. Evolving Body of Knowledge Projects

Projects	Started	Purpose	Primary HCD Supported Strategies
BKCASE	2009	Create, disseminate, and evolve the authoritative guide to the SE body of knowledge and recommendations on curricula for SE graduate programs ¹	1, 3, 4, 5
HELIX	2012	Understand and widely disseminate the characteristics of the SE workforce, including what enables them to be effective at their jobs	3, 5
SEEK	2013	Capture insights from SE experts about significant program successes and failures and portray them primarily in case studies augmented by multi-media materials for easy access and use in training, education and practice	1,3,4

5.4.3.1 BKCASE Project

The Body of Knowledge and Curriculum to Advance Systems Engineering (BKCASE) Project is (a) identifying and making readily accessible the vast knowledge that systems engineers need to know (SEBoK) and (b) providing recommendations to the SE academic community on SE graduate curricula (GRCSE). BKCASE began in 2009 as a SERC project led by Stevens Institute and the Naval Postgraduate School. Beginning in 2013, the International Council on Systems Engineering (INCOSE) and the Institute of Electrical and Electronics Engineers Computer Society (IEEE-CS) have become co-stewards with the SERC to guide and promulgate the SEBoK and GRCSE. Both products will undergo regular updates to reflect advances in the field and feedback from the user community. SEBoK articles have been accessed well over 100,000 times since Version 1.0 was released in September 2012. Several universities in the US, Europe, and Australia have begun adopting GRCSE curriculum recommendations. Table 5.4-2 shows the focus, deliverables, and investment in BKCASE through 2018. The SEBoK is novel in its form of delivery (a wiki), its governance model (shared among 3 organizations), its scale (spanning the technical aspects of the discipline, how that technology is effectively adopted and used, and the underlying science on which the technology is based), and its rate of change (multiple updates

¹ SEBoK is naturally aligned with the Evolving Body of Knowledge Program. GRCSE is naturally aligned with the SE and Technical Leadership Education Program. However, for historical reasons, BKCASE produces both SEBoK and GRCSE. Since SEBoK is far more demanding than GRCSE to create, promulgate, and evolve, BKCASE is categorized within the Evolving Body of Knowledge Program.

annually). Research in how to maintain this novelty and how to tailor the SEBoK to specific domains is the primary research focus for the next several years.

Table 5.4-2. BKCASE Project Timeline

Year	Focus	Key Deliverables
Pre-2014	Early versions of SEBoK and GRCSE, governance model to promulgate and support them	SEBoK 1.0, 1.1, 1.2, GRCSE 1.0, governance agreement between SERC, INCOSE, IEEE-CS, workshops
2014	Adoption, new partnerships, expanded content, broader community contributions	Agreements with other societies, domain-specific variants of SEBoK, SEBoK 1.3, 1.4, GRCSE 1.1, user groups, adoption workshops
2015	Continued adoption, partnerships, expanded content, broader community contributions	Additional society agreements and domain-specific SEBoK variants, SEBoK 2.0, GRCSE 1.2, user groups, adoption workshops
2016-2018	Broad community use	SEBoK 2.1, 2.2, GRCSE 1.3, user groups

5.4.3.2 Helix Project

Helix began in October 2012 to examine the “DNA” of the systems engineering workforce in both DoD and the defense industrial base. The project will answer three questions:

- What is the demographic picture of the systems engineering workforce? What is the distribution of people by age, education, title, role, activity, etc.? How does the distribution of people differ based on organizational mission, size, etc.?
- How effective are systems engineers and why? What are the forces most impacting effectiveness – experiences, proficiency in specific competencies, culture of the organization in which they work, etc.?
- What are employers doing to improve the effectiveness of the systems engineering workforce and how well are those efforts working? Are they using mentoring, job rotation, in-house training, etc. and how aligned are those efforts to the forces that most impact effectiveness of their workforce?

As more data is collected and analyzed, regular reports of aggregated anonymous data will provide an increasingly rich and varied set of insights into the systems engineering population.

Table 5.4-3 shows the focus, deliverables, and investment in the Helix Project through 2018.

Table 5.4-3. Helix Project Timeline

Year	Focus	Key Deliverables
Pre-2014	Establish methodology, small-scale data collection, publish early findings	Early findings report from both DoD and the defense industrial base

Year	Focus	Key Deliverables
2014	Large-scale data collection and analysis; begin regular publication of findings; possible expansion to non-defense and non-US organizations	Quarterly reports of findings; benchmarking studies
2015-2018	Data collected from enough organizations and individuals to paint a vivid and insightful image of the systems engineering population	Quarterly reports of findings, including changes in findings over time based on longitudinal data collection; benchmarking studies

5.4.3.3 SEEK Project

This project addresses a gap in the SE research literature: the lack of detailed case studies about SE successes and failures. The research will develop a series of case studies tailored to defense education needs. These case studies will support instruction at the Defense Acquisition University and at the Naval Postgraduate School, the federal service academies, and other government education and training providers. They will be managed by a board of advisors from stakeholders to increase the utility and portability of the case studies. They will provide core data for other SE research.

Much SE corporate knowledge resides in engineers nearing retirement. Those engineers have presided over the successes and failures of the last decade; they know the lessons learned and the technical details of what worked and what has not worked. This project will capture that knowledge. Case studies allow the community to capture the technical data of the projects, understand what worked and what did not, and then to generalize. They are invaluable for process improvement across Do/D and for education that is grounded in practical examples.

Table 5.4-4 shows the focus, deliverables, and investment in the SEEK Project through 2018.

Table 5.4-4. SEEK Project Timeline

Year	Focus	Key Deliverables
Pre-2014	Form project and set up infrastructure to capture expert knowledge	None
2014-2018	Grow pool of experts; conduct interviews and roundtable discussions; develop case studies	Several substantial case studies annually, integrated with the SEBoK, Defense Acquisition Guidebook, and INCOSE Handbook. The number will scale with funding, and the topics will be selected based on advisory board input.

5.4.4 EXPERIENCE ACCELERATION PROGRAM

This research program primarily implements HCD strategy 2 – *Educate and Train Faster*. It will include projects aimed at creating automated learning environments that simulate real world

experiences of systems engineers. Those experiences will be vivid and realistic enough to significantly accelerate the learning and maturation of those systems engineers. One project will evolve the current simulation platform, making it ever more robust and capable and enabling quicker and easier construction of new experiences. Other projects will add to the current catalog of experiences, developing new experiences that use the simulation platform. Experiences will vary based on the size and types of systems being acquired, the acquisition lifecycle, the novelty of the technology being acquired, and other parameters of interest. Over the five-year period from 2014-2018, other organizations will join the SERC in improving the experience platform and in developing additional experiences, creating a marketplace for experience acceleration. Table 5.4-5 offers a description of these projects and which strategies they primarily support. Table 5.4-6 shows the focus, deliverables, and investment in the Experience Accelerator Project through 2018.

Table 5.4-5. Experience Acceleration Projects

Projects	Started	Purpose	Primary HCD Supported Strategies
Experience Accelerator	2010	Create the “engine” that will be used to host a wide range of experiences, develop the first virtual experiences that use the engine, and validate the experience accelerator concept through trial use. Keep improving the engine over time as a broader set of experiences are created and trialed with ever more students. Create an open vibrant community that will develop additional virtual experiences that can be shared within the defense industrial base and DoD.	2
Additional Virtual Experiences	2014	Develop an increasingly broader and richer set of virtual experiences that are hosted on the Experience Accelerator engine	2

Table 5.4-6. Experience Accelerator Project Timeline

Year	Focus	Key Deliverables
Pre-2014	Build experience accelerator engine, first experiences, and validate concept with first students	Increasingly sophisticated versions of Experience Accelerator engine, first virtual experience, first use by students
2014-2018	Create an increasingly more complete and sophisticated engine, tools to build virtual experiences, and a marketplace community to create and apply those experiences	New versions of increasingly more capable engine and tools to create experiences, marketplace community with suitable governance structure

5.4.5 SYSTEMS ENGINEERING AND TECHNICAL LEADERSHIP EDUCATION PROGRAM

This research program primarily implements HCD strategies 2 and 3 – *Educate and Train Faster* and *Develop Effective Technical Leaders*. It will include two projects aimed at improving the quality of education in systems thinking and SE in universities that teach engineers who are hired by the DoD and the defense industrial base: the Engineering Capstone Marketplace Project, and the Technical Leadership Project. Table 5.4-7 offers a description of these projects and which strategies they primarily support.

Table 5.4-7. Systems Engineering and Technical Leadership Education Projects

Projects	Started	Purpose	Primary HCD Supported Strategies
Engineering Capstone Marketplace	2010	Originally intended to show how to conduct multidisciplinary senior capstone projects in classical engineering programs, especially those that increase awareness of and appreciation for DoD applications. Building on its early success, the project has morphed into a marketplace where companies and government organizations post on a website problems suitable for senior capstone projects. Students from multiple universities form teams to work on those projects under the supervision of faculty and the posting organization. This marketplace model has the potential to scale nationwide, involving thousands of students in hundreds of projects and universities.	2,4
Technical Leadership	2010	Develop innovative ways to teach technical leadership to the DoD acquisition workforce, including not only systems engineers, but also others who must understand technical leadership, such as program managers. Iteratively pilot the resulting courses and integrate them into the DAU curriculum.	2,3,4

5.4.5.1 Engineering Capstone Marketplace Project

The Engineering Capstone Marketplace Project is the evolution of research begun in 2010, which showed that a multidisciplinary senior capstone project could enhance development of SE competencies and increase interest in SE. The Marketplace Project is now building and piloting the infrastructure to affordably scale this approach nationwide between 2014 and 2018 and improve how thousands of students are taught engineering across the US. Sponsoring organizations contributing problems should get innovative solutions developed by students who come to appreciate and understand how to work in multidisciplinary teams that employ systems thinking and systems engineering. Universities should substantially increase the value that their senior capstone projects offer to students. Problems contributed by the defense industrial base and DoD will produce students who are more aware of and appreciative of national security issues, and are more likely to seek national security employment. Table 5.4-8

shows the focus, deliverables, and investment in the Engineering Capstone Marketplace Project through 2018.

Table 5.4-8. Engineering Capstone Marketplace Project Timeline

Year	Focus	Key Deliverables
Pre-2014	Develop and validate on a small scale approaches to fostering multidisciplinary senior capstone projects both within single universities and across universities	Reports on how to foster multidisciplinary senior capstone projects, experience reports from participating universities, infrastructure to support nationwide expansion of the approach
2014-2018	Expand the Marketplace to draw hundreds of students from all across the country and across many universities, industrial and government organizations to sponsor multidisciplinary capstone problems	Robust infrastructure capable of supporting large-scale involvement of universities, students, and organizations, experience reports, outreach mechanisms to engage a nationwide audience of students, universities, and organizations, analysis of the value and impact of the Marketplace

5.4.5.2 Technical Leadership Project

The Technical Leadership Project began in 2010, creating an innovative approach to educating technical leaders through three lenses: systems, business, and enterprise. A series of three five-day courses have been prototyped and piloted in 2012 and 2013. Each course contains a series of independent readings, lectures, case studies, and student in-class exercises to accelerate systems technical leadership learning. The courses take the student from (a) leading systems development in the face of uncertainty and ambiguity to (b) understanding how commercial businesses or organizations accountable for multi-system and multi-customers strategize, operate and measure performance to (c) the technical leadership expectations of an enterprise senior technical leader responsible for assessing and adapting multi-nodal structural and activity-based processes within DoD or commercial enterprises. Additional piloting will take place into 2014 when those courses will begin to be integrated into the DAU curriculum. Table 5.4-9 shows the focus, deliverables, and investment in the Engineering Capstone Marketplace Project through 2015, at which time it is likely to conclude.

Table 5.4-9. Systems Engineering and Technical Leadership Education Projects Timeline

Year	Focus	Key Deliverables
Pre-2014	Create and pilot three courses for the systems, business, and enterprise lenses	Course materials and reports from pilot classes
2014-2015	Mature the courses and integrate them into the DAU curriculum	New versions of course materials for standalone pilots and for integration into the DAU curriculum; reports from pilot classes

5.5 SUPPORTING ACTIVITIES

5.5.1 NEW PROJECT INCUBATION

While it is believed that that the aforementioned research programs have a great potential to have a transformative impact on the DoD and IC, there is a need to support new ideas in their infancy that may become the critical research programs for emerging challenges. This incubation capability will be supported by an annual open call to the SERC research collaborating universities to propose early stage research that can be nurtured through relatively small levels of seed funding. Preference will be given to proposals that contend with issues not currently being addressed by SERC research, or that use novel approaches. The Sponsors, SERC Research Council and Leadership will make the determination of which proposals will be awarded with this seed funding. The SERC incubator timeline is shown in Table 5.5-1.

Table 5.5-1. SERC Project Incubation Timeline

Year	Focus	Key Deliverables
Pre-2014	Create proposal format and process in consultation with SERC sponsors with input from SERC collaborators	Announcement of incubator proposal solicitation to SERC collaborating universities
2014-2018	Selection of top proposals for funding	Award of seed funding to selected projects

5.5.2 ACCELERATED DEVELOPMENT AND TRANSITION

Along with direct funding in each of these areas, incentives will be put in place to motivate PIs and researchers to find funding for their programs and projects outside of the sponsorship. These incentives come both from a requirement for the PI to create funding plans when they create or respond to a proposal, and matching funding for the initial external funding.

There are also incentives for the transition of the research into practice. As with external funding, while each RT is required to have transition plans in place in the proposal prior to award, additional funding will be provided as an incentive for this work. In addition, funds will be allocated for the development of educational materials and courses, to be shared by all SERC collaborating institutions, based on research results. The SERC accelerated development and transition timeline is shown in Table 5.5-2.

Table 5.5-2. SERC Project Incubation Timeline

Year	Focus	Key Deliverables
Pre-2014	Create and document proposal requirements for external funding and transition plans in consultation with SERC sponsors with input from SERC collaborators. Establish policies for matching, transition and education material creation funds.	Announcement of external funding and transition plan requirements for proposals to SERC collaborating universities
2014-2018	Selection of research for matching, transition and education material creation funding	Award of matching, transition and education material funding

5.5.3 INFRASTRUCTURE DEVELOPMENT

Note that the SERC Vision after completion of this 5-Year plan is that:

- The SERC operates the world's largest and most-visited *SE Research Web site*, including the largest and best-organized SE Research experience base.
- It continues to provide leadership in evolving the SE Body of Knowledge.
- It runs the most widely-attended and highest-rated SE Webcast series.

Focus is needed to develop the infrastructure that can be used by all of the research programs to achieve these goals. Our approach is to:

- create a list of primary IT services through a comprehensive functional decomposition
- define the resultant requirements through specific capabilities
- determine cost and time to create desired capabilities
- prioritize and schedule development

A set of potential set of SERC IT services are shown in Figure 5.5-1. These services are classified by those which are available to all who access the SERC website, those which are available to all SERC collaborators, and finally, those which are used internally by SERC staff.

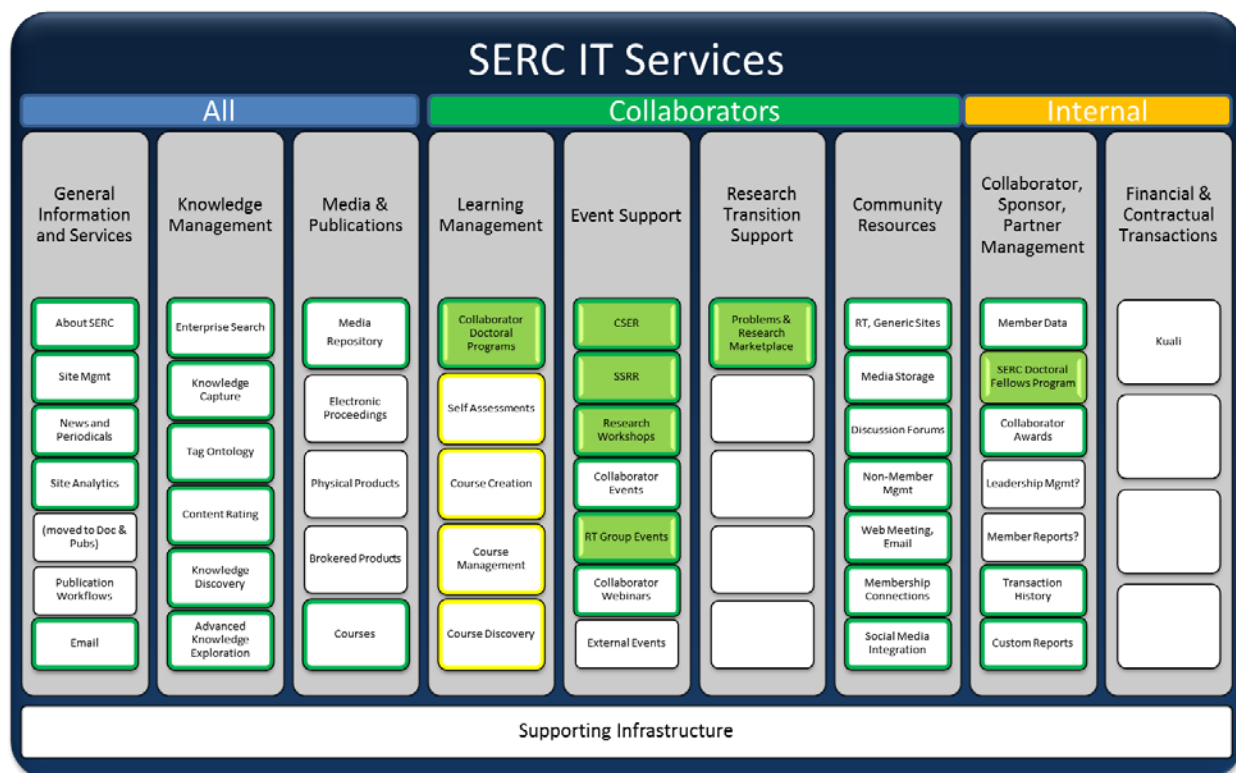


Figure 5.5-1. Potential SERC IT Services

This work will be scoped to be accomplished through SERC investment funding and will not require core funding. The SERC IT Services timeline is shown in Table 5.5-3.

Table 5.5-3. SERC IT Services Timeline

Year	Focus	Key Deliverables
Pre-2014	IT Services project plan	Prioritized IT Service list and plan
2014-2018	Development of IT Services	Phased delivery of IT services

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