Engineering Systems in the 21st Century: *Facing the Challenge*

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Abstract – Results from a workshop series sponsored by the U.S. Navy for promoting wise technology investments in the engineering and management of complex systems in the 21st century is described. Characteristics of complex systems and systems engineering practices are reviewed. Projected trends, research needs and recommended investment strategies for engineering complex systems are discussed. Current investments by the Office of Naval Research in the Engineering of Complex systems technology program are reviewed in the context of potential to impact the state of practice in engineering large-scale systems.

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1. INTRODUCTION

The likely continuation in military budget reductions will exacerbate the extremely difficult problem of deploying high readiness forces to meet our national commitments globally. Doing so at affordable levels (i.e., acceptable to the taxpayer as perceived by our political leadership) will be even more difficult. This means that creative approaches and fresh perspectives for both engineering design and management proficiency must be pursued and accomplished.

The development, implementation, and sustainment of a complex system are economic in nature because work must be appropriately defined and accomplished or excessive costs and low quality will result. The sequential development processes, organizational structures, and stand-alone tools of today are increasingly found to be inadequate to resolve the issues created as systems become more software intensive, more expensive to operate, and more dependent on the interoperability of a system of systems, such as an integrated battlespace. Resolving this problem requires establishing a disciplined approach that includes reaction to multiple and conflicting requirements, integration

across tools and development processes, and utilization of interdisciplinary team structures to optimize system (product and associated processes) effectiveness (cost and performance) over its life cycle. Specific goals are to reduce the cost of development, reduce product cost, shorten the cycle time of development (time to market) for engineering or reengineering of complex systems, and reduce operation and sustainment costs.

The engineering of complex systems is increasingly being accomplished through the use of the Integrated Product and Process Development (IPPD) approach using Integrated Product Teams (IPTs). Recent dramatic successes have been achieved in applying concurrent engineering principles to organizing projects using IPTs in such programs as the commercial Boeing 777 aircraft development. Large scale NASA and DoD programs such as the International Space Station and F-22 Fighter have adopted this approach and are forecasting major savings in downstream engineering development and testing. As a result, DoD has reengineered its oversight and review process and now directs IPPD using IPTs for all new major defense acquisition programs and a re-baselining of ongoing major defense acquisition programs to adapt the IPPD approach to the extent practical. The intent is to resolve issues as they emerge instead of discovering problems only during program reviews.

2. COMPLEX SYSTEMS

The systems of particular interest are those which might be described as large-scale, complex, real-time systems. Some characteristics [1] of these systems include:

- The use of technologies and solutions that cross multiple application domains (e.g., sensors, weapons, communications).
- A high degree of system automation through the use of large scale imbedded computer systems (generally several million lines of executable code) that use many heterogeneous resources that may be configured in distributed or highly parallel multiprocessor architectures.
- Response to hard real-time processing requirements driven by rapidly changing environments and

conditions; operate in multiple operating states and modes.

- The need for continuous, reliable, fault-tolerant operation.
- Demanding safety and security requirements.

These systems typically require the collaborative efforts of multi-contractor teams and sometimes multiple teams. They can take over ten years to develop and have a service life of thirty plus years. During the lifecycle of these systems, they will be periodically upgraded to maintain their capability and keep pace with technological advances. This places an emphasis on an "evolutionary acquisition process" that can lessen the impact of baseline changes and modernizations. System architectures that provide flexibility and ease of change are also essential.

Many systems throughout industry and the military possess one or more of the foregoing characteristics. However, *mission critical systems* tend to possess all of these characteristics simultaneously. This creates conflicting requirements which challenge the ingenuity of the design team to resolve. There also is a tendency toward nonlinearity, nondeterminism, and mathematical intractability due to the large number of interfaces, massive

amounts of data flow, and complex interactions which occur among the processes embodied within these systems. The result is that a mix of methods must be utilized to engineer the system including expert opinion and heuristic techniques in addition to best practices and traditional engineering methods.

The Aegis combat system [2] illustrated by Figure 1 provides a useful example of the characteristics discussed above. Each of the indicated combat system elements are in and of themselves "complex systems" since they typically require multiple technologies to implement, are highly automated and include embedded computing resources, include real-time constraints, must be reliable, safe and secure, and have multiple operating states and modes. It is also true that each of them typically represents an application domain (e.g., sensor, weapon, communications, navigation, control, etc.) for which there is a substantial body of technical knowledge and supporting culture. However, none of these individual elements is sufficient of themselves to accomplish the various warfare missions of the ship. It is necessary that they each function in consonance with other elements in the combat system to accomplish a single mission such as anti-air warfare (AAW). The primary elements required to accomplish AAW in the Aegis combat system are indicated in Figure 1. Viewed in this fashion, it is obvious that a "system of systems"

Figure 1. Aegis Ship Combat System

configuration with significant interfacing, data flow and control flow is required to accomplish AAW. When we add Anti-Submarine Warfare (ASW) as a simultaneous mission requirement, we see that some degree of sharing of combat system assets is required to accomplish the two missions simultaneously. This requires command level coordination, conflict resolution, and resource allocation strategies that are likewise supported by extensive interfaces, data flow and control flow between command, warfare control, and combat system elements. When other simultaneous mission areas are added such as Anti-Surface Warfare (ASUW), Strike Warfare (STW) and Electronic Warfare (EW), the full significance of the engineering challenge for this hierarchical "system of systems" is realized. Further, this is a single ship example; task force operations and joint warfare operations [3] increase the scale of complexity exponentially.

Examples of other systems which feature characteristics of large-scale complexity such as represented by the Aegis system exist in a variety of industrial and commercial applications. However, the distinguishing feature of military combat systems is the fact that a diverse array of weaponry is involved. Along with this is the significant role played by human operators and decision makers. Many of the tasks performed by operators and decision makers are unique cognitive and physiological capabilities that are very difficult to automate, yet are essential to achieve the system functionality and performance. Other tasks are not desirable to automate, due to all the many implications of whether or when to fire weapons.

3. WORKSHOP APPROACH AND FORMAT

The Workshop on Engineering of Systems in the 21st Century: *Facing the Challenge* (WES 21) is directed at involving industry, government, and academia in furthering the practice of systems engineering. It has been co-sponsored by the Office of Naval Research, the Naval Surface Warfare Center, the Navy Space and Warfare Systems Center San Diego Division, and the Navy Acquisition Reform Office. There have been a series of three workshops conducted thus far, the first (WES 21-1) in June, 1994. Each of the workshops has been documented in a proceedings [4, 5, 6].

The vision for these workshops is to "revolutionize the understanding and practices of engineering complex systems." The genesis of these workshops was to address the challenge of engineering increasingly complex systems at a time when the nation's priorities are in the midst of fundamental change. Meeting this challenge will require wise investments in systems engineering, enabling technologies, and their transfer to commercial applications. The workshops were to focus on the engineering of complex systems and improving the systems engineering practices used to conceive, design, manufacture, and support these systems.

WES 21-1 examined experiences and lessons learned from prior large-scale system developments such as Apollo, the

Space Shuttle, the Strategic Missile Program, and the Aegis shipbuilding program. It considered current trends such as the effect of shifting Federal budget priorities on the DoD industrial base. The consequence of corporate mergers, divesting traditional product lines, and shutting down of production lines is the breakup of longstanding engineering teams and the potential loss of proven engineering methods and techniques. Other important issues and related technologies that WES 21-1 considered included the use of Commercial-off-the-Shelf (COTS) components; Dual-Use Technologies; Concurrent Engineering; Affordability; Virtual Corporations; International Market Forces.

The second workshop (WES 21-2) was conducted June 12 – 14, 1995 at the University of Maryland, College Park, Md. There were 170 invited participants organized into focus groups in an expanded format. This format was built on the foundation established by WES 21-1 and extended it to provide more depth in process and product and also, the environment in which large-scale systems are developed. That is, the goal of any engineering enterprise should be to develop a product that satisfies an intended purpose. People and teams are organized to achieve the goal – using a process some or all of which they may have to develop. Supporting all of this is the underlying infrastructure. These activities may be bounded by both active (political) and passive (legal and regulatory) environments. The reality facing engineering today is that change will continue – from a technological, environmental, organizational, and work force perspective.

4. WORKSHOP FINDINGS

In many respects, WES 21-1 provided a beginning structure that WES 21-2 filled out. Hence, the results of these two workshops can be integrated and summarized as one product. A common theme emerged from these two workshops as to the need to be proactive to shape the future environment within which complex systems are engineered, as well as to communicate a clear view of what such an environment should be across the entire engineering community. The perspective of the focus groups was that the fundamental responsibilities of the engineers creating the complex systems of the 21st Century will not change. They will continue along the natural path of engineering – identifying and implementing the best technological solutions to meet the users' requirements. The single most important requirement for these talented engineers is the need to recognize the broad conceptual architectures – "the system of systems" – that are emerging today within the defense and commercial sectors. Engineers can no longer simply understand their own system or function such as mechanical, electrical or software engineering, but must understand how their system or function fits in the overall system engineering enterprise. Compounding this challenge is that engineers will find themselves under increased pressure to achieve these broad-based solutions effectively – in the shortest period of time with a reasonable expenditure of resources.

Integrated WES 21-1 and WES 21-2 Findings

The numerous opportunities identified by the focus groups to shape the future environment for engineering complex systems can be grouped into three common areas – meta-process, integration, and education.

Meta-process—Key to success in the future is understanding the meta-process for engineering complex systems and establishing mechanisms for communicating and documenting the process and resulting product. A meta-process describes the steps to be taken and the information to be captured and generated at each step in the development of a complex system. The meta-process is described in executable models and is independent of particular views, notations, and methodologies. It may be tailored to the methodology in favor at a particular institution.

Since everyone involved in the creation of a complex system needs to understand the process and their role in it, an important part of the process is creating strong communications throughout the team. Rapidly emerging computing and telecommunications technology provides an opportunity to mitigate the issues related to loss of corporate knowledge and overcome the challenges faced by non-collocated design teams.

Integration—In addition to communication among team members, the increased demand for quality and the heightened requirements call for tighter integration among tools than ever provided before. A test bed for integrated tools is envisioned to advance the tools available to automate engineering of complex systems, to demonstrate tool interoperability, and to lead to automated exploration of systems solutions in a world where reuse is frequent or dominant.

Education—A strong need exists to train individuals and teams in engineering of complex systems best practices (the meta-process) and in the use of an integrated tool set. There was a common recommendation to provide education and training to all stakeholders from policymakers to users to program managers, to engineers working the solution, to student engineers. In some cases, the material to be learned is available but must be synthesized and implemented. Suggested tools for learning ranged from using test beds to demonstrate successful approaches for engineering complex systems to making increased use of modeling, simulation, and multimedia training to expand understanding at all levels. Equally important is the need to provide a clear understanding of the process at all phases of the system development.

Findings of the Third WES 21

The objective of WES 21-3 was to identify the opportunities to improve the management and engineering of complex systems within the IPPD context as described in the DoD Guide for Integrated Product and Process Development (February 1996). A second objective was for government

program offices and prime contractors to make more effective use of teams, tools, and development processes. Products will be guidelines, suggestions for action, and high payoff technologies for Science and technology (S&T) program investment.

The focus of WES 21-3 was to identify opportunities to improve the management and engineering of complex systems within the IPPD context. Specifically, it was structured to address the following:

1. Develop requirements formulation processes within an IPPD context to improve the way requirements for complex systems are identified, defined, and communicated.
2. Define specific development processes, teams, structures, and tools to realize an integrated set of product and associated processes for specific product classes.
3. Establish requirements for an integrated tool set and identify new technologies that can enhance the implementation of IPPD.

A key finding from the WES 21-3 focus groups was that modern computing and telecommunications technology can greatly facilitate the functioning of Integrated Product Teams (IPTs). Virtual conferencing can facilitate collaboration by the team and the training of its members. Similarly, rapid progress in simulation and modeling technologies can be applied to support the IPTs if appropriate mega-system architectures and meta-models are developed to test alternative implementation strategies for new capabilities prior to committing to a system solution.

An additional finding was that traditionally, computer-aided tools have been developed to satisfy the needs of specific user constituents within an enterprise but not the enterprise as a whole. The current generation of systems engineering tools lacks the scope and scalability to effectively address the challenges of increasing system complexity and provide limited interpretability between tools even at the data exchange level.

In response to the foregoing, a new systems engineering paradigm was proposed which employs evolving simulation and modeling capabilities as part of an advanced system engineering environment (termed the integrated enterprise environment). The goal is to harness this technology to address the system life cycle from a total enterprise perspective that would support IPPD/IPTs. It was further proposed that a DoD task force be established to scope and define the integrated enterprise environment and follow a formal process that includes the establishment of one or more test beds for proof of principle testing and addressing of integration and scaling issues at all levels.

5. ECS TECHNOLOGY PROGRAM

The Engineering of Complex Systems (ECS) Technology Project, funded by the Office of Naval Research and

conducted at the Naval Surface Warfare Center Dahlgren Division, responds to many of the needs identified by the WES 21 series of workshops. ECS addresses the underlying technologies required to achieve an integrated methodology for the design and integration of large-scale, complex systems. The goal is to enable design teams to synthesize and evaluate system design options for mission-critical requirements with orders of magnitude improvements in productivity and accuracy over conventional methods. This in turn will provide high potential for achieving needed warfighting requirements and mission capabilities while simultaneously reducing cost and scheduling risks.

The approach taken by the ECS project focuses on technical tasks in systems design synthesis and system evaluation and assessment. These are addressed in the context of a generic forward engineering process and a reengineering process. Figure 2 depicts the phases of a typical forward engineering process, with feedback arrows indicating the usual iterative nature of the process. Also indicated are the areas of technology effort being conducted by the ECS project.

Systems Design Synthesis Task

The ECS Systems Design Synthesis task encompasses efforts in requirements specification, design capture, design structuring and resource allocation. The intent is to provide an integrated environment that facilitates a seamless flow across the phases of the forward engineering process. "Flow-down" from the overall systems level to specific application domains (e.g., combat system elements) of key system design information (top-level requirements, specifications, architectures, etc.) must also be enabled.

The objective of the requirements specification efforts, for example, is to support a multidisciplinary design team with a design environment that provides an interface that enables each of the design team members to interact with the design record in a manner that is "natural" to their area of expertise. If the problem is to design an automobile, the chassis, body, power train, electronics, and interior design experts must be able to interact with the total design as it evolves. A natural

Figure 2. ECS Forward Engineering Process

interface with an automated design repository can significantly increase productivity and assure consistency and completeness. This needs to be coupled with methods that assure traceability of the original requirements throughout the design process and the application of techniques for formal specification of requirements [9]. These provide a basis for evaluation of the product against the original specifications.

Figure 3 depicts the *multiple views design capture* process [10] being explored within the Systems Design Synthesis task. The information view (system entities, relationships between entities, and attributes), functional view, and behavioral view are reasonably well supported by currently

available commercial tools. However, the implementation view (candidate hardware, software, and human operator resources) are not currently well-supported. This is also true of the environmental view. Prototype capabilities to support these views are under development within ECS.

An additional objective of the ECS multi-view design capture effort is to establish a high degree of interoperability between automated capabilities which support these views. This will enable the implementation of an integrated environment for a seamless flow between the various design views, allowing the designer to access the design view most appropriate for each phase of the design process. The

Figure 3. ECS Multiple Views Design capture

Figure 4. ECS Assessment Environment

mechanism for accomplishing this is the *System Engineering Technology Interface Specification* (SETIS) [11] under development by ECS to support the exchange of both data and semantic information.

A third area of activity within this task is *design structuring, resource allocation and optimization* [12]. This effort explores capabilities to support partitioning the design, strategies for allocating resources, and optimization techniques. A key prototype, DESTINATION, guides the designer through a set of design factors [13] such as performance, safety, security, reliability, maintainability, extensibility, usability, cost, etc. Based on acceptable bounds for these factors established by the designer, Destination provides interactive support to guide the designer through alternative system implementations. A library of optimization algorithms can be accessed to evaluate how well each alternative satisfies the range of design factors.

Systems Evaluation and Assessment Task

The increasing complexity of naval systems makes it imperative that early and continual evaluation and assessment be performed to assure optimal design. Figure 4 provides a conceptual view of an integrated environment to achieve continual evaluation from the earliest stages of the design process through operational evaluation. It is based on implementing an infrastructure to integrate and support a system design repository, system design analysis capabilities, and a system evaluation and assessment

repository. Such an environment also provides a baseline for the system life support environment.

The evaluation and assessment capabilities required to accomplish the assessment environment depicted in Figure 4 require a very active program in *modeling, measurements and instrumentation, virtual prototyping, and infrastructure and repositories*. It employs emerging technologies such as multimedia, intelligent agents, virtual reality, and object oriented technology to ensure the generation and application of timely modern products. Modeling technology produces the quantitative and qualitative results needed to determine viable alternatives and perform tradeoffs between such alternatives. Technology efforts in measurements and instrumentation provide metrics for all aspects of system development including metrics on products, processes, components, and system life cycle. In addition, technology is addressed that enables designers to observe and evaluate system behavior in the least intrusive manner possible. This includes three over-lapping categories of instrumentation: invasive, minimally invasive, and non-invasive. Key areas of work are: (1) identification and validation of key metrics for modeling and assessment, (2) extension of the existing software reliability program [14] to address system reliability, (3) a performance modeling capability [15] driven solely by metrics collected via computer instrumentation, and (4) an integrated measurements framework [16] for total system evaluation and assessment using metrics. Key prototypes in process include the Statistical Modeling and Estimation of Reliability Functions

for Software (SMERFS), Metrics Information System Tool (MIST), and the Knowledge Based System Evaluation (KBSE) environment.

Advancements in computer simulation and visualization technology provide an opportunity for systems engineering technology to benefit from *virtual prototyping*, or the application of virtual reality technology to system engineering [17]. Virtual prototyping makes it possible to perform virtual design of alternative candidate architectures and assess the suitability of each to satisfy the specified requirements before implementing hardware and software. Further, it is becoming feasible to perform virtual manufacturing and virtual test and evaluation to explore production issues and operational suitability. Virtual reality technology is effective in obtaining customer input in the early stages of design on the degree to which alternate designs satisfy intended missions and design goals. It is also effective in evaluating the desired role of operators and decision-makers in the system and in obtaining user feedback on operability aspects of the design.

6. RESULTS

The ONR funded ECS program has developed several prototypes that aid in requirements analysis, capturing a conceptual design from multiple views, evaluating and optimizing a candidate design, and creating and maintaining a design repository for complex systems. These have been implemented in an integrated test bed environment. Efforts are underway to demonstrate the feasibility for the integrated toolset to perform synergistic design of the hardware, software and human elements of complex systems. Early successful applications have been in the analysis of requirements specifications for large-scale system developments. The ECS automated capabilities have proven to save significant amounts of time over typical manual techniques in determining completeness, consistency, and ambiguity of candidate requirements.

A particularly significant application is the development of a Human/System Engineering Environment (H/SEE) to address shipboard manning reduction. The ECS framework is being extended to incorporate human system integration methods and tools to enable engineering evaluation of human versus non-human implementation of system functions and tasks. The H/SEE will be applied to planned new ship programs to dramatically reduce the typical shipboard manning levels in order to reduce life-cycle costs.

7. CONCLUSIONS

The WES 21 series of workshops have provided valuable information from a broad cross-section of the community involved in the development of large-scale, mission critical systems. This ranges from an assessment of the current state-of-practice to long-term trends and technology needs for the advancement of the practice. Recommendations for a science and technology investment to address the identified needs have also been obtained from the workshop

participants. WES 21 series has proven to be a very effective mechanism for engaging the systems engineering community in a dialogue on the needs of "next generation" system developers.

WES 21 series has also served to validate the investment in the ONR funded Engineering of Complex Systems technology program. The ECS program is developing processes, methods, and tools to support the establishment of the integrated methodologies needed to assure high quality, affordable, complex systems for DoD 21st Century requirements.

REFERENCES

- [1] Harrison, Robert, Laplante, Phillip A., and Stoyenko, Alexander D., "Doubling the Engineer's Utility," *IEEE Spectrum*, Vol. 31, No. 12, Dec 1994, pp. 32-39.
- [2] Stein, K. J., "Aegis System Tested Successfully," *Aviation Week and Space Technology*, Vol. , No. , Apr 7 1975, pp 36-40.
- [3] Owens, William A., "The Emerging System of Systems," *Proceedings of the U.S. Naval Institute*, Vol , No. , May 1995, pp. 35-39.
- [4] Crisp, H., Francis, J., and Lee, D., Editors, *First Annual Workshop on the Engineering of Systems in the 21st Century. Proceedings*, Naval Surface Warfare Center, Dahlgren, VA, Jun 1994.
- [5] Crisp, H., Francis, J., and Lee, D., Editors, *Second Annual Workshop on the Engineering of Systems in the 21st Century Proceedings*, Naval Surface Warfare Center, Dahlgren, VA, Jun 1995.
- [6] Crisp, H., Francis, J., and Lee, D., Editors, *Second Annual Workshop on the Engineering of Systems in the 21st Century Proceedings*, Naval Surface Warfare Center, Dahlgren, VA, Oct 1996.
- [7] Alford, Mack and Malcolm, Nadine E., "Systems Engineering: Its Roots, Its Future," *CASE Trends*, Oct 1993, pp 57-61.
- [8] Rehtin, Eberhardt, "The Art of Systems Architecting," *IEEE Spectrum*, Vol. 29, No. 10, Oct 1992, pp. 66-69.
- [9] Harrington, Gail, Ramash, Bala, and Rondeau, Kathleen, *A Model of Requirements Traceability to Support Systems Development*, Naval Postgraduate School Technical Report NPS-AS-93-017, Sep 1993.
- [10] Hoang, Ngocdung, Howell, Steve, and Karangelen Nicholas, *Mission Critical System Development: Design Views and Their Integration*, Naval Surface Warfare Center, Dahlgren, VA, NAVSWC TR 91-586, Oct 1991.

[11] Howell, Steve, Lock, Evan, and Nguyen, Cuong, "Integrating Systems Engineering Tools via an Interface Specification," *Computer Based Systems Engineering Workshop, Group D*, London, England, Dec 1992.

[12] Howell, Steve, Lock, Evan, and Nguyen, Cuong, "Destination: An Environment for System Design Structuring and Allocation Optimization," *The Fifth Annual Software Technology Conference*, Apr 1993.

[13] Howell, Steve and Nguyen, Cuong, *Systems Design Factors: The Essential Ingredients of System Design*, Naval Surface Warfare Center, Dahlgren, VA, NSWCDD TR-92/268, Mar 1994.

[14] Farr, W. and Smith, O., "A Tool for Software Reliability Modeling," *Proceedings of the SIMTECC'WNN 92*, 1992 International Simulation Technology Conference and Workshop on Neural Networks, Nov 1992, pp. 256-272.

[15] Chang, M. and Crigler, J., *A Statistical Characterization of the Effect of Tactical Loading on the Aegis Tactical Computer System*, Naval Surface Warfare Center, Dahlgren, VA, NSWCDD TR , 1995.

[16] Balci, Osman, DeVaux, David, and Nance, Richard, "Measurement and Evaluation of Complex Navy System Designs," *Proceedings of the 1993 Complex Systems Engineering Synthesis and Assessment Technology Workshop*, Naval Surface Warfare Center, Dahlgren, VA, NSWCDD MP-93/172, Sep 1993, pp.126-140.

[17] Jones, Gary W., Jons, Otto P., and Ryan, J. Christopher, "Using Virtual Environments in the Design of Ships," *Naval Engineers Journal*, Vol. 106, No. 3, May 1994, pp. 91-106.

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