APL Applied Systems Engineering – Part II: Guest Editors' Introduction

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This issue of the Johns Hopkins APL Technical Digest *continues the presentation of articles that describe APL's approach to systems engineering that began in* APL Applied Systems Engineering—Part I *(volume 29, issue 4). Although the diversity of systems applications was clear in the first systems engineering issue, this diversity becomes even more evident in this second issue as we explore more complex issues in air defense, command and control, network communications, counter-improvised explosive devices, human-systems engineering, and nanosystems. APL's strong systems engineering culture and standard processes ensure that its products are fit for use regardless of the scope and complexity of the domain.*

INTRODUCTION

APL has been developing systems for its government sponsors for 70 years. The APL approach to systems engineering is captured in the systems engineering spiral, which is shown in Fig. 1 and whose phases are described in the following bullet points.

- **Critical needs:** Operational data collection or mission analysis may reveal a need to achieve new capabilities.
- **Capability assessment:** Once a need is recognized, it is always prudent to determine whether presently available systems and operational capabilities could be leveraged to meet the need by application of new tactics or procedures, for example.
- **Concept exploration:** Candidate concepts and corresponding models and analyses are developed. Next, technology readiness and alternative systems approaches are explored, and critical experiments and studies of new features of the system design are conducted.
- **Solution validation:** Prototyping of parts or all of a system may be required to validate an emerging technology, to validate and refine development requirements, and to verify that the design can be produced and is operationally suitable.
- **Solution implementation:** The prototype system is fabricated, and operational tests and evaluation

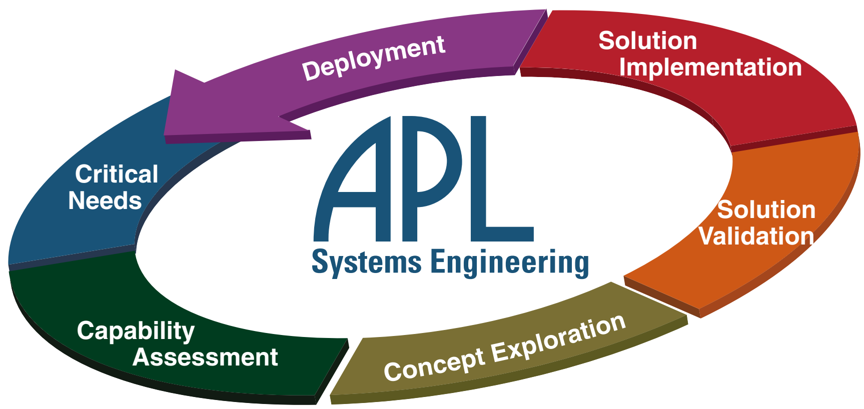

Figure 1. Overview of the phases encompassed by APL's systems engineering process, known as the systems engineering spiral.

activities are conducted to validate the satisfactory performance of the system, leading to full-scale development of an affordable and functional system.

- **Deployment:** The system is taken to the field for operational use, and data are collected to ensure that the system continues to meet its operational requirements and satisfy the need for which it was built.

The development of complex, adaptive systems that often must perform autonomously in extreme environments is a true test of all of the underlying research, architectures, procedures, and testing that occur within the systems engineering process. Success requires pervasive use of "systems thinking" linked to broad and deep expertise in the given domain and coupled with in-depth, hands-on experience and understanding of the operational environment within which the system or system-of-systems must operate. The systems engineer must exercise strong interdisciplinary leadership and collaborate with government institutions, private industry, and professional societies to bring the best expertise and resources to bear on the world's challenging problems.

THE ARTICLES

This issue of the *Digest* addresses APL's systems engineering approach to an additional cross section of programs at the Laboratory.

In an article on systems-of-systems in air and missile defense, Sommerer et al. investigate—with a focus toward what we can do in the future—the principles of engineering systems-of-systems and the application of those principles to air and missile defense. The authors examine three different complex systems, highlighting different systems engineering methods that are all consistent with the APL systems engineering spiral. They also attempt to integrate the lessons learned and suggest key tenets that must be followed in the future if we want to successfully execute this complex form of systems engineering. Not only do the authors address the technical issues related to consistent requirements setting, functional decomposition, and interface control, but they also touch on the difficulty of testing all the component systems together as well as perhaps the most difficult area, the political issues.

The "Systems-of-Systems Network Engineering" article, written by Bath and Miller, investigates future networked forces in a systems-of-systems context that includes many networked nodes and shared communications links. Bath and Miller use three examples of major naval combat systems—Aegis, the Cooperative Engagement Capability, and Ballistic Missile Defense—and show how the key systems engineering processes were applied to these exceedingly complex networks. In each case, the Integrated Fire Control systems were matured through approximately 10 years of extensive critical experiments in the field. Engineering a truly networked naval, and eventually joint, Integrated Fire Control system with real-time performance requirements has proven to be a major systems engineering challenge.

Cooley and McKneely's article on command and control (C2) engineering investigates a very interesting but exceedingly complex issue. From the time that tactical decision aids were adopted for use in the military, a debate has been held over whether C2 is an art or science. The human factors engineering community has dissected the C2 concepts to determine what content and presentation of information is necessary to facilitate good decisions. Their research has involved both physical and cognitive studies of commanders in controlled environments. Meanwhile, many C2 developers have used rapid prototyping—developing knowledge and heuristics by interviewing recognized experts and then codifying these rules into systems that are put into operational environments to assess their capability. This paper shows how the combination of these varied approaches may provide a key to good systems engineering practices in C2 systems.

A unique approach to a systems engineering technique is addressed in the article by Nolen, Moreno, and Gingras on collaborative systems analysis used in the maritime reconnaissance environment. In the early 1980s, APL built a central facility for warfare analysis, incorporating the processes and techniques developed in the preceding two decades. This facility became known as the Warfare Analysis Laboratory (the WAL), and analysis events performed there became known as WALEXs (WAL exercises). These WALEXs foster collaboration through a disciplined analytical approach that presents a common problem, often as a scenario, and solicits an open discussion that encompasses the multiple perspectives of a diverse set of expert participants. This exercise can play a critical role in each systems engineering phase, and the article strives to demonstrate its benefits in the Navy's 2009 analysis of alternative study to assess the potential options for the EP-3 replacement, commonly referred to as EP-X.

Small complex systems are the subject of an article by Sample and Charles. Their focus is on systems derived from nanotechnology—the creation of functional materials, devices, and systems via control of matter on the nanometer-length scale. The article also discusses how we can start to apply systems engineering as a discipline to ultimately integrate nanoscale devices with associated required architectures and then into systems and associated services. This necessitates the investigation of the potential of nature—such as systems built by the self-assembly of fundamental components—instead of the top-down approach of conventional human-engineered systems.

Improvised explosive devices (IEDs) have increasingly become a weapon of choice for terrorists or insurgents and have led to many deaths and injuries. The rapid turnover and use of technology to develop threat devices make countering them a significant challenge. Pesci describes the Laboratory's efforts in understanding and developing means to counter remote-controlled IEDs by using systems engineering in a rapid-prototyping environment. Producing a cost-effective and technically capable solution required modification of the traditional systems engineering approach, placing APL in a leadership position in an area of critical importance.

Hebeler, McKneely, and Rigsbee describe, within a systems context, the application of human-systems integration for the design of military GPS handheld devices. Service member satisfaction with the usability and utility of new technologies they are given and how well those technologies fulfill their expectations is often very low unless human factors are included throughout the development of the system. Using the systems engineering process, user interviews to focus on users' desired features, and iterative prototype demonstrations and testing by the user were critical to the successful design.

Finally, Rigsbee and Fitzpatrick describe the related use of a user-centered design process to develop the graphical user interface for the next-generation Tomahawk Weapons System. The systematic top-down approach focused on the overall system and user goals to identify the required functions, subfunctions, tasks, and components. The use of scenarios was also very important in describing a variety of real-world cases that the system would need to accommodate.

The successful application of systems engineering to complex problems is the true test of systems concepts and approaches. APL has an experience base of many decades of maturing the field of systems engineering by simply practicing it in all we do.

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