APL Applied Systems Engineering: Guest Editors' Introduction

Samuel J. Seymour and Michael J. O'Driscoll

This issue of the Johns Hopkins APL Technical Digest *highlights APL's approach to systems engineering. There are six steps in APL's systems engineering process: critical needs are identified, current capabilities are assessed, new or existing capabilities are explored and conceptualized, prototyping is performed, a solution is implemented, and the final system is deployed. The articles in this issue of the* Digest *describe how this systems engineering "loop" has been applied to a number of different APL programs. The success of these programs has and will continue to require the pervasive use of systems thinking that is linked to broad and deep domain expertise and coupled with in-depth, hands-on experience and understanding of the operational environment within which the system or system-of-systems must operate. Also critical to the success of these programs is APL's strong interdisciplinary leadership and collaboration with government institutions, private industry, and professional societies. Expecting an increased emphasis on systems engineering in the development and delivery of technology and systems throughout the world, APL is prepared to respond to new and changing challenges of its sponsors and our nation.*

INTRODUCTION

The Johns Hopkins University Applied Physics Laboratory has a national and international reputation for successfully applying systems engineering principles to solving very complex technical challenges. We consistently use systems engineering to provide critical contributions to some of the most intractable problems confronting our current sponsors, selectively taking on new and different challenges facing the nation. Starting with APL's deep domain experience, our professionals consistently improve their capability to observe and understand the operational environment within which the system or the system-of-systems must function.

We match this attention to our sponsors' requirements with internal efforts to learn and share best practices throughout the Laboratory.

Expecting an increased emphasis on systems engineering in the development and delivery of technology and systems throughout the world, APL will be ready to respond to new challenges by ensuring that our internal focus in the systems engineering domain remains strong and that we evolve to meet the demands of the rapidly changing world. We want to provide our sponsor community with the kind of knowledge and expertise that emphasizes systems engineering applications in guiding future developments, whether developing a system, serving as a trusted agent, or fulfilling an independent evaluator role. Several key discriminators underlie our success:

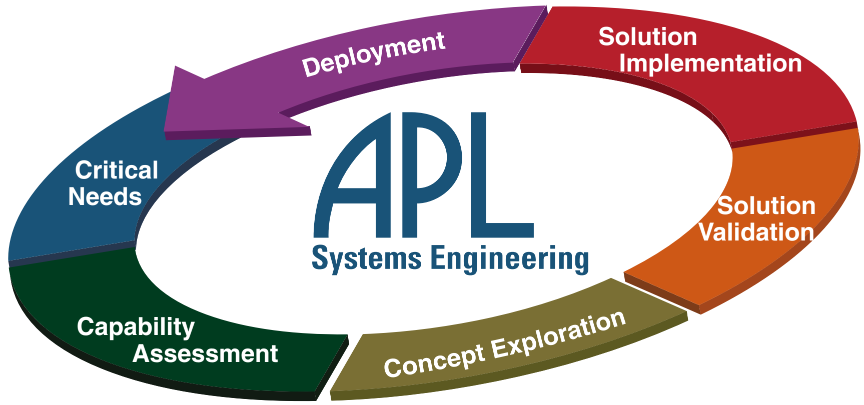

Figure 1. Overview of the phases encompassed by APL's systems engineering process, known as the systems engineering "loop."

- Pervasive use of systems thinking linked to broad and deep domain expertise
- In-depth, hands-on experience and understanding of the operational environment within which the system or system-of-systems must operate
- Frequent employment of scientific investigations, prototyping, and critical experiments to improve technical readiness, determine feasibility, validate requirements, and mitigate risk
- Performance of work that enables us to provide critical contributions to the nation's most critical challenges while also striving to anticipate and define the future critical challenges that will impact the mission capability of our U.S. government sponsors
- Exercise of a strong interdisciplinary leadership role, partnering with government institutions, private industry, professional societies, and academia throughout the world in support of our sponsors
- Proper support to our staff to ensure that they will continually excel in the systems engineering practices of personal observation, extensive data collection and analysis, and deep engagement with the end user
- Provision of practical insights to students in undergraduate and graduate systems engineering programs through The Johns Hopkins University

Recognizing that there are several ways to describe traditional systems engineering approaches, we have adopted for this issue of the *Digest* the systems engineering diagram shown in Fig. 1, whose phases are described in the following paragraphs.

- **Critical needs:** Operational data collection or mission analysis may reveal a need to achieve new capabilities. Scientific evidence from experimental work may reveal the need for a new scientific instrument to collect specific new information toward a scientific discovery. Analysis and planning are performed to define the need for a system, both operational and technical, and then to determine its feasibility. These needs can be communicated through such diverse media as scientific papers, studies, or official military documentation.
- **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. This determination can be accomplished by the use of analysis or studies, further data collections, or critical experiments. If it is determined that a new system is needed, an appropriate architecture compatible with related systems may be identified.
- **Concept exploration:** If a new system capability is needed, whether it is the first of its kind or an upgrade of an existing system capability, candidate concepts and corresponding modeling and analyses are often developed. These are then used in "strawman" form to trade off which approach can potentially provide the lowest risk and/or highest performance, is closest to operational utility, is most economical, or offers a combination of these qualities. Next comes an exploration of technology readiness and alternative systems concepts, the conduct of critical experiments, and studies of new features of the system design. The one or few concepts emerging as the leading candidates are often mod-

eled and defined in increasing detail to gain more definitive characterization of these metrics and to support the drafting of operational requirements and specifications.

- **Solution validation:** If a significantly different capability, or significant development risk, is accepted for the selected conceptual approach, prototyping of parts or all of a system may be required. This prototyping may be for several purposes, such as validation of an emerging technology, validation and refinement of production requirements, and verification that the design can be produced in numbers and is operationally suitable. Often this phase involves formal demonstration in a representative laboratory or simulated operational environment.

- **Solution implementation:** During this phase, fabrication of the production article and operational tests and evaluation activities are conducted to validate the satisfactory performance of the system, leading to full-scale production 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 to satisfy the need for which it was built. If a new threat or a needs gap emerges, or there are advances in technology that indicate a new need, then the activities shown Fig. 1 may be re-entered, and a new round of these activities may be started.

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 that is linked to broad and deep domain expertise 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 a cross-section of programs at APL as Part I of a series on Applied Systems Engineering. These programs span the breadth of our endeavors on land as well as in, on, and under the sea, from missions in extreme space environments to complex software developments and information systems. We will also describe our approach to the quality control of our systems engineering process. Each of the authors in this issue addresses the systems engineering loop and underscores how they applied it to their program.

Systems engineering for complex information systems in a federated, rapid development environment is addressed by Charles Spaulding, Scott Gibson, Stephen Schreurs, Duane Linsenbardt, and Antonio DeSimone. In this environment, four challenges drive the approach: various subsystem scales, fielding capabilities quickly with changing demands, evolving technologies and capabilities to address rapidly changing mission needs, and building the system with disparate interfaces from components provided by the heterogeneous mix of solutions providers who cooperate in a loose federation. APL, with a DoD sponsor, has implemented an approach called threat engineering that has proven successful in this area.

Robert Sweeney, Jeffrey Hamman, and Steven Biemer address software development in an extremely large simulation called STORM+ that was envisioned to be utilized as a campaign model for the Office of the Chief of Naval Operations staff during their assessment process. Applying systems engineering principles and practices to a software development effort has always been difficult when the developers use a life cycle process that does not include traditional systems engineering. This was the case here: the STORM development history has been a series of releases, scheduled approximately every 6 months, with a large number of organizations involved. The authors describe in detail the systems engineering process employed on this unique simulation environment in the hope that this example will provide future software project teams confidence in embracing systems engineering as a dynamic framework for proactive project management.

Next, David Kusnierkiewicz and Glen Fountain address systems engineering in NASA space flight missions, which have always presented unique challenges to maximizing science return in the face of tightly constrained programmatic (cost, schedule, etc.) and technical (mass, power, etc.) resources. This environment requires multiple systems engineering trades within multivariable trade spaces to optimize the system design. This article illustrates the application of APL systems engineering discriminators to the NASA MESSENGER and New Horizon missions to Mercury and Pluto, respectively.

The article by Guy Clatterbaugh, Bruce Trethewey Jr., Jack Roberts, Sharon Ling, and Mohammad Dehghani takes an in-depth look at some of the systems designed at APL that must function in extreme environments. These harsh conditions require special attention from the systems engineers to perform risk assessments and propose risk mitigation strategies early in the concept development phase, including use of simulations and testing. Examples range from an implantable insulin pump to deep ocean sensing systems to body armor design.

John Gibson and Stephen Yanek investigate the long-term systems engineering efforts of APL with the Navy's Strategic Deterrent System: the Fleet Ballistic Missile (FBM) Strategic Weapons System. APL's technical contributions to the Navy's FBM system have continued for more than 50 years. This article focuses on APL's efforts to evaluate the current capability of this system through its testing in different operational settings for the purpose of improving performance or expanding capabilities. Our work during the prior phases in the APL systems engineering has uniquely positioned us to identify the needs and dictate the nature and scope of deployment phase efforts.

Sam Seymour and Ronald Luman then take a look at the academic perspectives of systems engineering at APL, discussing a new Systems Institute and the Whiting School of Engineering's academic programs. They start by examining three key perspectives of systems engineering and the evolution of systems engineering process models applied to the particular problem. As these models evolve, so does the relatively young and dynamic systems engineering educational field. The authors next investigate significant academic trends in graduate education at both the master's and the doctorate levels, emphasizing research and quantitative methods as well as competition from regional and national universities for students and research funding.

Finally, Elinor Fong, David Kusnierkiewicz, Deborah Mendat, and Peter Tennyson discuss the quality management processes at APL. They describe how APL has codified our approach to the systems engineering process. They describe the challenge we faced in defining a systems development process that encompasses the broad range of work we do, establishing a set of minimum requirements that comply with the International Organization for Standardization's ISO 9001 quality management standards, ensuring that the requirements thus established were consistent with the sometimes sensitive nature of our work, capturing our existing best practices, and retaining and enhancing the existing efficiencies and values of APL systems engineering.

The applications of good systems engineering practices presented in this issue touch only on a selected set of examples in the hope that they will inform and inspire, capture what has made APL successful in the past, and point to the direction for tomorrow. We encourage the documentation of APL systems engineering practices and will share more examples in Part II of our *Digest* series on Applied Systems Engineering.

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