Open Architecture in Naval Combat System Computing of the 21st Century

Network-Centric Applications

by

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Abstract

This paper describes the Navy's Open Architecture (OA) effort. At its most fundamental, OA is an integrated engineering discipline, a technical approach, and a business strategy for information systems that is based on mainstream commercial-off-the-shelf (COTS) information and computing technologies and systems. The OA initiatives seek to reduce multiple infrastructures that result from a myriad of competing architectures, and also to embrace a product-line approach that will generate true economic efficiencies

With this in mind, the Navy is developing a comprehensive strategy, plan, and program for an OA approach and strategy to address weapon system affordability, interoperability, and performance for today's fleet and the Navy after next. In the fall of 2002, the Navy stood up several new Program Executive Offices (PEOs), including the PEO for Integrated Warfare Systems (PEO IWS), which focuses on surface ship and submarine naval warfare technologies and systems. PEO IWS will help select common standards and products in the areas of frameworks, middleware, resource management, and operating systems, using both established and evolving industry standards to avoid proprietary solutions that might constrain rather than enhance interoperability, operational effectiveness, and future technology insertion. Furthermore, the computer program architecture will enable the introduction of common functions across multiple systems and platforms.

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At its most fundamental, OA is an integrated engineering discipline, a technical approach, and a business strategy for information systems that is based on mainstream commercial-off-the-shelf (COTS) information and computing technologies and systems. A key requirement is to take advantage of widespread "open"—i.e., "non-proprietary"—commercial standards for practices, products, specifications, and standards that are to be selected based upon performance, cost, industry acceptance, long-term availability and upgrade potential.[1] In this regard the Department of Defense and Navy OA programs seek to capture important benefits—faster insertion of new technologies and systems with less complexity and reduced total ownership cost—by leveraging commercially funded or developed technologies and taking advantage of increased marketplace competition. The OA initiatives seek to reduce multiple infrastructures that result from a myriad of competing architectures, and also to embrace a product-line approach that will generate true economic efficiencies. According to the Department of Defense's Open Systems Joint Task Force, the OA "bottom line" is superior and more affordable weapon systems.[2]

In the fall of 2002, Chief of Naval Operations Admiral Vernon E. Clark published "Sea Power 21," his vision of the 21st-century Navy that would see innovative concepts and technologies integrate sea, land, air, space, and cyberspace to a greater extent than ever before.[3] "In this unified battlespace," Admiral Clark affirmed, "the sea will provide a vast maneuver area from which to project direct and decisive power around the globe…. Future naval operations will use revolutionary information superiority and dispersed, networked force capabilities to deliver unprecedented offensive power, defensive assurance, and operational independence to Joint Force Commanders." Three operational concepts—*Sea Strike*, projecting precise and persistent offensive power; *Sea Shield*, projecting global defensive assurance; and *Sea Basing*, projecting joint operational independence—lie at the heart of the Navy's "Sea Power 21" vision. These three operational concepts are to be enabled by "FORCEnet," which Admiral Clark explained as "an overarching effort to integrate warriors, sensors, networks, command and control, platforms and weapons into a fully netted, combat force." It is the "glue" that binds together Sea Strike, Sea Shield, and Sea Basing into a coherent whole.

Writing in the February 2003 issue of the U.S. Naval Institute *Proceedings*, Vice Admiral Richard W. Mayo and Vice Admiral John Nathman noted that FORCEnet's architecture requires "…standard joint protocols, common data packaging, seamless interoperability, and strengthened security."[4] This was, in essence, a strong endorsement of the Navy's initiatives to embrace Open Systems Architecture (OSA)—or, more succinctly, Open Architecture (OA)—as the vehicle that will provide the Service with affordable computational enhancements directly linked to advancements within the commercial computing marketplace.

With this in mind, the Navy is developing a comprehensive strategy, plan, and program for an Open Architecture approach to address weapon system affordability, interoperability, and performance for today's fleet and the Navy after next. In the fall of 2002, the Navy stood up several new Program Executive Offices (PEOs), including the PEO for Integrated Warfare Systems (PEO IWS), which focuses on surface ship and submarine naval warfare technologies and systems. Within its charter, PEO IWS has embraced the challenge of promoting Navy-wide and Joint OA solutions. PEO IWS will help select common standards and products in the areas of frameworks, middleware, resource management, and operating systems, using both established and evolving industry standards to avoid proprietary solutions that might constrain rather than enhance interoperability, operational effectiveness, and future technology insertion. Furthermore, the computer program architecture will make common across systems and platforms those functions that are executed repeatedly. This will allow a greater reuse of computer programs and a broader vendor base, which will enable more rapid and cost-efficient upgrades of our warfare systems.

The Challenge of Accelerating Computing Technologies

For several decades following World War II, defense needs drove the high-technology marketplace, particularly in the United States. Following the Sputnik embarrassment in 1957, U.S. defense requirements and virtually unlimited budgets set the pace for the development of new systems and platforms supported by advanced technologies that had limited application in the commercial or civilian sectors. Warfighting needs, especially for real-time performance and simultaneous interface with numerous sensor, weapon, and command-and-control systems, could be satisfied only with custom-designed computer hardware and tightly coupled software, most of it "hard-wired" for specific applications. As defense requirements increased, the cost of continuing to meet them with military-standard computers and systems grew, as well. Increasingly, however, it became extremely difficult to keep ahead of the threats, particularly within constrained budgets.

Beginning in the 1980s, moreover, the needs of the global civilian marketplace took precedence in innovation and product development, predominantly in the commercial computing and information-technology industry. Prices in non-defense sectors fell dramatically, fueled by burgeoning demand for information technology and systems and the advent of low-cost, high-performance microprocessor chips, inexpensive memory and disks, and local area networks. Meanwhile, Defense Department budgets, despite the buildup during the Reagan Administration through 1986, could not keep pace with the cost growth in military-unique systems, which increasingly fell behind their commercial counterparts in fundamental capabilities and economies of scale.

Today the twin challenges of high military-unique costs and rapid technological obsolescence are daunting because design, development, and acquisition timelines can span as much as 15 years before a military system or platform reaches the operating forces. Meanwhile, commercial technology cycle times are being measured in months, far outpacing our ability to field advanced systems or to upgrade and modernize in-service systems. This is especially telling in the information technology and computing arenas, confirming Gordon Moore's 1965 prediction that computing memory capacity roughly doubles every 18-24 months. Even more accelerated cycle times are now common throughout the information technology domain, with processor speed, communications performance, and mass-storage capacity growing almost exponentially, while the cost per unit of computing "power" has plummeted. Clearly the continued reliance on military-specific, proprietary, stove-piped, and vertically integrated systems would leave the Navy and other services far behind the commercial state of the art.

The Challenges of the Navy's "Legacy" Systems

- Limited computational and processing capability
  - Current systems are operating at 99% capacity in non-stressed environments
- Difficult or unable to add new warfighting missions
  - Full use of offship warfighting (e.g., FORCEnet and Global Information Grid) constrained or unexecutable
  - "Stove-piped" systems diminish interoperability and ability to extend the battlespace to meet threats
- Bypassed by commercial industrial base, making software upkeep costs prohibitive
  - Some $3 billion spent across the Future Years Defense Plan (FYDP) in PEO IWS, alone, to develop and maintain computer programs
  - Require cost-prohibited testing and certification when new capabilities added
  - Bind Navy to limited commercial base due to proprietary nature

Open Architecture Defined

Informally, an open architecture system is one for which change and growth of both functionality and capacity can be accomplished with minimum cost and minimum impact on existing system components through the use of widely accepted hardware and system software standards, standard application components, and well-defined interfaces.[5] More formally, from the Office of the Secretary of Defense, an open system "implements sufficient non-proprietary specifications for interfaces, services, and supporting formats to enable properly engineered components to be utilized across a wide range of systems with minimal changes, to interoperate with other components on local and remote systems, and to interact with users in a style that facilitates portability."[6] The attributes of an open system include the following:

- Use of public, consensus-based standards
- Adoption of standard interfaces and protocols to facilitate new or additional systems capabilities for diverse applications
- Adoption of standard services and defined functions
- Use of product types supported by multiple vendors
- Selection of stable vendors with broad customer base and large market share
- Interoperability with minimal integration requirements
- Ease of scalability and upgradability
- Portability of applications

The Internet is an excellent example of an open system. Anyone can develop applications that will run on the Internet because the publicly available standard interfaces, protocols, and defined functions are the gateway for participation. Multiple vendors provide the software and hardware for Internet use. The customer base drives the vendors' success and market share, while creating *defacto* interoperability, upgradability, and portability of applications.[7]

In the past the Navy has acquired systems that—although they performed their functions and tasks exceedingly well—were unique in their designs and engineering; required unique parts, equipment, and services to support them; were supported by a limited number of suppliers; and became unaffordable to maintain. There are numerous instances, moreover, in which a system or platform was scrapped rather than upgraded or modernized because the cost to do so became prohibitive.[8] Thus, the challenge for weapons systems designers and engineers is to take advantage of OA systems when it makes good warfighting and business sense to do so. When all is said and done, if an OA solution does not enhance our ability to meet mission needs at reduced costs, then it is probably not the solution we desire.

An Integrated Warfare Approach

The PEO IWS open architecture program has as its primary objective the consolidation of Navy computing systems into a single open-system computing approach. There are two primary focus areas: (1) implementing the process to determine the composition of common "core" computing architecture and standards; and (2) deriving a warfare systems functional architecture within the OA. To be truly successful the approach must be easily adaptable to all platforms and applications, not only in the Navy but also the other U.S. armed services, as well in the militaries of America's friends and allies. The intent is to transform ship, submarine, aircraft, and warfare-focused shore commands by revolutionizing their computing plants and programs in an OA environment that maximizes fundamental commonality and interoperability across warships, aircraft, weapons, sensors, and virtually any defense program or capability that relies on computers.

Navy OA will be based on mainstream COTS technologies and systems and widely adopted open commercial information technology standards and non-proprietary standard interfaces, services, and formats. Navy OA will have a single Service-wide functional architecture that is extensible and scalable in function, capacity, and workload to meet Joint warfighting requirements, and that will enable reusable computer programs. Within a common functional architecture and computing environment, the OA program will enable the Navy to develop and evolve common warfare applications, services, and computing resources one time rather than independently across multiple programs. Key metrics include portability, scalability, extensibility, and flexibility of use.

As Vice Admirals Mayo and Nathman explained, "Priority actions to implement FORCEnet will include web-enabling the Navy; establishing open architecture systems and standards to allow rapid upgrades and integration; building common databases to widely shared information; implementing standard use interfaces to access information; and establishing portals that allow users to pull data from common servers."[9] OA is fundamental to FORCEnet success.

The PEO IWS OA program will field an Engineering Development Model (EDM) that runs on the OA Computing Environment (OACE) and contains selected common and specialized warfighting services and applications. Figure 2 illustrates the EDM's notional open systems architecture and the relationships between the commercial computer industry and the defense industry in providing general and domain-unique hardware, middleware, and software.

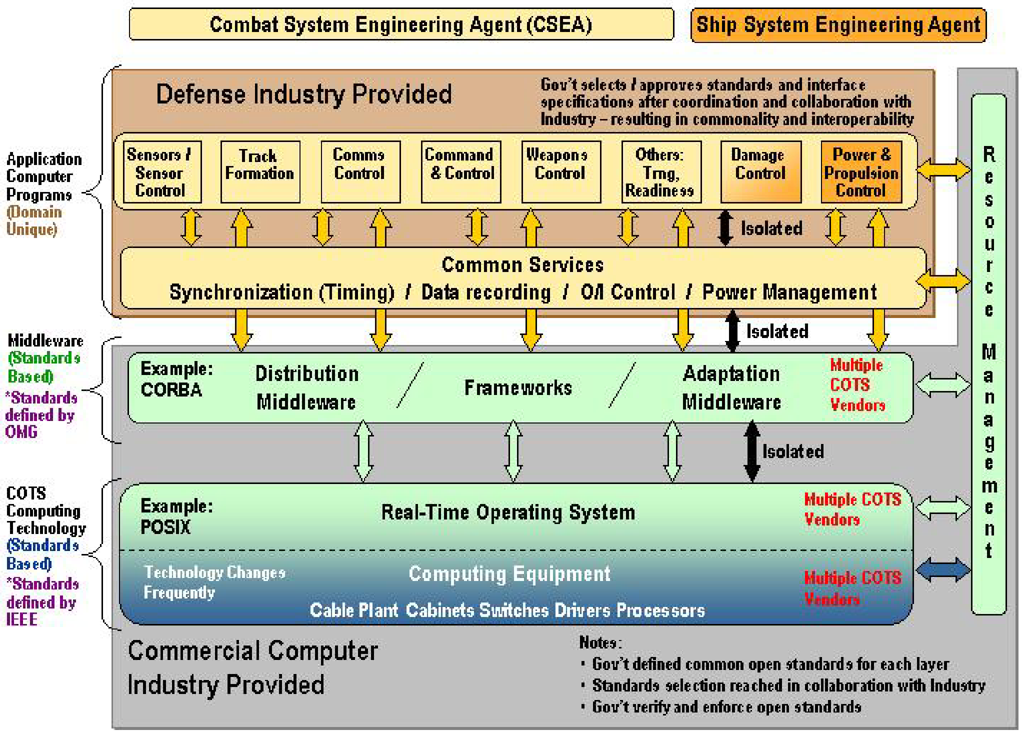

Figure 2: Notional Open System Architecture

The first "spiral" of this EDM will be operational in Fiscal Year 2003. By 2004, the first spiral on the road to an open Aegis system will be operating on the EDM. By 2005, a number of DD(X) applications will also be running. Each year additional combat system services and applications from differing surface warship classes and warfare areas will be added. This risk reduction stage of the OA initiative will conclude with the successful demonstration and operation of a full multi-warfare OA combat system. The goal is to field in the fleet an enhanced combat capability based on OA in FY 2008 and thereafter continue to field OA solutions under an evolutionary approach. Specific EDM goals are as follows: [10]

- Combat system, weapon system, command support systems, and hull, mechanical, and electrical capabilities that continue to pace the threat
- System design and common components that foster affordable development and life-cycle maintenance and maximizes reuse
- System design and common components that reduce upgrade cycle time and time to deployment for new features
- Architecture that is technologically refreshable despite rapid COTS obsolescence
- Improvements in naval warfare system human systems integration

- Interoperability enhancements

The principal results of a decade-long collaboration between Naval Surface Warfare Center's Dahlgren Division (NSWCDD) and Defense Advanced Research Projects Agency (DARPA) are, first, a growing list of validated commercial OA offerings for military applications and, second, a new and expanding military market for commercial products. Important for today's and tomorrow's fleet, the Navy increasingly can implement combat systems with "shrink-wrap" commercial products that possess the essential characteristics demanded by warfighting functions while at the same time providing enhanced ease of technology "refresh" and reduced total ownership costs.

For at least the last ten years, computer processor performance has effectively doubled every 18 months. Figure 3 shows the growth in processor throughput and associated reduction in execution time for the SPY Radar Control Program realized by this increase in processor performance. The same warfighting functions that required 12.3 milliseconds (ms) to execute when implemented on the HP-743 in 1995 can today be executed in less than 2ms when executed in an AMD Athlon processor using Lynx Operating System. This means we now have substantial excess execution time available to support new warfighting functions.

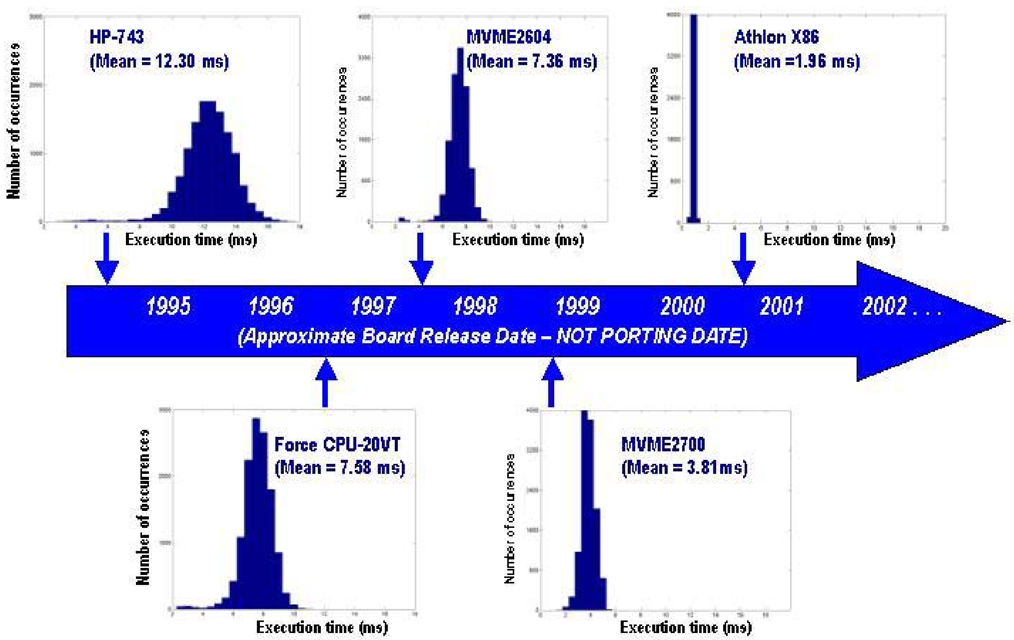

Figure 3: ARCG Computing Performance

The Navy OA program will also take advantage of other Navy, as well as other-service, open architecture initiatives. In addition to HiPer-D, several Navy Department programs have been OA pioneers, including:

- The *Virginia* (SSN 774) class nuclear-powered attack submarine program embraced an open systems approach from the earliest stages of the design process, which has allowed extensive use of non-developmental items, COTS technologies and systems, and commercial standards, particularly in the submarine's combat system.

- Acoustic Rapid COTS Insertion (A-RCI) is a three-phase program that replaces existing legacy submarine sonar systems, including BQQ-5 (SSN 688), BSY-1 (SSN 688I), BSY-2 (SSN 21), and BQQ-6 (SSBN 726) sonars, with a more capable and flexible COTS-based open systems architecture, and provides the submarine force with a common, highly capable sonar system. It allows development and use of complex algorithms that were previously well beyond the capability of legacy processors.

A "Sea Enterprise" Solution

The Navy OA program and other Navy open architecture initiatives will be key to meeting some of the "critical challenges" that Admiral Clark acknowledged in finding and allocating resources to re-capitalize the Navy. "We must replace Cold War-era systems with significantly more capable sensors, networks, and platforms," he underscored.[11] The "Sea Enterprise" solution he outlined is to be based on lessons learned from the business revolution to reduce overhead, streamline processes, and substitute technology for manpower, "to achieve enhanced warfighting effectiveness in the most cost-effective manner."

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[1]Department of Defense Instruction 5000.2-R, 15 March 1996. Although Secretary of Defense Donald H. Rumsfeld in the fall of 2002 announced a complete restructuring of the Defense acquisition instructions, the goal of open systems continues to be embraced. See the Memorandum, Defense Planning Guidance Flow-Down Implementation, Office of the Under Secretary of Defense, Acquisition, Technology, and Logistics, 4 October 2002, in which the open systems is highlighted as a key element of interoperability and acquisition reform.

[2]See, generally, the Open Systems Joint Task Force (OSJTF) web site: www.acq.osd.mil/osjtf.

[3]Admiral Vern Clark, U.S. Navy, "Sea Power 21: Projecting Decisive Joint Capabilities," U.S. Naval Institute *Proceedings*, October 2002, pp. 32ff. In successive issues of the *Proceedings*, articles provided additional details on Sea Strike, Sea Shield, Sea Basing, and FORCEnet.

[4]"FORCEnet: Turning Information into Power," U.S. Naval Institute *Proceedings*, February 2003, pp. 42-46, at 43.

[5]Michael W. Masters, Chief Scientist, Advanced Computing Programs, NSWCDD, "HiPer-D Open Architecture: Advanced Concepts Demo," briefing dated 8 November 2002. See also, Masters, "Engineering Distributed Real-Time Systems: The New State-of-the-Art," mimeo, 7 March 2002.

[6]OSJTF definition. In addition to other materials available on the OSJTF web page, see Dr. Avrid G. Larson, Charles K. Banning, and John F. Leonard, "An Open Systems Approach to Supportability," mimeo, undated; and J. Michael Hanratty, Robert H. Lightsey, and Dr. Avrid G. Larson, "Open Systems and the Systems Engineering Process," mimeo, undated. See also, Naval Surface Warfare Center Dahlgren Division, "Design Guidance for the Navy Open Architecture Computing Capability," Version 1.0, 1 October 2002, p. 4; and "Air Force Open Systems Implementation Guide," *op.cit.*, p. 4.

[7]An industrial-age metaphor of an open system is the development of the commercial tire industry during the last century. Initially, automobile designers and engineers produced cars with a plethora of incompatible axle-wheel-hub-tire combinations. Owners of one make or model

were compelled to go to a single source for repairs or upgrades. Gradually, however, standards crept into the industry. Today consumers are able to buy tires from many suppliers, both domestic and foreign, rather than being forced to buy from a single source, as would be the case if interface characteristics were unique. Costs and quality are controlled by a global marketplace dynamics and competition, and the continued support of the axle-hub-wheel-tire "system" is not subject to the risk of a single supplier that could go out of business or stop supporting the standard. And, as tire technologies change—from solid rubber tires, to balloon tires, to bias-ply designs, to steel-belted radial-ply technologies—the customer can take advantage of them without having to scrap his car before its expected service life is reached. See Hanratty, Lightsey, and Larsen, *op.cit.*, p. 4.

[8]For example, one conclusion of the 1988 Surface Combatant Force Requirements Study (SCFRS) was that beginning with the late-1950s' FRAM II (Force Rehabilitation And Modernization Phase 2) program most of the proposed upgrades to the Navy's surface warships through the mid-1980s were not fulfilled because of cost constraints. This was an element in the debate about extending the proposed Cruiser Conversion program to the first five *Ticonderoga* (CG 47) Baseline 1 AEGIS cruisers.

[9]Mayo and Nathman, *op.cit.*, p. 45.

[10]"Design Guidance for the Navy Open Architecture Computing Capability," p. 2.

[11]"Sea Power 21," *op.cit.*, pp. 40-41.