DEFENSE STANDARDIZATION PROGRAM

CASE STUDY

Acoustic–Rapid Commercial Off-the-Shelf Insertion

This case study describes how the Naval Sea Systems Command (NAVSEA) and the Program Executive Officer, Submarines, developed an innovative acquisition process to dramatically decrease sonar system development time and cost, while leveraging the significant investments made by the commercial computer, telecommunications, and other industries.

Acoustic–Rapid Commercial Off-the-Shelf Insertion

Innovative Acquisition Process Reclaims Submarine Superiority

Background and Problem

Over the last 35 years, submarine sonar systems had become large and complex due to the requirements to process ever-increasing amounts of sonar array data in a real-time environment in order to detect, track, and identify targets of interest. Special-purpose equipment was required to maximize the processing power that would fit in the limited space aboard a submarine.

As with almost every piece of tactical equipment the military bought, these sonar systems were developed and manufactured using detailed military specifications (MilSpecs). With MilSpecs, the development and production of new acoustic hardware components could take 4 to 5 years. In addition, sonar system development and procurement were tied to submarine new construction, which extended the time between system design and fleet deployment. This link also resulted in different sonar systems for each ship class, making fleet-wide improvements unaffordable. Because of the MilSpec hardware and numerous different sonar system configurations in use, the software architectures incorporated numerous operating environments, programming languages, development environments, and graphics tools. Thus, each class of submarine not only had different hardware, but also had different application software. Fielded systems, when introduced, were guaranteed to lag the current state of technology.

The support infrastructure for these complex and varying legacy systems had to provide training, spares, maintenance, and repair—which required technical documentation, detailed drawings, and ongoing training for operators and maintainers. Because the Navy owned the designs and planned on using them for up to 20 years, the Navy had to track the vendors that provided components and integrated circuits. As equipment aged, components became unavailable, and the Navy had to either

redesign the system or buy sufficient spares—both expensive options. The software maintenance of the different classes of submarines also was expensive.

The end of the cold war brought significant changes to DoD, resulting in an environment in which old acquisition methods would no longer work. Defense spending fell dramatically, even though the specialized nature of MilSpec sonar systems meant that increasingly expensive technology would be required to gain incremental improvements in capability. Moreover, Russia continued to develop and manufacture new submarines, despite economic hardships. Russia's latest version (the Severodvinsk) was estimated to be as quiet as a *Los Angeles*-class submarine, eliminating the acoustic advantage held by the United States in the early 1990s. In addition, the proliferation of quiet diesel electric submarines throughout the world had made the ability to detect and track these threats in new harsh acoustic environments a necessity and a challenge for even the best sonar.

The ever-improving stealth of potential threats required the Navy to implement computationally intensive signal processing algorithms that better isolated the sonar signal of interest and reduced background noise. The only way the Navy could accomplish this effort was by replacing existing acoustic systems with a new sonar system based on easily programmable and powerful distributed computer systems.

In response to that requirement, NAVSEA's Submarine Combat Systems Program Office restructured its existing sonar system upgrade programs. Specifically, it pooled the budgets for several independent upgrade programs to fund an all-encompassing upgrade using commercial off-the-shelf (COTS) products. This broad upgrade program—named the Acoustic–Rapid COTS Insertion (A-RCI) program—was approved for development in June 1996.

Approach

The Navy needed a dramatic, innovative process to reclaim acoustic superiority. It looked to four fundamental enablers:

- *Navy and DoD acquisition reform efforts.* Specification reform resulted in the near-total elimination of specialized MilSpecs and requirements, mandating the use of commercial standards instead. This reform opened the door to the military's use of COTS hardware and software in production systems. In addition to lowering the unit cost of the hardware, the authority to use COTS products expanded the universe of companies that could develop the hardware and software for sonar systems beyond the traditional defense contractors.
- *Commercial computer hardware revolution.* Driven by the demands of the commercial marketplace and fueled by the incredibly rapid pace of improvements in integrated circuit technology, computer processing power increased exponentially while becoming more affordable. The tremendous growth in computer

capability provides the scientific community with the capability to execute the complex algorithms necessary to significantly improve real-time acoustic signal processing. The lower hardware costs allow for the procurement of high-performance computers within a reasonable budget. The use of COTS products also significantly lowered logistics cost by reducing the training time, spares inventory, support documentation, and number of support items.

- *Migration of MilSpec computing hardware to commercial hardware.* Two small business and innovative research efforts done in the early 1990s—one on the feasibility of migrating existing Navy sonar system software to available commercial hardware, and the other on the feasibility of using advanced open systems architectures (OSAs) to support the real-time processing needs of Navy sonar systems—demonstrated the ability to run the existing sonar system software on commercial processing hardware employing OSA. The research also demonstrated that the increased processing power available from commercial computer hardware allowed for the use of improved signal processing algorithms.
- *Breakthrough process to improve functionality.* Improved computer processing hardware means nothing without improved software to run on it. NAVSEA developed the Advanced Processing Build (APB), a streamlined, cost-effective method to rapidly bring new functionality to the operating fleet.

Outcome

The use of modern COTS processors and commercial software languages in A-RCI opens the door to easier future upgrades of sonar systems. The Navy conducts periodic technology insertions (TIs) in which COTS components are replaced with newer, more capable, and more supportable components. Because A-RCI is designed to use commercial open standards, the Navy can select from a number of available components. The software design also makes upgrading easier by its use of middleware to handle hardware-specific aspects of the design instead of hardware-specific application code. This approach eliminates the traditional problem of block obsolescence and the resultant need to buy large quantities of expensive spares to support a long equipment lifetime. In addition, older sonar systems were significantly restricted in making changes to their user interfaces by the cost and complexity of their design. Because of the flexibility inherent in the new COTS graphical user interfaces used in A-RCI, it is much easier to modify the operator-machine interface based on fleet input.

As part of the design for continual improvement, the A-RCI program and the Navy's sonar advanced development community developed a process to help expedite the introduction of new functionality into A-RCI. A-RCI uses a revolutionary, four-phase APB implementation process. The APB process, a fundamental change in the Navy's acquisition strategy, couples advanced development with engineering development, leading to significant savings

through early algorithm testing, software reuse, and a reduction in lead-time from algorithm concept to fleet introduction. The four phases are as follows:

- Phase 1—algorithm evaluation—is a survey of promising algorithms from the research and development (R&D) community. A peer review group—composed of Navy, Navy laboratory, and industry personnel—interactively reviews fleet priorities and surveys R&D activities of the Office of Naval Research and the Defense Advanced Research Projects Agency, industry independent R&D, and broad agency announcements for algorithms to determine their tactical importance, maturity, expected performance, and computational resource requirements.
- Phase 2—algorithm assessment—is a test of relatively mature algorithms that promise to provide improved performance to the fleet. Using real-world data collected from U.S. submarine exercises and provided by the Office of Naval Intelligence, this testing provides a projection of algorithm performance using real-world ocean noise and target signatures of interest. Phase 2 is unique in that the peer review group provides feedback to the developers based on real data.
- Phase 3—system real-time implementation—incorporates acceptable algorithms into an end-to-end sonar processing string on actual shipboard hardware. This processing string constitutes an APB. Phase 3 laboratory testing, conducted by the A-RCI's independent test and evaluation organization, is a critical step in the build-test-build process. It ensures readiness for at-sea testing and provides confidence to the community, including the end users in the fleet, that ideas have been properly implemented.
- Phase 4—at-sea testing—is the most important phase of testing before including the algorithms in A-RCI hardware. At-sea testing is the culmination of the APB test process, permitting live examination of the strengths and weaknesses of the new build and quantitative measurements of performance.

Following Phase 4, a decision is made on transitioning the new functionality to the fleet as a certified A-RCI software and hardware suite.

Although the APB process ensures that the fleet is continually upgraded with the latest algorithms, the Navy simultaneously uses a process of hardware TIs to ensure that fleet hardware is ready to receive the latest APB functionality. Every 2 years, the A-RCI computer production hardware baseline is reviewed and updated to the latest mainstream technology. This enables the Navy to realize the maximum capability for the procurement dollar, because, typically, computer processing hardware gets more powerful and less expensive every year.

Originally, A-RCI signal processors were high-end modular COTS cards costing around $350,000 per drawer. By 2003, the same processing capability could be provided by two mainstream dual Intel processor computers costing $10,000 each, an order-of-magnitude savings. By migrating to mainstream COTS computers, submarines can be easily

upgraded with new computers as technology continues to improve.

In addition to procuring the most modern computer hardware for new installations, every submarine is on a TI schedule in which its hardware suite is upgraded every 4 years. This ensures that the ship's system can continue to process the latest software and minimizes the risks from hardware obsolescence. Normally, each ship will receive two to three APBs (delivered annually) on a given hardware suite before needing a technology insertion. And the Navy designed the process to minimize the impact of acoustic upgrades on a ship's operational schedule by making it possible to upgrade both hardware and software without scheduling time at a major shipyard.

The introduction of the APB process and TIs has forced the entire acquisition community to review its procedures for acquiring systems. The rapid changes in functionality and hardware have generated new and innovative acquisition approaches in areas such as requirements development, standardization, contracting, testing, training, and funding.

Requirements Development

The Navy's new process demands continual iteration among the program office, the fleet, and the contractors to ensure that fleet requirements are driving the APBs and TIs. The program office communicates planned system capability and technology developments, while the fleet has the opportunity to provide feedback on new system capabilities and fleet priorities.

Standardization

The original hardware architecture of the most widely used legacy submarine sonar system in the U.S. Navy, the AN/BQQ-5, was based on a Mil-Spec—Standard Electronic Module (SEM). The SEM was modified several times over the years, but each module was custom built with only limited use beyond specific sonar systems. The packaging of the modules into the MilSpec format was mandatory, because equivalent commercial electronics were either expensive or could not meet the performance requirements of the system design. When a change was necessary, the development and production of a new SEM module could take as long as 3 years. To maximize hardware performance, complex software architectures were used.

With A-RCI, the Navy is minimizing the use of anything other than high-use commercial specifications (such as those developed by the Institute of Electrical and Electronics Engineers) or standard operating systems (such as LINUX) that use free, open source code. The use of commercial standards does not eliminate issues of configuration management. To ensure that APBs and TIs are designed against the proper baseline, NAVSEA maintains configuration management of COTS hardware and software changes and establishes which versions are in use. To provide flexibility in the selection of processing hardware, middleware is used that acts as a buffer between the application software written by A-RCI developers and the underlying hardware and base operating system. This approach protects

the major Navy investment in application software from hardware and operating system changes. The middleware is open source and used by all A-RCI developers.

Use of Multiple and Diverse Contractors

A unique characteristic of the A-RCI program is the competitive-like environment maintained by NAVSEA through the use of multiple and diverse contractors. The concept of prime contractor with multiple subcontractors has been replaced with a systems integrator and more than 20 other contractors who have separate contracts with the Navy for hardware and software. The systems integrator is Lockheed Martin. Other major contractors are General Dynamics and Progeny. This arrangement spurs a healthy competitive-like environment for both cost and technical solutions, in part due to the professional pride each prime contractor has in its products and efforts. Many independent contractors, along with frequent change, continually demonstrate the openness of the A-RCI architecture. All A-RCI participants are encouraged and incentivized to think "team" rather than a more organizational view.

Small business also is a large factor in NAVSEA's success. The A-RCI program uses many small businesses because they bring fresh ideas, innovation, flexibility, and new processes. Due to their size, small businesses can adapt more easily to changing technologies and requirements because they have fewer organizational barriers. For the Navy, this has a "rub-off" effect on larger businesses by showing them how to be more responsive and innovative and how to reduce costs. In many instances, small businesses have reduced costs as a direct result of using the latest innovations and ideas.

Despite the fact that multiple contracts may create additional administrative burden—due to possible enhanced government oversight and intellectual property concerns—the advantages of multiple contracts outweigh the disadvantages. NAVSEA's contracting arrangement has resulted in many positive benefits: use of leading-edge technology, rapid development, cost savings, fleet schedule adherence, and increase in industrial base technologies. Multiple contracts sustain a continually competitive environment. They also enable more businesses to become involved and provide the Navy with the opportunity to select the best option for each element of the acoustic system. At the same time, the Navy is able to obtain a level of effort that maximizes each contractor's unique strengths.

Integrated Product Team Pricing

Integrated product team (IPT) pricing, also known as one-pass contracting and alpha contracting, is a concept, adopted by NAVSEA, in which the government and contractor develop the statement of work and pricing in an open, parallel process.[1] This process promotes improved understanding of each side's position and reduces time to award, as well as proposal costs. For example, the Navy awarded the initial A-RCI development contract as an undefinitized contract action. In that case, the IPT process

reduced the amount of time required to finalize the statement of work and pricing for the contract from the typical 270 days to 155 days. After contract award, the government-contractor team completed cost negotiations in 1 day, with the final cost differing only 1 percent from the start of negotiations. The team did not need to change the statement of work after contract award because there were no misunderstandings about the efforts required to develop the A-RCI system.

Flexible Contract Vehicles

In lieu of firm-fixed-price (FFP) contracts, NAVSEA uses cost-reimbursement-type contracts for the development and production of A-RCI kits. Currently, NAVSEA is using cost-plus-incentive-fee (CPIF)/cost-plus-award-fee (CPAF) contracts. This hybrid contract vehicle offers several advantages:

- A CPIF/CPAF contract balances risk and savings/overruns between the contractor and the government, and both sides share in the savings. To increase the contractor's incentive to perform in an exemplary manner, some of the award-fee criteria are based on quantitative rather than qualitative standards. Quantitative criteria provide the contractor very clear guidance on the basis for the incentive/award-fee decision. In addition, a CPIF/CPAF contract vehicle incentivizes stakeholders to develop low-cost, technically superior solutions. In contrast, an FFP contract discourages government involvement and risk taking by the contractor—primarily in the area of innovation—and any cost savings go to the contractor. Moreover, an FFP contract does not work in a time of rapid technology change.
- A CPIF/CPAF contract maximizes contractor and government flexibility. For example, the contractor is more likely to purchase hardware for production at the last possible moment, which enables the use of the latest COTS technology and maximizes the possibility of lower hardware and inventory costs. Under an FFP contract, the contractor may or may not use the latest technology, because of the increased cost and technical performance risks it assumes under a fixed-price contract. For development and support efforts, which are procured on a level-of-effort basis, the government's ability to terminate the contractor's efforts is greatly enhanced—level of effort can be terminated at any time with virtually no advance notice. This greatly reduces the chances that development efforts can go astray, from both cost and technical standpoints, in part because the government can stop these efforts within a day of deciding to do so and without potentially expensive and cumbersome formal termination procedures.

Testing

The serial testing of a traditional acquisition program does not meet the needs of the APB process. It is critical to involve the operational test and evaluation community early in the APB process. Moreover, the test process must become an evolutionary—versus a one-time—process, because the

system configuration continually evolves. Similarly, the traditional processes used to update an operational requirements document and a test and evaluation master plan (TEMP) are too cumbersome to support evolutionary acquisition programs. With A-RCI, a memorandum of agreement was signed by all parties involved to use appendixes to the TEMP to implement changes from the APB process. This approach is designed to require a less cumbersome approval process, enabling timely implementation of changes. In addition, letters are used to provide APB content and test requirements in advance of the formal TEMP appendix approval.

Training

The primary technology enabler for the support of A-RCI hardware is the interactive electronic technical manual (IETM). The use of an IETM changed the nature of maintenance training from "how to repair" to "how to access the information on how to repair." The IETM also facilitates automated reporting products to communicate back to the systems integrator support infrastructure. The IETM integrates the supply documentation for repaired parts; facilitates preventive maintenance monitoring; supports electronic maintenance requirements cards; and supports reliability, maintainability, and availability data collection.

Funding

The budget to support the A-RCI system cannot sustain the large up-front outlays required to make lifetime buys or to make large block upgrades across the fleet at fixed intervals. Hence, the A-RCI program uses the incremental update strategy. By using small incremental changes to keep pace with the COTS market, the A-RCI program is able to take advantage of the primary benefit of COTS items—continuous infusion of new technology. The downside to this approach, however, is that a budget shortfall in 1 year affects all following years. Likewise, early funding and multiyear funding would provide more time to develop and execute technology insertion before the scheduled installation date.

Benefits

The Navy will benefit from A-RCI in five key ways:

- Improved sonar performance
- Increased number of modernized submarines
- Increased commonality across sonar systems
- Faster introduction of improvements
- Lower development, acquisition, and support cost.

Improved Sonar Performance

In real-world exercises and operations, the A-RCI submarine sonar system has unequivocally demonstrated that U.S. Navy submarines have regained a clear acoustic advantage—by enabling more rapid detection, a higher detection rate, and longer holding time (time from initial contact detection until contact is lost). In addition, technical assists—an overall measure of supportability effectiveness—have shown a reduction from legacy requirements since

the introduction of A-RCI. NAVSEA achieved this reduction while reducing the factory conversion training for sailors from 20 weeks to 4 weeks.

Increased Number of Modernized Submarines

By pooling the budgets from several independent upgrade programs to fund an all-encompassing upgrade using COTS hardware, the Navy accomplished a much broader upgrade development effort than could have been accomplished under existing budgets. A-RCI enabled the Navy to extend the improvements available from the more powerful COTS processors to a greater number of submarines than under the original upgrade programs. Since 1996, NAVSEA has retrofitted 46 out of 73 submarines in the fleet with A-RCI. The Navy will modernize the entire fleet by 2006. Under the broader umbrella of antisubmarine warfare, the Navy is applying the A-RCI processes and functionality to both surface ship sonar and the Integrated Undersea Surveillance System (IUSS).

Increased Commonality Across Sonar Systems

A-RCI brings sonar system commonality to the fleet, reducing maintenance and training requirements. Instead of six separate systems (*Los Angeles*, *San Juan*, *Ohio*, *Seawolf*, SSGN, and *Virginia*) with independent maintenance schools and different operator-machine interfaces, A-RCI is a common system for use on all submarine classes. Now, a sailor from a *Los Angeles*-class fast attack submarine will be able to transfer to an *Ohio*-class ballistic missile submarine and be ready to operate and maintain the sonar system. Training packages developed for APB improvements will be applicable for all crews, reducing the work required to provide the

training. Because of the increased commonality, the number of scheduled maintenance actions is approximately 56 percent lower, and operation and maintenance training now requires 4 weeks instead of the previous 20 weeks. The physical reduction of the number of units of the system and the use of computer-based training (interactive multimedia instruction and interactive courseware), which eliminated the need for tactical hardware, contributed to the reduction in training time.

In addition, the New Attack Submarine (NSSN) *Virginia* and A-RCI programs are using the same contractor teams to develop their respective sonar systems. There will be extensive leveraging of the two programs' efforts to develop systems with as much common hardware and software as possible. This strategy will significantly reduce the overall cost of developing the two systems and will further reduce the training and maintenance requirements of the fleet.

Faster Introduction of Improvements

Another A-RCI benefit is to get sonar system improvements to the fleet faster than in the past. Normally, a new sonar system takes a decade or more to progress from concept to operational unit. NAVSEA installed A-RCI on the first ship less than 2 years after it started the program, and it completed three major upgrades in the first 3 years. In addition, the NSSN program will be able to take advantage of the ongoing technology improvements associated with A-RCI to help ensure that its ships are delivered with up-to-date sonar systems. This is a significant improvement over the traditional approach, in which the sonar systems are designed and delivered years before the submarine is completed, resulting in almost immediate obsolescence at ship delivery.

Lower Cost

The Navy expects the A-RCI process to result in projected spare parts savings of $3 million per hull over the legacy sonar systems previously used. And by obtaining COTS products more quickly than MilSpec items, the Navy can maintain smaller inventories. With A-RCI's pay-as-you-go, just-in-time support, there is near-zero inventory, resulting in an $8 million inventory reduction over 4 years. The CPIF/CPAF approach also has contributed to an underrun of cost goals, while delivering systems with the latest technology and, in most instances, on schedule. These cost, schedule, and performance improvements have earned NAVSEA two Hammer awards for significant contributions in support of reinventing government principles.

Future Efforts

The Navy will continue to streamline the A-RCI process, while adding more discipline. For example, NAVSEA will continue its pursuit of new technology, but hopes to build a formal, repeatable process to replace its current ad hoc process. In addition, NAVSEA will expand its search overseas for new technology by leveraging the Foreign Comparative Testing Program to learn of promising new technologies outside of the United States.[2]

At the same time, NAVSEA will continue to

reengineer old business processes to improve their alignment with the rapid pace of improvements that COTS products and OSA enable. A-RCI exploits the price and capability benefits of COTS products but creates vulnerabilities due to the rapid, uncontrollable, COTS product life cycles. These vulnerabilities result from the clash between the dynamics of COTS products and the relative inertia of traditional support infrastructure: test, maintenance, training, and supply support. For example, the operational requirements document and operational evaluation process currently do not keep pace with the rapid TI rate—lagging by as much as two generations of APBs. Likewise, the Navy must decrease the time required to incorporate new training. When a new system is delivered, onboard training is available, but it is difficult to get new training into the formal training system.

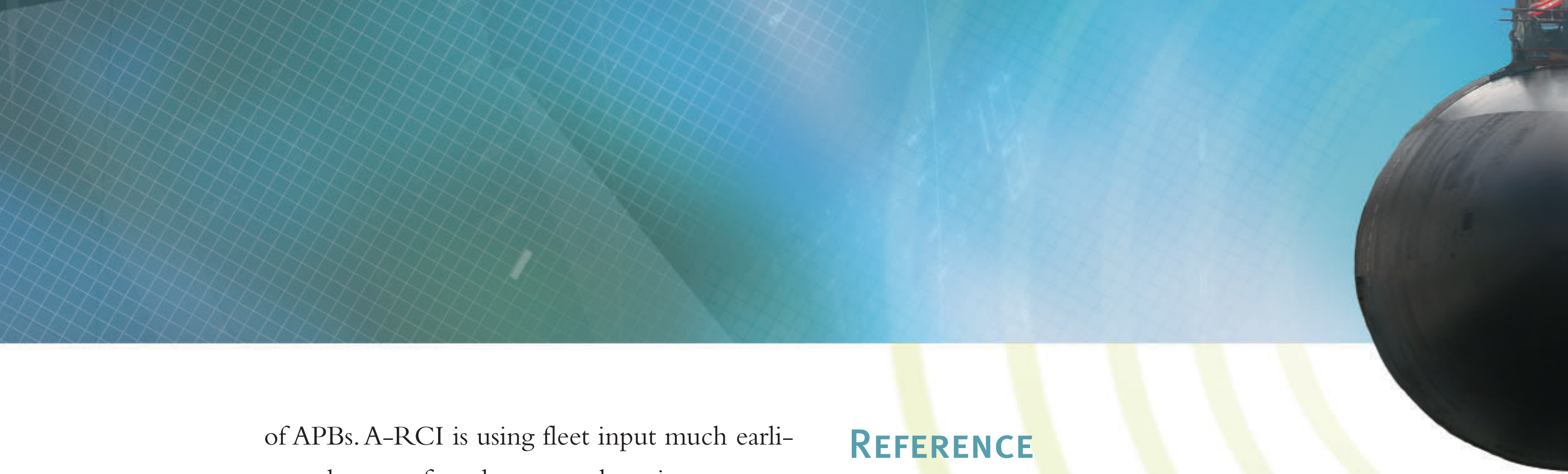
The Navy has extended the A-RCI process to other platforms, and the surface antisubmarine warfare and IUSS Navy has adopted A-RCI-like processes. The Navy's objective is to replace legacy systems with COTS products/OSA as rapidly as possible for submarines, surface ships, and surveillance platforms.

Finally, the Navy would like to apply the A-RCI process to new ship construction. It is likely that sonar technology will undergo multiple upgrades during the time required to design and construct a new ship. The challenge will be to enable the acquisition process to accommodate upgrades of the ship's combat system design while under construction.

Lessons Learned

Several lessons learned by NAVSEA may apply to other areas:

- *Use OSA and COTS products as enabling forces.* OSA and COTS products breed competition and innovation, while allowing for system upgrades with far more capability than existing systems have today at a fraction of their cost and implementation time.
- *Use the rapid cycle time of COTS products to your advantage.* The rapid cycle time makes it possible to upgrade hardware to provide processing power for more advanced applications, replace components before they become obsolete, and reduce system and spares procurement costs. This mimics the support philosophy for standard office computers and enables the Navy to avoid the manpower-intensive screening and repair process of low-cost commodity computers.
- *Involve all stakeholders in the technology insertion decision process.* By including the government and contractors in a joint team, NAVSEA is able to research and select the best path for technology insertions. NAVSEA also incentivizes industry to reduce system cost by using the latest technology.
- *Involve the end user in all stages of design.* Fleet operators should be involved before, during, and after each phase of software development. They also should be involved in the generation



of APBs. A-RCI is using fleet input much earlier and more often than any submarine sonar development program in history.

- *Ensure budget stability.* The traditional, front-loaded funding profile does not support COTS technology insertion; stable funding levels are needed. A long-term, stable operations budget is required to support technology insertion and planned periodic updates matched to the ships' schedules.
- *Be aware that IPT pricing requires special conditions.* IPT pricing should be reserved for large-dollar or other critical actions, because it is labor intensive. To be successful, IPT pricing requires that the members of the government/contractor team trust one another and share common goals, that each side be willing to change existing processes and procedures, and that team members communicate openly.
- *Set realistic cost targets and fee objectives.* When using flexible contract vehicles, such as CPIF/CPAF, cost targets and fee objectives must be realistic. In addition, performance specifications and both qualitative and quantitative award-fee criteria should be used. Innovation, sustainment, schedule, and quality issues should be emphasized.

Reference

N.H. Guertin and R.W. Miller, "A-RCI—The Right Way to Submarine Superiority," *Naval Engineers Journal*, March 1998.

Notes

[1]The IPT process applies only to sole-source contracts and works best in urgent situations, when funding, schedule, or threats bring sufficient pressure on the government and contractor to change their normal ways of preparing and negotiating contracts.

[2]Authorized by Congress and administered by the Director, Strategic and Tactical Systems, Office of the Under Secretary of Defense (Acquisition, Technology and Logistics), the Foreign Comparative Testing (FCT) Program demonstrates the value of using non-developmental items to accelerate the acquisition process and cut rising development costs. The principal objective of the FCT Program is to support the U.S. warfighter by leveraging non-developmental items of allied and other friendly nations to satisfy U.S. defense requirements more quickly and economically.

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