A Revolutionary Use of COTS in a Submarine Sonar System

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The AN/BQQ-10(V) Acoustic Rapid Commercial off-the-shelf (COTS) Insertion (A-RCI) submarine sonar system has been repeatedly cited as one of the Department of Defense's premier examples of using COTS technology to provide significantly improved system performance at far lower costs than previously possible. The ability to rapidly and inexpensively upgrade a ship's sonar hardware suite to provide continually increasing sonar performance has helped to restore United States submarine superiority over all potential adversaries. As part of this revolution in RCI, the program has identified several lessons on using COTS hardware and software that can help other programs making the same leap into the COTS world.

By the mid-1990s, the United States Navy's submarine force had lost its once seemingly insurmountable lead in detecting and tracking foreign submarines. The use of improved acoustic quieting measures on foreign submarines as well as the worldwide proliferation of modern diesel-electric submarines had sharply reduced the acoustic advantage that the United States had held since the mid-1950s. In addition, the end of the Cold War brought about a significant reduction in available funding to develop and field the improvements necessary to restore superiority. The operating forces were forced to use carry-on commercial systems in an effort to regain some of the advantage that had been lost. These *black boxes* did provide some help but were not fully integrated with the remainder of the ship's combat system, thereby reducing their effectiveness in maintaining tactical control.

In an effort to restore United States submarine sonar superiority and eliminate the need to bring on temporary equipment to meet mission requirements, the Navy began developing the Acoustic Rapid Commercial off-the-shelf (COTS) Insertion (A-RCI) sonar system, later designated the AN/BQQ-10(V). Knowing that the $1.5 billion development cost and the $90 million shipset cost for a new military specification (MIL-SPEC) system was unaffordable, the A-RCI sonar system was designed from day one to use COTS hardware and software components to provide the most up-to-date and powerful computer processing capability possible. This allowed the use of advanced signal processing algorithms to exploit the much quieter target acoustic signatures now available.

Using these advanced algorithms, the U.S. Navy submarine force has now regained the tactical advantage, and an ongoing technology insertion program means that improvements will continue to be made. In addition, using COTS components instead of MIL-SPEC hardware brought the development cost down to about $100 million and the shipset cost down to $10 million. Since the A-RCI system was designed to replace the different sonar systems on the various submarine classes with a common system, it also reduced the support infrastructure and made it possible for all submarines to have the most modern and capable sonar system available. Commonality also makes it easier to improve the maintenance and operational skill level, and increase the operational experience of the sailors serving in the fleet. The A-RCI program's experiences in using COTS for a critical military system can be of great benefit for other defense programs making the same leap into the COTS world.

Initial Implementation

The first A-RCI hardware suite consisted of a combination of custom and COTS Versa Module Europa (VME)[1] cards to provide the necessary processing power in the limited space available on a submarine. COTS operating systems and hardware drivers were used to the maximum extent practical to minimize the scope of the required software development effort. However, several limitations with this architecture were soon discovered.

The custom cards were prone to failure and were difficult to program. Although technically a COTS product, the signal processing cards were very specialized, leading to high procurement costs and the use of an operating system with limited peripheral driver support. The implementation of the sonar system also used the COTS hardware and software in non-standard ways (i.e., fibre channel standard networks for interprocessor communications vice disk access, Asynchronous Transfer Mode local area networks) making it more difficult to get vendor support or leverage lessons learned from commercial implementations.

Finally, since the A-RCI program was only a small player in the COTS market, receiving timely vendor support for problems found during integration and test was a hit or miss affair. If the vendor felt we were a valuable customer, we would get good support for correcting noted problems; but more likely, the vendor focused its efforts in fixing problems discovered by its more mainstream customers.

The most important lesson learned from this implementation was that as more mainstream hardware and software components were used, fewer problems were discovered during testing, and the vendor was more likely to fix the problems. This revelation became one of the tenets for the technology insertion process that would soon be implemented.

The Technology Insertion Process

One of the key enablers for both the technology insertion process and using COTS hardware in the A-RCI sonar system is using Multipurpose Transportable Middleware (MTM) to isolate the application code from the underlying hardware and its associated drivers and operating systems. MTM was developed and is still maintained by Digital Systems Resources, now a part of General Dynamics Advanced Information Systems.

MTM is a freely licensed set of software utilities that allows for high-speed data passing between the various application software modules running in the A-RCI sonar system, while isolating the modules from the hardware and network protocols. This isolation allows the hardware and associated drivers to be updated without impacting the large amounts of complex application code. Instead, the impact of the hardware change is limited to the MTM that was designed to easily handle change.

By isolating change from the application code, many hours (and dollars) are saved with each hardware technology insertion. Because of MTM's benefits, the A-RCI sonar system's hardware has been successfully upgraded five times in the last seven years to reduce system cost and complexity and improve system-processing performance.

The first two technology insertions to the A-RCI hardware baseline were done to eliminate most of the custom VME cards in the system and to provide improved display performance. Elimination of the custom VME cards reduced system cost, improved system reliability, and made software programming easier and faster. Instead of having to code at an assembly level to discrete hardware components, the code could be written in a high-level language (typically C), and features of the COTS operating system could be used to the maximum extent. Simplifying the coding allowed the programmers to spend more time writing better code and debugging problems instead of dealing with the details of the hardware interface.

The VME signal processors with its associated proprietary operating systems and interfaces continued to be used to meet the processing density requirements. However, the decision was made to migrate the display system from VME to a commercial workstation technology when it became apparent that there would be little vendor support for high performance graphics on VME processor boards.

After a survey of available high-end computer workstations, the decision was made to use the HP J5000 workstation and the HP-UX operating system. The choice of this widely used COTS operating system opened the door for display development using standard Motif and Open Graphics Library software libraries. Using standard libraries and their application programming interfaces have made possible rapid updates to the displays to fix problems and implement fleet-user recommendations. This rapid response to user need has become a hallmark of the A-RCI program.

Starting in 2000, the performance levels of mainstream COTS processors became high enough to consider using them for complex signal processing applications. Since then, the technology insertion process has focused on migrating the remainder of the sonar system to mainstream COTS processors with a mainstream operating system.

Market surveys in 2000 indicated that Intel x86 family processors would increase its domination of the server market and that the Linux operating system would become widely supported by device developers. Based on this research, the signal processing applications were shifted from VME cards to Compaq eight-way Pentium III servers running the Linux operating system. An immediate impact of this decision was a large decrease in system acquisition cost. In addition, shifting to a symmetric multiprocessor (SMP) architecture freed the programmer from having to discretely control each individual processor and allowed focusing on making the application code as robust and reliable as possible. Another benefit of using the open-source Linux operating system was its broad user/developer base to help troubleshoot problems. Linux and the software written to use it are also more familiar to most software programmers, leading to higher productivity.

The 2002 and 2004 technology insertions continued the migration to mainstream COTS hardware and software. The signal processing servers were changed from the eight-way SMP servers to less expensive dual processor Intel XEON-based servers running at higher clock speeds. In addition, the display servers were changed to dual processor Intel XEON-based servers to reduce the number of different hardware types/operating systems present in the sonar system. Since both the display and signal processing servers now used a common hardware baseline, software development was easier because data transfer was now simpler (no more byte swapping), and a common set of device drivers could be used for both server types. Just as important, the dual processor architecture maintained the previous generation's flexibility of not having to individually program each processor.

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To the maximum extent possible, the system networks were also migrated to Gigabit Ethernet to stay within best commercial practices and provide the most robust set of hardware and device drivers. However, the scope of change in the 2000 and 2002 technology insertions resulted in significant changes to the system network and cabinet enclosures from the previous generation. Therefore, as part of the technology insertions in 2002 and 2004, a concerted effort was made to make the system network architecture more flexible and to make the cabinet enclosures easier to upgrade during future technology insertions. This effort is succeeding as the cabinet enclosure and cabling system differences between the 2002 and 2004 technology insertions are minimal. Now, when a new processor design is chosen in a future technology insertion, no multi-million dollar cabinet redesign will be required.

Eliminating the need to redo a large portion of the shipboard cabling and change-out cabinets will also ensure that future technology insertions can be done in a standard length port maintenance period of about 35 days for about 20 percent of the cost it had previously taken. Reducing change external to the cabinets is imperative to minimizing the shipboard impact of technology insertion.

The Benefits of COTS

The A-RCI sonar program takes advantage of the many benefits of using COTS hardware and software for military applications. A significant benefit is the ability to use computer systems much closer to commercial state-of-the-art systems than was ever possible with MIL-SPEC systems. This has allowed the use of advanced computation-intensive signal processing algorithms and easy-to-use displays to improve the operator's ability to detect signals of interest. Using COTS processors also makes it much easier to develop, purchase, and install upgrades to the sonar system to keep its performance at the highest possible level.

In addition, using standard rack-mounted server boxes means that ongoing improvements in commercial computers can now be rapidly inserted into the system with minimal changes required. This is similar to the way a business using Hewlett Packard and Dell computers would upgrade its server farm. Importantly, the ongoing technology insertion process eliminates the need to maintain obsolete COTS hardware; instead, when a ship's computer hardware becomes obsolete and unsupportable, it is replaced with an up-to-date system.

Using COTS hardware components brings the benefit of using COTS operating systems, device drivers, and libraries. This has enabled the system software developers to focus on the applications versus the support software. In addition, mainstream software is better tested and more robust than custom software. Using open-source software such as Linux brings the advantage of a large developer base so that software problems will be resolved in a very timely manner. The large developer base also ensures that any security holes are quickly discovered and corrected and that no malicious code is inserted into the operating system. This is one reason why Linux has a much lower incidence of security breaches than the proprietary Microsoft Windows operating systems. Although COTS operating systems, device drivers, and libraries are used, the critical application software is still written and maintained by the system developers using secure facilities.

The lower hardware cost and the continuous improvement cycle associated with commercial computer hardware is what allows the A-RCI technology insertion process to succeed. If the cost of hardware components were equivalent to the MIL-SPEC hardware used in the past, the pace of system upgrades would be unaffordable and the Navy would soon be behind the technology curve like it was in the mid-90s. Using a COTS technology insertion process has enabled a 10x increase in system throughput and an 86 percent reduction in hardware cost per billion floating point operations per second in a six-year period. Low hardware cost has also allowed the A-RCI sonar program to purchase system equipment from several vendors, ensuring that a continuous price competition exists.

Because integrating COTS components is within the capability of firms much smaller than the traditional major Department of Defense (DoD) contractors, a much broader business base is also available. Configuration control of the system is maintained by requiring all system equipment vendors to work together in specifying the COTS components.

The Downside of COTS

The downside to using COTS software is the lack of insight into the code details. Since the system contractor does not write the software, the programmers have a much-reduced understanding of the code than they would have with internally developed software. This could make the development team dependent on the skills of the open-source community to fix any problems noted during integration and testing – an unacceptable situation. This situation is prevented by researching the COTS products selected to verify they are in use by many other developers with similar applications and requirements. This broad user base helps ensure the software is well tested and robust before it is used by the A-RCI system.

A more significant downside is a result of using COTS hardware in a non-office environment. COTS servers are designed for use in well air-conditioned spaces and not the sealed, water-cooled cabinets used on submarines. Cooling the processors has become a significant issue, currently limiting the team's ability to use the full capability of today's processors. In the future, it may not be possible to continue providing increased processing power with each technology insertion unless improved cabinet cooling methods can be implemented.

Process Migration

The benefits of this new COTS business model have so significantly outweighed the disadvantages (primarily with respect to cost and rate at which capability can be added) that the model has been expanded to include the entire non-propulsion electronics suite on the newest class of submarine: the USS Virginia attack submarine. The process has expanded from what was simply a single sonar sensor and processor to a 20-million source lines of code system of systems that includes *all* sensors, ship's navigation, combat/fire control, and ship monitoring functions.

Rapid COTS insertion is also being used to upgrade older submarine classes' combat control systems and is planned for use on undersea weapons. This ability to rapidly insert improved capability in the form of software and hardware has become a hallmark of acquisition reform. Software and hardware solutions that are one-time developments are now implemented in many systems, including those in use on submarines, surface ships, undersea surveillance systems, and aircraft.

Conclusion

The AN/BQQ-10(V) A-RCI sonar system would not be the success it is today without its embrace of COTS hardware and software. The only way to economically take advantage of the advances in computer processing is to buy from the mainstream market. The less the hardware has to be modified to work in the system, the more rapidly and inexpensively it can be implemented. Moreover, COTS hardware brings with it COTS software. The contractor must learn to live within the limitations of the software and not try to make it incrementally better. Time spent in this manner is time not spent improving the more critical system application software. By picking COTS software that is well used and tested, the contractor can reduce problems observed, but also must accept the loss of total control over the code.

If COTS hardware is used, an ongoing technology insertion program is required to reduce obsolescence issues and maintain the system at its highest capability. A-RCI has successfully implemented five technology insertions and has an ongoing plan to continue with the process. Making the technology insertion process affordable is the MTM, which helps to isolate the complex application code from the underlying hardware and device drivers. A-RCI has shown that it is possible to reap the benefits of COTS computer hardware and software while still meeting all military requirements. It is now up to other DoD programs to make the same leap.

Final Points

Adopting a RCI process is not painless. Overcoming organizational bias, MIL-SPEC thinking, severe skepticism, and the not-invented-here syndromes were tremendous challenges for the A-RCI program to overcome in its early stages. It required an extraordinary culture shift for all stakeholders to achieve what today is almost taken for granted. The combined sense of urgency due to 1) the need to regain technological superiority, and 2) severe budget cuts drove the U.S. Navy's submarine force to the RCI solution. Without those kinds of drivers, no amount of hearing *this is a good idea* will result in other DoD programs adopting RCI processes. RCI is a business decision that requires dedicated believers to succeed and change the *status quo* of systems acquisition, and properly leverage the power and agility of the commercial, non-government business world.

Knowing that RCI may be the only efficient way to quickly regain technological superiority at a reduced cost does not mean that those who manage such programs should always sleep well at night. What have been discussed here are implementations in modern *sensor and* *combat systems*. These are systems that warfighters depend on when they are in harm's way to be 100 percent effective. It is this balance between efficiency in cost and effectiveness in war that should keep program managers awake at night with these questions:

- How can we be 100 percent assured that COTS products contain no latent defects that may have deadly consequences when they manifest themselves?
- What represents the necessary and sufficient testing and verification to preclude unacceptable consequences?
- How much do we really want to be dependent on a potentially fickle commercial market for critical systems in our military machines?
- What is the minimum acceptable cost/risk ratio for a critical technology?
- What is the necessary and sufficient amount of discipline required in the process so that capability is rapidly inserted, without undo risk, and without unduly constraining the process?

It is the description, quantification, understanding, and reconciliation of these issues and their risks that must become the main focus and challenge of the program manager's efforts in an RCI program. They certainly have become the focus for the submarine force's A-RCI program.◆

Note

1. VME is a standard developed in 1981 for embedded computer hardware form factor and data transfer protocol.

About the Authors

Capt. Gib Kerr is a mechanical/nuclear/acoustic engineer by training, a nuclear submariner by qualification, a combat systems program manager by assignment, and a systems acquisition professional by choice. He has done a little of everything, including traditional jobs onboard submarines, flag officer's staff, repaired and built submarines, and has been a fleet repair officer (repairing surface ships, submarines, and one helicopter). A consummate team player and trained facilitator, he has led, been a member of, and facilitated numerous Integrated Product Teams and Process Action Teams and facilitated several organizational reengineering and restructuring projects. Kerr's strength is in getting disparate organizations working together, assessing performance and value management to develop and implement sound technical and business solutions. He has been working Navy submarine acquisition programs for the past seven years.

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