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Boudreau, Michael

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Michael Boudreau
Senior Lecturer, Graduate School of Business & Public Policy
Naval Postgraduate School
Monterey, CA, USA
mboudreau @nps.edu

Abstract – *Acoustic Rapid COTS Insertion (A-RCI) is a success story in the use of Modular Open Systems Approach (MOSA)/Open Architecture (OA)—beginning with towed-array sonar on 688 Class Submarines and later encompassing all sonar systems on all attack submarines, some surface ship sonar applications and even aviation anti-submarine warfare. The DoD has long considered Open Systems Design a "best practice" that should be used during system development. However, as is often the case with best practices, the "lessons learned" have not been trumpeted widely across DoD acquisition organizations. The purpose of this A-RCI case study is to create a learning vehicle for the application of MOSA/OA which then could be used for the training and education of acquisition practitioners and future acquisition leaders.*

Keywords: Advanced Processing Builds (APB), Modular Open Systems Approach (MOSA), Open Architecture (OA), System Lifecycle Cost (LCC), Spiral Acquisition, Maintenance Free Operating Period (MFOP), Total Ownership Cost (TOC).

1 Background

In the mid-1990s, the submarine community recognized the impending loss of US technical superiority in submarine acoustics when foreign submarines began to exhibit major reduction in noise signature. This resulted in a critical need to improve acoustic sensing systems to better recognize foreign submarines. Although new capability was critically needed, required resources were not available to support the developmental effort. Critical need and the absence of sufficient funding constituted a crisis—demanding a revolutionary approach to achieve necessary technological improvement.

The approach came to be called A-RCI—Acoustic Rapid COTS Insertion. A-RCI took an integrated acoustic system that was difficult and time-consuming to change and converted it into a federated system that could be upgraded in modules—that is, "plug and play." Such an approach was common in the private sector in the 1990s and even before. Although the idea wasn't new, the application of this approach to an existing warfighting system was daunting. Even today, there are arguments within the DoD about whether federated systems are a sound approach for warfighting systems. Acoustic Rapid COTS Insertion progressed at a seemingly crushing pace, with software changes being implemented annually and hardware changes biannually. A-RCI was, therefore, a "poster child" for evolutionary acquisition. The results of A-RCI were astounding cost reduction, dramatic improvement in technical performance, successful use of COTS hardware in a critical warfighting application, logistics support improvements, and an acquisition model that might have broad application across the DoD.

2 Scope and Methodology

2.1 Expert Interviews

The scope of this research effort included two elements. The first was to interview key participants in A-RCI and to gain their perspectives on key contributors to the success of A-RCI. The second element included literature research related to acquisition processes and practices, modular open systems approach (MOSA)/open architecture (OA), and written documentation related to A-RCI.

2.2 Literature Research

Published information was used to document A-RCI outcomes, gain additional information on A-RCI/APB techniques and processes, and also to provide comparative background information. There is a body of mandatory and discretionary guidance published by the Office of the Secretary of Defense, the Chairman of the Joint Chiefs of Staff and by the DoD Components. Much of this material is on the AT&L Knowledge Sharing System website maintained by the Defense Acquisition University for the Under Secretary of Defense (AT&L). Defense acquisition policy and processes are addressed in the DoD 5000 series.

Other published materials include books, journals, periodicals, Government documents, reports, best practices, theses, studies, speeches and briefings. Much has been written on federated systems, A-RCI, MOSA, and spiral acquisition. The Defense Acquisition University has developed and compiled educational materials on spiral development and MOSA best practices and has placed significant information online. In addition to the DAU websites, there are other significant materials that are web accessible, including the Open Systems Joint Task Force website [1]. Finally, considerable associated work has been commissioned by the Program Manager, Naval Open Architecture, Program Executive Office for Integrated Warfare Systems (PEO IWS).

3 Data and Analysis

3.1 The Crisis

As mentioned earlier, during the mid-1990s, it became apparent that the US Navy had lost its acoustic superiority as other nations introduced "quieting" technologies into their submarines [2]. Improvement in the Navy's acoustic capability presented an immediate need, unsupported by necessary funding. Not only was there insufficient funding, there was not time: developmental programs for warfighting systems stretched over ten or more years. For submariners, this indeed was a *crisis.*

3.2 The Strategy—MOSA

Navy developers employed a new approach in response to their crisis. Their answer was a modular open systems approach. Federated systems were being developed and utilized widely in the private sector, but such an approach was not well understood for naval warfighting applications. The A-RCI case study is worth relating because of the creative approaches taken by the submarine community. The path that A-RCI took was multifaceted, and the approaches used are instructive for others considering MOSA. The effort was truly daunting and, in many ways, inspiring.

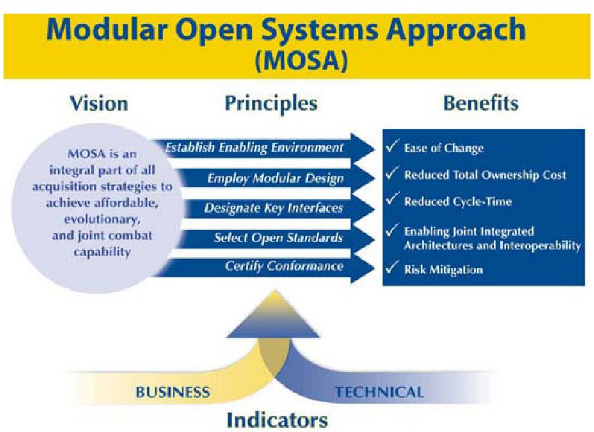

Figure 1. Modular Open Systems Approach (MOSA)

Legacy systems such as existing submarine sonar systems circa 1980 were not modular in their design. Therefore, the early A-RCI effort required modularizing the existing sonar systems. It was necessary, then, that the operational community accept operational limitations while the system was being modularized.

A-RCI's pursuance of modularity led to separation of hardware and software for purposes of system improvement. In this way, processors (the hardware) could be commercial-off-the-shelf (COTS) and could be upgraded in consonance with the evolving commercial market. The application software could be developed separately from the processors as long as the two would interoperate through use of transportable middleware. The transportable middleware provided freedom to run application software on different processors. All this was made possible through the control of key interfaces. Although this aspect might seem almost trivial, modular systems are very different from fully integrated systems wherein changes in software may have major unexpected consequences in functions that are seemingly unrelated to the change.

The A-RCI developmental process included a Build/Test/Build sequence. New system capabilities were compared to previous system capabilities. A-RCI was able to demonstrate system upgrades through the use of recorded operational events. In this way, competing systems could be tested and judged on their ability to process and display *real data* recorded during *actual* operational events.

3.3 MOSA Business Strategy

A-RCI evolutionary strategy was that software changes would be accomplished *annually* through a developmental effort called Advanced Processing Builds (APBs), while COTS processors (the hardware) would be selected *bi-annually*. This was a highly demanding acquisition "op tempo," progressing much more rapidly than usual Defense developmental work.

MOSA encouraged materiel developers to broaden communication links with users, contractors, and research labs in order to orchestrate both a competitive and collaborative effort. The competitive "playing field" had to be established to attract innovative contractors who might be new to DoD contracting or might be intimidated by large prime contractors.

Intellectual Property rights had to be respected, while at the same time, data and design information needed to be shared through mechanisms that were perceived as fair to competitors. Intellectual Property rights and the protection of proprietary data were addressed and controlled within the terms and conditions of the contract. Today, as a result of A-RCI and other MOSA efforts, there is helpful guidance that can be used in constructing such contracts.

The A-RCI experience illustrated that open code and the sharing of code enabled collaboration and enhanced the success of open systems design. Prevailing thinking was that intellectual property rights should be made available as part of the price of entering into the competition. In that way, code and design information could be shared with other participants to maximize progress [3].

3.4 Changing the Culture

In reaching out to small innovative contractors, large contractors, academic labs, and Government activities, it was necessary—in the case of A-RCI—to change the nature of the "prime contractor." The outcome was that the prime contractor was removed from the source selection process and became the "prime system integrator." The competing solutions were demonstrated using real-world sensor input, and the best solutions were selected through "peer review."

Peer review of new developments is recognized within the A-RCI/APB program as being one of the primary reasons for success. Oversight of peer review was uniquely challenging and, at least in the A-RCI/APB experience, required the PM be technically competent, proactive, and disciplined/structured.

The *peers* included fleet (users) representatives, algorithm developers, and evaluators. The program office, together with trusted advisors, selected persons with professional reputations for individual excellence, coupled with demonstrated ability to place Navy interests above organizational agendas. An illustrative peer group arrangement is depicted in Figure 2 below.

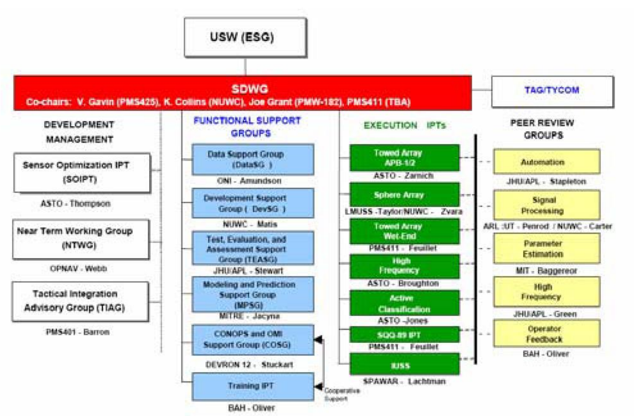

Figure 2. Sonar Development Working Group

3.5 Systems Engineering

In the case of A-RCI/APB, a Systems Engineering Process (SEP) and structure were needed for guiding and synchronizing the work of the various players, accommodating a complex testing regimen, carefully controlling key interfaces, and incorporating standards to enable interoperability of hardware and software. During development, software took shape under the direction of the NAVSEA's Advanced Systems Technology Office (ASTO). Software development was accomplished by small innovative contractors, academic research labs, and Government labs participating competitively and collaboratively. But these entities were not, as yet, organized under a prime contractor. Later in the process, software development was consolidated under the direction of a software APB integrator. Following a cycle of Build/Test/Build, hardware and software systems and components were handed-off to the prime system integrator for assembly of the upgrade package and installation onto submarines. All of this occurred at a rapid op tempo. As may be envisioned, no single contractor was perfectly positioned to accomplish SEP from beginning-to-end—as a prime contractor would have done in a traditional development. Beyond the question of who should be responsible for the Systems Engineering Process, end-to-end, over the entire developmental cycle, spiral development required repetitive developmental cycles—further complicating management of the SEP.

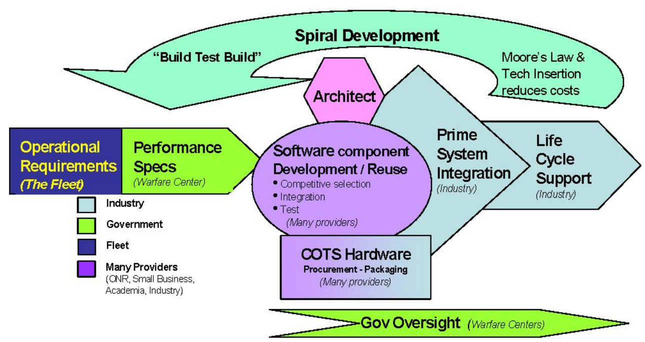

Figure 3. System Development Model [4]

For future programs, SEP responsibility might reside with the Government materiel developer (or be separately contracted) during testing and peer review—before being handed off to a prime system integrator. Needless to say, SEP management is potentially a serious risk area.

3.6 User Participation

Stakeholder involvement and buy-in were major contributors to focusing and speeding the A-RCI/APB processes [5]. The Submarine Tactical Requirements Group (STRG) set A-RCI/APB requirements that initiated each spiral. Beyond that, user groups provided feedback in such areas as ease of operation, suitability of configuration, required training, and supportability, for example. Users, of course, were heavily involved in at-sea testing and during submarine retrofit periods; this undoubtedly placed additional workloads on submarine crews as they had to determine system upgrade time, training time, and operator feedback. Yet, in this way, A-RCI user participants served as a communication link between developers and fleet users. The ensuing dialogue contributed substantially to sailor acceptance of A-RCI/APB in the fleet.

3.7 Communication Forums

Participation in essential dialogue involved many different forums and extended through each developmental sequence and into the next. The importance of dialogue between users, materiel developers, and contractors cannot be overemphasized.

3.8 Summary

In summary, several facets combined to make the A-RCI culture change revolutionary within the DoD. Changing the nature of the prime contractor to a prime system integrator, gaining the participation of non-traditional technical participants, the peer review process which leveled the competitive playing field, the op tempo of the spirals, the intimate user participation, and the intricate communications structure all profoundly facilitated the success of A-RCI/APB. In the aggregate, this effort took heroic commitment by many different parties who historically were not "friendly" or cooperative. How could this cultural change be catalyzed? Part of the answer lay in process and contractual mechanisms. Part also resulted from leadership, which is discussed below.

4 Leadership

Strong leadership is essential to proactive change. Several of the A-RCI leadership aspects are as described below.

Mandate. Senior leaders provided pressure to change. Without this "forcing function," it would have been difficult for mid-level leaders/managers to achieve major change. There were undoubtedly elements of positive and negative motivation; participants both wanted to effect change and also had the sense that if they could not get the job done, they would be replaced. The "mandate" has to be balanced—in the case of A-RCI, senior leaders upheld such balance extraordinarily well, judging by the outcome.

Mid-level Leadership. The A-RCI appeared to have excellent leaders in various positions, who accepted the challenge and effected change.

In the aggregate, A-RCI worked because stakeholders, "formed a community that learned to be comfortable with change—not just technical things or even business processes" [5]. This was a reflection of a new leadership vision that was widely embraced by A-RCI participants.

5 Measurable Effects

Technical Performance. Within 18 months, A-RCI had provided a 7-fold increase in processing capability.

Reduced Lifecycle Cost. The Navy is currently validating a historical cost comparison of A-RCI and its predecessor system. Preliminary results compiled from 10 years of data indicate that lifecycle cost has improved by nearly 5:1. This comparison includes development, production, and maintenance costs of A-RCI and its predecessor.

Cost Avoidance. A-RCI provided many examples of cost savings/cost avoidance.

Processing Cost. Processing cost was reduced by a factor of 60—that is, 1/60 the cost of the specially developed processors used previously [6].

Cost of Obsolescence. Although not quantified, there were two aspects to ARCI's obsolescence costs. First was the use of upgrades to avoid paying the high cost required to provide outdated, scarce components. Second was harvesting obsolete components that had been removed from upgraded systems to support older systems in the fleet that had not yet transitioned through upgrade.

Cost of Post-deployment Software Support (PDSS). Once modularized, post-deployment software support was less expensive. That is, software changes made to modular components were less complex (therefore, less expensive) than changes made to fully integrated systems. The reason was that the changes must be carefully controlled at key interfaces, but there was less work required to deal with unexpected secondary effects.

5.1 Logistics Impact

A-RCI has demonstrated that system upgrades can include logistics focus. The program's impacts on logistics were generally very positive.

For example, one A-RCI initiative (and a profound example of logistics focus) that was unforeseen at the outset was the creative employment of spare components in a way that reduced the need for "open cabinet" repairs to sonar systems while on deployment. Maintenance-Free Operating Period (MFOP) became feasible because commercial processors fit into less space than their developmental predecessors. It was found that sonar system spare components could be installed and fully powered within electronics cabinets, enabling them to be immediately available in the event of a primary system malfunction.

Additionally, as previously explained, modularization impacts Lifecycle Cost (LCC) through less expensive replacement of obsolete hardware and software. Likewise, PDSS is simplified because software is re-used where possible. A-RCI also has illustrated that much of the necessary maintenance can be shifted to contractor logistics support (CLS); further, demonstration has shown that some software defects can be addressed remotely by CLS.

Yet another logistical aspect has been highlighted by this research: the A-RCI experience has shown that the character of sonar training has changed. It has been refocused to address performance weaknesses. Some maintenance training has been reduced or eliminated as the result of MFOP, providing the potential for increased employment training. Upgraded training packages still are necessary, of course, to achieve full benefit of the system modifications [7].

Sometimes offered as a criticism of A-RCI is the fact that operators and maintenance technicians needed frequent updates and, possibly, needed to be familiar with multiple generations of sonar systems. However, as cumbersome as this seems, it may have been no more difficult than in the past. Nevertheless, there seems little question that the rapid op tempo of A-RCI evolutions did present training challenges for operators and maintainers.

5.2 Other Ramifications

Portability and Software Re-use. The portability of modular software to other systems and other platforms offers additional opportunity for cost savings or cost avoidance.

Scalability. One of the questions resulting from A-RCI is whether the modular open systems approach is applicable in larger, more complicated applications.

Implementation. Though there isn't room to completely explore current and future implementation in this discussion, two warfighting systems, Virginia Class Submarine Non-propulsion Electronic Systems (NPES) and E-2 Hawkeye Electronic Surveillance Aircraft have successfully implemented MOSA. Two of DoD's most challenging warfighting systems, the Army's Future Combat Systems (FCS) and National Missile Defense, seem to be good candidates for MOSA.

5.3 Treatment of Obsolescence

From a logistics perspective, one of the major benefits of open systems is the freedom to exercise the "plug and play" feature at such time as a module becomes obsolete and is no longer able to be supported. Plug and Play replacement is useful because all of our warfighting systems experience sustainment issues as soon as production has been completed. A- RCI/APB is now seen as an example of the flexibility to act proactively. In the future, that same flexibility may be useful in response to component obsolescence.

5.4 Comparison of Legacy vs. New Systems

Legacy warfighting systems that have converted to MOSA are in better competitive position for upgrade funding than those unable to become modularized.

5.5 Financial Management

A-RCI funding streams have changed from the widely recognized pattern of RDT&E, followed by Production, followed by Operations & Support. As spiral development continues, there is need for continued RDT&E funding, albeit at a reduced level, in order to take advantage of MOSA.

5.6 Summary

Acoustic Rapid COTS Insertion/Advanced Processing Build (A-RCI/APB) shows the promise of a modular open systems approach (MOSA). A-RCI was a leader, finding its way when few rules and guidelines were available. Today, there is a body of information showing the benefits of A-RCI. Rules and guidelines have emerged to help guide other programs through MOSA; many of those guidelines are the result of the A-RCI experience. Other programs' successes, such as Virginia Class Non-Propulsion Electronic systems (NPES) and E-2 Hawkeye aircraft upgrade, suggest that A-RCI was not simply a one-time success. In the aggregate, these several successful programs are an indication that other acquisition programs might use MOSA with similar benefits. The A-RCI experience indicates that some Acquisition processes need to be retooled to interface with and reap the advantages of rapid spiral development.

6 Conclusions

6.1 A-RCI/APB has successfully applied MOSA, deriving major performance and logistics improvements.

The A-RCI program drastically changed its technical and business practices—embracing business and technical principles and disciplined processes that currently comprise the Modular Open Systems Approach. The results were a series of substantial technical improvements, reduced cycle-times, transition to COTS processors, and software sharing across weapon platforms.

6.2 A-RCI demonstrated significant Total Ownership Cost or system Lifecycle Cost benefits.

The Navy is currently validating a historical cost comparison of A-RCI and its predecessor system. Preliminary results compiled from 10 years of data on both A-RCI and its predecessor indicate that lifecycle cost has improved by nearly 5:1.

6.3 The A-RCI/APB example shows that MOSA can be applied to a legacy system.

A-RCI/APB was modularized by first separating software from hardware. The integrated software was further modularized into functionally partitioned software modules and transportable middleware. MOSA includes feasibility assessment of open-system solutions—an essential business and technical consideration when starting with a fully integrated legacy solution.

6.4 A-RCI/APB demonstrates that modular upgrades can be accomplished very rapidly through spiral development, in contrast to traditional systems development.

A-RCI/APB was able to produce an Advanced Processing Build annually and upgrade COTS processing hardware every two years. Implementations in the submarine fleets resulted in each submarine obtaining upgraded software at about two-year intervals and new COTS processors at approximately four-year intervals.

6.5 Funding implications of A-RCI need to be studied and understood.

Traditional funding profiles do not support the A-RCI example. Traditional funding entails three overlapping funding profiles of increasing size: RDT&E, Procurement, and the O&S accounts (primarily O&M and military personnel). Annual increments of spiral development require continuous streams of RDT&E, Procurement, and the O&S accounts—smaller, more flat annual amounts, continuously, as long as the annual spirals continue.

This is an abbreviated version of the complete research report. The complete research report may be accessed from the Acquisition Research Program website www.acquisitionresearch.org.

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