A Product Line Approach to Weapon Systems Acquisition

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Introduction

Ever since Henry Ford established the first production line for automobiles, we've been sold on the value of production lines. Confidence that each part will fit correctly, work properly and perform reliably has been the cornerstone to Ford's efficient manufacturing process. Once a process has been validated in which a product can be built repeatedly identical, then product variations may be created – variations that may meet the varying needs and tastes of the consumer. The most usual form of variation being a part substitution that provides a functional or visual change that complies to a pre-established interface. Companies that know the needs of their customers will produce product lines. The production line has been used virtually in every mass production industry since.

Both commercial industry and the military have recognized the need for standards to assure quality and performance. And for the past half-century, two independent standards bodies have been defining the quality and performance thresholds of products for the commercial and military sectors. But for the past ten to fifteen years we've been witnessing a convergence of these two market places. The military has been investing heavily in technologies to apply as *force multipliers*. Technologies such as communication electronics, satellite-based navigation, new and advanced data processing, and sophisticated data fusion techniques are being integrated into command and control weapon systems. But what is fascinating is the source of much of these technologies – is the commercial sector. Commercial industry is producing increasingly more products with military application then ever. The Department of Defense (DOD) is rarely the market leader. And technology is advancing at unprecedented rates.

Beneath the production line concept lie standards. These standards establish specific interface standards as opposed to process standards that tell contractors "how to" build component form, fit and function. Standards are accepted by industries that wish to participate in that market. Companies producing commercial products usually comply with standards by professional associations such as: *ANSI*, *ISO*, *UL*, *SAE*, and *IEEE*.[1] In the past, companies that supplied military products had to comply with military standards. These two market places evolved separately. It was not practical to adopt commercial quality for military products because of the severity of the military environments. Military standards were spawned to meet their peculiar needs. Commercial standards allow us to develop systems that can be supported by a wide range of readily available products. They allow us to develop subsystems and components that are testable. They allow us to check for conformance. They give us economies that were previously unrealizable as well as higher levels of performance. And they enable us to support legacy systems and internationalization. Our involvement in establishing standards and specifications has been an important investment

[1] ANSI; American National Standards Institute: ISO; International Organization for Standards: UL; Underwriters Laboratory: SAE; Society of Automotive Engineers: and IEEE; Institute for Electrical and Electronics Engineers, Inc.

that we can leverage today. And one way to leverage that investment is to implement acquisition solutions that are based on the best ideas and practices from our experience in this process. A Product Line Approach to weapon systems acquisition is one idea, and this approach is gaining favor every day.

This paper focuses on the Product Line Approach and the key features of this approach. We emphasize **open systems** and Architectures and the development environment to support the approach. We discuss examples where this approach has produced outstanding results, and we summarize findings that should encourage senior executives and program managers to embrace the approach.

Product Line Approach

A Product Line Approach is a simple concept that is firmly grounded in industrial engineering and manufacturing. It encompasses the idea of the assembly line, where basic platforms or frameworks are fitted with subsystems or components to form a larger system to deliver a specified capability. The subsystems and components are designed to specified levels of openness and feature modularity and the interchangeability of parts. Some subsystems or components may be common to a variety of weapon platforms and identically interface with each platform.

Linda Northrop, who is the Manager of the Product Line Systems Program at Software Engineering Institute, defined a Product Line as, "a group of products sharing a common, managed set of features that satisfy specific needs of a selected market."[2] Product lines take advantage of commonality. Consumers would certainly enjoy the cost benefits associated with common parts. Designers, however, should not feel compelled to use common parts (more on this later). Another quality of product lines is controlled product variability. Well-defined manufacturing processes usually employ quality ensuring techniques such as Statistical Process Control that quickly identify process variances that define product quality and, thus, bound product variability.

A Product Line Approach also incorporates an open system strategy, along the lines of the strategy defined in DOD 5000.2-R. "…An open system strategy focuses on fielding superior warfighting capability more quickly and affordably by using multiple suppliers and commercially supported practices, products, specifications, and standards [that are] selected based on performance, cost, industry acceptance, long term availability and supportability, and upgrade potential."[3] This definition emphasizes the need to choose widely accepted standards for system interfaces and encourages system developers to leverage commercial technology wherever possible. An **open systems** approach incorporates this notion and argues for engineering decisions that are driven by business considerations, modular design of hardware and software, and buying rather than developing system components.

Secretary of Defense, Dr. William J. Perry, was among the first to advocate an **open systems** approach, and he mandated the greater use of performance and commercial specifications in 1994. In November of 1994, the USD (A&T) issued a directive to use **open systems** for the acquisition of weapon systems electronics. On March 15, 1996, DoD 5000.2-R expanded that directive to include **open systems** for all system elements. And on March 23, 1998, the Defense Science Board's Summer Study of the "Open Systems Joint Task Force" concluded that an "Open System Process is an essential Warfighting and Title 10 Core Value." There's a lot of policy emphasis on the idea of **open**

[2] *Architecture-Based Systems*, Linda M. Northrop, Manager, Product Line Systems Program, Carnegie Mellon University, Software Engineering Institute

[3] See DOD 5000.2R, Dated 23 March 1998.

systems, and the Open Systems Joint Task Force (OS-JTF) is specifically chartered to champion an **open systems** approach as the preferred technical approach and business strategy for acquiring all weapon systems.

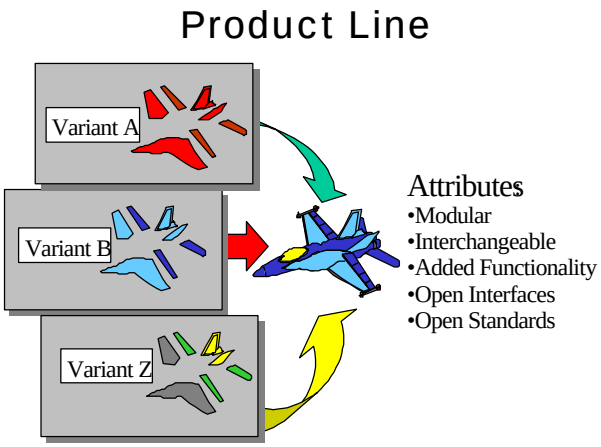

Figure 1. Product Line

Figure 1 illustrates the essence of the Product Line Approach. The idea is to design and manufacture a system with subsystems and components to meet unique customer requirements. And a single production line can accommodate the building of multiple configurations to meet those requirements. An excellent example of the Product Line concept at work is manifested in the Joint Strike Fighter (JSF), where the British, U.S. Air Force and the U.S. Marine Corps advocate variants for their unique needs, and the engineering impacts of those differences are integrated at the production line. The major attributes of this idea are modularity, interchangeability, added functionality, open interfaces, and open standards. The basic platform for each variant is the same.

A Product Line Approach offers many benefits. A major benefit is the opportunity to modernize a system with minimal integration and verification effort. The concept is that many technological advances occurring in the commercial sector will capitalize only by introducing products the consumer will buy. Provided these products comply with commercial interface standards they should, therefore, comply with military systems that employ those same commercial standards. Thereby negating the outlay for further research and development. The scheme to implement new technologies may be done by a "modernization through spares" process in which new and improved components are procured and distributed for installation in the field. This is easy, testing could be limited to installation checkout, and operational availability would hardly be affected. Operational availability would likely be enhanced. We need the ability to quickly integrate new technologies to improve performance, to decrease risk, and to reduce costs.

A case for product lines can be made by examining the Navy's AYK-14[4] and the CDNU[5] programs. These two programs have put naval aviation in an excellent position to pursue common hardware solutions due to their similar size, cooling and interface requirements. Cost of ownership is reduced due to shared development costs, increased procurement quantities (economies of scale), reduced support infrastructure and common paths for modernization. But the case for commonality is not new. The use of **open systems** architectures has given us the ability to meet the requirements of many users in a common approach with less effort then in the past. The navy is in an excellent position to pursue common hardware solutions because of past efforts like AYK –14, yet the navy has the flexibility to use other implementations in their design solutions because they standardized on the interface, not the piece part.

[4] AYK-14 is the Navy standard airborne computer
[5] CDNU is Control Display Navigation Unit. For additional information visit http://www.sarda.army.mil/SARD-ASB/Acronyms.htm#C

A Product Line Approach also facilitates the smooth transition to a "Plug and Play/Fight" environment in the field at the platform system level.

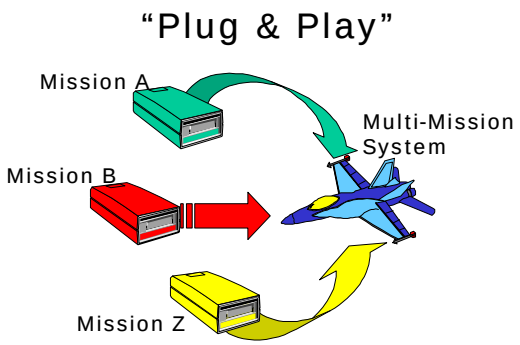

Figure 2. Plug and Play

Figure 2 illustrates the Plug & Play/Fight Concept. The major elements of this idea are Modular Design, Operational Tempo, Deployment, Cost of Ownership, Support, and Training.

Modular design makes it easy to quickly change modules and parts on location. And we can do this at dramatically reduced costs. We simply take out a component that has failed and replace it with a new one in the field. A Modular Design also provides greater mission flexibility and all that that implies. A major benefit here is that a modular design enables us to field fewer systems, and fewer systems mean reduced manpower, reduced logistics footprint, reduced deployment and related issues. Fewer systems also mean lower costs of ownership and decreased support and training costs.

Operational tempo is also enhanced when there are fewer platforms in the area of operations. For example, with fewer systems on the flight ramp, we can rearm, refuel, and reconfigure for missions more efficiently and more effectively. And we can fly more sorties because of shorter turnaround times, increasing our combat effectiveness.

The potential advantages for deployment are enormous. Consider for a moment that we might be able to field one weapon system with the capacity to quickly reconfigure to service various other missions. If we do this, we can reduce the number of systems to deploy to the theatre to achieve the required operational capability. Conceivably, a single platform and several subsystems could replace many single or limited-mission platforms.

An excellent example is the Army's PM Signals Warfare. In the-1970 – 1980 timeframe, combinations of six separate and unique systems conducted the Army's intelligence and electronic warfare capabilities. Six outdated programs QUICKFIX (AN/ALQ-151), TACJAM (AN/MLQ-34), TRAFFICJAM (AN/TLQ-17A), TEAMPACK (AN/TRQ-103), TEAMMATE (AN/TRQ-32) and TRAILBLAZER (AN/TSQ-114) were combined into a single program known as IEWCS[6] in which common modules could be deployed from four different platforms. Each module featured interfaces common to the four platforms that could easily plug in and deploy to execute their respective missions. Estimates for life cycle costs savings were projected at nearly $845 million[7]. **Authors note: there may be a misperception that the Army restructured the IEWCS program due to fallacies of the acquisition strategy or some shortcoming of the open systems approach. The approach used by the acquisition team is still considered correct and the open systems approach and findings are valid.**

There is another twist on this notion. And this is the idea of product affinity, where a single component is used in a range of platforms. And if each platform has identical interfaces for the component, it can be used across a range of

[6] IEWCS – Intelligence and Electronic Warfare Common Sensor

[7] Open Systems Joint Task Force Case Study of the U.S. Army's Intelligence and Electronic Warfare Common Sensor (IEWCS), 15 November 1996, pages 31-35

systems. Figure 3 illustrates this idea. The benefits of product affinity include economy of scale, logistics, training, paying for recurring engineering only once, and modernization through spares.

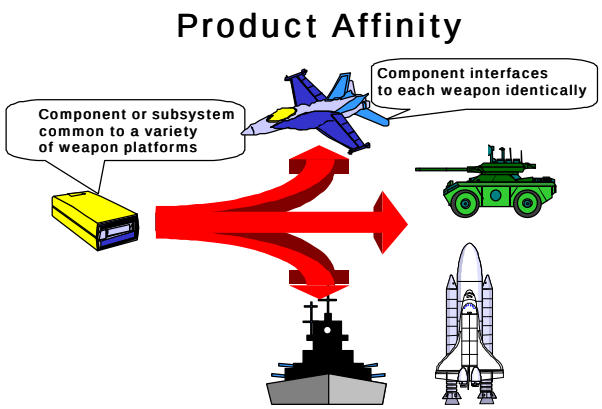

Figure 3. Product Affinity

A Plug and Play/Fight concept brings obvious advantages such as reduced cost of ownership, improved supply support, and less-sophisticated maintenance training. The Research and Development (R&D) costs are likely to be greater, because of requirement to invest more resources in the product line. But we should realize large savings in O&S costs over time.

Another benefit of the Product Line Approach is "Reuse." This term is familiar to many of us who have worked in system and software development. The idea is to reuse modules again and again. Figure 3 illustrates the idea behind **Bold Stroke** an initiative in the Boeing Corporation to extend the advantages of the Open Systems Core Avionics Replacement (OSCAR) program to a fleet of aircraft – the F/A-18E/F, the F/A-18C/D and the F-15E. The objective of the OSCAR program is to modernize the AV-8B (Harrier) aircraft to make it more operationally viable through the year 2023.

The reason the Harrier is being modernized is because of delays to the Joint Strike Fighter (JSF). The Harrier was not expected to remain in force inventory was because the JSF would eventually serve in its stead. But as JSF

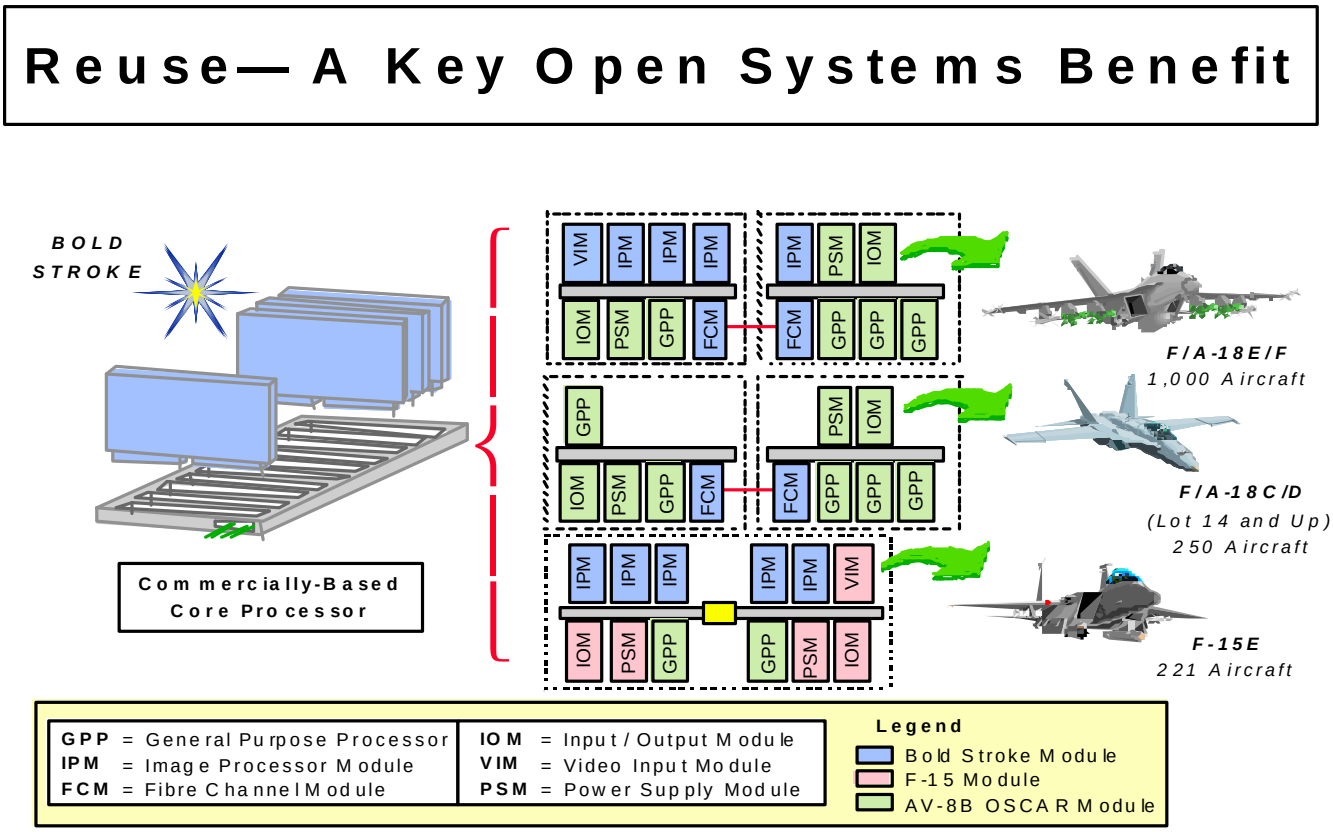

Figure 4. Reuse - A Key Open Systems Benefit

program delays mounted up, force planners had to acknowledge that the Harrier would not only have to be supported through the duration, but also modernized. New tactical weapons, such as JDAM[8] and AMRAAM[9] are entering the inventory. Satellite-based navigation equipment is replacing land-based stations. Newer, more secure communication is beginning to replace older analog radios. To accommodate new weaponry, and avionics, many core changes to the Harrier were required affecting the equipment right down to the backplane.

Boeing is a major producer of tactical aircraft. The circumstances leading to the Harrier's modernization could be reasonably anticipated for other aircraft. Boeing management initiated a program embracing product-line approaches and **open systems** principles they called **Bold Stroke**. The idea was to extend OSCAR experiences into their family of aircraft. Boeing wanted to provide "hooks" for affordable modernization.

Referring to figure 4, "Reuse – A Key Open Systems Concept", many of the modules developed for OSCAR (stores management and mission computer processors and input/output devices) were directly applicable to the F/A –18 C/D and E/F models and the F-15E. Without further non-recurring engineering investment these modules were integrated into each of the other tactical aircraft. At Boeing's own expense, they developed modules (image processors, fiber channel modules and video modules) that were compatible with the avionics systems for each aircraft.

[8] JDAM is Joint Direct Attack Munition. For more information refer to Boeing's website: http://www.boeing.com/defense-space/missiles/jdam/jdam.htm

[9] AMRAAM is Advance Medium Range Air-to-Air Missile. For more information refer to Air Force website: http://www.af.mil/news/factsheets/AIM_120_AMRAAM.html

The central idea in **Bold Stroke** is to use a commercial-based components and standard interfaces that can be common across platforms and provide capability to accommodate "Plug and Play" components.

Figure 5. Managing Technologies

So how do we apply a product line approach? We start in the requirements phase of a weapon system acquisition, when there are adequate opportunities to determine if commercial components can satisfy our needs. Figure 5: Managing Technologies, suggests four things to consider. After we know our basic requirements, we should first do market research to identify technologies that are going to have staying power and/or the capacity to be modularized in the design. Second, we need to look at the technology trends. What is the future of the technology? What are the attributes of the product line? Will technological obsolescence be an issue? Where do we establish the baseline? What are the technological risks? Are there vendor monopolies? What is the competition? How can we leverage that? And the list goes on.

The results of market research should be information to assist program managers and their acquisition teams make informed decisions on the systems architecture. Projections on evolving technologies and how those technologies affect subsystem availability, reliability, maintainability and cost should all be factored into acquisition and support strategies.

These projections are not only relevant to system components, but also to interfaces and the commercial standards that may be used to define system interfaces. Design managers must be equally concerned with matters affecting the longevity of interface standards for they evolve with technology trends like products.

Finally, we need to think about system planning. When is the system going to production? And how does the schedule correlate with the technology trends? We don't want to baseline on old technology; we should baseline on a product line.

Moving to a Modular Open Architecture

An **open systems** architecture is the key to leveraging the marketplace for affordable modernization. And we can create "openness" by selecting interfaces that are based on non-proprietary, consensus-based standards. A systems architecture provides a high-level view of the weapons system and gives us some idea as to where we might use these interfaces and their standards. This view helps acquisition officials identify opportunities for commonality, horizontal technology integration, new technology insertion, and multiple sources of supply. And by taking advantage of these opportunities, PEOs and program managers can field superior weapons systems faster and at a lower cost of ownership.

But the degree to which PEOs and program managers can realize the benefits of an **open systems** approach depends on how widely the standards are supported in the market place and how widely they are used in the systems community. That is, if we apply similar standards across a large number of weapon platforms or across several different weapon system domains like avionics or ground vehicles, we will likely achieve more benefits (e.g., increased commonality, reuse) than if we apply the standards to a particular weapon system.

The application of the **open systems** approach to legacy systems is beneficial as well. But the benefits are less obvious. Legacy systems usually have size, space, power, cooling and shape factor constraints. And for these systems, the open system solution can provide form-fit-function interface (F3I) solutions within the existing packaging, power, and environmental constraints. In such cases, the **open systems** solution frequently requires less system resources by using newer, more efficient technologies. The open system approach is similar to F3I except that the **open systems** approach emphasizes choosing interfaces that are broadly accepted in the marketplace to allow for as many suppliers as possible over the long term.

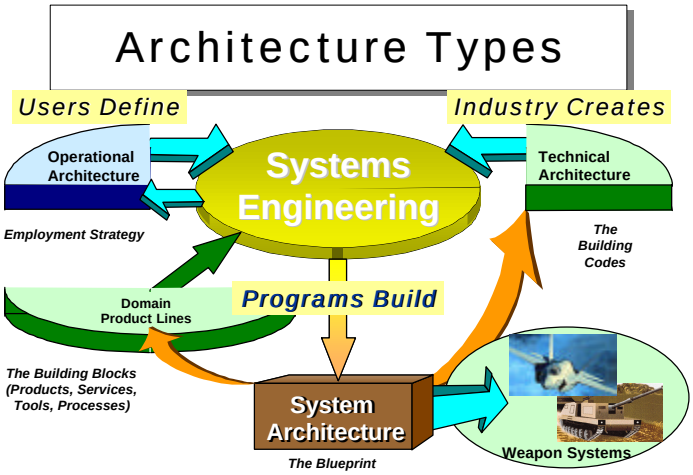

Figure 6. Architecture Types

Acquisition managers have to deal with three types of architectures (see figure 6.). The first is the operational architecture. The operational architecture is the environment in which the system must operate. It defines the rules for interoperability. It is a systems engineering process input. The next is the systems architecture. The systems architecture is the physical arrangement of subsystems and components that defines the system. The third is

the technical architecture. It is the rules associated to the domain of the systems

Operational Architecture

The operational architecture specifies the user requirements that are inputs to the systems engineering process used to build the system. This architecture describes the "operational elements, assigned tasks, and information flows, required to support the warfighter. It defines the type of information, the frequency and timeliness of the exchange, and what tasks are supported by these information exchanges."[10]

Technical Architecture[building codes]

The technical architecture sets forth rules that constrain the design of the system during the systems engineering process. These rules govern the arrangement, interaction, and interdependence of the parts that make up a conformant system, one that satisfies a set of requirements. It defines services, interfaces, standards and relationships. The Technical Architecture is the framework for engineering specifications and is based on Operational Architecture Requirements.

Commonality

Does the product line approach cause or force commonality? The product line approach may cause commonality, but it certainly does not force it. Acquisition teams may either accept or reject commonality in their product lines, but are not consigned to the notion of commonality.

The concept of **open systems** promotes design flexibility to permit alternative implementations and opportunities for affordable modernization. Commonality, by its very nature limits design options, causing sub-optimization, in other words, performance inefficiencies, maintenance limitations and cost burdens.

Findings/Summary

Our experience to date shows outstanding results for those who have adopted a product line approach to acquisition. And our findings are shown on this slide.

- **Improved Return on Investment**

A product line approach, which applies basic principles of the **open systems** approach promises huge returns on investment. We made reference to the Army's IEWCS program in which cost avoidance was projected at about $845 million. The IEWCS program was restructured for reasons not related to their acquisition strategy, but their results validated **open systems** and the product line approach. This program clearly illustrated the potential of an **open systems** development to provide opportunities for affordable technology insertion across application domains and services.

- **Decreased Deployment Burden**

We have already discussed some advantages for deployment. The sheer volume of equipment required to support military operations in remote areas is staggering. Initial supplies delivered by airlift will typically require 72 hours. The bulk of the remaining equipment and support will arrive via surface transportation, which typically requires 14 days. Transportation Command officials estimated the DESERT STORM deployment was equivalent to moving the city of Memphis. Product line concepts in which single-mission equipment could be replaced by multi-mission equipment would certainly have a profound effect on mobility and force projection.

- **Improved Operational Tempo**

[10] Ibid.

Implications of product line approach to operational tempos are mission sortie turnaround times. Multi-mission systems developed to these product line concepts would have the capacity to rapidly reconfigure on the flight-line to execute their next mission in roughly the amount time it would take to refuel, and rearm.

- **Reduced Support**

As industry standards replace military standards in defense equipment, there will be increased availability of commercial components. Spare parts will be available, possibly, through multiple vendors and more locations. Many of these spare parts may be interchangeable with components used in other military systems, which is attractive to both the customer and the supplier. This interchangeability (not necessarily commonality) will also increase the amount of familiarity to technicians. The more familiar the spare parts are to the technician, the less sophisticated the maintenance training required, which is huge advantage.

- **Access to Technology**

Incorporating industry standard interfaces provides affordable access to commercial technology. With modest qualification testing to verify performance, commercial technologies may be easily incorporated.

- **Improved Performance**

State-of-the-art system performance is readily accessible to systems employing standard interfaces. Closed systems, in contrast, will languish in obsolescence as pertinent technologies go unrealized. To tap this source of technology, system developers have to create these “hooks” for technology.