Product Line Approach to Weapon Systems Acquisition

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This paper focuses on the product line approach and its key features. 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 summarize findings that should encourage senior executives and program managers to embrace this approach.

Ever since Ford established the first automobile production line, America has been sold on its value. The cornerstone of Ford's efficient manufacturing process has been confidence in each part to fit correctly, work properly, and perform reliably. Once a repeatedly identical process has been validated, product variations may be created that may meet differing consumer needs and tastes. The most usual variations are substitutions that provide a functional or visual change to comply with a pre-established interface. Companies that know their customers' needs will produce such product lines. Thus, the production line has been used virtually in every mass production industry.

Both commercial industry and the military have recognized the need for standards to assure quality and performance. 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 10 to 15 years we have been witnessing a convergence of these two marketplaces.

The military has been investing heavily in *force multiplier* technologies, including communication electronics, satellite-based navigation, new and advanced data processing, and sophisticated data fusion techniques that are being integrated into command and control weapon systems. What is fascinating is that 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.

Accepted Standards

Beneath the production line concept lie standards. These 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 desire to participate in that market.

Companies producing commercial products usually comply with standards by professional associations such as the American National Standards Institute, International Organization for Standards, Underwriters Laboratory, Society of Automotive Engineers, and Institute for Electrical and Electronics Engineers.

In the past, companies that supplied military products had to comply with military standards. These two marketplaces 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. Finally, they enable us to support legacy systems and internationalization.

Our involvement in establishing standards and specifications has been an important investment that we can leverage today. 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 that is gaining favor every day.

Product Line Approach

A product line approach is a simple concept that is firmly grounded in industrial engineering and manufacturing. It encompasses the assembly line idea, 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 interchangeable parts. Some subsystems or components may be common to a variety of weapon platforms and identically interface with each platform.

Linda Northrop, manager of the Product Line Systems Program at the 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." [1] 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 to 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 by the DoD: "… 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." [2]

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 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, mandating greater use of performance and commercial specifications in 1994. In November of 1994, the Undersecretary of Defense (Acquisition and Technology) 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. On March 23, 1998, the Defense Science Board's summer study of the Open Systems Joint Task Force (OS-JTF) concluded that an "open system process is an essential warfighting and Title 10 core value." There is a lot of policy emphasis on the idea of open systems, and the OS-JTF is specifically chartered to champion an open systems approach as the preferred technical approach and business strategy for acquiring all weapon systems.

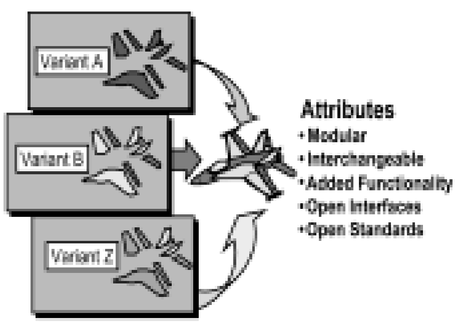


Figure 1. *Product Line*

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. 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 U.K., U.S. Air Force, and U.S. Marines 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.

Benefits Abound

A major plus is the opportunity to modernize a system with minimal integration and verification effort. 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 also 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 easy installation in the field. Testing could be limited to installation checkout. Operational availability would hardly be affected, and would more likely be enhanced. We need the ability to quickly integrate new technologies to improve performance, decrease risk, and reduce costs.

A case for product lines can be made by examining the Navy's AYK-14 standard airborne computer, and the Control Display Navigation Unit 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 poised 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.

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 illustrates the plug-and-play/fight concept. The major elements of this idea are modular

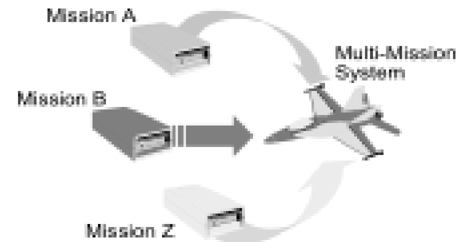


Figure 2. *Plug and Play*

design, operational tempo, deployment, cost of ownership, support, and training.

Modular design makes it easy to quickly change modules and parts on location at dramatically reduced costs. Simply remove a component that has failed, and replace it with a new one in the field. Modular design also provides greater mission flexibility and all it implies. A major benefit is that a modular design enables fielding 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 operations area. For example, with fewer systems on the flight ramp, operators can rearm, refuel, and reconfigure for missions more efficiently and more effectively. Operators can also fly more sorties because of shorter turnaround times, increasing combat effectiveness.

Potential advantages for deployment are enormous. For example, we might be able to field one weapon system with the capacity to quickly reconfigure to service various other missions. If so, we can reduce the number of systems deployed to the theatre to achieve 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 Project Manager Signals Warfare. Between 1970 and 1980, combinations of six separate, unique systems comprised 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 Intelligence and Electronic Warfare Common Sensor, in which common modules could be deployed from four different platforms.

Each module featured interfaces common to the four platforms that could easily plug and deploy to execute their respective missions. Life cycle cost savings were estimated at nearly $845 million. [3][1]

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

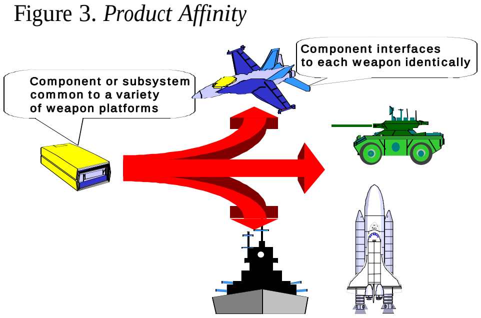
Benefits Continue Over Time

A plug-and-play/fight concept brings obvious advantages such as reduced cost of ownership, improved supply support, and less complicated maintenance training. While research and development costs are likely greater due to investing more resources in the product line, large savings in operations and support costs should be realized over time.

Another benefit of the product line approach is reuse. The idea is to reuse modules again and again. Figure 4 illustrates the idea behind Bold Stroke, an initiative in the Boeing Corporation to extend 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 OSCAR program objective is to modernize the AV-8B (Harrier) aircraft to make it more operationally viable through the year 2023.

The Harrier is being modernized because of delays to the JSF. The Harrier was not expected to remain in force inventory because the JSF would eventually serve in its stead. But as JSF program delays mounted, force planners acknowl-

Figure 3. *Product Affinity*



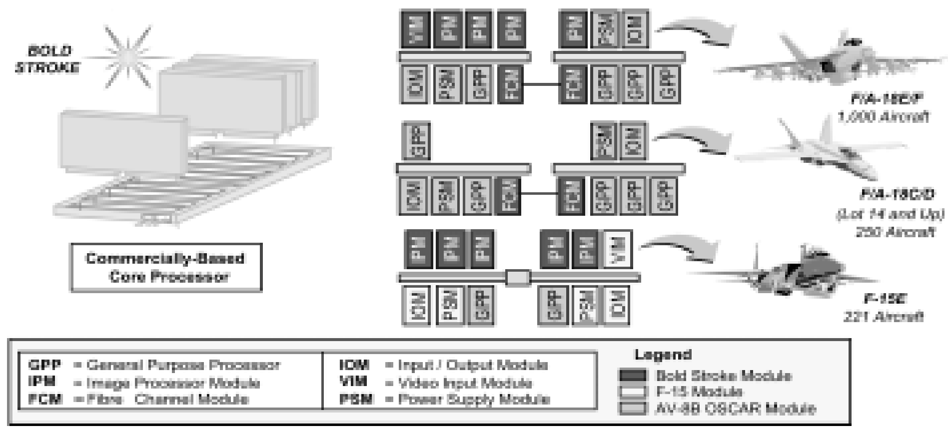


Figure 4. *Reuse: A Key Open Systems Benefit*

edged that the Harrier would not only have to be supported through the duration, but also modernized.

New tactical weapons, such as Joint Direct Attack Munition and Advance Medium Range Air-to-Air Missile 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 equipment right down to the backplane.

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

Referring to figure 4, 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 nonrecurring 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.

Bold Stroke uses commercial-based components and standard interfaces common across platforms, and accommodates plug-and-play components.

Product Line Application

So how do you apply a product line approach? Start in the requirements phase of a weapon system acquisition, when there are adequate opportunities to determine if commercial components can satisfy needs. Figure 5 suggests four considerations. After you know basic requirements, conduct market research to identify technologies that are going to have staying power and/or the capacity to be modularized in the design. Second, look at the technology trends. What is the future? What are the product line attributes? Will obsolescence be an issue? Where is the baseline? What are the risks? Are there vendor monopolies? What is the competition? How can we leverage it?

Market research should result in information to assist program managers and their acquisition teams in making 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, which evolve with technology trends like products.

Figure 5. *Managing Technologies*

Finally, think about system planning. When is the system going to production? How does the schedule correlate with the technology trends? Do not baseline on an old technology; 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. Openness is created by selecting interfaces based on nonproprietary, consensus-based standards. A systems architecture provides a high-level view of the weapon system and gives an idea of appropriate interface use and standards. This view helps acquisition officials identify opportunities for commonality, horizontal technology integration, new technology insertion, and multiple sources of supply. By taking advantage of these opportunities, program evaluation officers (PEOs) and program managers can field superior weapon systems faster and at a lower cost of ownership.

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 marketplace, and how widely they are used in the systems community. That is, if similar standards are applied across a large number of weapon platforms or across several different weapon system domains, like avionics or ground vehicles, more benefits (e.g., increased commonality and reuse) will likely be achieved than if standards are applied 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. 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.

Architecture Types

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

The operational architecture specifies 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 [4]."

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.

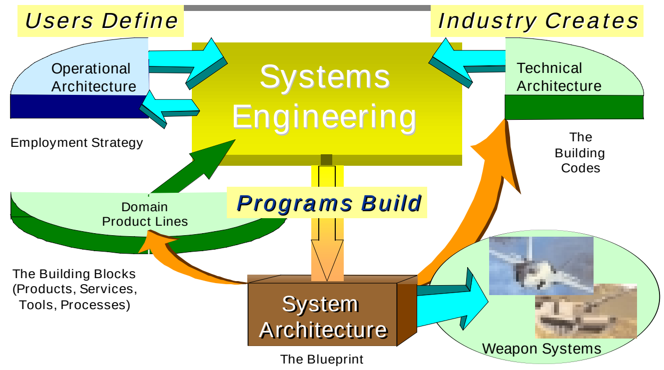


Figure 6. *Architecture Types*

Commonality Issues

Does the product line approach cause or force commonality? It may cause it, 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, or in other words, performance inefficiencies, maintenance limitations, and cost burdens.

Conclusions

Experience to date shows outstanding results for adopting a product line approach to acquisition. Findings include:

Improved Return on Investment

A product line approach, which applies basic principles of the open systems approach, promises huge returns on investment. We cited the Army's Intelligence and Electronic Warfare Countermeasures Suite (IEWCS) program in which cost avoidance was projected at about $845 million. The IEWCS program was restructured for reasons not related to the acquisition strategy, but the 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 typically require 72 hours. The bulk of the remaining equipment and support 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, Tenn. Product line concepts in which single-mission equipment is replaced by multimission equipment would certainly have a profound effect on mobility and force projection.

Improved Operational Tempo

Implications of product line approach to operational tempos are mission sortie turnaround times. **[Continued on page 23.]**

required, follow a WBS-like approach.
2. An IV&V process improvement activity is needed to address the CMM level requirements. This activity is at the same level of importance as the other IV&V activities.
3. All items that will change continuously over the life cycle, should be placed in appendices that are hyperlinked to the project master files if possible, or copies in the same Windows folder as the IV&V plan.
4. Hyperlink all document references in Section 2 to project master files if possible to reduce redundant maintenance efforts.◆

References

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The author thanks Robert Lewis and Rodney Tuten of the Naval Surface Warfare Center (Dahlgren, Va.), and John W. Guthrie, Thomas Blackwell, and Mark Sullivan of EG&G Technical Services.

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Multimission systems developed to these concepts would have the capacity to rapidly reconfigure on the flightline to execute their next mission in roughly the time it would take to refuel/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, benefitting 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 is 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 technology hooks.◆

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2. *DoD 5000.2R,* March 23, 1998.
3. *OSJTF Case Study of the U.S. Army's IEWCS.* November 15, 1996.
4. IBID

Note

1. 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.

About the Authors

Col. J. Michael Hanratty served more than half of his 30-year military career in acquisition and research and development, including as the director of Open Systems Joint Task Force, Office of the Secretary of Defense, Arlington, Va. He also held project management positions at the Advanced Research Projects Agency and the U.S. Army Research Laboratory, teaching positions in the Electrical Engineering department at the U.S. Military Academy, and command and staff positions in the 101st and 82nd Airborne divisions. Hanratty received a master's in electrical engineering from the Naval Postgraduate School and a doctorate in electrical engineering from the Georgia Institute of Technology. He is a registered professional engineer in the Commonwealth of Virginia.

Dr. James H. Dixon is president and CEO of WALCOFF Technologies, an information technology firm headquartered in Fairfax, Va. He has more than 37 years of experience in the military, academia, and business. He is an expert in operations research and mathematical modeling and has been a program director/manager and senior systems engineer on several classified C3I and information systems engineering programs. Dixon has a doctorate in international relations and quantitative methods; a master's in public policy and public administration, and in political science; and a bachelor's in aerospace management. He also served on the faculties of the U.S. Military Academy, West Point, N.Y. and The National War College in Washington, D.C.

Charlie Banning is a senior program analyst for WALCOFF Technologies. He has more than 20 years of experience in the military, academia, and business. He has a well rounded view of the product line approach and is an advocate of open systems. He has taught graduate level courses on systems engineering at Advanced Program Managers, Intermediate Systems Acquisition, and Advanced Systems Planning Research and Development Engineering Courses. Banning is a Level 3 qualified project manager. He has a master's degree in systems engineering from George Mason University and a bachelor's degree in electrical engineering from the Virginia Military Institute. He is also a graduate of the Program Manager's course at the Defense Systems Management College.