Applying Best Practices to Weapon Systems Takes the Right Environment

Creating the Incentives — Reasons Why Best Practices Will Work for Program Managers

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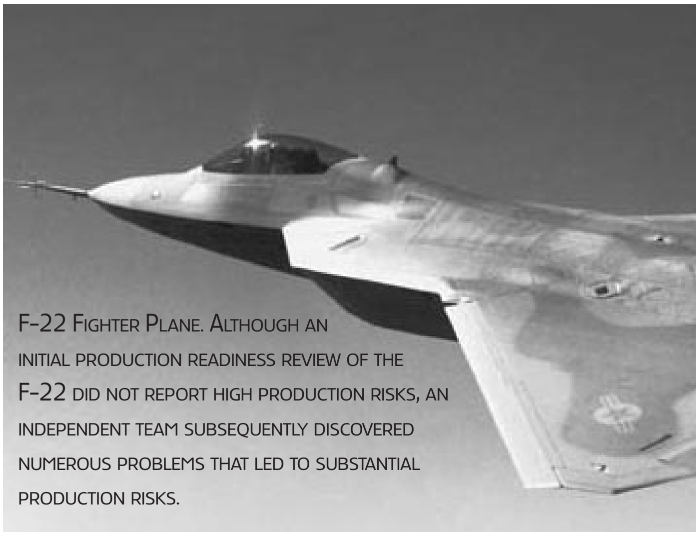
The Department of Defense (DoD) plans to increase its investment in new weapons to about $60 billion in fiscal year 2001 – a 40-percent increase over fiscal year 1997. DoD has high expectations from this investment: that new weapons will be better and less expensive than their predecessors and will be developed in half the time. With its traditional management approach – which produces superior weapons, but at much greater cost and time than planned – DoD will not meet these expectations. However, current practices employed by some leading commercial firms to reduce cost and schedule during development of new products – by as much as 50 percent – can illuminate ways for DoD to make similar improvements.

Boeing 777 Airliner. In matching requirements to mature technologies, Boeing decided against using a new alloy on the 777.

Elemental Step — Changing the Environment and Incentives

Although Congress can help set and reinforce incentives for DoD to complete programs within cost and schedule, the ability to do so falls squarely within the province of DoD's acquisition practices. Acquiring weapons more quickly and less expensively that will still defeat the threat will require different incentives for managing programs within cost and schedule estimates. The best commercial companies succeed in these areas by providing a development environment that rewards early attainment of knowledge, matures technology before



F-22 Fighter Plane. Although an initial production readiness review of the F-22 did not report high production risks, an independent team subsequently discovered numerous problems that led to substantial production risks.

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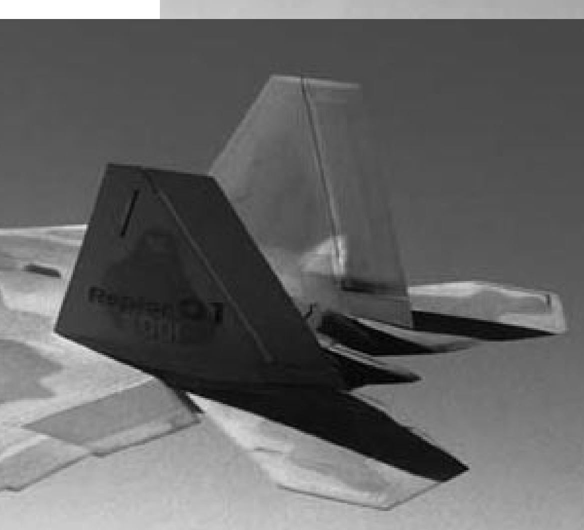
Photos courtesy Boeing

it is incorporated into new products, and keeps product development focused on design and production concerns.

This article highlights observations and relevant acquisition information from the General Accounting Office's (GAO) work in examining best practices within DoD and the commercial world. We found clear differences in the practices of leading commercial firms and those of DoD weapon programs. We also found that the way success and failure are defined for commercial and defense programs differs considerably, which creates a different set of incentives for the people managing the programs. Thus, the practices that work—that help a program succeed—in the commercial sector will not automatically work in the defense sector. However, to buy weapons better, faster, and cheaper, DoD needs these practices. Changing the environment and incentives for programs is the elemental step.

C-17 Globemaster III. The U.S. Air Force/McDonnell Douglas C-17 Globemaster III is designed to fulfill airlift needs well into the next century -- carrying large combat equipment and troops or humanitarian aid across international distances directly to small austere airfields anywhere in the world.

Developed by Boeing, the Joint Direct Attack Munition (JDAM) is a guidance kit that converts existing unguided free-fall bombs into precision-guided munitions.

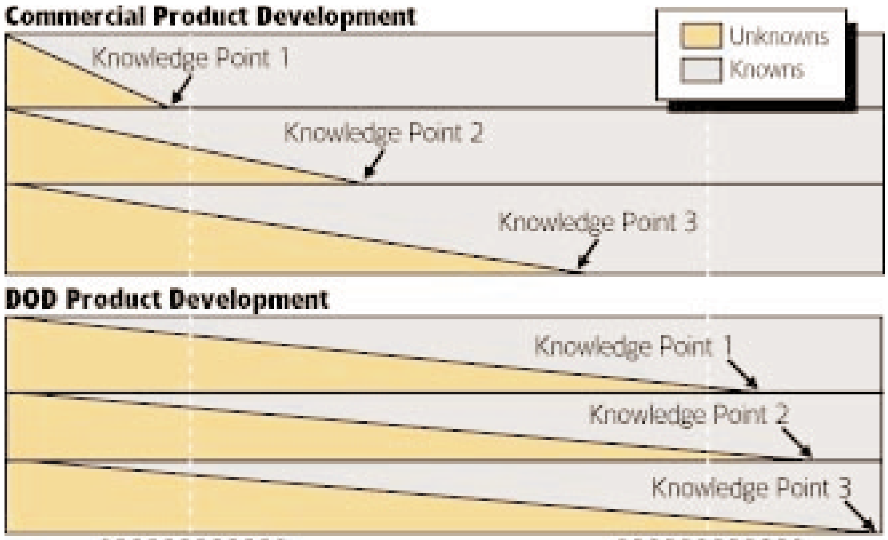


What We Did and Why

At the request of the Senate Armed Services Subcommittee on Acquisition and Technology,[1] GAO completed studies in 1998 and 1999 that assessed whether best commercial practices offer ways to improve DoD's practices for developing weapon systems.[2] Our studies also examined how differences between commercial and DoD environments affect their ability to employ practices for developing new products.

Our first step was to analyze RAND's database of over 200 Selected Acquisition Reports compiled since the 1960s to determine historical cost and schedule patterns for DoD acquisitions. We found a consistent pattern of cost and schedule increases in acquisitions as they transitioned from development to production. We then gathered information from two major DoD programs, the C-17 and the F-22, and from two newer programs, the AIM-9X Sidewinder Mis-

Comparison of Three Key Knowledge Points for Commercial and Military Product Developments



Knowledge Point 1: Knowledge that a match exists between technology and requirements.
Knowledge Point 2: Knowledge that the design will work as required.
Knowledge Point 3: Knowledge that the design can be produced.

sile and the Joint Direct Attack Munition (JDAM).

We also visited six commercial firms with proven track records for innovative and successful product development practices: Boeing Commercial Airplane Group, Chrysler Corporation, Cummins Engine Company, Ford Motor Company, Honda Motor Company, and Hughes Space and Communications. These firms reduced the cost and cycle time for developing new and better products.

Continuing our efforts, we visited each DoD program and gathered data about the types of information on hand at key junctures during the development phases of the program. This included new technologies needed to achieve performance characteristics, engineering drawings released at critical design review points, and the extent to which key manufacturing processes were in control as the transition to production began. We gathered similar data from each commercial company.

Significant cultural differences that drove behaviors between the two sectors became apparent early in our study. For example, commercial managers tended to focus on production and the successful sale of the end product, while DoD managers tended to focus more on the next milestone review. To commercial program managers, the development cycle times for weapon system programs – on the order of 15 years – seemed almost like a foreign language. One program manager remarked that it was his experience that people developing new products cannot truly focus on a goal that is more than five years away.

Attaining Key Product Knowledge Early Critical to Program Success

The successful management of cost, schedule, and performance risk in developing a product is tied to how soon the program team attains full knowledge about key dimensions of the product. Knowledge means that program managers and decision makers have reached virtual certainty about an aspect of the product being developed such as a critical manufacturing process. In essence, knowledge is the inverse of risk. Regardless of the product being developed, at some point in the process the program team attains full knowledge about all aspects of that product. Similarly, we found the level of knowledge that most significantly affects program outcomes converges at three critical points:

- When a match is made between the customer's requirements and available technology.
- When the product's design is determined to be capable of meeting performance requirements.
- When the product is determined to be producible within cost, schedule, and quality targets.

The chart on the left illustrates these three knowledge points and the differences between the commercial best practices we observed and the practices of the C-17 and F-22 programs.

As can be seen, the successful commercial firms gained more knowledge sooner about a product's ability to meet customer needs, performance, and producibility. On the other hand, the practices employed on the F-22 and C-17 programs allowed key knowledge about all three product dimensions to be deferred until much later in development – and even into production. As a result, discovery and resolution of unknowns (for example, the maturity of key technologies and ability of the design to work) continued, even as the program team was trying to concentrate on production concerns.

As production approaches, the difficulties and surprises associated with gaining such critical knowledge late in development invite the discovery of problems and attendant cost and schedule perturbations. Tracing program progress through the three knowledge points will not only show the differences in how the practices are employed, but also the potential for recognizing risk – in the form of absent knowledge – early in a program.

Knowledge Point 1

A match exists between available technology and product requirements. (Indicator: Product requirements can be met without depending on immature technology.)

Leading commercial firms will not launch a new product development unless they have high confidence that a match is reached between what the customer wants and what the firms can deliver. Critical to getting this match is the firms' practice of keeping technology development from mixing with product development. They do, in fact, fund and take risks with new technologies, but not on a product they have committed to develop and manufacture for customers. They take their technology risks off line, and demand a high level of maturity before a technology can graduate onto a product development. For example, Hughes waited 10 years for the requisite solar cell technology and the industrial base to mature before developing a new class of satellites with this technology.

Maturity is defined by proof that the technology will work and can be produced at an acceptable cost, on schedule, and with high quality. To get the match between product requirements and available technology, the companies bring solid technological knowledge to the requirements process in the form of current, high-fidelity information from predecessor programs, people with first-hand experience on those programs, or new technologies that have been proven mature.

The DoD programs we reviewed did not attain a match between technology and requirements at the time of launch. Unlike commercial products, substantial technology development takes place on weapon system programs. In fact, in the acquisition cycle, a weapon system program is launched *during* technology development. DoD accepted varying – but consistently higher – degrees of technological risk on the four programs we reviewed. Although the potential for available technology to meet product requirements is examined in DoD programs, requirements are allowed to drive technology and reach beyond what is proven.

For example, although the C-17 was developed using mostly nondevelopmental items or commercial parts, its use of aluminum lithium – a new and unproven technology that held promise for reducing weight on the aircraft – proved regrettable. It was used on the first 50 aircraft produced, only to lack in durability and maintainability. Aluminum lithium is now being removed in favor of a more proven alloy.

> DoD managers see the acquisition of the weapons under their purview as aligned with national interests. They do what they believe is right, given the pressures they face. The difference is that the definition of program success determines what is right, and that definition differs in the [defense and commercial] sectors.

What piqued our interest in this example was the fact that about the same time the decision was made to include aluminum lithium on the C-17, Boeing decided against using it on the 777. Although the alloy's light weight was highly desirable as a way to lighten the airliner, manufacturing managers argued that not enough was known about its longevity and how it needed to be handled in the manufacturing facilities. The alloy was rejected for the 777 on the strength of these unknowns.

Knowledge Point 2

The design will work. (Indicator: Percent of engineering drawings available at critical design review.)

The completion of engineering drawings and their release to manufacturing signify that program managers are confident in their knowledge that the design performs acceptably and can be considered mature. Both DoD and commercial firms consider a design to be complete when about 90 percent of the engineering drawings are completed. Both sectors schedule a critical design review (CDR) to review the drawings, confirm the design is mature, and "freeze" it to limit alterations later in the process.

The commercial firms we visited had released over 90 percent of their products' engineering drawings by the time of the CDR, which was held about midway through development. Very few design alterations were allowed after the CDR even when this freeze raised program costs, because the risk associated with major design changes was seen as too large. A good example of this was on Boeing's 777 program. Early in the requirements-setting process, one airline indicated that it wanted folding wingtips to move the airplanes in and out of hangars of different sizes. Boeing accommodated this in the design by building in a bulkhead to accommodate a hinge in the wingtip – a feature that added weight to the aircraft. Later, when the customer did not need the fold-up feature, Boeing left the bulkhead in the design and absorbed the weight penalty rather than run the risk of a redesign after the design had been proven.

CDRs were also held on the C-17 and F-22 programs midway through development. However, at the time only 56 percent of the C-17 drawings were done, and less than one-third of the F-22's drawings were done. The C-17 did not get to the 90-percent drawing release level until after several production aircraft had been delivered. In the time between the CDR and production, several technical problems occurred during C-17 testing that resulted in re-designs, cost increases, and schedule delays. For example, flight-testing revealed that the wing could not meet requirements and needed a major redesign.

Knowledge Point 3

Production units will meet cost, schedule, and quality objectives. (Indicator: Key processes under statistical control.)

The companies we visited attained the knowledge that manufacturing processes would produce a new product conforming to cost, quality, and schedule targets *before* production began. This meant more than knowing the product could be manufactured; it meant that all key manufacturing processes were under statistical process control, such that the quality, volume, and cost of their output were proven acceptable. The C-17 and F-22 DoD programs demanded less proof of producibility before approving production. For example, only 13 percent of the C-17's key processes were under statistical process control when it began production in 1989, and seven years later all key processes were still not under control. The F-22 was faring better, having reported about 40 percent of its processes under control two years before production. JDAM reported promising results, with about 69 percent of its key processes under control one year before production.

The ability to establish statistical process control for the key manufacturing processes during product development is, to a large extent, a cumulative effect. It is dependent upon the knowledge gathered from the beginning of product development (when the firm chooses appropriate technologies for the product), continues through critical design reviews (when product design is matured and drawings are "frozen"), and culminates when manufacturing personnel achieve consistent results from the processes.

Different Demands

In recent years, changes leading commercial firms made in their practices for developing and manufacturing a major product yielded the kinds of results DoD seeks. But these practices cannot be readily adopted in the current acquisition climate. The environment in which a DoD program is managed imposes different demands on its program managers than those found in the commercial sector. The way success and failure are defined for commercial and DoD programs differs considerably, which creates a different set of incentives and leads to different behaviors for managing the programs. Specific practices take root and are sustained because they work — they help a program succeed in its particular environment.

The success of a commercial program is determined by the amount of profit the firm makes on items sold to customers. The point of sale occurs after product development is complete; program success is determined in production when the customer buys the finished product. Failure is clearly defined as the customer walking away and buying a competitor's product. This reality, coupled with the pressure to shorten cycle times to meet market demands, makes production concerns a primary focus in the decision to begin product development and make technology trade-offs. It shapes an environment that encourages early identification of unknowns and judging risks accordingly. Not knowing something about a product is *not* okay — it gets a "red" in the parlance of DoD's red-yellow-green stoplight chart.

Strong incentives, both positive and negative, stress realistic estimates of cost, schedule, and performance. A low-balled or optimistic estimate could lower profit or cause the customer to walk away. In other words, unrealistic estimates invite failure. As a Chrysler vehicle manager told us, an important aspect of the program manager's role is to say "no" to anything, such as incorporating immature technologies that may disrupt the product's cost, schedule, or performance targets. Moreover, a program manager has the responsibility to reject a technology or design feature that might otherwise improve vehicle performance if those who propose it cannot prove — with either facts and data from predecessor technology or actual prototypes — that the component can be produced within cost, quality, and quantity targets.

The definition of success is more complicated in DoD. The point of sale begins at the start of program development when competing demands encourage over-promising performance while underestimating cost and schedule. Success is measured throughout development as the customer (the Services and Congress) pays for the product on an installment basis. Production is generally so far off — perhaps 10 years or more — that it does not curb technology or design decisions that promise performance but carry high cost and schedule risks. By the time production does begin, the customer is deeply vested and unlikely to walk away. As a result, and in contrast to the commercial environment, success in weapon system programs is substantially ensured before end items are produced.

The pressures and incentives in the DoD environment explain why the behaviors — and practices — of program managers differ from those in commercial programs. Risks in the form of ambitious technology advancements and tight cost and schedule estimates are accepted in the DoD environment as necessary for a successful launch. Clearly, some of these risks derive from the increased capability desired by the user. However, the risks are also shaped by the competition for funding. Problems or indications that the estimates are decaying do not help sustain the program in subsequent years, and thus, their admission is implicitly discouraged. Although these practices can be devastating to a commercial program, they work in DoD product developments because they can help a program survive.

To illustrate, the initial production readiness review held for the F-22 in 1995 reported no high risks – no "reds" – despite the fact that less than one-third of the engineering drawings were done at the time. In other words, not knowing was an acceptable risk. The next year, an independent team found the program to have significant manufacturing and producibility problems – and the costs have continued to escalate beyond estimates.

These pressures of the defense environment are not unknown.[3] A 1994 Defense Systems Management College (DSMC) study noted that government program managers found their formal role of objective program management at odds with their informal role as program managers.[4] The study, which relied on over 80 interviews with DoD and industry program managers, also stated that, "A feeling of responsibility for program advocacy appears to be the primary factor causing government managers to search aggressively and optimistically for good news relating to their programs, and to avoid bad news, even when it means discrediting conventional management tools that forecast significant deviations from plan."

None of the foregoing should be interpreted as a criticism of DoD program managers' abilities or intentions. We did not observe that commercial managers were somehow better or more ethical than their DoD counterparts. On the contrary, DoD managers see the acquisition of the weapons under their purview as aligned with national interests. They do what they believe is right, given the pressures they face. The difference is that the definition of program success determines what is right, and that definition differs in the two sectors.

Nor does the foregoing discussion deny that tangible differences can exist between the complexity of military and commercial products or that user needs can necessitate taking greater risks on some military developments.

The point is that attaining technical, design, and production knowledge is fundamental to commercial and DoD product developments, and best commercial practices in these areas can help DoD programs get better outcomes. Still, changes in the defense environment are essential to the successful adoption of those practices. We now turn our attention to these changes.

Leading commercial firms achieved these goals [better, faster, cheaper] because they asked their PMs to do less to develop the product, not to develop technology and defend the program as well.

Charting a Course for Better Outcomes

DoD's guidance on how to prepare weapons for successful transition to production [some of it now 10 years old], already has much in common with best commercial practices. In recent years, DoD has embarked on several initiatives that draw lessons from commercial practices, such as cost as an independent variable and integrated product teams. However, changing the mechanics of a weapon's development, without changing the environment that governs its incentives, may not produce desired results.

For example, program managers cannot be expected to meet program cost estimates if technology costs continually increase because of changing requirements over which they have no control. Thus, the challenge for DoD and congressional decision makers may not lie so much in the "how to" aspects of product development as in creating the incentives – the reasons why best practices will work for program managers. Therein lies the challenge decision makers must meet if they are to realize the goal of "better, faster, cheaper."

For commercial practices to help weapon system programs, they must help a program succeed in the DoD environment. Thus, the DoD environment must become conducive to such practices. We think at least two factors are critical to fostering such an environment.

Separate Development

First, program launch decisions must not hinge on the current practice of overpromising performance and underestimating resources to be successful. The pressure to amass broad support to launch a program creates pressure to embrace far more technology than can reasonably be delivered on time. The primary way to relieve this pressure is by separating technology development from product development and redefining the point for launching programs as the point at which technology development ends and product development begins.

One could argue that this approach won't work for weapon systems. That is, because DoD has to maintain the technological superiority of its weapons, the Department has to push technology faster and to take greater risks than the commercial sector. Clearly, DoD's weapons have to continue their superiority – something they cannot give up in the effort to be faster and cheaper. The question is not whether technology should be pushed but how to make the push. This is where commercial experience is relevant. Leading commercial firms keep their programs on track by making the technology push and taking risks before the program is launched – not within the bounds of a program whose purpose is to put end items in production.

Technology development's pace and resource requirements are hard to gauge; failures are expected in the discovery process. In a product development or a weapon system, on the other hand, success is expected. Concomitant with defining the program launch later in the acquisition cycle must be the willingness of decision makers in DoD and the Congress to support research and development efforts to advance technology outside of individual programs.

Confront Risks Early

Second, once a program is underway, program managers must be encouraged to identify unknowns as high risks so that they can be aggressively worked on earlier in development. In commercial programs, the threat of the customer walking away forces program managers to confront risks candidly and attack them early. Discipline is provided from within the programs. To help create a similar situation on weapon system programs, DoD must send the signals that create incentives for acquisition managers to identify unknowns and ameliorate their risks in early development. The more powerful vehicles for sending these signals may be decisions on individual programs, rather than broad policy announcements.

For example, incentives could take the form of a decision to fully fund one program's efforts to mitigate a high risk identified early or requiring another program in which risks are revealed late to absorb the associated financial consequences. The indicators we used in the three knowledge points are one way to identify such risks earlier. Congress will need to back these incentives with its actions.

Better Position to Succeed

The goals of better, faster, and cheaper, are admirable and desirable. Yet they will not succeed if they are mainly additive; that is, if weapon system program managers and program teams are simply asked to do more. Leading commercial firms achieved these goals because they asked their program managers to do less: to develop the product, not to develop technology and defend the program as well. The key to achieving similar goals on weapon systems may well be fostering an environment within DoD that puts its program offices in a better position to succeed.

Endnotes

1. The Readiness and Management Support Subcommittee has taken responsibility for these issues in the current Congress.
2. *Best Practices: Successful Application to Weapon Acquisitions Requires Changes in DoD's Environment* (General Accounting Office/National Security and International Affairs Division [GAO/NSIAD]-98-56, Feb. 24, 1998) and *Best Practices: Better Management of Technology Development Can Improve Weapon System Outcomes* (GAO/NSIAD-99-162, July 30, 1999). To order copies, call (202) 512-6000, fax your request to (202) 512-6061, or download the reports from GAO's Web site at **http://www.gao.gov.**
3. We reported on DoD's acquisition culture in *Weapons Acquisition: A Rare Opportunity for Lasting Change* (GAO/NSIAD-93-15, December 1992).
4. *Critical Issues in the Defense Acquisition Culture* (Defense Systems Management College, December 1994).

Army Roadshow Dates

Army Acquisition Workforce 2000 Briefing Dates	Mobile Acquisition Career Management Office	Location
April 15	April 15–16	Atlanta, Ga.
April 28	April 28–29	Fort Monroe, Fort Lee, Fort Eustis, Va.
May 3	May 4–5	Fort Monmouth, N.J.
May 4	May 5–6	Picatinny, N.J.
May 19	May 19–20	Fort Bragg, N.C.
June 15	June 15–16	Warren, Mich.
July 12	July 12–13	Europe (Germany)
July 13	July 15–16	England
Aug. 10	Aug. 10–12	Natick, Mass.
Aug. 23	Aug. 24–25	Huntsville, Ala.
Sept. 14	Sept. 15–17	Edgewood/Aberdeen Proving Ground, Md.
Nov. 4	Nov. 4	Yuma, Ariz.
Nov. 16	Nov. 16–17	White Sands Missile Range, N.M.
Nov. 18	Nov. 18	Fort Huachuca, Ariz.
Dec. 20 (tentative)	Dec. 20	Rock Island, Ill.