

**USING SPIRAL DEVELOPMENT TO
REDUCE ACQUISITION CYCLE TIMES**

by

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The Center for Public Policy and Private Enterprise provides the strategic linkage between the public and private sector to develop and improve solutions to increasingly complex problems associated with the delivery of public services—a responsibility increasingly shared by both sectors. Operating at the nexus of public and private interests, the Center researches, develops, and promotes best practices; develops policy recommendations; and strives to influence senior decision-makers toward improved government and industry results.

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Executive Summary

The U.S. military's mission expanded significantly following the terrorist attacks of 9/11/01 and with the subsequent Global War on Terror (and the invasions of Afghanistan and Iraq). In order for the military to effectively respond to, and counter, these rapidly evolving asymmetric and irregular threats, the military needs an acquisition system that will provide the required weapons quickly, efficiently, and with low risk.

Unfortunately, rather than becoming more efficient, the DoD has faced ever-lengthening development cycles. Long developments have typically been justified as required to fulfill the military's demand for cutting-edge hardware. Moreover, long development cycles do not necessarily provide better results. A technology that appears to have a high utility at initiation may only prove to be marginally useful once the technology is fully matured and deployed. Additionally, at a time when the threat is rapidly changing, long development cycles may produce weapons that are effective for a problem that no longer exists. Importantly, history shows that the longer a system's development cycle, the more likely a program is to experience significant cost growth. This comes at a time when, we believe, the nation's future budgetary situation—as mandatory federal budget expenditures rise—will constrain and, more likely, exert an increasing downward budgetary pressure on future defense spending.

The DoD has historically used a linear acquisition strategy known as the “waterfall” method. The waterfall method gave military planners the illusion of stability, as firm end-requirements would be determined early in the development process. As a result,

key development decisions would be made before sufficient knowledge was available to make accurate assessments.

Recognizing the benefits of a concept developed by Barry Boehm¹ to improve the software development process—a concept he called “spiral development”—a growing number of senior DoD officials came to believe that it should be extended to the acquisition of the DoD’s software-intensive weapons systems and, subsequently, to all weapon systems. In a military context, spiral development is understood as a cyclical development strategy, wherein a basic capability is fielded, and incremental capability improvements are periodically made in subsequent blocks. By shortening development timetables and ensuring the use of mature technologies, spiral development reduces the risk of program delay or failure.

Although the spiral development process appears complex at first glance, a simple logic underlies the theory. The spiral development process has four, well-defined stages that a project moves through during the progress of each (and every) individual spiral. A spiral development project may undergo any number of spirals. One project may be developed in just a single spiral, spun-out to provide an urgently needed, interim capability. Another project may go through a dozen spirals and spin-outs as it is continually modified and updated. The flexibility of spiral development allows planners to determine the appropriateness of the project incrementally, at the end of each spiral. The DoD officially endorsed spiral development as a key implementation process for the preferred evolutionary acquisition strategy in the 2003 version of *DoD Instruction 5000.2*.

One of spiral development’s primary attributes is that it can help to ensure the rapid deployment of weapon systems. Specifically, when systems are developed incrementally, and when technology is mature enough to be integrated, risk is minimized. As a result, delays in development are reduced—keeping cost growth in check as well. Spiral development is also advantageous because of its ability to allow for evolving requirements. Because spirals are flexible and can be changed as the program progresses, spiral development permits constant refinement over-time, allowing the user and

¹ See Barry Boehm’s seminal article “A Spiral Model of Software Development and Enhancement,” *Computer, IEEE*, 21(5): 61-72, May 1988.

developer to hone in on requirements as they change. Finally, spiral development can help foster a robust defense industrial base, with the potential for competition at the beginning of each spiral (creating broader opportunity, encouraging innovation, and also leading to increased pressures on private industry to become more efficient in production).

We believe that to effectively accomplish the required modernization of the military to meet the challenges of the twenty-first century, the DoD must use spiral development as an acquisition strategy. Spiral development can allow the DoD to field weapons faster, decrease acquisition costs, promptly adapt to changing threat requirements and foster a more competitive defense industrial base.

In order to illustrate the challenges and benefits of using spiral development in the DoD, this report examines several case studies that demonstrate implementation of spiral development over various types of military acquisitions. We first examine the Predator Unmanned Aerial Vehicle (UAV) program, as it is one of the most successful UAVs ever built and an exceptional example of spiral development in practice. The Predator demonstrates the adaptability feature of the spiral development process. In this case, the platform itself evolved in terms of capabilities and technical performance, just as the user was evolving the platform's application during combat.

The second case we examine is the Navy's Acoustic-Rapid COTS Insertion (A-RCI) program. The A-RCI program displays the value of spiral development when used to upgrade legacy systems. This case demonstrates how continuous improvement, through incremental spirals, allows existing platforms to be upgraded for a minimal investment.

The third case we examine is the Global Hawk UAV program. This program demonstrated the advantages of spiral development early-on, but began to have cost and schedule issues when the Air Force continued to add new requirements and did not keep the cost targets (as "requirements"). These new performance requirements (without cost controls) resulted in a significantly larger air vehicle, and significant program cost growth.

Next, we examine the Navy's Littoral Combat Ship (LCS) case as an example of spiral development program that was not properly executed; it was not a well-disciplined program. An aggressive schedule and unrealistic cost estimates led to numerous delays and cost-increases. Unrealistic assumptions, coupled with little flexibility in the Navy's requirements, ultimately diminished the effectiveness of the spiral approach in this case.

Finally, we include a review of the commercial development of INTELSAT. Although it was not a spiral development in the formal sense, the program successfully developed satellites quickly and efficiently, using mature technologies and periodic updates.

In order to implement spiral development DoD-wide, it is necessary for decision-makers to account for several challenges that could impede the expanded use of spiral development practices. First, DoD's acquisition culture is resistant to change, as it is currently founded on decades of education and training rooted in Cold-War-based acquisition philosophies. Second, current funding processes, both within the DoD and the federal government itself, are not structured to support the flexibility and change of spiral development. Third, the regulatory environment is not designed to address an acquisition strategy that requires flexibility and quick development/action. Fourth, continuously changing requirements, without adequate cost/performance trade-offs (commonly known as the "requirements creep") is still a major factor in current programs and leads to cost increases and schedule delays. Fifth, many current programs are initiated without decision-makers having the knowledge of risk necessary to successfully complete the tasks they have already committed to doing. Sixth, communication between all stakeholders is vital for spiral development to be effective; and, at present, this level of communication is not common in many system development programs. Finally, supportability of programs is key; if shareholders do not communicate with the logistics community as capabilities and requirements change, logistics support becomes extremely complex and difficult to manage.

In light of these challenges, the authors of this report make the following specific recommendations:

- 1. Use Mature Technologies and Knowledge-based Practices.** The wider use of mature technology (for each spiral) and knowledge-based practices is vital, as it has been proven to directly reduce cost and schedule risk.
- 2. Program Must Have Greater Requirements Flexibility.** Increased flexibility in program requirements is key as technology is developed incrementally; spiral development is designed to use cost, schedule and performance trade-offs, over-time, to ensure ultimate program success.
- 3. Address the Budget Challenges.** Current budget challenges must be overcome, and wider acceptance of the spiral approach, through funding procedures, must be recognized.
- 4. Adapt Test and Evaluation Processes.** The testing and evaluation process is not designed to accommodate spiral development; these procedures must be redesigned to account for a spiral approach to acquisition.
- 5. Incorporate Logistical Concerns Early in the Development Process.** Fifth, logistics must be accounted for and incorporated early in the development process and must include communication with all key stakeholders.
- 6. Ensure that Programs are Properly Managed.** Programs must be properly managed under spiral development; an important factor in their success is the progression from one block to the next, and this requires sufficient oversight and management.
- 7. Implement Modular-Open-System Approach.** Further use of a modular-open-system approach will allow greater opportunity for the inclusion of the lowest-cost and best-performing components in a system sooner rather than later.
- 8. Ensure Programs use Concurrent development.** Spiral development relies upon the concurrent development of sequential spirals; i.e., spiral N and spiral N+1 will partially overlap. Consequently, planning for spiral “N+1” is a critical spiral “N” task.

It is our belief that if these steps are taken, spiral development can be properly implemented and expanded DoD-wide. In order to accomplish this, however, Department leadership must overcome numerous challenges. We believe that current cases exemplify

the benefits that can be had from spiral development and hold a promise of even greater achievements in future programs. To achieve the required DoD modernization for the twenty-first century, developers must begin to field better-performing, lower-cost systems, faster; we believe spiral development to be at the core of that effort.

I. Introduction

The United States currently faces an uncertain and rapidly changing threat environment. This situation is in stark contrast to America's experience during the Cold War, with the singular and generally predictable threat posed by the Soviet Union. Following the collapse of the Soviet Union, the United States military began to undertake a variety of less traditional missions, such as nation-building and peacekeeping—missions outside the realm of its more traditional areas of expertise. The military's operational mission expanded significantly following the terrorist attacks of 9/11/01 and with the subsequent Global War on Terror and the invasions of Afghanistan and Iraq. In order for the military to effectively respond to, and counter, these rapidly evolving, asymmetric and irregular threats, the military needs an acquisition system that will provide the required weapons quickly and efficiently.

Military planning during the Cold War was relatively stable, predictable and consistent. The DoD employed a threat-based planning approach to prepare for possible conflict with the Soviet Union and its allies. Intelligence could provide reasonably accurate estimates regarding enemy capabilities, numbers, and disposition. The goal for the DoD's acquisition community was to stay technologically ahead of the enemy. Developers could reasonably assume that future needs—tanks, planes, and ships—would not differ from the past substantially in mission requirements, merely in quality. The United States could prepare for a threat it understood (or at least believed it understood) well.

Circumstances changed following the fall of the Soviet Union. The absence of a clear and present threat led to a period of military retrenchment, as the nation demanded to reap the benefits of the "peace dividend." Issues submerged during the Cold War suddenly became important enough to warrant military action; consequently, the military's role expanded during the post-Cold War era. New missions included providing humanitarian assistance, disaster relief, drug interdiction, border patrol, and nation-building. In an effort to respond to these new missions, the military used the available forces, weapons, and doctrine—with varying degrees of success.

September 11th, 2001, brought to light one of a range of unforeseen threats that directly threatened the United States homeland. Suddenly, terrorists, rogue states, failed states, and other non-state actors became prominent national security concerns. The scope of the military's action would increase significantly following the terrorist attacks of 9/11 and the subsequent military interventions in Afghanistan and Iraq.

With the development of these new, more complex threats, the United States needs a defense acquisition system flexible enough to effectively and efficiently respond in a timely manner. There are several factors (that include severe budget constraints, lengthening acquisition cycles, and the legacy “waterfall” acquisition method) that help to define the DoD's current acquisition environment; these are discussed below.

Budget Constraints

The nation's overall future budgetary situation will constrain future DoD funding. As mandatory federal budget expenditures rise—particularly for Social Security, Medicare and Medicaid—there will be increasing downward budgetary pressure on defense spending. Moreover, the acquisition budget may fall at an increased rate, as the Congressional Budget Office projects a relative decline in the percentage of the DoD budget spent on acquisition. As a result, the acquisition budget will face reductions for two reasons: (1) the overall decline in the military budget and (2) the relative decline of the acquisition budget as a portion of military spending.

The military budget, as a percentage of GDP, has steadily declined since the end of the Korean War. This decline was accelerated by the substantial military budget cuts following the end of the Cold War that were enacted to recoup the perceived peace dividend. Military spending fell, as a percentage of GDP, from an average of 5.75% in the 1980s to 3.96% in the 1990s (Table 3.1) (Office of Management and Budget 2004). Although military spending has increased since 2001 due to increased military operations, the Congressional Budget Office projects a further decline in the percentage of GDP allocated to defense in the near future (see Figure 1).

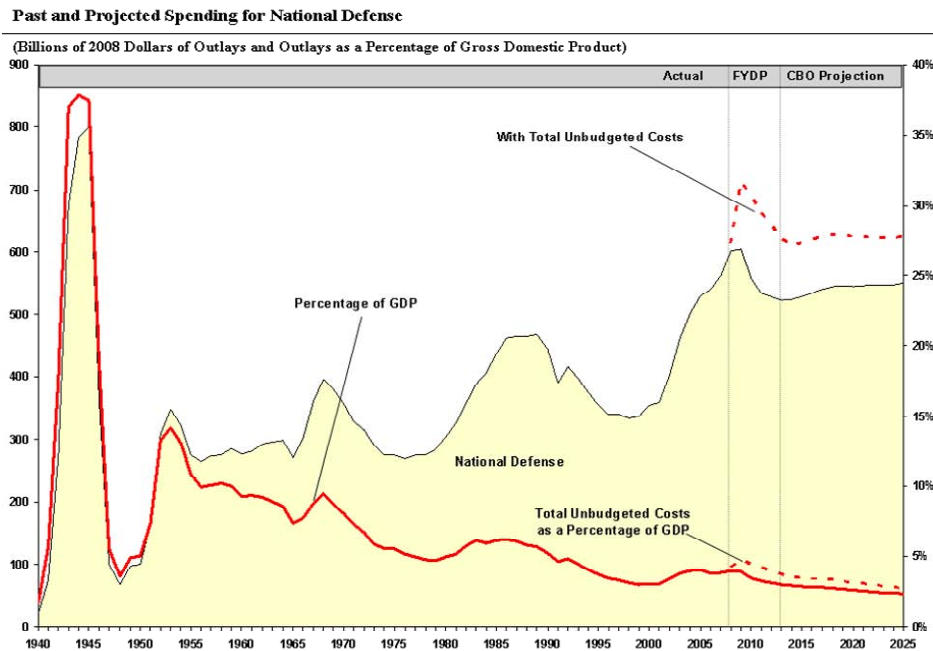


Figure 1: Past and Projected Spending for National Defense (CBO 2008)

The growth in mandatory expenditures will further constrain future U.S. military expenditures. Entitlement programs such as Social Security and Medicare project massive deficits starting early in the 2010s and growing worse as the Baby Boomers retire in increasing numbers. By 2017, the annual growth rate of Social Security spending is expected to rise from 4.5% to 6.5%, while Medicare and Medicaid are projected to grow in the range of 7% to 8% annually. Servicing the large and expanding public debt, already 9% of federal spending in 2006 (Walker 2007) will restrict funds available for discretionary expenditures.

Acquisition (RDT&E and Procurement) will be most adversely affected by the DoD's budget decline. As shown in Figure 2, this portion of the budget is projected to shrink over the next 15 years. Operations & Maintenance (O&M) funding currently represents nearly two-thirds of the DoD budget, while resources devoted to modernization represent only one third. The Congressional Budget Office forecasts significant increases in spending on personnel and O&M, which are projected to rise 30% and 20% respectively by 2024. During this same period, funds invested in RDT&E are expected to decline by

roughly one-third—which will negatively impact innovation and modernization within the military (Congressional Budget Office 2006). CBO projections may underestimate RDT&E cutbacks due to factors ranging from the length of military presence in Iraq and Afghanistan to the rapidly growing costs of healthcare for the care of soldiers, civilian personnel, and their families. Ultimately, the declining military budget will force the nation to make many hard decisions as “the Department of Defense must cope with conflicting imperatives—adapting to a rapidly-changing security environment, while preserving the capability to field a military unparalleled in history” (21) (CSIS 2004).

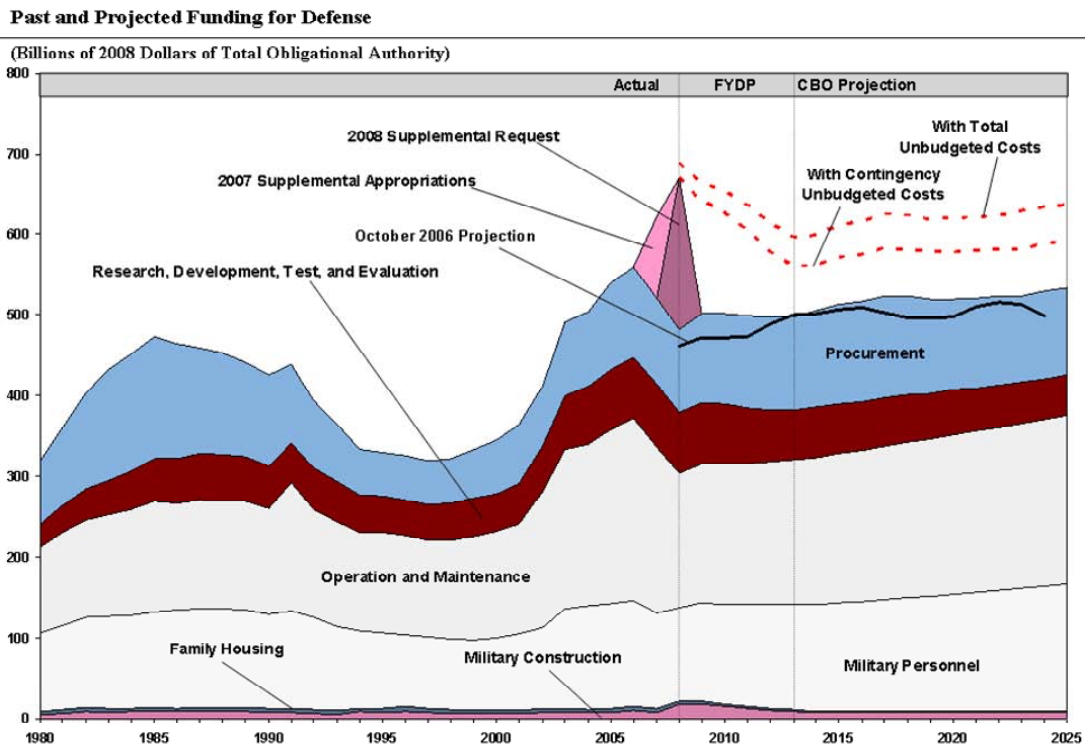


Figure 2: Past and Projected Funding for Defense (Billions of 2008 Dollars of Total Obligation Authority) (CBO 2008)

Delayed Schedules

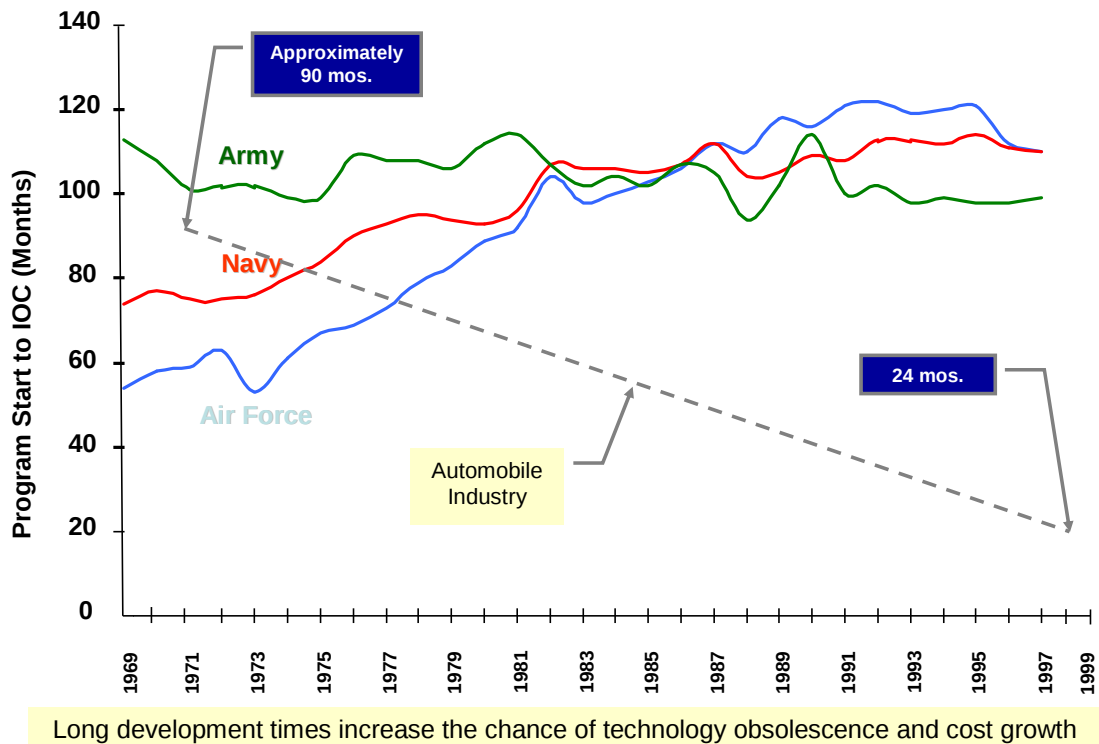
As technology has become increasingly complex over the past decades, the DoD has faced ever-lengthening development cycles. Long development cycles have typically been justified as required to fulfill the military's demand for cutting-edge hardware. Historically, though, the longer a development cycle, the more likely a program is to experience significant cost growth. As the time horizon extends, it becomes more difficult to properly estimate the risks associated with development.

A recent Government Accountability Office (GAO) report highlights the problem of the lengthy development cycles that DoD acquisitions currently experience. The weighted-average acquisition cycle time estimate of 27 major weapons acquisition platforms was 170.2 months—a little over 14 years (see Figure 3). On average, these programs experienced growth cost of 19.1%, RDT&E cost growth of 33.5% and acquisition cycle growth of 23.5%. Certain projects, such as the Air Force's F-22 and Joint Strike Fighter, experienced even greater growth in cost and cycle times. Program cost growth, primarily occurring in RDT&E, would have grown even more if the military did not reduce requirements capabilities and procurement numbers. Despite these increases, the GAO warns that future development delays and rising costs are likely, as many technologies for these programs have yet to reach maturity.

	First full estimate	Latest estimate	Percent change
Total Cost	\$506.4	\$603.1	19.1%
RDT&E Cost	\$104.7	\$139.7	33.5%
Weighted average acquisition cycle time in months	137.9	170.2	23.5%

**Figure 3: Cost and Cycle Time Growth for 27 Weapons Systems (Billions of Constant 2007 dollars)
(GAO 07-406SP)**

In contrast to the difficulties faced by DoD acquisition projects, private industry has been able to significantly reduce development cycles. From 1969 to 1998, the average cycle time of an average DoD development program increased from approximately 80 months to 107 months. In contrast, the private automobile industry experienced significant reductions in average cycle times, from approximately 90 months to 24 months (Figure 4 below). Much of the decrease in cycle times took place during the 1990s, when the private automotive, aircraft, spacecraft and electronics industries decreased cycle time by an average of 50-75% (Ward 2006).



Source: DSB Briefing, Dan Czelusniak, 12 June 1998

Figure 4. Average DoD Program Cycle Times (by SAR Reporting Years)

Long acquisition cycles have other undesirable effects on development projects. Long and fixed development cycles have not enabled DoD acquisition projects to include new technologies as they become available on the market. Today, most technical innovation

occurs outside of the government; consequently, the DoD loses many relevant opportunities. Moreover, with the increasing speed of technical innovation, systems become obsolete at a faster rate. As a result, many programs or components of systems involving a lengthy development cycle become obsolete even before the deployment of the system.

Furthermore, long development cycles do not necessarily provide more reliable results. A technology that appears to have a high utility at program initiation may only prove to be marginally useful once the technology is fully matured and deployed. Long development cycles may also produce weapons that are designed for a problem that no longer exists.

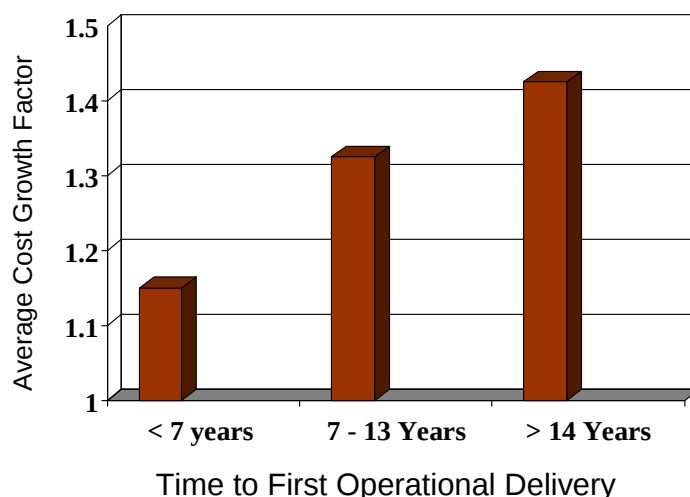


Figure 5. Average Cost Growth for DoD Programs (McNutt PhD Dissertation 1998)

The final issue is the impact of long development cycles on cost growth. The longer a military program is in development, the higher the average cost growth factor. The average cost growth factor indicates how much the cost of a program increases over the program's original estimate, given as a percentage of the original estimate. The shorter time period a military program is in development, the lower the average cost growth factor. A RAND analysis of Selected Acquisition Reports in 1996 found that programs taking less than 7 years to reach first operational delivery overran their initial planned

development budgets by an average of 15%, while programs taking longer than 14 years overran their initial planned development budgets by an average of 42%. Clearly, development cycles should be kept as short as possible to minimize the risk of cost growth (see Figure 5).

Waterfall Method

The Department of Defense has historically used a linear acquisition strategy known as the “waterfall” method. The waterfall method gave military planners the illusion of stability, as firm end requirements would be determined early in the development process. Key development decisions, however, would be made before sufficient knowledge was garnered to make an accurate assessment of feasibility. A program would only be considered complete when the final requirements were met, regardless of changes that may occur during development. The need to maintain technical superiority over adversaries pushed the military to design systems that would provide revolutionary steps in warfighting. These leaps in capability were predicated on the successful and flawless development of immature technologies. The need for serial “big-bang” innovations drove long cycle times. As a result of this risky development strategy, tight schedules would often slip as immature technology could not meet design specifications. As the development timetable lengthened, and the DoD paid for expensive engineers to remain on the project, the cost of programs rapidly escalated.

At one point, all private firms utilized the waterfall technique of development. Over time, however, firms began to adopt new cyclical acquisition techniques to survive, as competition became fiercer. Firms developed new acquisition methods because they discovered that long development periods *cause* cost growth. The longer a project is in development, the more time likely something will “go wrong”: budget instability, schedule changes, cost increases, new technology, requirements “creep,” etc. Problems associated with linear acquisition projects included the inability to incorporate newly matured technologies into designs, the inflexibility to change end requirements to respond to emerging threats, and difficulty in incorporating user feedback into future modifications. All too often, a military project would set itself up for failure by

establishing a baseline development timetable that exceeded a decade. Overall, the waterfall method was too rigid to adapt to changes that might, and more often than not did, occur during development.

Report Roadmap

Section One of this report has provided an overview of the contributing environmental factors impacting the present state of DoD acquisition. Section Two will provide a brief history of spiral development itself, explain in detail the process, and outline the evolution of government policy. Section Three will examine five cases of spiral development: the Predator UAV program, the Acoustic Rapid COTS Insertion (A-RCI) program, the Global Hawk UAV program, the Littoral Combat Ship (LCS) program, and commercial development of INTELSTAT. Each of these cases will provide background information on the circumstances surrounding the case, an overview of the program itself and important developments, along with results of each and any lessons learned. Section Four will provide overall findings regarding the implementation of spiral development in DoD acquisitions thus far and our recommendations for the increased and improved use of spiral development. Section Five will provide our final conclusions.

II. Spiral Development

History

Throughout the 1970s and 1980s, firms pursuing software development experienced many of the same challenges that the DoD faced in its military acquisition. During this time period, software development became an increasingly intricate and complicated undertaking. Even with teams of programmers with specialized knowledge, large-scale projects often experienced debilitating delays and cost overruns. The DoD and the software industry employed the same linear acquisition strategy and experienced equally disappointing results.

In 1988, Barry Boehm first put forth the Spiral Development theory in his article *A Spiral Model of Software Development and Enhancement*. The paper explicitly provided a software development strategy that increased efficiency markedly over its predecessor. As described by Boehm, the Spiral Development model “creates a *risk-driven* approach to the software process rather than a primarily *document-driven* or *code-driven* process.” (emphasis in original) (Boehm 1988). The process emphasizes effective risk management as the key to effective development, not strict adherence to a predetermined (and often arbitrary) schedule. Boehm based the paper on his personal experience utilizing this development strategy while designing large government software programs for TRW Defense Systems Group during the 1980s. Boehm would go on to refine his model and its assumptions in later works.

Boehm surmised that the sequential development process tended to perform poorly because it was inflexible. By committing early to a final developmental approach, before the acquisition team had sufficient knowledge, a firm would make decisions without an effective understanding of the associated risks. All too often, due to the lack of knowledge, senior management would set desired, yet unrealistic end-goals. By being committed to fixed long-term objectives early in the development process, most projects precluded the incorporation of important innovations that arose during development. To overcome the challenges faced by the linear development model, Boehm proposed the

spiral development process: a “risk-driven, process-model generator [...with] two distinguishing features. One is a cyclical approach for incrementally growing a system's degree of definition and implementation, while decreasing its degree of risk. The other is a set of anchor point milestones for ensuring stakeholder commitment to feasible and mutually-satisfactory system solutions”(3)(Boehm 2000).

Boehm also summarized the most important features of the spiral development model as “cyclic concurrent engineering; risk-driven determination of process and product; growing a system via risk-driven experimentation and elaboration; and lowering development cost by early elimination of nonviable alternatives and rework avoidance”(3)(Boehm 2000). All of these aspects characterize a process that emphasizes knowledge-based development, founded upon effective risk management. Due to this prominence, spiral development has two primary advantages over the traditional acquisition method: its cyclical approach allows users to provide feedback at every development step, and developers can identify potential trouble spots at an early stage.

Spiral Development: The Process

Although the Spiral Development process appears complex at first glance, a simple logic underlies the theory. The spiral development process has four, well-defined stages that a project moves through during the progress of each (and every) individual spiral. A visual depiction of a theoretical spiral development process is presented below, in Figure 6. (In a realistic scenario, however, each phase is unlikely to constitute an equal investment of time.)

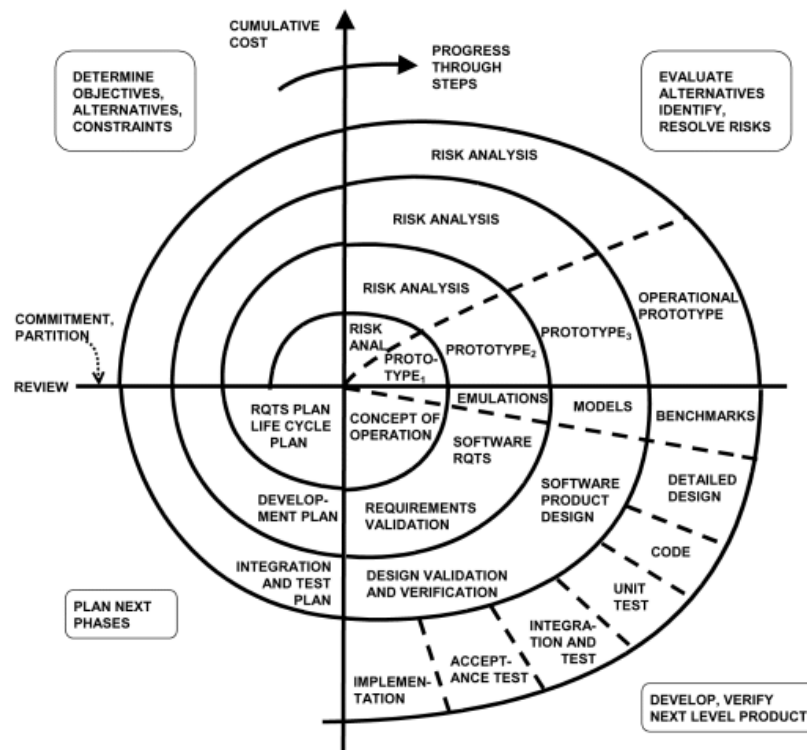


Figure 6. Spiral Development Model. (Source for Image: <http://www.stsc.hill.af.mil/crossTalk/2001/05/boehm1.gif>)

The first stage is the determination phase. In this segment, project managers decide on the objectives, alternatives and constraints of the project for the entire spiral. The goal of this stage is to determine all feasible avenues of development that the project could pursue in the current spiral. By the end of the phase, the engineering team develops several design options to explore.

During the second stage, all alternatives from the first stage are assessed with regard to their risks. After the risk analyses are complete, the project team comes to a decision on the best course of action for the spiral. By the end of this phase, the design team produces prototypes to test the validity of the initial analysis.

The third step of spiral development is the longest. In this phase, the time-intensive process of development and verification of the product occurs. Development continues

until the final product of that spiral is produced and tested. Validation of the product is also undertaken to assure quality control.

In the final phase, program managers plan for future spirals. All the project's participants conduct an assessment in light of the most recent spiral. This phase ultimately culminates in a milestone checkpoint, during which project leaders determine the future course of the program. At this point, a project may either be ended, further developed, or "spun-out" into production. If more progress is deemed necessary, the requirements for future spirals will be extensively planned. A new spiral may not commence until a thorough plan detailing the goal and requirements of that spiral are completed. Once a plan of action is agreed to and approved from above, the spiral process once again begins at the first phase determination.

A spiral development project may undergo any number of spirals. One project may be developed in just a single spiral, spun-out to provide an urgently needed interim capability. Another project may go through a dozen spirals and spin-outs as it is continually modified and updated. The flexibility of spiral development allows planners to determine the appropriateness of the project incrementally at the end of each spiral.

Recognizing the benefits of the spiral development concept, a growing cadre of senior DoD officials came to believe that the process could, and should be, extended to the acquisition of the new class of software-intensive weapons systems. In a military context, spiral development is understood as a cyclical development strategy—wherein a basic capability is fielded, and incremental capability improvements are periodically made in subsequent blocks. By shortening development timetables and ensuring the use of mature technologies, spiral development reduces the risk of program delay or failure. The speedy deployment of a major weapons system (in 3-5 years) allows the military to more rapidly respond to an emerging threat. The weapons developed in the first increment may provide a weapon only somewhat better than what is already fielded. Continuous upgrades, however, allow for improvement in capability to eventually attain a "revolutionary" edge over opponents. Although a system will be less than full capability (and less than fully tested) when first deployed, the project is more likely to remain

within cost, more likely to be delivered earlier than a comparable, traditional acquisition project, and more likely to remain more adaptable to future threats—all while the risk of failure is reduced.

Policy

The DoD recognized that a knowledge-based acquisition strategy is essential to effectively managing risk. A knowledge-based acquisition strategy is one which relies solely upon the use of mature technologies so as to minimize the risk of costly development delays. As concluded by many government and independent reports, “immature technologies are markers for future cost growth” (GAO 2007). Consequently, the DoD embraced Evolutionary Acquisition (EA), a strategy based on the use of mature technologies. The belief was that evolutionary acquisition would allow for faster implementation of improvements as new technologies became available, would better balance needs and capabilities with resources, and would take advantage of user feedback in refining requirements and capabilities.

The DoD officially endorsed evolutionary acquisition as the preferred strategy for weapon system acquisition in the *DoD Instruction 5000.1* series issued on October 23, 2000. Evolutionary Acquisition is based upon five key tenets: rapid deployment; incremental development of capabilities; constant refinements and adaptability of requirements; intensive collaboration between the user, tester, developer and supporter; and development using mature technologies. Technology maturity was evaluated using Technology Readiness Levels (see Figure 7). In that year’s version of the *DoD Instruction 5000.2* series, spiral development was also identified as the preferred strategy for software development programs.

Evolutionary Acquisition is the DoD’s preferred broad **strategy** to satisfy operational needs; while **Spiral Development** is the preferred **process** for executing such a strategy.

DoDI 5000.2, May 12, 2003

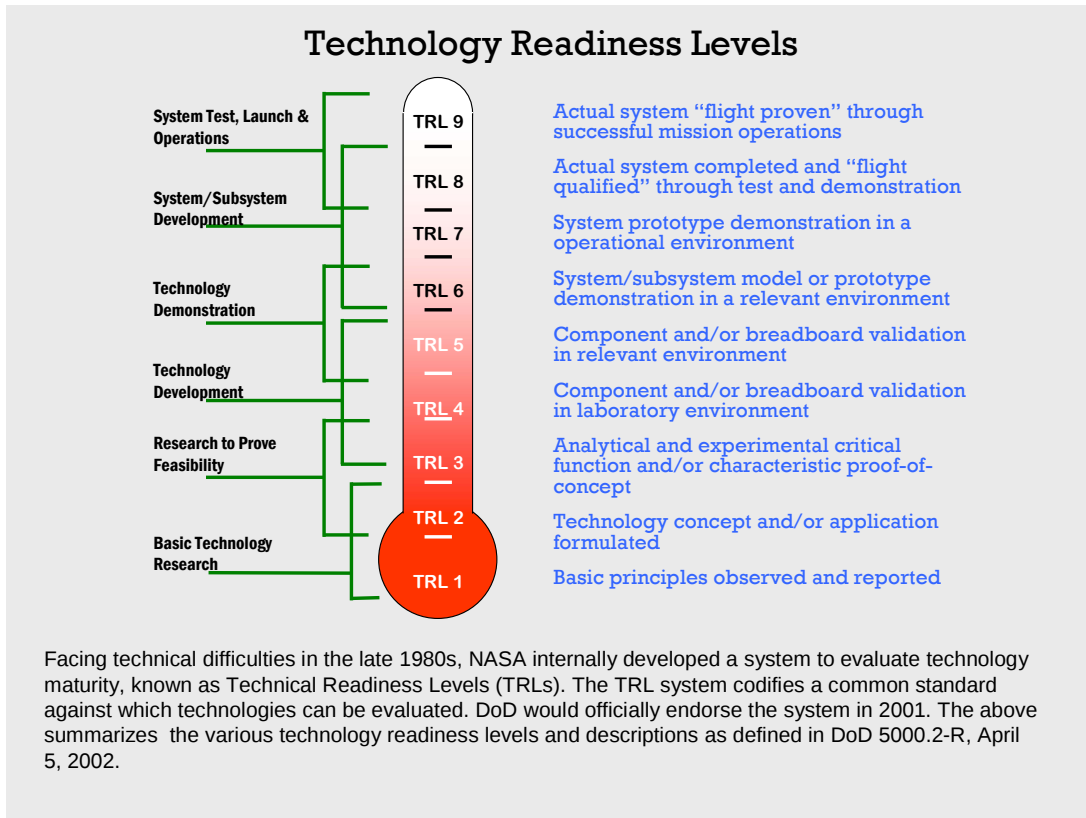


Figure 7. Technology Readiness Levels

The initial implementation of evolutionary acquisition and spiral development was hindered in part by the DoD's ambiguous definition of the relevant terms and how they should be implemented. The issue was specifically addressed in the revised version of the *Instruction 5000.2* series in 2003. With this publication, the Department recognized that the evolutionary acquisition strategy has two implementation processes: Incremental Development and Spiral Development. In both cases, desired end-capabilities² are clearly defined. A capability is the desired function that the deployed weapon system will achieve. With incremental development, the system's final requirements are known. With Spiral Development, although the desired capability is identified, specific end-state requirements are not known quantitatively at the program's initiation. Furthermore, requirements for future increments may change depending upon technology maturation and user feedback from initial increments.

² Capability is the ability to achieve a desired effect under specified standards and conditions through combinations of ways and means to perform a set of tasks. It is defined by an operational user and expressed in broad operational terms (CJCSI 3170.01F 1 May 2007).

Upon official endorsement of evolutionary acquisition and spiral development, many DoD projects “discovered” that they had, in fact, been following an evolutionary acquisition/spiral development path all along, as program managers rushed to reclassify their programs. Although labels changed, underlying acquisition practices did not change. Consequently, acquisition problems continued.

Congress also amended Title 10 to explicitly define spiral development to preclude arbitrary program redefinition or the introduction of “product improvements” that were really brand-new development efforts or programs. The new law stipulates:

U.S. Code Title 10, Subtitle A, Part IV, Chapter 144, Sec 144

(g) Definitions.—In this section:

- (1) The term ‘spiral development program’, with respect to a research and development program, means a program that—*
 - (A) is conducted in discrete phases or blocks, each of which will result in the development of fieldable prototypes; and*
 - (B) will not proceed into acquisition until specific performance parameters, including measurable exit criteria, have been met.*
- (2) The term ‘spiral’ means one of the discrete phases or blocks of a spiral development program.*
- (3) The term ‘major defense acquisition program’ has the meaning given such term in section 139(a)(2)(B) of title 10, United States Code.*

Figure 8 provides a visual representation of a how a DoD spiral development program should be developed within the DoD’s current acquisition process, emphasizing the concurrent nature of spiral development. The Milestones can be viewed as corresponding to decision points at each axis in the spiral development model above.

Spiral Development

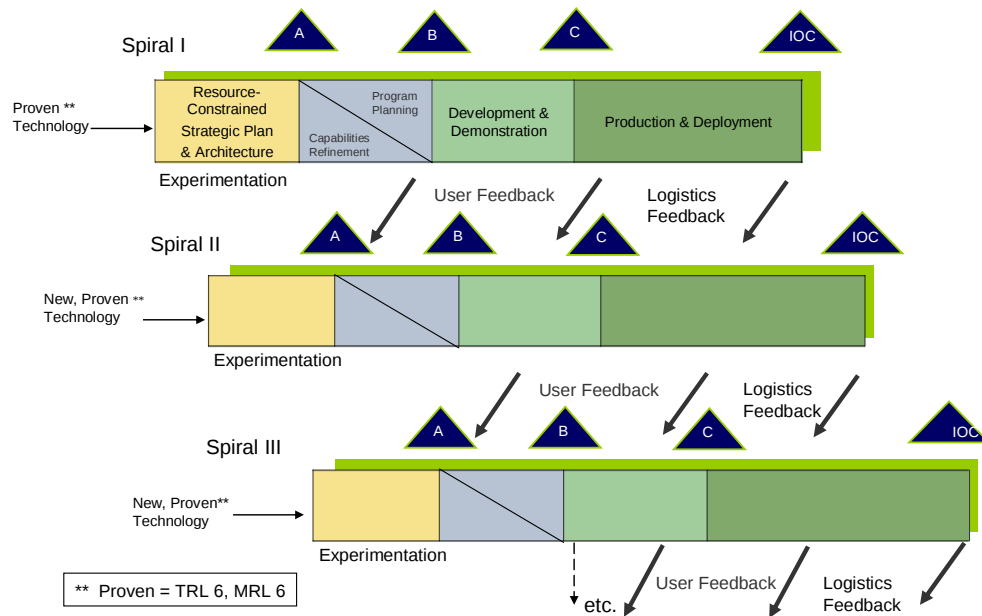


Figure 8. Spiral Development Program

Advantages of Spiral Development

With Spiral Development, the DoD believes it will field weapons systems faster, reduce acquisition costs, and be able to more easily adapt to changing threat requirements (greatly reducing the risk of technological or operational obsolescence), while facilitating a more robust and competitive defense industrial base. Spiral development derives the following advantages, primarily from effective risk management:

Rapid Deployment

By minimizing technological risk, spiral development minimizes the likelihood of development delays. Spiral Development's shorter development cycle yields a more rapid deployment, which offers several advantages. First and foremost, greater capabilities are provided to those that need it the most: the troops in the field. Faster development and deployment of weapons allow a recognized deficiency or a (known) needed capability to be filled quickly. Second, the DoD would be able to more promptly

respond to new threats and challenges. Decade-long development strategies are inadequate when responding to today's nimble adversaries or incorporating rapidly changing commercial technologies. Finally, by emphasizing short acquisition cycles, spiral development reinforces the use of mature technologies, reducing the risk in developmental projects.

Lower costs

All too often, the idea of a new DoD weapon, based upon untested technology, captures the imagination of military planners who want to field the next war game-changer. Historically, these extensive R&D efforts, undertaken at considerable cost, frequently resulted in schedule slips and cost growth. The objective of Spiral Development is to reduce the program costs by only using mature technologies, which reduces the possibility of delays while the technology matures.

The DoD should continue to pursue the development of high-risk, high-payoff, innovative technologies (acknowledging a high failure rate)—but these should not be the basis for current developmental programs.

Adaptable Requirements

With no set end-point for development, spiral development undergoes constant refinement to allow the weapon to adapt to changing DoD needs. Although each spiral is thoroughly detailed with explicit goals and requirements, final specifications for subsequent increments are not articulated until knowledge from the preceding steps are taken into account. Preceding increments provide important information about the possibilities of future increments. Perhaps an initially desired capability is simply not attainable with technology today, but—with the development of a new technology—may warrant inclusion in a subsequent increment. Most importantly, constant refinement greatly reduces the chance of technological or operational obsolescence. Constant information sharing between the user, tester, developer and supporter ensure that a project's capabilities properly represent the current needs of the military. Rapid

deployment of technology ensures that weapons employ the most cutting-edge and most useful technology available to the military.

Facilitates a more robust and competitive defense industrial base

Spiral development would help the DoD foster a more robust defense industrial base. Shorter development cycles would potentially allow the Department to compete every spiral of a program (depending on contractor performance in the previous block)—encouraging innovation, and driving down prices. Furthermore, a greater number of companies would be able to bid on DoD contracts, as the competition would rely on the knowledge of mature technologies and not on the promise of future developments. And, it must be emphasized, this competition (at each spiral) could often be at the sub-system level—at which new technology frequently evolves most rapidly.

III. Cases

A. *Predator Unmanned Aerial Vehicle*

Before the war, the Predator had skeptics because it did not fit the old ways. Now it is clear, the military does not have enough unmanned vehicles.

President George W. Bush, 11 Dec 01

Background



The use of unmanned aerial vehicles (UAVs) has become increasingly prevalent since the turn of the century. UAVs represent a transformative technology that can be utilized for a number of vital missions in which human occupation is undesirable due to danger, length

of mission, or repetitiveness of a task. Several missions UAVs currently undertake include armed reconnaissance in denied areas, communication relay and signal jamming.

The Predator UAV program is one of the most successful UAV programs to date and is an excellent example of spiral development. Although the Army initially wanted to pursue the Predator program, the Vice Chairman of the Joint Chiefs of Staff designated the Air Force as the lead Service. The Air Force developed the Predator UAV as an Advanced Concept Technology Demonstration (ACTD). ACTDs are intended to exploit mature and maturing technologies to solve important military problems by having both the operational user and research and development communities work together to design and modify a system. The Predator ACTD began in November 1993 with an ambitious

30-month schedule for 3 systems and 10 air vehicles. In July 1995, the Predator was flying operational reconnaissance missions over Bosnia for Allied forces (GAO 1999).

Program Overview

Initially, the goal for the Predator program was to develop an inexpensive UAV (roughly \$4 million each) that could provide real-time reconnaissance, with a twenty-four hour loitering capability. Specifically, the Predator was designed to orbit a target area for an extended period of time, take high-resolution photos of ground targets, and transmit them back to its operators. In contrast to the fully autonomous Global Hawk, the Predator is controlled in flight by a ground operator.

In the spring of 1995, the Predator underwent a proof of concept demonstration as it participated in Roving Sands, an annual joint air defense exercise. The Predator performed so well during this exercise that the Air force decided to deploy four of the UAVs to Albania in support of military operations in Bosnia in July of 1995. This deployment occurred only 18 months after the initial contract was awarded. The Predator program proved its worth in Bosnia by transmitting real-time reconnaissance information directly to shooters, considerably reducing the sensor-to-shooter cycle.

Based on its success and operational utility in Bosnia, the decision was made to forgo the typically required System Development and Demonstration (SDD) phase of acquisition. Instead, the program would be modified over time, as technically and financially feasible. Feedback from the operational users would be incorporated incrementally to upgrade the capabilities of the system (Drew 2005; Federation of American Scientists 2002)—in other words, program managers were to take a spiral development approach.

In 1996, the first upgrades to the initial design were completed, primarily in response to operational difficulties in Bosnia. For example, the first Predators were not equipped with radar systems and, consequently, had to fly beneath cloud cover to perform their missions. Flying at a low level increased the vulnerability of the craft to both enemy fire and mechanical failure. Two of the Predators were lost, one for each of those reasons. Hence, the Predator was upgraded with a synthetic aperture radar (SAR) and Electro-

Optical/Infra-Red sensors. This new sensor suite enabled the Predators to see through clouds, and, as a result, it could operate more safely at higher altitudes.

In July 1996, Predator formally concluded the 30-month ACTD. The system was transferred to the U.S. Air Force's newly formed 11th Reconnaissance Squadron, while the program transitioned to low-rate initial production (LRIP) via the formal military acquisition process. In August 1997, less than four years after ACTD initiation, the Predator entered full production (Office of the Assistant Secretary of Defense (Public Affairs) 1997).

The Predator system was used continuously in eastern European operations through the 1999 Kosovo air campaign. The system was used to collect intelligence on targets and refugees, as well as to assess battle damage. At the same time, other Predator UAVs participated in various interoperability demonstrations with a Navy carrier battle group and a Navy submarine (The Defense Airborne Reconnaissance Office 1997). Following the success of the first Predator, known as Predator A (referred to in later variants as MQ-1 and RQ-1), the feedback and design modifications were leveraged in the year 2000 to create a new, and considerably larger air vehicle, known as Predator B (referred to in later variants as MQ-9 and RQ-9).

Predator B began flying in 2001 and is considerably larger than its predecessor. This larger UAV has increased capacities across the board—to include a turboprop engine, which provides substantially more electrical power for the vehicle's payload and increases its transit speed and time on station. In addition, the mission of Predator B has evolved by allowing it to carry out multiple missions simultaneously, and independently attack targets with Hellfire missiles, GBU-12 laser-guided bombs, or GBU-38 Joint Direct Attack Munitions (see Figure 9). The Predator can provide continuous monitoring of suspected target areas, while retaining a rapid attack capability if a window of opportunity arises (Drew 2005).



Figure 9. Predator B with Hellfire missiles.

As indicated by Figure 10, Predator A and B differ considerably in their characteristics and performance. Predator B, a new air vehicle, leveraged the accomplishments of the spiral approach taken during initial developments of Predator A.

	Predator A	Predator B	Percent Change
Approximate maximum takeoff weight (lbs)	2,250	10,500	467%
Maximum Air Speed (knots)	117	220	200%
Wingspan (ft)	55	66.0	120%
Maximum payload (lbs)			
Internal	450	850	189%
External	300	3,000	1000%
Approximate ceiling (ft)	25,000	50,000+	200%
Endurance (hrs)	40	30+	-25%
Primary mission	Persistent ISR and Strike	Multi-Mission ISR and Strike	

Figure 10. Characteristics of Predator A and B (General Atomics 2008).

Later, the platform was used extensively by the Central Intelligence Agency for data collection and tracking the movement of suspected terrorists. Immediately after the 9-11 attacks, for example, the Predator was deployed to Afghanistan to provide intelligence

and a strike capability in support of Operation Enduring Freedom. During both Operation Iraqi Freedom (OIF) and Operation Enduring Freedom (OEF), the Predator family of UAVs has been used extensively for surveillance and attacks in support of the military and CIA missions (to include Pakistan (ABC News 2005), and Yemen (Priest 2002)).

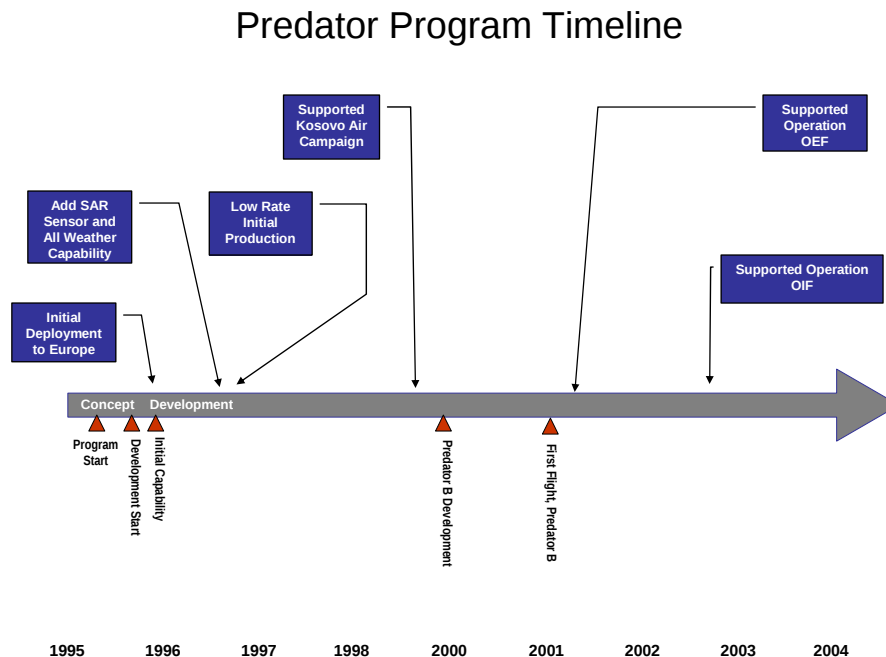


Figure 11. Predator Program Timeline

Results and Conclusions

The early, disciplined-development approach of the Predator allowed the weapon to be fielded quickly. After initial success in Bosnia, the program was transitioned rapidly from an ACTD to a deployed weapon. Due to the accelerated schedule, significant concurrency—in production, testing, evaluation and mission assessment—took place. The change in the Predator’s concept of operations, along with user requirements, was primarily driven by increasing operational experience (Drew 2005).

The Predator program was ideally suited for spiral development. The initial design was relatively simple and stable, and all technologies used in the program were fully mature.

Consequently, initial deployment and upgrades were inexpensive and manageable. By fostering an open line of communication between the design team and the operators, Predator evolved to meet the changing needs of the user. The Air Force successfully maintained a self-imposed cost constraint of \$5 million for a fully outfitted Predator A (The Air Force considers costs below \$5 million as expendable). This cost cap forced the program to make cost performance tradeoffs and to keep the program affordable (Drew 2005).

The Predator development provides a clear case of the adaptability of the spiral development process. Evolution occurred, not only in terms of the technical spiral development of the platform, but also in regard to its operational employment on the battlefield. Lt. Gen. Jack Hudson, Commander of the Air Force Aeronautical Systems Center, stated “*The Predator is a great example [of acquisition flexibility]. Warfighters identified a need and we [the Air Force] made incremental improvements to the Predator in short order, sometimes in a matter of weeks. We [the Air Force] develop them, test them and have them in the field*” (Kaufman 2008). Feedback from extensive use in OIF and OEF will drive future development and improvements, enabling the most recent technologies to meet the most urgent needs of the user.

B. Acoustic Rapid COTS Insertion (A-RCI)

Background

The Acoustic Rapid COTS Insertion (A-RCI) program displays how the spiral development process may also be applied to the modernization of legacy systems or subsystems. The impetus for this program began in the mid-1990s, as the Navy's submarine acoustic superiority over potential threats was rapidly diminishing. This program set out to once again reassert dominance in this field, but within the post-



Cold War environment of shrinking military budgets. Estimates for designing and developing unique systems to meet the military specifications were high—\$1.5 billion for research and development, and \$90 million per ship-set for implementation. The Navy could not afford this level of investment, and instead chose to pursue an incremental improvement strategy. Overall, the A-RCI program has been heralded as an unbridled success by the Navy that has brought about “astounding cost reduction, dramatic improvement in technical performance, and an acquisition model that might have broad applicability across the DoD” (3)(Boudreau 2006).

Program Description

The A-RCI program, designated AN/BQQ-10, was a four-phase program for transforming three legacy submarine sonar systems (AN/BSY-1, AN/BQQ-5, and AN/BQQ-6) into a single system. The program's acquisition strategy would utilize more capable and flexible Commercial-off-the-shelf (COTS) components as the basis for a sonar system that is far more capable and flexible than earlier designs. The program would also implement a Modular-Open-Systems Approach (MOSA) to reduce future implementation costs. Using this configuration, this system would allow a “plug-and-

play” format that would allow seamless and efficient upgrades to occur frequently, with little or no impact on submarine scheduling—making it an ideal candidate for spiral development (Boudreau 2006).

The A-RCI program’s spiral development approach enables the Navy to update the hardware on a two-year cycle, while the software is updated annually to create a new software baseline. Using this approach, the Navy can continue to efficiently leverage the advances in the dynamic commercial technology market to consistently provide the fleet with near-state-of-the-art processing capability (Rosenberger 2005).

The initial A-RCI technology insertions eliminated most of the custom cards used in the system’s initial configuration. This immediately and dramatically improved the performance of the operator’s displays, increased the system’s reliability, yet kept development and acquisition costs low. Moreover, programs for the hardware components could now be written in a higher-level language, instead of at the tedious assembly level previously required. Programmers could now devote more time to the system’s performance, instead of dealing with details of the hardware interface. With subsequent technology insertions in 2002 and 2004, the program was able to transition to the then-current commercial processors, the Intel XEON-based servers running at even higher clock speeds (Kerr 2004).

Results and Conclusions

The A-RCI program proved that the spiral development process could be an effective means to upgrade legacy systems. Continuous improvements, through incremental spirals that follow a knowledge-based approach, allow for significant increases in capabilities while keeping costs low. Specifically, through



2004, using its spiral technology insertion approach, the A-RCI program enabled a 10x

increase in system throughput and an 86% reduction in hardware cost per billion floating point operations per second, in a six-year period (Kerr 2004). As a result of the increasing reliability of the commercial systems, the Navy introduced a pilot program to test the concept of a Maintenance-free Operating Period (MFOP) for the A-RCI program. The pilot program's goal was to eliminate the need for maintenance of the A-RCI system while the submarine was underway; all maintenance would be deferred to the next in-port period. Of the four submarines that participated in the testing over the course of one year, no maintenance was required in any of the four—exceeding everyone's expectations. Furthermore, system operational availability improved. The mean-time-to-repair decreased by an order of magnitude, from 20 minutes to 2 minutes, using the embedded spares approach (Kerr 2006).

The A-RCI program addressed the challenge of modernizing the Navy's sonar capability while under severe budgetary pressure. With its innovative spiral approach, the Navy was able to significantly improve the fleet's sonar performance by leveraging the rapid advances in commercial computer technology, while at the same time keeping development and support costs low. Furthermore, the modular open systems approach allowed fielded systems to be updated seamlessly and in a cost-effective manner. The Navy was also able to put in place an extremely effective Performance-based Logistics (PBL) contract with the system developer. Leveraging the two-year spiral upgrade cycle, the contractor has developed an innovative approach to minimize the required inventory while exceeding the fleet's requirements and steadily reducing the costs of repair by an estimated 32%, based on the then-current costs (Gansler 2006). The combination of these strategies—spiral development, COTS, and MOSA—created a synergism that reduced development cycles to a fraction of their former figure.

C. Global Hawk

Background:

As the mission of the U.S. armed forces continues to evolve in the post-Cold War era, the military has relied more heavily upon the use of Command, Control, Communications, Computers and Intelligence (C4I) to act



as a force multiplier. An important component of C4I is unmanned aerial vehicles (UAVs). The Global Hawk RQ-4A and B variants are fully autonomous reconnaissance UAVs that have been used extensively in both Iraq and Afghanistan. The military chose the Global Hawk as one of the test beds to assess the feasibility of the spiral development process in light of the military's historic difficulty in developing UAVs. As noted by one study, "the United States has seen a three-decade-long history of poor outcomes in unmanned aerial vehicle (UAV) development efforts. UAV and tactical surveillance/reconnaissance programs have a history of failure involving inadequate integration of sensor, platform, and ground elements, together with unit costs far exceeding what operators have been willing to pay" (Drezner 2002b). In the case of the Global Hawk, the military desired the development of a feasible concept vehicle as quickly as possible.

The Global Hawk RQ-4A, also identified as the Conventional High Altitude Endurance (CONV HAE) or Tier II+ UAV, was the DoD's attempt to build an unmanned, fully autonomous, reconnaissance air vehicle. Global Hawk was envisioned as the primary platform for missions requiring long-range deployment, wide-area surveillance, and a long sensor dwell-time over the target area. Global Hawk was to be deployable from

outside the theater of operation, and to immediately provide extended on-station time in low- to moderate-risk environments in order to provide imagery of high-threat locations using electro-optical (EO), infra-red (IR), and synthetic aperture radar (SAR) sensors. Unlike prior UAVs, the Global Hawk was outfitted with a variety of survivability features, including the capability to operate at high altitudes and with built-in self-defense measures (The Defense Airborne Reconnaissance Office 1997).

Program Description:

Global Hawk was initially developed as an Advanced Concept Technology Demonstration (ACTD) program. As an ACTD, the primary purpose of the program was to leverage technology demonstrated in real-world situations to evaluate its viability as a full-fledged military acquisition program. Because this program was designed from the onset to adhere to spiral development principles, the most important goals were to remain within the required **\$10 million per unit flyaway price** and to keep the program on schedule. The plan was to use the first spiral to provide a base-line capability, while using additional spirals to rapidly insert additional capabilities into production when ready. To accomplish these goals, the program office was willing to allow competing firms to trade all other performance goals as necessary to meet cost and schedule parameters (Drezner 2002a; Johnson 2002).

The Defense Research Projects Agency (DARPA) released the Solicitation for this UAV project in April 1994 and awarded the Teledyne Ryan team the contract in May 1995. The first Global Hawk RQ-4A prototype completed its first flight on February 28, 1998. After initial flight testing, a second Global Hawk was produced in November 1998 that included a sensor payload. Trials for its military application began in 1999. The rest of that year saw several setbacks for the Global Hawk program, as the second prototype was lost due to “an erroneous *flight termination* test signal that had been sent from Nellis AFB, Nevada; while a high-speed taxi accident at Edwards AFB set back AV-3 in September 1999” (Roberts 2006). Despite these setbacks, the Global Hawk maintained its initial development schedule (presented below in Figure 12). In March 2001, based on the successful demonstrations and operational deployments of demonstrator aircraft, the

DoD approved the Global Hawk for a concurrent start of system development and low-rate initial production of six air vehicles. At that time, the Air Force planned both to use spiral development to develop more advanced capabilities as well as to acquire 63 air vehicles (GAO 2004).

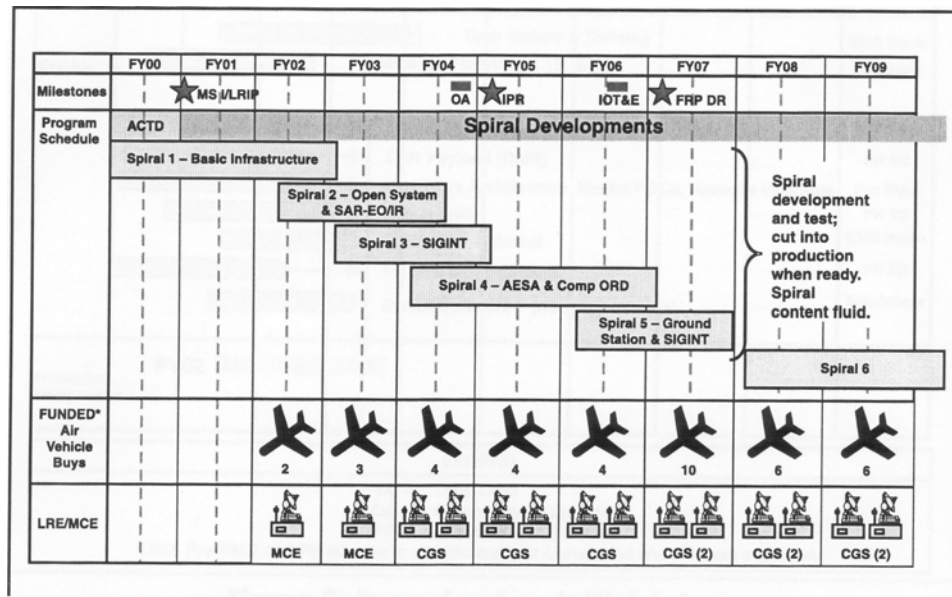


Figure 12. Global Hawk's Initial Development Schedule.

Following 9/11, the existing fleet of Global Hawks was hurried into operational service for the initiation of Operation Enduring Freedom (OEF). It would also be used extensively in Operation Iraqi Freedom (OIF). While still in the development phase, the Global Hawk would go on to log over 3,000 flight hours, a majority of that number being operational missions in support of OEF and OIF. The Global Hawk platform has been in continuous service since its initial operational status and continues to serve in both Iraq and Afghanistan. Overall, the Global Hawk took little more than six years to develop from initial solicitation to first operational fielding of the system (Northrop Grumman Global Hawk Program 2006).

During its service in combat operations, the Global Hawk RQ-4A provided the military with a vast amount of real-time intelligence.

With just one air vehicle deployed, the system was credited with identifying 38% of Iraq's armor and 55% of the time-sensitive air defense targets using electro-optical (EO),

infrared (IR), and synthetic aperture radar (SAR) images to target Iraqi forces. These early combat deployments demonstrated the effectiveness of carrying multiple sensor capabilities on the same platform. (Coale 2006)

Following the RQ-4A's operational success, the Air Force decided to design a new, larger and more capable variant of the Global Hawk, known as the RQ-4B. Originally, the RQ-4B components were to be 90% compatible with the A model. Desiring even more capability, the Air Force decided to design a significantly larger B variant. Ultimately, the B variant, when compared to the A, could carry a 50% larger payload, fly for two hours longer and retain the approximate 10,000nm range (Figure 13, below, compares the key characteristics of the two aircraft). The development of the RQ-4B project was to be funded with the original budget for the 4A; however, at the same time, the Air Force relaxed the unit flyaway cost requirement.

Key characteristics		
	RQ-4A	RQ-4B
Payload capacity	2,000 pounds	3,000 pounds
Take-off weight	26,750 pounds	32,250 pounds
Wingspan	116.2 feet	130.9 feet
Fuselage length	44.4 feet	47.6 feet
Endurance	31 hours	33 hours
Time at 60,000 feet	14 hours	4 hours
Average speed at 60,000 feet	340 knots	310 knots
Approximate range	10,000 nautical miles	10,000 nautical miles

Figure 13. Key Characteristics of the RQ-4A and RQ-4B (GAO 2004)

As the focus of Global Hawk acquisition shifted from Model A to Model B, the program was restructured in March 2002. The new strategy included 51 air vehicles; of these 51 air vehicles, 7 were to be constructed as RQ-4As and 44 built as RQ-4Bs (GAO 2004). The development period was extended from 7 years to 12 years, while the procurement period was shortened from 20 years to 11. As a result, the funding profile changed dramatically—the RDT&E funding requirements increased, and are now spread over a longer (12 yrs) development timeline. Conversely, in order to accommodate a shorter (11 yrs) procurement period, the procurement funding requirements were compressed radically (Henning 2005). In December 2002, the program was again restructured as a result of the Air Force’s request to change the Global Hawk’s mission configuration; instead of buying all RQ-4Bs with multiple intelligence capability, the RQ-4Bs would now have a mix of multi-mission and single-mission capabilities. Additionally, these two restructurings increased low-rate initial production quantities to 19 (subsequently increased to 20) air vehicles: 7 RQ-4As and 12 (now 13) RQ-4Bs (GAO 2004). As of 2006, development and production of RQ-4A was complete. RQ-4B currently remains in production.

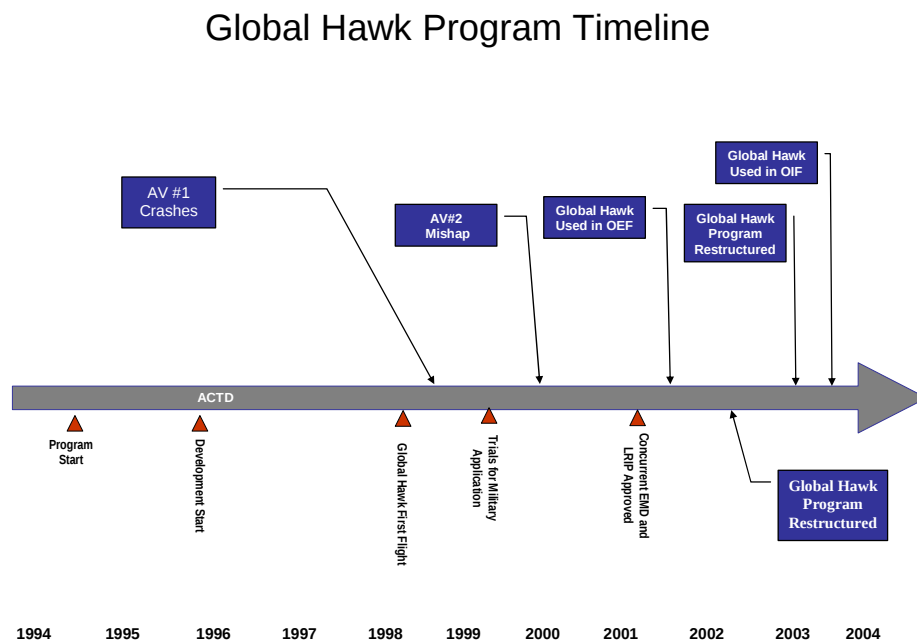


Figure 14. Global Hawk Program Timeline

Results and Conclusions:

Many independent commentators have regarded the Global Hawk RQ-4A program as a great success. It is the first automated air vehicle to receive the Federal Aviation Administration's national Certificate of Authorization, allowing it to fly anywhere in U.S. airspaces without prior authorization. The vehicle is also the "first unmanned aerial vehicle to achieve a military airworthiness certification" (Northrop Grumman Global Hawk Program 2006). The Global Hawk RQ-4A was the first UAV to fly across the Atlantic Ocean and later became the first UAV to fly across the Pacific Ocean.

The success of the Global Hawk RQ-4A program validated the spiral development process: despite notable setbacks, the program's flexibility allowed the program to develop with only modest changes to the initial budget and time constraints. The Global Hawk program effectively shifted requirements between spirals to avoid development bottlenecks stemming from delays in technological maturity. Spiral development also allowed the program to be accelerated quickly to meet a new challenge, principally OEF. Finally, Global Hawk proved that incremental deployment of capabilities was feasible.

The restructured Global Hawk program eventually faced significant cost and schedule difficulties. The program's problems stemmed principally from two sources: an unrealistically low initial estimate of cost and the RQ-4B program restructuring. The first problem arose because no technical surveys were undertaken to understand the true costs and timeline needed for the capabilities requested. The costs for the program were, in large part, based on what the Air Force was willing to pay for the Global Hawk's theoretical capabilities. The second problem arose from uncontrolled requirements creep, without a re-baselining of the project. For example, the program insisted on including a capability, known as Automatic Contingency Generation (ACG), in the first baseline (instead of the first production lot as originally planned). The ACG is a software program to autonomously re-route the air vehicle during an inflight emergency to an alternate airfield, while avoiding no-fly zones. However, the complexity of the ACG was not fully understood, and, consequently, a significant amount of additional time was spent trying to field the ACG capability in the first baseline. As a result, the fielding of

the first production hardware and training courses were both delayed (Coale 2006). This capability could have easily been deferred to a future software release.

It may be argued that the Global Hawk program ceased to follow a spiral development path when the decision was made to significantly increase the size (it was 50% larger) and to enhance the capabilities of the second Global Hawk variant, the RQ-4B, while eliminating the cost targets. Despite the commonality in names, the RQ-4B version was virtually a new development that only shared broad characteristics with the A variant. The RQ-4B is a classical case of requirements creep; as a result, as of September 2007, the R&D cost increased over 270% (GAO 2008). Additionally, as indicated by RAND in one study on the effectiveness of the ACTD process and the Global Hawk: “The constrained budget and tight schedule of the ACTD does not address the complete development needs of a major defense system. An ACTD is focused on demonstrating military utility, not the operationalization of a system”(Drew 2005). As a result, lifecycle costs, with all of the support implications, were not a major consideration during the ACTD portion of the Global Hawk program.

Even with its initial problems, which were not associated with the process of spiral development itself, the Global Hawk RQ-4A experienced no overall cost growth, nor were there any major delays in its scheduling. The results for the RQ-4B are less clear—as cost growth in the Global Hawk program was considerable with regards to the redesigned RQ-4B. A simple analysis of the situation by Michael Sullivan, GAO director of acquisition management, is “They were able to build the A model pretty well. But they added requirements that have now put them behind in cost and schedule” (Erwin 2006). Originally, the RQ-4B was designed only to be a slightly larger and more capable version of the RQ-4A, at a small increase in price. Instead, however, the B model grew significantly in both size and cost.

The RQ-4A followed the spiral development process along with a proper knowledge-based foundation. Although the spiral development process was not implemented flawlessly, this test bed provides important information vital for future implementation of this policy. Notably, the experience proved that the process was able to overcome the

overly optimistic initial expectations to deliver a widely praised system that was both on time and on budget. A testament to the DoD's admiration of the program was the subsequent decision for a redesign of the RQ-4B into an even a larger and more sophisticated model than originally envisioned. Unfortunately, this overhaul was not properly planned, and the program ceased to follow a knowledge-based approach to development. The perils of pursuing a development project without sufficient knowledge are highlighted by the ballooning cost of the program and the delayed delivery schedule. Measured management oversight is needed to restrain requirements creep. Finally, DoD weapons programs must learn to accept interim capabilities that will be increased incrementally.

D. Littoral Combat Ship

Background



The focus of defense in the twenty-first century has shifted away from the traditional threats posed during the Cold War towards unpredictable and asymmetric threats. The U.S. Navy now requires more mobile and adaptive forces to respond to a

variety of new threats and operational goals. One prominent new concern is the ability to control various strategic points of interest along coastal waterways and inland rivers, facilitating green water operations.

To address these coastal operations in green water, the Navy has chosen to build a new surface combatant, known as the Littoral Combat Ship (LCS). The mission of the LCS is to counter diverse “asymmetric” threats such as coastal mines, submarines, global piracy, and terrorists. Secondary missions include homeland defense, maritime intercept operations, and support of special operations forces. The LCS has the capability to perform tasks such as intelligence gathering, scouting, and ground combat support using helicopters and UAVs. The LCS was designed to share tactical information with other Navy aircraft, ships, submarines, and joint units. This platform, optimized for shallow water, principally operates within 100 miles of shore to protect coastlines but retains the capacity to be deployable across the ocean.

The Navy’s design concept for the LCS consists of two distinct parts: the ship itself and the mission package it carries and deploys. The ship is referred to as the “seaframe” and

consists of the hull, command and control systems, launch and recovery systems, and certain core systems like the radar and gun. The mission packages are intended to be modular in that they will be interchangeable on the seaframe. Each mission package—based upon the use of a modular, open systems architecture to add further flexibility and capability to the design—will consist of systems made up of manned and unmanned vehicles and the subsystems these vehicles use in their missions (O'Rourke 2008b). An LCS ship will have the ability to quickly adapt to changing mission requirements by swapping mission-specific modules that include hardware, additional systems components and personnel (Defense Industry Daily 2008). Being reconfigurable allows the LCS to preserve a single mission focus while retaining the ability to change that mission on demand. The ship retains its core capabilities regardless of the installed module.

The Navy pursued a highly aggressive development program for the LCS, which sought to significantly reduce the time needed to design and build a surface combatant ship. These gains would accrue from the use of a Commercial-off-the-Shelf platform (the basis for the ship's hull), Cost as an Independent Variable (CAIV) (allowing capabilities trade while enforcing spending caps), and spiral development—to fulfill the Navy's strong desire to introduce new capabilities in later development spirals, when the requirements demanded it (Hamilton 2006). In spite of this ambitious attitude, the LCS program (to date) has been a highly complex endeavor and has been plagued with difficulties.

The DoD awarded the first LCS contracts to both Lockheed Martin and General Dynamics in May of 2004. Their teams were asked to prepare initial designs which would be further down-selected for the Detailed Design & Construction phase of acquisition (both teams used Commercial and foreign off-the-shelf designs—and subcontractors). Preliminary designs gave the LCS a displacement of roughly 3,000 tons, or half of a U.S. Coast Guard Cutter; a maximum speed of roughly 45 knots, or nearly 50% faster than other navy surface combatants; and a reduced crew requirement of only 75 sailors, compared with the more than 200 for a comparable Navy Frigate. In addition, the Navy was seeking to procure ships in numerous spirals (called flights); each flight could then have the latest technologies and available improvements by taking advantage

of the spiral development approach to improve the platform design over time (Drew 2005; PEO Ships 2008). The combination of the spiral development approach, along with the use of mission-specific modules for flexibility and adaptability, makes the LCS program notably different from any other Navy ship-building program.

Program Description

The Navy's strategy was to break the LCS acquisition into "flights" for the seaframe and "spirals" for mission packages in order to develop improvements while fielding technologies as they become available. The initial flight of ships, referred to as Flight 0, was intended to serve two purposes: to provide a limited operational capability and to provide input to the Flight 1 design through experimentation with operations and mission packages. Flight 1 was to provide more complete capabilities, but would not serve as the sole design for the planned buy of more than 50 LCSs. Flight 0 was planned to consist of four ships of two different designs and would be procured in parallel with the first increment of mission packages—Spiral Alpha (GAO 2005).

Consistent with this spiral approach to development of the LCS, in FY05 Congress approved the Navy's plan to fund the construction of the first two LCS seaframes using research and development funds as opposed to shipbuilding funds. In December of 2004, Lockheed Martin was awarded a contract for the Detailed Design & Construction phase for LCS 1.

In October of 2005, an additional contract for Detailed Design and Construction was awarded to General Dynamics for LCS 2. The Navy's acquisition strategy was to develop and build the first spiral of 15 ships, known as Flight 0, using these two designs. Subsequent flights could then be competed between them. While specifics of the competition have yet to be determined, it is probable that this acquisition would not be a winner-take-all scenario; the firms would likely have an opportunity to compete for construction at each additional flight, leading to the possibility that the winner of the design competition may not be the winner of all the construction work (Jean 2007).

Each team had a very different design approach for their version of the LCS, with Lockheed Martin's design based on what is known as a semi-planing monohull, and General Dynamics' design based on an aluminum trimaran (United States Navy 2008). In FY2006, Congress funded the procurement of LCSs 2, 3, and 4, in addition to establishing a \$220 million per unit procurement cost limit on the fifth and sixth LCS seaframes—plus adjustments for inflation and other such cost fluctuations. In this budget, however, Congress required that the acquisition of future LCSs be contingent upon the Navy certifying that a stable design for the LCS platform had been achieved (O'Rourke 2008a).

The LCS program was having severe difficulties staying on schedule and on budget due to significant requirements and design changes and the desire to incorporate them into



Flight 0. In spite of these, Congress continued to support the program, and in FY07 funded the procurement of LCS 5 and 6. In response to a Navy request, Congress also amended the existing unit procurement cost cap for all LCS ships (beginning with the fifth) from \$220 million to \$460 million, but this change alone appeared not to be enough. In part because of the aggressive schedule, along with other requirements for the LCS program, the program experienced several delays in design, development and production. On the LCS 1 ship, repeated and large cost increases caused the Navy to issue a stop-work order for LCS 3 ship in January 2007 (O'Rourke 2008a).

In March of 2007, the program was restructured, but LCS 5 and 6 were subsequently canceled. Congress reasoned that this funding could be used to cover cost overages on existing LCS contracts. The Navy announced that the existing stop-work order on LCS 3 would be rescinded, once Lockheed Martin's contract was restructured from a cost-plus to a fixed-price, incentive-fee contract. Additionally, General Dynamics' contracts were also to be restructured to fixed-price, incentive-fee contracts. The Navy reiterated that it

would use an operational evaluation to choose the final design, and subsequent units would be procured using a full-and-open competition process.

LCS Program Timeline

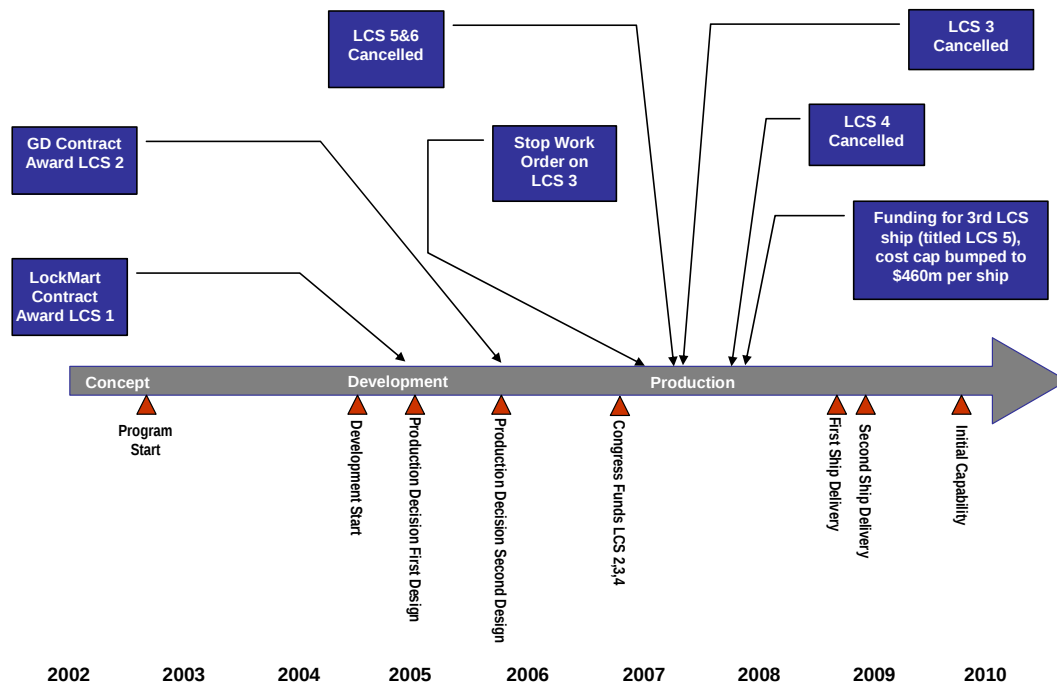


Figure 15. LCS Program Timeline.

Despite the Navy's noble efforts to salvage the ships that remained under the LCS program, set-backs, schedule delays, and cost overruns continued to plague the program. The Navy and Lockheed Martin could not reach an agreement on how to restructure the acquisition. In light of these efforts, only one month after the announcement of a program restructuring, LCS 3 was terminated. To preserve the spiral intent of the program, Lockheed was permitted to continue the development of technologies that were to be included with LCS 3 with the hope that they could be integrated into future LCS ships built by Lockheed. Finally, General Dynamics, like Lockheed, could not reach an agreement with the Navy on how to successfully re-negotiate their contract. As a result, LCS 4 was also canceled in November of 2007. In FY2008, Congress funded the procurement of one more LCS (called LCS 5, but it would actually be the third ship), and

notably reduced the Navy's FY funding request for the program overall, while amending the LCS seaframe per-unit cost cap to \$460 million per ship for all ships procured in FY2008 and beyond (O'Rourke 2008b).

Results and Conclusions

From its inception, the Navy's LCS Program had even more challenges than the typical DoD Acquisition Category-1 program. The resultant program did not address the challenges well and has been a difficult undertaking thus far; it can not be considered a well-managed program. We believe the root causes were an overly aggressive schedule coupled with unrealistic cost estimates. For example, overly optimistic cost estimates on LCS 1 and LCS 3 underestimated the changes that would be required to meet military requirements, and drove subsequent cost increases from \$216m in FY05 to \$531 in FY09. These increases ultimately lead to the stop-work order on LCS 3. Figure 16 depicts cost growth estimates for the LCS 1 and LCS 2 sea frames.

	FY 2005	FY 2007	FY 2009	FY07 % Change	FY09 % Change
LCS 1	\$215.5	\$274.5	\$537	27%	95%
LCS 2	\$213.7	\$278.1	\$507	30%	82%

Figure 16. LCS Cost Growth Estimates (O'Rourke 2008b).

The schedule was equally unrealistic. A typical DoD Acquisition Category-1 program takes roughly 14 years from inception to production. The LCS attempted to accomplish this feat in just 2 years. Furthermore, the proposed LCS designs were based upon the assumption that the ships would be based on proven Commercial-off-the-Shelf (COTS) designs. In reality, these COTS design did not meet all of the detailed Navy specifications; but, rather than meeting these incrementally, the Navy insisted on meeting all of them for LCS 1 and 2.

Much of the difficulty in meeting Navy specifications has been attributed to the application of an updated version of the Naval Vessel Rules (NVR), which are construction standards for shipbuilding created by Naval Sea Systems Command

(NAVSEA) and the American Bureau of Shipping (ABS). These rules, which are frequently updated, address many key aspects of ship design, such as safety, stability, structural integrity, propulsion, etc. In the case of the Lockheed Martin-designed LCS 1, the newest version of the NVR was not released until after its original design was completed (O'Rourke 2008b). Figure 17 demonstrates the major discrepancies between the draft version of the NVR (as circulated during the design phase of LCS 1) and the actual version that was released.

	Draft Feb 2004 NVR			21 May 2004 NVR		
NVR Part	Pages	# Tech Rqmts	# of Sections	Pages	# Tech Rqmts	# of Sections
Part 0 -Intro/General Provisions	166	1537	9	184	713	11
Part 1 -Hull and Structure	140	1042	4	220	1643	6
Part 2 -Propulsion and Maneuvering	238	2265	2	628	6386	7
Part 3 -Electrical Systems	270	2383	5	417	2967	5
Part 4 -Control and Navigation	210	1680	4	233	2229	5
Part 5 -Auxiliary Machinery Sys	199	1409	6	765	9223	15
Part 6 -Habitability and Outfit	421	2217	14	156	2410	16
Part 7 -Military Environment	10	24	3	17	19	3
Part 8 -Materials and Welding	650	2704	18	587	3845	20
Total	2,304	15,261	65	3,207	29,435	88

Figure 17. Comparison of May 2004 and February 2004 NVR Specifications (Moosally 2007).

While both General Dynamics and Lockheed Martin worked hard to negotiate these standards and attempted to integrate them over-time, the ABS and the Navy were unable and/or unwilling to allow deviations from the standards.

Moreover, since building a ship requires precision sequencing that allows for just-in-time production of major sections of the ship, these changes had to be incorporated after assembly and delivery of these elements—significantly adding difficulty to the requirement changes. When coupled with the program's concurrent design and build

strategy, this fact alone severely limited the ability for either firm to accurately predict cost and schedule impacts.

The ambitious schedule and technical requirements for the program, in conjunction with real-time mission pressures, combined to place an extraordinary amount of strain upon both the program office and the contractors, ultimately undermining their effectiveness. The LCS program did attempt to use a spiral development approach. However, unrealistic assumptions, coupled with little flexibility in the Navy's requirements for the initial spiral, diluted the benefits.

E. Commercial Development of the INTELSAT Satellite

The International Telecommunications Satellite Organization (INTELSAT) has, since its inception in 1964, pursued development of its satellite vehicles by utilizing techniques akin to evolutionary acquisition and spiral development—before those strategies were fully developed. Although differences in these development processes exist, they also share many similarities. The INTELSAT example shows how spiral development can even be implemented successfully by an international government organization, with a market monopoly, to keep development costs low and acquisition schedules on time.

The International Telecommunications Satellite Organization (INTELSAT) has been the world's largest commercial satellite communications services provider since its creation. Formed as an international government organization to help facilitate satellite communications for the benefit of all nations, the entity was given an effective monopoly on the commercial satellite market due to the high cost of entry. Over time, however, it became feasible, and then even profitable, for commercial firms to enter the market and compete with INTELSAT. In the late 1980s, its historical role as a “non-profit international consortium, to provide satellite telecommunications services on a non-discriminatory basis to all nations [... was forced to] mov[e] rapidly toward its new role as a corporate telecommunications business competing for customers in a deregulated industry” (7-3297)(Nichols 2001). In 2001, the company transferred its assets to a private company in accordance with a congressional mandate that fully deregulated the communications satellite industry.

INTELSAT satellite development provides a useful comparison with the DoD acquisition process for two reasons. First, while INTELSAT was very successful at developing satellites quickly and efficiently, the DoD's record is more ominous. Cost overruns, technical delays and cancellations were common for the DoD in this high-risk area.

The key difference in outcome can be directly attributed to the knowledge-based approach that INTELSAT used. The second useful comparison lies in the oversight process. Both INTELSAT and the DoD have extensive external supervision. For INTELSAT, the “cumbersome nature of the intergovernmental decision-making process”

(5)(Hecker 2005) restricted its ability to respond rapidly to changes in the market. For the DoD, the large bureaucracy, along with the need for congressional approval of budgetary changes, greatly restricts responsiveness.

Even though it was originally a monopolist, INTELSAT followed an evolutionary acquisition approach to acquiring new satellites. Their strategy emphasized short development cycles and keeping costs low. During these years, it was noted as a “dynamic force [... whose] traffic growth and new service offerings have required six generations of new satellite designs [in the 21 years between 1965 and 1986], each offering ever-increasing capacity and introducing new technologies” (1461)(Bennett 1984). During this time period, total bandwidth increased 60 fold—from 50 MHz to 3,030 MHz; and the telephone channel capacity grew just over 561%—from 480 to 270,000 channels (1)(Jefferis 1989). INTELSAT, as do virtually all commercial satellite firms, continues to rely on short development cycles to respond to changing technology quickly, while keeping costs low. The newest satellite ordered by INTELSAT was announced in January 2007 and will be launched in 2009 (de Selding 2007).

The rapid development and deployment of commercial satellites was, and remains, in sharp contrast to the developmental path of many military programs. Military satellite development, in which “performance has been the overriding design criterion [... experiences] development times [of on average] 15 years” (1039)(Parker 2002). Military satellite programs rarely delivery projects on time or budget because such programs place a premium on quality that is promised by insufficiently matured technology. This trend continues today with the Transformational Communications Satellite (TSAT), designed to enable the doctrine of joint and network-centric warfare. Upon program initiation in 2004, “The DoD estimated [...] that it would launch the first satellite in April 2011. TSAT’s current [...] initial launch date has slipped to September 2014” (2)(GAO 2006c). Not only was the initial development period for the military satellite twice that of its commercial counterpart, but the commercial satellite development time is equal to the delayed period of the military satellite program. Moreover, it is likely that there will be further delays to the TSAT program as it moves forward. As long as the DoD continues

to design around specific requirements or immature technologies, it will continue to face significant cost growth and scheduling issues.

When INTELSAT submitted a request for a development proposal, it did not stipulate all end capabilities, let alone requirements. Their request would include basic desired performance parameters, along with optional features that may be technically feasible at that point in time. Responding firms had to provide an analysis of their “Must Bid” options, while they were able to respond to the “May Bid” options at their own discretion. INTELSAT considered the “Must Bid” options as “likely to be included at some stage during the lifetime of the project and by requesting detailed technical proposals, individually costed, the Board of Governors would be able to judge if and when they should be exercised” (1)(Silk 1989b). Even options deemed “Must Bid” would not necessarily be implemented on the final spacecraft. Further, “so as to maximize the benefit to INTELSAT, bidders were also requested to suggest alternative proposals that they considered would be attractive to INTELSAT” (3)(Silk 1989a). In this way, INTELSAT actively requested the developer’s input on a project and the possibility of applying new technology of which it was not aware.

The INTELSAT satellite development process stipulated the need for adaptability. In this way, satellites could add new capabilities after becoming initially available, once the necessary technology became mature. One such example is the INTELSAT VI, developed in the mid-1980s. This satellite “incorporated significant growth potential into its initial design. The inclusion of such growth capability in an initial design is unique as launch economics normally dictate finely tuned satellite designs, which maximize satellite capacity for a given launch weight constraint” (1468)(Bennett 1984). Although there is concern that the initial flights may not capture all of the value possible, “this growth potential gives INTELSAT the flexibility to easily use added launcher capabilities to introduce new and innovative services in order to meet the challenges of the future” (1468)(Bennett 1984).

Throughout all INTELSAT satellite development projects, there remained only one firm requirement: short development time. Most programs, such as the INTELSAT VIII, were

“procured on an aggressive three-year delivery schedule” (81)(Rush 1993). The limited development periods forced the development team to only use technologies that were proven effective and could be implemented quickly.

INTELSAT development tended to use mature technologies that were already space-proven. When the INTELSAT VII was developed in the late 1980s, most of its components were already commercially available. For the spacecraft bus, INTELSAT used the FS-1300, which “combines mature, flight-proven subsystems with a large structure and scaled-up power subsystem to create an economical, high capacity bus... that address the INTELSAT VII requirements in a cost-effective manner” (3)(Templeton 1989). Many of the individual components were augmented in the same way. The satellite’s Attitude and Orbit Control was commended: “all of the hardware is flight proven and off-the-shelf with extensive in-orbit experience” (9)(Templeton 1989), and this principle was generally applicable. Just as importantly, the program did not allow development of risky technologies to proceed. For example, the “Ion Thruster³ May Bid” option [on the INTELSAT VII] was not included [in the final design] since the technology was considered not sufficiently mature for inclusion on a large operational satellite” (3)(Silk 1989b).

Lessons Learned:

The experience of Intelsat proves that an institution that follows evolutionary acquisition and spiral development can have continued development success. This flexible acquisition process allowed a product to be constantly updated with the latest technological innovations. By using only space-proven, mature technologies in step with a knowledge-based acquisition method, cost and risk were kept to a minimum. Finally, the history of INTELSAT shows that while extensive external supervision is cumbersome, an entity can still pursue an effective acquisition process with a proper internal organization.

³ An ion thruster is a form of [spacecraft propulsion](#) that creates thrust by accelerating [ions](#) (a charged atom or molecule).

IV. Finding and Recommendations

The DoD has historically pursued acquisition development using the linear “waterfall” method. In the DoD’s experience, however, weapon programs frequently had a tendency to experience increases in costs, reductions in capabilities and delays in schedule with this method. In 2000, the DoD officially adopted a new acquisition strategy, Evolutionary Acquisition, to provide more flexibility in development and avoid past problems. The DoD’s preferred process to implement Evolutionary Acquisition is Spiral Development.

In spiral development, a weapon’s desired capability is known at program’s initiation, but the system’s requirements are refined over-time, with each successive spiral, based on feedback from the users and tests. Requirements for future increments depend upon technology maturation and user feedback from the initial increments. Overall, spiral development is a knowledge-based acquisition process that facilitates effective risk management.

Implementation of spiral development presents several formidable challenges to the DoD; when it’s applied to weapon system acquisition, spiral development changes everything throughout the acquisition process. We believe the challenges listed below arise from both internal and external sources, and must be overcome to successfully implement spiral development within DoD programs.

Challenges to Implementation

DoD Acquisition Community’s Culture is Resistant to Change

The DoD acquisition community’s culture has developed over the last 60 years; how that community collectively perceives goals, objectives, requirements and risk will not change overnight. Furthermore, we believe there is still a widespread lack of understanding regarding the purpose, and even definition of spiral development, which further hinders

its implementation. Therefore, simply identifying spiral development as the DoD's preferred process does not guarantee that a program will employ that strategy or, if it does, that it will be successfully implemented.

For spiral development to achieve its full potential, the acquisition workforce must fully internalize and embrace it. This will require a cultural change for senior leaders, as well as other program personnel. Leaders must consistently emphasize the process and highlight successful exemplars, so that the institution as a whole does not back-slide into old habits. Unfortunately, for the DoD, with its history and large, complex hierarchical organization, even when "the acquisition organization manifests a need to change form [...] its very form inhibits such change" (Nissen 2006).

Budgetary and Appropriation Processes are Not Structured to Support Spiral Development

To plan, execute, and fund its weapon system acquisition programs, the DoD relies primarily on three principal decision-making systems: the Joint Capabilities Integration and Development System (JCIDS), the Defense Acquisition System (DAS), and the Planning, Programming, Budgeting, and Execution (PPBE). Whereas specific events (these include validating requirements, receiving approval to start development or production) drive the JCIDS and DAS processes, the PPBE process is calendar-based. Furthermore, the budgeting process can take close to 2 years to get from beginning of the budget planning cycle to budget execution.

Spiral development, comparatively, is an innovative process, and its full benefits can only be realized when requirements can be shifted between spirals in order to always maximize the "bang-for-the-buck." For this strategy to achieve its full potential benefits, the budgetary and appropriations process must provide this flexibility, while ensuring the programs remain manageable and transparent from a regulatory perspective. However, Congress has not been inclined to fund this new type of acquisition model, which does not have firm end-requirements and may evoke a perceived loss of oversight. None-the-

less, spiral development can provide, through appropriate decision points, adequate oversight while enabling DoD acquisition to be more flexible and efficient.

The DoD must also change its internal practices. Currently, the Services have a propensity to fund and budget development projects based on how much they value the theoretical end product. This rewards system, however, does not always take into account the technical risks and costs associated with development. When programs begin to face technical difficulties, schedule slips, and cost overruns (as they often do), the DoD shifts resources from other projects to cover the shortfalls. As a result, the Department ends up partially and inefficiently funding many projects, instead of efficiently funding a few projects.

Regulatory Environment Impedes Spiral Development

The current regulatory system (DoD regulatory measures, along with the Federal Acquisition Regulations) is “simply not designed to deal with a program that changes constantly and swiftly. The result is that corporate decision-makers require that the program seek approval for each spiral, each time that it significantly changes, which means lots of briefings, reviews, and coordination” (Pingel 2003).

Under the traditional development process, extensive reviews are undertaken—as the project must meet program milestones. Full reviews, especially in preparation for the Milestone C production decision, could take a year or more of testing. For spiral development, however, the time from development to production is much shorter. Frequently, spirals may not end in operational spin-outs that significantly alter the specifications of the weapon. As a result, little utility is derived from comprehensive retesting. As such assessments are pursued, the cost and time to development are significantly increased without a comparable advance in the understanding of the weapon’s quality. These reviews also delay the fielding of spin-outs, decreasing the effectiveness of the spiral development process.

Programs Still Find it Hard to Control “Requirements Creep”

In order to capture the benefits of reduced development time and costs from spiral development, project managers must ensure that “requirements creep” does not occur. The flexibility of this process allows a project to rapidly adapt to new threats; “however, this benefit must be kept in check to ensure there is not a requirements potluck” (Henning 2005). While each program has a defined end-capability, each spiral has a defined goal and objective. Only under extreme circumstances should the program be allowed to evolve away from its original end-capability, or a spiral from its end goal.

Continuous assessments should be done to ensure that the project is on track to fulfill its defined goal. If requirements discipline is not maintained, then development time and costs will begin to “spiral” out of control as projects try to become all-encompassing, all-capable systems. Adding a new requirements, especially those supporting capabilities not originally envisioned for the project, will cause costly development revisions that undermine the effectiveness of the process. Although spiral development is flexible, it is not infinitely so. A careful assessment must be made before new requirements are added to a spiral development project and must be determined with the overall goal of the project in mind.

Projects Continue to Start without Sufficient Knowledge

Many Weapon systems programs do not follow a knowledge-based development process that exclusively uses mature technologies. The GAO, in its FY 2008 *Assessment of Selected Weapons*, assessed the only 12% of the major programs it reviewed had all of their critical technologies mature at the development start (which the GAO identifies as a best practice) (GAO 2008).

Frequently, overly optimistic expectations for technological development are still proposed by contractors and endorsed by the acquisition community. Feasibility analyses tend to be limited for a number of reasons. A prominent example is the need to secure initial funding for a program. The desire for projected end-state capabilities is tempting.

However, programs that proceed based on immature technologies are much more likely to experience significant cost growth and schedule slippage, as previously discussed.

Spiral Development Requires Extensive Communication and Collaboration among Stakeholders

Communication between the many stakeholders involved with weapon system acquisition (the acquisition community, the contractor and the user community) still tends to be inadequate, even when leaders are using a linear process. For example, difficulties in developing precise contract language still arise from a lack of communication between the developers and the weapon system user. Developers still have difficulty defining requirements with specific guidance to the contractor that are not overly restrictive or that stifle innovation. User feedback is limited, and often comes too late in the process to make a discernable difference. These issues, if not addressed, will only manifest themselves more with spiral development—especially when several spirals are operating concurrently.

If Not Properly Managed, Spiral Development Can Create Logistics Complexity

A final area of particular concern is the collaboration between the development and logistics community. Most of a system's lifecycle costs are accrued in providing logistics support after the weapon system is deployed. Spiral development can exacerbate these problems by purposefully requiring the continuous fielding of several versions of a weapon system. The program logistic costs can increase significantly as the number of fielded variants increases, especially if the funding is not made available to retrofit the systems to a common baseline.⁴ Having blocks of dissimilar vehicles, with different designs, subsystems, and components, can also make contracting for long-range support, as well as preparing mission-ready spares packages, more difficult (#1570) (Drew 2005). Although many of these problems can be mitigated through careful planning and

⁴ For systems fielded in large numbers, such as the F-16 or F/A-18, this is already the case—with the many block configurations these programs support.

configuration control, many in the logistics community are wary of the potential impacts from a poorly executed spiral development program.

Recommendations

The DoD must gain control of and shorten weapon system development cycle time in order to provide the affordability, agility, and responsiveness that the military will need to face the challenges of the twenty-first century. By implementing a true “spiral development” process as the norm for development, the DoD can achieve lower cost, lower risk and faster fielding. Development should be based on proven mature technology, and realistic budgets and funding. Moreover, spiral development requires better planning and discipline, as well as improved communications and collaboration between the developer, user, contractor, tester, and logistician in order to achieve success.

We offer the following specific recommendations for the DoD if it is to better implement spiral development:

1. Use Mature Technologies and Knowledge-based Practices

In general, development programs that follow a knowledge-based acquisition strategy using fully mature technologies reduce development costs, risks, and development cycle time. Specifically, the DoD has demonstrated that when it followed this approach (using mature technologies), it had more successful outcomes that were similar to commercial companies (GAO 2002). In order to maximize the effectiveness of spiral development, all spirals must follow this knowledge-based approach. Each block should be based on proven technology, with a five-year cycle goal from the start of system development to achievement of the initial operating capability; it should focus only on those elements that will field capabilities during that block’s period.

The DoD already has a policy that mandates that new projects should only begin when all technologies are mature. However, this is often not the case, and numerous programs are funded that do not follow this guideline. Designated Senior Acquisition Executives need

to better enforce this policy and not approve programs until they can demonstrate that all critical technologies are fully mature (i.e., at least TRL-6).

2. Program Must Have Greater Requirements Flexibility

To effectively implement spiral development, users must allow more flexibility with their requirements so that developers can make the needed cost, performance, schedule trade-offs as they arise. These revisions may change the outcome of a specific spiral, but not that of the final required capability. Current DoD programs do not generally demonstrate this adaptability until budget overruns require action. Users must also trust that the programs will continue as planned, and be willing to accept less-capable systems (the “80% solution”) earlier that will then evolve to desired capability in later blocks. However, cost must be viewed as a design constraint—otherwise, program baselines may be less well defined.

3. Address the Budget Challenges

Development teams need to be able to take advantage of opportunities as they arise or to avoid technical difficulties as necessary. As requirements shift between spirals, programs need greater latitude to realign funds within the scope of the total program, if necessary. Effective oversight can be maintained through the more thorough pre-planning stage, along with periodic milestone reviews.

When using spiral development, program managers will find that requirements evolution will make it more difficult to develop program cost estimates; however, it must be done. Programs must continue to budget for R&D in future blocks, even while the current block is underway.

4. Adapt Test and Evaluation Processes

The DoD’s testing and evaluation policies and procedures were designed to support the legacy acquisition process with its single-stage development. With spiral development, systems are developed, acquired, and deployed in stages. Therefore, testing and evaluation policies and procedures must be evaluated and adapted to support spiral

development and its multi-staged approach. The goal of the testing and evaluation programs should be to explore the system's (and its components') strengths and weaknesses to provide feedback to future spirals (Nair 2006). Early operational testing is still important, but the test community must view partial capability enhancements of early blocks as a system success.

Those programs that make satisfactory progress should be fully supported. Those programs that do not exhibit such progress should be reevaluated and, if appropriate, should be restructured or cancelled.

5. Incorporate Logistical Concerns Early in the Development Process

Evolutionary acquisition and spiral development produce fielded weapons much faster than under the traditional method. These systems are also frequently updated with each subsequent spiral. Although this process can provide the warfighter with more capability sooner, it can create greater demands on logistics planning and support. Different system configurations can impact the provision of spares, training, and maintenance. Minimizing these impacts requires the early and consistent involvement of logistics planners. Logistics planning must be fully integrated—from the program's inception through all the spirals; and effective communication is vital.

Although some equilibrium may have to be reached between faster fielding and lifecycle logistics considerations, we believe that shorter cycle times should generally prevail.

6. Ensure that Programs are Properly Managed

By their nature, programs that use a spiral development strategy will generate a higher volume and intensity of program office and contract activity. There may be several spirals under contract concurrently. Furthermore, the programs should maintain and, if appropriate, exercise the option of competition (prime and/or subsystem) at each block—depending on performance and cost results from prior blocks. This level of activity will require program offices' to potentially have larger staffs (to prevent burnout) with a different skill mix than exists today.

7. Implement a Modular Open System Approach

The use of a Modular Open System Approach allows for the more rapid insertion of updated technologies. This capability reduces the development cycle time and facilitates the implementation of spiral development. Its use should be broadly expanded within DoD weapons programs.

Modularity is defined as a “special form of design which intentionally creates a high degree of independence or ‘loose coupling’ between component designs, by standardizing component interface specifications” (Sanchez 1996). Modularity facilitates less complicated and more expeditious integration of new components into previously fielded systems. Modularity also increases the incentives for developing and fielding modifications to current assets by reducing the transaction costs associated with their implementation. If modularity is implemented correctly, new components should be more interchangeable with old components. One of the primary benefits is the improved capability to make rapid improvements.

Although physical compatibility should be a goal, modularity is particularly important for software and software-intensive systems. Software compatibility, with published interfaces, helps to enable developers to deliver applications that can be seamlessly implemented in a fielded system.

8. Ensure Programs use Concurrent development

Concurrent development is an important enabler of spiral development, and represents an important distinction between evolutionary acquisition and the traditional method of acquisition.

Spiral development relies upon the concurrent development of sequential spirals; that is, the development cycle of spiral N and spiral N+1 will partially overlap. Rather than the spirals having a dependent relationship (spiral N+1 is initiated at the successful completion of spiral N), they have an interdependent one; they are coupled. Spiral N+1 is initiated before the previous spiral is completed, but it is dependent on information and

feedback from that development. Consequently, planning for and initiating spiral “N+1” is a critical spiral “N” task. This level of concurrency requires frequent, bi-directional communications to be effective. If communication is poor or infrequent, the development team may find that decisions made in earlier stages “impose constraints that may hinder subsequent stages and thus result in irreconcilable conflicts (and thus waste) or additional time and costs in development” (AitSahlia 1995).

V. Conclusions

During the Cold War era, the defense establishment was primarily concerned with weapon system performance and maintaining technical superiority over the Soviet Union; cost was a secondary objective. The post-Cold War era saw the focus shift to cost and to collecting the “peace dividend.” With the terrorist attacks of September 11, 2001, our perception of national security was altered again. The world was still a dangerous place; however, in this new world, with irregular and asymmetric warfare, the focus of DoD acquisition must be on schedule. Shorter acquisition cycles can field better performing weapons sooner, at lower cost. Our troops and our country deserve no less.



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