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## COMPETITION AND INNOVATION UNDER COMPLEXITY

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The products of the Department of Defense (DOD) acquisition process are perceived as becoming increasingly complex, emphasizing multifunction and multimission system configurations. Such weapon systems utilize network capabilities and systems-of-systems engineering and integration methodologies throughout their life cycles. The management and oversight of these complex programs have similarly become more complex. Changes may be needed in the organizations and procedures used to manage the development, production, and sustainment of these complex weapon systems.

This chapter discusses how “complexity” may affect the conditions under which competition and innovation yield the desired benefits.<sup>1</sup> Competition and innovation are not ends in themselves, but rather are a means to attain certain benefits in the context of weapon system design, development, production, and support. What are those benefits? What are the conditions under which competition and innovation yield the desired benefits? Have those conditions changed in ways that affect either the role of competition and innovation in defense programs or the benefits derived from that application?

The following discussion defines what is meant by “complexity” in the context of weapon system acquisition. It next describes the traditional view of competition and innovation in the acquisition environment prior to and through the 1990s. Given the changes commonly associated with complexity as defined here, the discussion then examines the implications for competition and innovation and ends by

identifying implications for acquisition policy. This chapter draws substantially on past published work by RAND and others as well as unpublished work at RAND; useful references are listed at the chapter's end.<sup>1</sup>

### **DEFINING COMPLEXITY IN DEFENSE ACQUISITION PROGRAMS**

Before we can usefully discuss the implications of complexity for the use of competition and innovation in weapon system design, development, production, and support, we must first establish a working definition of complexity. In the context of DOD weapon systems, complexity can be thought of in three overarching dimensions—technical, organizational, and environmental. *Technical* complexity includes weapon system functionality and capability, including that related to the use of embedded information technology. *Organizational* complexity addresses the structures and interactions of the government and industry organizations responsible for system design, development, production, and support. *Environmental* complexity includes the political and economic context of the acquisition process, the threat environment, and the operational environment (how the systems are intended to be used). We expand on these three dimensions of complexity in the paragraphs that follow.

Weapon systems have become more complex over time. This is something of a truism and applies to the historical evolution of programs, not just to the more recent programs that have caught our attention. In general, new programs appear to be more complex than their immediate predecessors in terms of technology, functionality, and, perhaps to a lesser extent, their operational concept. Historically, this is the result of a natural evolution in which weapon designers and military users continually strive to improve and enhance warfighting capabilities. Under certain conditions, the use of competition stimulates innovation in weapon systems. Such an evolutionary pattern of improvement, whether derived from demand-pull or technology-push, applies equally to the commercial sector as well. It is the relative increase in complexity from one generation to the next that is of special interest. If each evolutionary step is relatively small, then management and oversight processes and practices will have time to adapt in parallel, and the required degree of adoption will be small. However, if the evolutionary step is large, there may be a significant mismatch be-

tween the complexity of the acquisition program and the institutional capacity to manage that program effectively.

Taken together, the three dimensions of complexity—technical, organizational, and environmental—suggest that we have entered an era in which the relative increase in complexity from the previous generation is fairly large.

The relative complexity of the weapon system itself is captured in technical complexity. Elements of technical complexity include the use of electronics, information technology, and software to provide critical functionality and capability beyond more traditional means. That these are increasing can be measured by the percent of acquisition program funds devoted to these technologies. These technologies reside in sensors, data processing, automation, communication, and data exchange. Many recent weapon systems are multifaceted, multifunction, multimission systems that include many more specific functions and performance capabilities than predecessor programs. Some programs, such as the first generation of semiautonomous unmanned air vehicles (UAVs) have no strong precedent and introduce entire new sets of capabilities.<sup>2</sup> Many recent programs also include the notion of “systems of systems” (SOS) in which many distinct systems are linked together through a common data network. In an SOS, each weapon system provides functionality by itself, but when linked together, the entire SOS provides capability that no single component system, nor all of those systems operating independently, could. The technical challenges in such complex systems emphasize systems engineering, software engineering, and system integration to a much higher degree than in the past. The Joint Strike Fighter (JSF, F-35), the Future Combat System (FCS), and DDG-1000 Zumwalt Class destroyers are often cited as examples of complex systems. Such programs also tend to be fairly large (as measured by total program cost), which also makes them politically visible, adding an organizational dimension to complexity.

In a recent analysis, Robert A. Dietrick concluded that the complexity of weapon systems has been increasing over time.<sup>3</sup> He defines complexity in terms of the number of interactions among subsystems and the degree of integration of those subsystems, as well as the degree of integration at the component and part level—all aspects of technical complexity. Dietrick provides examples in aircraft avionics, airborne sensors, and computer processors; his definition of complexity is similar to what we mean by technical complexity. Further, Dietrick

suggests that increased complexity—really increased functionality and capability—adversely affects program cost, schedule, and performance outcomes, though it is only one such factor.<sup>4</sup>

It is not just the weapon system itself that is complex, however. The second dimension of complexity concerns the organizations responsible for program management and program execution. Complex weapon system programs are managed by increasingly *complex organizations*. The relative increase in capabilities designed into modern systems requires increased breadth and depth of the government and industry workforce. The relatively large size (cost) of these programs adds an increased political dimension to program management. Large government program offices are staffed by a mix of military, civilian, and support contractors performing the full range of functions across a program's lifecycle. There are generally high levels of teaming among the industry components (at the prime contractor level and at lower tiers) because no single firm possesses the resources, capabilities, and political diversity required to fully execute the program itself. Government has increasingly relied on industry for both programmatic and technical capabilities, including program management, industrial base management, requirements formulation, systems engineering, and system integration. Officials of at least three programs—DD(X) (now DDG-1000), Deepwater, and FCS—have publicly stated that one reason they relied on industry for such important program management functions was due to a concern that the capabilities required to manage these complex systems did not exist in-house.

One consequence of complexity is the very large cost of complex systems. JSE, if it follows current plan, will be the largest defense acquisition program ever executed, and FCS and the DDG-1000 Zumwalt Class Destroyer are in the same league. Expensive programs are politically visible and therefore vulnerable, which causes them to be managed with this in mind.

The lower industrial base tiers have become increasingly important as a source of innovation required to achieve program technical and system performance objectives. DOD policy, and economic policy more broadly, has often asserted that smaller firms are often more innovative. Mark Lorell has observed that it was often (though not exclusively) a smaller or second-tier firm that developed a key technological innovation leading to the next stage in the evolution of the U.S. combat aircraft industry.<sup>5</sup> Continued support of the Small Business Innovative

Research (SBIR) grant program also seems to support the notion that smaller firms located in the lower defense industry tiers are an important source of innovation. In most major defense acquisition programs, however, government-managed competition only occurs at the prime contractor level. Although the prime contractors might hold competitions among lower-tier firms for specific capability, the government may have little insight into these lower-level competitions, and little direct knowledge of the industrial base beyond the key second-tier firms involved in a program. Thus, the DOD has little information, and little ability to influence, competition in a portion of the market that may be an important source of innovation. As the top-tier firms focus more on system engineering and system integration functions, the lower tiers become an important source of technological innovation that is not being actively managed by DOD.

Finally, the complexity of the *acquisition environment* has increased. The threat environment is both broader and less predictable than in the past, resulting in increased complexity in terms of force and capability planning. The operational concepts of some complex systems are themselves complex in order to fully take advantage of new net-centric capabilities (e.g., FCS). Nontraditional or asymmetric warfare (e.g., counterinsurgency) introduces additional operational complexity. The complexity of the government and industry organizations and the rules governing them—statute, regulation, policy, processes—has also increased markedly.

These three dimensions of complexity—technical, organizational, and environmental—can be expected to affect the use of, and benefits from, competition in weapon system programs, including the resulting innovation attained through competition.

However, other factors affect competition and innovation that are not necessarily related to complexity, such as:

- Significant consolidation throughout the defense industry at all the tiers, but especially at the prime contractor level;
- Fewer and less frequent new program starts; and
- Large programs (e.g., JSF, FCS) that in the past would each have been multiple independent programs.

These trends and their implications need to be considered in any assessment of the affect of complexity on competition and innovation.

As we argue below, these noncomplexity trends may in fact dominate any effects on competition, while increased complexity has opened new areas to competition and innovation.

### **TRADITIONAL VIEWS OF COMPETITION AND INNOVATION**

Competition and innovation are not ends in themselves, but rather are means to achieve certain goals.

Competition has long been a foundation of acquisition policy and contract awards for research and development (R&D), production, and services. In fact, there is a very strong bias in acquisition policy and federal regulation toward the use of competition, most recently illustrated by a policy directive from the under secretary of defense for acquisition, technology, and logistics.<sup>6</sup> In the defense acquisition context, we expect competition to provide lower prices, higher-quality products, cost control, improved efficiency, and innovation. In this sense, competition is sometimes thought of as a primary driver of innovation, though innovation may have other sources as well.

The conditions under which competition yields these benefits include the following:

- A large viable industry base, such that more than two firms or teams (with different firms) bid on a project. Viability includes both financial strength and a healthy and capable workforce.
- Some degree of industry or product sector maturity. If only the initial innovator plays, there is no competition.
- Product substitutability, which means that products are functionally similar across different firms.
- Many programs (i.e., frequent new starts) and a stable or growing budget. This condition is equivalent to a stable or growing demand function.
- Minimal barriers to entry. Such barriers might include capital equipment requirements or investment levels, workforce knowledge and skills, and even familiarity with government and DOD contracting and budgeting statutes and regulations, as these will affect program execution.

These conditions are part of the microeconomic model generally taught in undergraduate introductory economics classes. In particular, the plausibility of the “invisible hand” of a competitive market producing desirable outcomes depends on these and other conditions (e.g., free and full information). The lack of these conditions in particular defense sectors may prevent the expected benefits of competition from being realized.

It is important to note that an industry sector with only two firms and a government policy (implicit or explicit) to maintain the viability of both firms does not provide competition at the top tier (prime contractors). Although competitions can be held between teams led by these two different firms, each team knows at the outset that even if it loses, it will still receive a large enough portion of the program, or other programs, to remain viable. The industry base for large Navy surface combatants (Bath Iron Works and Northrop Grumman Ship Systems) and Navy submarines (Northrop Grumman Newport News and Electric Boat) are good examples of this challenge.<sup>7</sup> Both the DDG-1000 and Virginia Class submarine programs have made preservation of the supporting industry base explicit goals of their acquisition strategies. As a result, the use of competition in these programs, and the benefits expected from competition, differ somewhat from the traditional.

Competition is thought of as a primary driver of innovation. However, competition is not sufficient in itself to generate innovation. Innovation depends on other factors as well, including funding levels; the existence of a core or “critical mass” of talent, capabilities, and resources in the same place at the same time (to include virtual collocation and other advanced collaborative tools in some cases); and a regulatory and institutional environment that encourages intelligent risk taking and out-of-the-box thinking.

Innovation is expected to result in new warfighting capabilities based on new concepts or technologies. Innovation is valued to the extent that it creates a warfighting competitive advantage between the United States and its adversaries. Innovation is also expected to be a primary source of a firm’s competitiveness (thus coming full circle in this discussion). Beyond innovation of weapon systems or their use, innovation is also expected to result in improved business, design, development, production, and support processes (generally, increased efficiency).

Innovation arises from R&D investment, creativity, expertise, and sensing market trends. Technology-push and demand-pull both play roles in defense innovation. There are several frameworks that allow one to organize and think about the relationships between the factors affecting innovation. One such framework includes personnel capabilities and management, program management more generally (flexible vs. rules based), organization (institutional structure), technology, and workforce education and experience. These are not trivial factors: Defense Advanced Research Projects Agency (DARPA) was set up specifically to enhance innovation in defense-related technologies and concepts. With its highly educated workforce, flexible management, and relatively loose organizational structure, DARPA encourages out-of-the-box thinking. Its rules are set up to enable testing new concepts and technologies as quickly and inexpensively as possible. And DARPA has had many notable successes.<sup>8</sup>

Paul Bracken extends the work of two prior studies of innovation to develop a framework or model of innovation specific to the defense industry.<sup>9</sup> Six sets of factors are identified:

- National factors, which include education level, strength in science and technology, and supporting infrastructure (e.g., communication, transportation).
- R&D investment in a wide variety of projects, technologies, and sectors.
- Status and attractiveness of the sector (i.e., excitement and dynamism) as indicated by the degree to which industry in that sector is admired by consumers and students, the degree to which it is pushing the state of the art, and its ability to attract and retain top people.
- Competition in the sector, as determined by company strategies, industry structure, and rivalry.
- Demand conditions—in other words, the customer demanding capabilities requiring innovative new technologies.
- Related supporting industries including lower tiers and science and technology (S&T) base.

Note that competition is present in this model as a factor directly affecting innovation. The characteristics of the competition are impor-

tant under this framework—that is, competition for ideas rather than cost or market share as the key driver of innovation in technology and product capability.

Additional factors affecting innovation or the conditions that facilitate innovation not explicitly identified in the models above include the following:

- An institutional and regulatory environment that encourages new concepts;
- Early adopters who are willing to buy and use initial versions of the innovation;
- A potential for significant demand for the product;
- High potential payoff; and
- Minimal barriers to entry.

A supportive institutional and regulatory environment is a critical foundation for innovation. An institutional structure that continually reinforces the status quo will hinder the ability of new concepts to be developed and tested. Feedback from early adopters is needed to help refine the product, demonstrate utility, and transition the innovation from the lab to a user community. In the past, the government has often been that earlier adopter. A large demand function establishes a potential market able to sustain enough sales to make the initial investment worthwhile. Since that investment entails risk, there must be a perception of a payoff commensurate with perceived risk, whether in terms of system performance, profit, or market share. Barriers to entry must be low enough to avoid seriously hindering the investment required for firms to establish a new market niche.

Industry sectors that are highly regulated tend to be relatively poor innovators. Increased formal rules and processes or large firms and bureaucracies may stifle innovation; there is less inherent flexibility, different expectations, and less openness to change. A tight regulatory structure and formal rules of behavior are thought to limit innovation (e.g., DARPA vs. DOD).

There is a set of assertions commonly made with respect to competition and innovation for which evidence is problematic. That does not mean that these assertions are incorrect, only that they are difficult to demonstrate with high confidence.

- Smaller, more flexible firms are more innovative. Some evidence supports this, though small firms often have difficulty finding the resources required to fully develop, test, market, and gain acceptance for a new concept or technology.
- Commercial firms are believed to be more innovative than the defense industry. This assertion underlies DOD policies concerning the use of commercial processes and products as well as alternative contracting strategies such as the “other transaction” authority (OTA) established to attract nontraditional firms to defense work.
- Innovation often comes from second tier or niche firms, not just the industry leaders. An interesting example of this phenomenon is in the military aircraft sector over the past 100 years: each new “technology era” in military aircraft (biplane, propeller monoplane, subsonic jet, supersonic jet, and stealth) was initiated by a second-tier aircraft firm or a niche firm (e.g., aircraft engines) that would then become a dominant player for that era.<sup>10</sup> To some degree, this assertion offers some support for the notion that smaller firms tend to be more innovative.<sup>11</sup>

#### **HOW COMPLEXITY MIGHT AFFECT COMPETITION AND INNOVATION IN DEFENSE ACQUISITION PROGRAMS**

Complexity itself has affected the nature of competition and innovation in the defense industry.

Many of the more recent programs are larger and more technically complex in terms of the use of information technology, system interdependence, and interoperability. Larger complex programs may require larger firms with substantial resources, breadth of capability, and the infrastructure to manage them effectively. Firms remaining in the defense market are relatively larger than they used to be and are themselves more complex (vertically and horizontally). The lead firm may focus more effort on system engineering/integration roles, including software development, rather than component and subsystem development and fabrication. In this sense, industry consolidation might be seen as an enabler for managing complexity.

The top-tier defense firms have restructured to better address technical, organizational, and environmental complexity. Technical com-

plexity emphasizes systems and systems-of-systems engineering and integration, which in turn require an emphasis on this capability at the prime contractor level. Most of the top-tier defense firms have restructured in a way that reflects this focus, combining their military work under a new “integrated defense” business unit and hiring or training systems engineers. Boeing, Northrop, and Lockheed Martin all followed this pattern. These integrated defense business units also position the firms to better address interdependency and interoperability across system types, a challenge driven at least in part by technical, organizational, and environmental complexity. The emphasis on systems integration and system engineering capabilities offers a new niche for competition and innovation; the prime contractor competition in several recent programs—missile defense, FCS, DD(X)—emphasized systems engineering and integration explicitly.

This also elevates the role of the lower tiers; DOD-managed or influenced competition may now be more applicable and more important below the level of prime contractor. If DOD decides competitions at the prime contractor level because the government itself is unable to address the organizational complexity of a program, then competition at the lower tiers will be left to these large firms, who may decide such competitions based on different criteria than the government might prefer. At a minimum, increasing DOD awareness of the complete business base supporting a program may provide valuable information to policymakers on how competition can be applied in a particular case.

Complexity has also influenced the factors affecting innovation in many of the same ways. High barriers to entry remain, including capital investment and a workforce with the requisite characteristics. Complexity introduces yet another set of required workforce and organizational capabilities. There are many fewer firms at top industry tiers in mature industry sectors (e.g., fixed wing and rotary aircraft, large surface combatants, submarines, heavy armored vehicles). The government or defense-specific barriers to entry also remain, including knowledge and business processes that satisfy statutes and regulations as well as limited profit and limited growth in the defense sector.

An abundance of technical innovations (and associated concepts) has driven some of the complexity seen in today’s acquisition programs. Complex systems have both advantages and disadvantages; they tend to be more costly, less reliable (more parts), harder to fix,

and less predictable in behavior due to emergent properties. However, they also offer new capabilities useful to the warfighter.

But technical, organizational, and environmental complexity have also created new opportunities requiring substantial innovation in concepts and technology, leading to new capabilities and new niches within the defense industry. In more established sectors, innovation can be in the systems integration function, or in people, organizations, or management structures that bring diverse skill sets together. The potential of information technology to provide new capabilities or replace manned function with unmanned systems (e.g., automated fire control, shipboard firefighting, autonomous vehicles) has only just begun.

Although technical complexity dominates many discussions, it is not just technology that can be complex. Organizational and environmental complexities also offer opportunity for innovation. The changing nature of the threat has opened new sectors where less maturity gives innovation a relatively higher expected payoff. These capability areas include unmanned vehicles (air, ground, sea surface, and underwater), counterinsurgency (improvised explosive device, or IED, defeat, detection, communication/translation), space, and cyber warfare. Such new capabilities have implications for organizational structure of both the acquiring and user communities within DOD.

The technical, organizational, and environmental complexity discussed above may affect the conditions under which competition and innovation yield their expected benefits within the context of defense acquisition. However, there are other factors that also affect competition and innovation in defense programs, independent of complexity. There are relatively fewer new programs as compared to prior periods, at least in established defense sectors, reducing opportunities for competition (and innovation), but this was driven largely by budget pressure in the 1990s. There are fewer firms in the defense industry at all tiers, and, in some cases, very few firms are capable of designing, developing, and producing critical materials or components. Barriers to entry in the defense industry have always been high and are perhaps even higher now, at least at the top tiers. Workforce capability in the defense industry has also been identified as an issue; the older, experienced workforce is nearing retirement, and fewer younger workers are entering the defense industry. A scarcity of certain skills in the workforce can lessen a firm's ability to compete.

## **IMPLICATIONS FOR POLICYMAKERS**

Complexity has contributed to changes in the nature of the weapon systems that DOD buys as well as changes in defense industry structure, how competition may be applied at the program level, the value of that competition, and the drivers of innovation. Policymakers should be aware of such changes when considering allocation of funds across possible weapon system investment portfolios, new program starts, acquisition strategies for programs, and management structure and processes.

Acquisition officials should consider the following observations when thinking about the application of competition to programs within an increasingly complex acquisition environment and implications for innovation:

- Little real competition currently exists in mature defense industry sectors. Complexity of programs or systems is only one cause. Other causes include fewer new programs providing opportunities for competition, an industry base that continues to consolidate in terms of the number of firms with specific capabilities, and increased teaming on large programs (i.e., spreading the business base).
- The globalization of the defense industry—an issue that has not been addressed in this chapter—offers some competitive opportunities by expanding both the number of programs and number of firms in the broader defense market. U.S. firms have competed in programs for other nations by offering versions of products sold to the U.S. military. Non-U.S. firms have competed in DOD programs either directly or by teaming or acquiring U.S. firms (e.g., BAE and EADS). There are both near- and long-term impacts to globalization that warrant further study.
- Relatively new defense industry sectors such as unmanned vehicles offer opportunity for competition that can lead to innovation as well as provide other benefits expected from competition. These new sectors are expanding markets with lower barriers to entry and few truly dominant players.
- The organizations that manage complexity in weapon system programs are themselves complex. This applies to government and industry program offices as well as oversight organizations

in the military services and the Office of the Secretary of Defense (OSD). In complex organizations, the interactions of many stakeholders can occasionally produce counterintuitive results.

- Government has traditionally focused competition at the prime contractor level. With competition among these large firms increasingly focused on system engineering and system integration functions, the competition that might produce technological innovations may more often happen at lower tiers. The government currently has few mechanisms to influence or manage competition among lower-tier firms.
- Bureaucracies tend not to innovate well, by their very nature. They are generally set up to ensure standardized processes rather than to develop new ideas. This characteristic applies to both government and the increasingly large defense industry firms in the top tier. In contrast, innovation seems to be facilitated by removing programs or projects from the mainstream. Examples include DARPA's accomplishments as well as the accomplishments of the several "rapid reaction" organizations set up to support warfighters in Iraq and Afghanistan. Historically, the relative success of classified (or "black") programs has been attributed in part to the nonstandard acquisition environment accorded them. Similarly, some large defense firms have set up advanced program operations to insulate them from the mainstream and foster innovation, such as Boeing's Phantom Works and Lockheed's Skunk Works.

One of the more important observations is that the factors affecting competition the most—fewer programs, budget pressure, industry consolidation—have little to do with complexity per se. Although complexity may change the nature of a competition by emphasizing large-scale systems engineering and integration rather than strict cost and performance variables, these other factors will still limit how competition can be applied in mature defense industry sectors. In contrast, complexity appears to have provided more opportunity for competition and innovation in relatively newer defense industry segments.

How can complexity in weapon system development be managed? There are two interrelated approaches; a mix of both is probably needed. One approach is to limit technical complexity in weapon

system design by developing metrics for such complexity and using those metrics as part of the decision process when formulating a program's acquisition strategy. Such metrics might include the number of independent systems or large subsystems that need to be integrated, the number of interactions of systems within a weapon system, the number of external (or complementary) systems interactions required, and the number of organizations involved in design, development, and management.

A second approach is to adapt management techniques and institutional structures to better manage complexity. Hypotheses could be developed and tested at a smaller scale (e.g., program level) before applying more widely. For instance, if technical complexity in a weapon system makes cost, schedule, and performance more difficult to predict, then an organization structured to respond to such uncertainties can be designed. Being responsive to uncertainty requires a good monitoring approach as well as considerable flexibility in making cost-performance tradeoffs and allocating funds across a program. Pilot programs of the past have used this basic approach and have found some success—e.g., the initial JDAM (joint direct attack munition) pilot program or DARPA's Predator and HAE-UAV (high-altitude endurance unmanned aerial vehicle) programs. Simplifying decision processes may help minimize organizational complexity.

Policymakers should also acknowledge that the technical, organizational, and environmental complexity factors affecting acquisition suggest that we may not want to preserve the current government and industry structure; rather, we may want to consider how government can effect changes that respond to the evolving nature of acquisition and that create an environment that encourages innovation. Similarly, it is not clear that the current acquisition process needs to be maintained. Changes in the characteristics of what we buy and in the nature of the threat suggest a need for changes in the processes and institutional structures associated with acquisition. The policy levers that DOD has used in the past to shape industry, generate competition, and stimulate innovation are still relevant today and include the following:

- DOD is the only buyer for many new technologies. It can act as the early adopter for innovative concepts and technologies. DOD can use this status to shape R&D in the directions it wants to go.

- RDT&E (research, development, testing, and evaluation) funding—both the amount and distribution—is a major lever for DOD. DOD can diffuse private sector risk and ensure that a broad set of concepts and technologies are being pursued.
- The frequency and type of new programs, clearly related to funding amounts and distributions, are also critical. More programs provide more opportunity for competition and innovation. The increased use of smaller, focused concept and technology demonstration projects is an important policy lever. Advanced Technology Demonstrations (ATDs) and Advanced Concept and Technology Demonstrations (ACTDs) are examples of program structures whose use facilitates both competition and innovation. Careful attention must be paid to transitioning the results of such technology demonstration activities to major defense acquisition programs, particularly in terms of the doctrinal and sustainment issues often overlooked in technology demonstrations.
- Improved use of evolutionary acquisition strategies may also offer opportunities for competition and innovation. Such programs could be planned as a series of incrementally developed capabilities in which some portion of that incremental capability can be competed in an effort to encourage innovation.
- Use of less constrained contracting mechanisms, such as OTA, can attract nontraditional firms and allow the flexibility to both generate and pursue new ideas.

At the same time however, it is important to recognize that current acquisition policy and practice, which have remain relatively unchanged for several decades, embody lessons in how to acquire complex systems and thus should not be discarded under the pretext of change without careful review.

#### NOTES

1. This work, which was sponsored by the Office of the Secretary of Defense under contract W74V8H-06-C-0002, reflects the views of the author. It does not reflect the views of RAND or any of its sponsors.

2. Robert S. Leonard and Jeffrey A. Drezner, *Innovative Development: Global Hawk and DarkStar—HAE UAV ACTD Program Description and Comparative Analysis*, MR-1474-AF (Santa Monica, Calif.: RAND Corporation, 2002).

3. Robert A. Dietrick, "Impact of Weapon System Complexity on Systems Acquisition," in James R. Rothenflue and Marsha J. Kwolek, *Streamlining DOD Acquisition: Balancing Schedule with Complexity* (Montgomery, Ala.: Center for Strategy and Technology, Air War College, Air University, Maxwell Air Force Base, September 2006).

4. Because technical complexity is very difficult to measure empirically, few analyses of program outcomes do more than simply raise the issue and assert a relationship.

5. Mark Lorell, *The U.S. Combat Aircraft Industry, 1909–2000: Structure, Competition, Innovation*, MR-1696-OSD (Santa Monica, Calif.: RAND Corporation, 2003).

6. John J. Young, Jr., under secretary of defense for acquisition, technology, and logistics, Memorandum, *Subject: Prototyping and Competition*, September 19, 2007. Competition has a long history in the U.S. defense industry. The very strong positive bias toward competition has its roots in the culture of capitalism and entrepreneurship that has driven much U.S. economic history.

7. Bath Iron Works and Electric Boat are both subsidiaries of General Dynamics. The various shipbuilding portions of Northrop Grumman have recently merged into a single entity. Thus, in some ways, there are really only two firms covering all large Navy shipbuilding programs—subs, surface combatants, carriers, and amphibious assault ships.

8. Richard H. Van Atta and Michael J. Lippitz, *Transformation and Transition: DARPA's Role in Fostering an Emerging Revolution in Military Affairs, Volume I: Overall Assessment*, IDA Paper P-3698 (Alexandria, Va.: Institute for Defense Analyses, April 2003); Defense Advanced Projects Research Agency, *Technology Transition*, January 1997, <http://www.darpa.mil/body/pdf/transition.pdf>.

9. Paul Bracken, "Innovation and the U.S. Defense Industry," June 6, 2002 (unpublished input to RAND project). The two prior studies are Michael Porter, *The Competitive Advantage of Nations* (New York: Free Press, 1990), and Richard Nelson, ed., *National Innovation Systems* (New York: Oxford University Press, 1993). See also, John Birkler et al., *Competition and Innovation in the U.S. Fixed-Wing Military Aircraft Industry*, MR-1656-OSD (Santa Monica, Calif.: RAND Corporation, 2003).

10. Lorell, *The U.S. Combat Aircraft Industry*.

11. A similar analysis in other industry sectors has not been performed, so it is uncertain how widespread this pattern is.

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