

GAO

Report to the Chairman and Ranking
Member, Subcommittee on Readiness
and Management Support, Committee on
Armed Services, U.S. Senate

March 2001

BEST PRACTICES

Better Matching of Needs and Resources Will Lead to Better Weapon System Outcomes



DISTRIBUTION STATEMENT A
Approved for Public Release
Distribution Unlimited

20010316 040



G A O

Accountability * Integrity * Reliability

Contents

Letter		5
Executive Summary		6
Chapter 1		14
Introduction	How Product Requirements Are Set Is Key to Program Outcomes	16
	Objectives, Scope, and Methodology	20
Chapter 2		25
Timely Matching of Requirements and Resources Is Critical to Product Development Outcomes	Early Matching of Customer Expectations and Developer's Resources Is Critical to Program Success	25
	Trade-offs Are Critical to Matching Customer Expectations With Developer Resources Before Starting Product Development	28
	When Matching Did Not Occur Before Program Launch, Developers Were Forced to Add Unplanned Resources	31
Chapter 3		34
Several Factors Enable Customer Wants and Developer Resources to Be Matched Before Program Launch	Systems Engineering Tools Are Critical for Identifying Gaps Between Developer's Resources and Customer's Expectations	35
	Flexibility in Setting Requirements Is Key to Closing Gaps Between Customer Expectations and Developer Resources	44
	Balance in the Roles of the Customer and Product Developer Makes for Effective Trade-offs	50
Chapter 4		55
Characteristics of DOD's Acquisition Process Make It Hard to Match Expectations and Resources Before Program Launch	Current Process Puts Requirements Setting and Systems Engineering on Opposite Sides of the Launch Decision	56
	Incentives of Current Process Create Pressure on Product Requirements	58
	More Successful Weapon System Programs Have Departed From the Normal Process	62
	Constructive Changes in DOD's Policy Not Enough to Match Customer Expectations With Developers' Resources	63

Chapter 5		66
Conclusions and Recommendations for Executive Action	Conclusions	66
	Recommendations for Executive Action	68
	Agency Comments and Our Evaluation	69
Appendixes	Appendix I: Comments From the Department of Defense	70
	Appendix II: GAO Staff Acknowledgments	74
Related GAO Products		75
Tables	Table 1: Customer and Product Developer Interests in a Product's Development	17
	Table 2: Matching of Expectations to Resources and Product Development Outcomes	26
Figures	Figure 1: Knowledge-based Process for Applying Best Practices to the Development of New Products	15
	Figure 2: The Requirements Process	18
	Figure 3: Commercial and DOD Organizations Involved in Requirements Setting Processes	19
	Figure 4: Timing of Match Between Customer Expectations and Resources	27
	Figure 5: Caterpillar Mining Truck	29
	Figure 6: Timeline for Development of the 797 Mining Truck	29
	Figure 7: Effect of FUSE Trade-offs on Matching Customer Expectations with Developer's Resources	31
	Figure 8: Navy's Development of the Radio Frequency Countermeasures System	32
	Figure 9: Basic Steps in Systems Engineering Process	35
	Figure 10: Systems Engineering Used for Successful and Problematic Cases	36
	Figure 11: Tactical Unmanned Aerial Vehicle	40
	Figure 12: Crusader Artillery Vehicle	43
	Figure 13: Global Hawk Unmanned Aerial Vehicle	48
	Figure 14: Timeline for Developing Crusader's Requirements	57
	Figure 15: Revised DOD Acquisition Process	64

Contents

Abbreviations

BAT	Brilliant Anti-armor Submunition
DOD	Department of Defense
FUSE	Far Ultraviolet Spectroscopic Explorer
NASA	National Aeronautics and Space Administration



GAO

Accountability * Integrity * Reliability

United States General Accounting Office
Washington, D.C. 20548

March 8, 2001

The Honorable James Inhofe
Chairman
The Honorable Daniel Akaka
Ranking Member
Subcommittee on Readiness and Management Support
Committee on Armed Services
United States Senate

As you requested, this report examines how best practices offer improvements to the way the Department of Defense defines and matches weapon system requirements to available resources such as cost, schedule, and mature technologies. It also examines the importance of the timing of this match and identifies practices that can improve the prospects for making the match before starting an acquisition program. We make recommendations to the Secretary of Defense on how to better align the requirements setting and program approval processes to infuse more knowledge earlier into each process.

We are sending copies of this report to the Honorable Donald H. Rumsfeld, Secretary of Defense; the Honorable Gregory R. Dahlberg, Acting Secretary of the Army; the Honorable Robert B. Pirie, Jr., Acting Secretary of the Navy; the Honorable Lawrence Delaney, the Acting Secretary of the Air Force; the Honorable Mitchell E. Daniels, Jr., Director, Office of Management and Budget; and to interested congressional committees. We will also make copies available to others upon request.

If you have any questions regarding this report, please call me at (202) 512-4841. Other key contacts are listed in appendix II.

Katherine V. Schinasi
Director
Acquisition and Sourcing Management

Executive Summary

Purpose

Although the Department of Defense's (DOD) annual weapon system investment has been increased from about \$90 billion 3 years ago to almost \$100 billion for fiscal year 2001, DOD's buying power will be weakened if weapons continue to cost significantly more and take much longer to develop than planned. DOD would like to get the most out of this investment and has set goals to develop new weapons in half the traditional time and within budget. It has a long way to go; long-standing problems that work against delivering new weapons within estimates have proven resistant to reform. When one program encounters such problems and needs more money than planned, it comes at the expense of delaying or canceling other programs. This means less overall modernization and a lower, unpredictable return on investment. The ability to execute a program more predictably within cost and schedule estimates would lessen the need to offset cost increases by disrupting other programs.

GAO has issued a series of reports on the success leading commercial firms have had in significantly reducing the time and money to develop new and more sophisticated products—the kinds of results that DOD seeks. The best practices of these firms center on obtaining knowledge about the technology, design, and production of a new product at key points in time. The most critical juncture is the decision to start development of a new product, for which firms insist on having a match between what the customer wants in a new product and what resources they have to develop that product. Significant cost and schedule increases in weapon system programs can be traced to not having achieved this match at program start.

This report addresses how the process of setting requirements for new products can be managed in a way that does not exceed the developer's resources yet provides a product the customer wants. In response to a request from the Chairman and the Ranking Member, Subcommittee on Readiness and Management Support, Senate Committee on Armed Services, GAO assessed (1) the effect the timing of the match between the customer's needs and the developer's resources has on a product's cost and schedule; (2) the best practices for obtaining this match during the requirements setting process, compared with more traditional DOD practices; and (3) the progress made and challenges DOD faces in adopting best practices for setting requirements on individual weapon systems.

Background

The decisions made in translating the ideas for a new product into actual features and characteristics dictate the amount of resources that will be necessary to bring the product to market. Thus, they may be the most highly leveraged of all product development decisions. In the past, it has not been unusual for weapon system requirements to be set so high that the initial estimate of the resources necessary to develop a responsive weapon falls considerably short of the mark. For both commercial and DOD products, a natural amount of tension precedes the setting of requirements, because it is common for a customer's initial expectations to exceed what the developer can do within known or available resources. The resources a product developer can consider available include (1) knowledge—the technology and capabilities the developer has to engineer and manufacture the product and (2) the time and money the developer has to design, test, and deliver the product. A process of negotiation and trade-offs is usually necessary to match customer expectations and developer resources before a product can be successfully developed and produced.

Among the key sources of information GAO relied on in this review were experiences from nine major product development programs from DOD, the National Aeronautics and Space Administration (NASA), and two commercial firms recognized for their success in setting product requirements. GAO reviewed the requirements setting process for all nine programs. For each program, GAO interviewed key managers and obtained documentation to determine (1) the process that was used to achieve the match between customer expectations and resources to form the eventual product's requirements, (2) the timing of this match and the tools used to achieve it, and (3) the extent to which the requirements setting process affected the program's subsequent progress or success. While the commercial products differed significantly, much commonality existed among the firms' practices for managing the requirements for a new product. The commercial examples in the report were chosen for their excellence; as such, they do not necessarily represent the standard practices of commercial industry as a whole.

Results in Brief

A match between a developer's resources and a customer's expectations is eventually met on just about every product or weapon system development. A key distinction between successful products—those that perform as expected and are developed within estimated resources—and problematic products is when this match is achieved. When a customer's needs and a developer's resources were matched before a product

development started, the more likely the development was to meet cost and schedule objectives. When this match took place later, after the product development was underway, problems occurred that took significantly higher investments—sometimes double—of time and money.

GAO identified three factors that were key to matching needs and resources before product development began. First, developers employed the technique of systems engineering to identify gaps between resources and customer needs before committing to a new product development. Second, customers and developers were flexible. Leeway existed to reduce or defer customer needs to future programs or for the developer to make an investment to increase knowledge about a technology or design feature before beginning product development. Third, the roles and responsibilities of the customer and the product developer were matched, with the product developer being able to determine or significantly influence product requirements. In cases where these factors were not present at program launch, product development began without a match between requirements and resources. Invariably, this imbalance favored meeting customer needs by adding resources, which resulted in increased costs and later deliveries.

DOD has recently revised its acquisition policy to encourage a more evolutionary approach for setting requirements and developing new weapons. This policy merits support; if effectively implemented, it could facilitate a better match between customer needs and developer resources before program launch. DOD, however, faces two significant hurdles in implementing the policy. First, the mechanics of obtaining funds to start programs are unchanged. Specifically, requirements must still be set before a program can be approved and a program must be approved before money can be paid to the product developer to conduct systems engineering. Such mechanics deny the knowledge needed to match customer expectations with developer resources before starting a program. Second, many of the same incentives still exist—such as the competition for program funding—to push requirements up, making them more difficult to meet and less flexible to negotiate.

GAO makes recommendations to the Secretary of Defense on ways to realign the mechanics and incentives of the requirements setting and program approval process with the need to match customer expectations and developer resources before weapon system programs are started.

Principal Findings

Timely Match of Requirements and Resources Is Critical to Product Development Outcomes

For the nine development programs GAO examined, there was a relationship between when customer expectations were matched with available resources and the programs' ability to meet cost and schedule predictions. In cases where needs and resources were matched before program start, like Caterpillar's 797 mining truck and NASA's Far Ultraviolet Spectroscopic Explorer, cost growth was 20 percent or less and product development schedules were met. In cases where programs were started with requirements that exceeded resources, like the Crusader artillery vehicle and the Radio Frequency Countermeasures system, cost growth ranged from 55 percent to nearly 200 percent and schedule delays were about 25 percent. Key to the successful cases was the ability to make early trade-offs either in the design of the product or in the customer's expectations to avoid outstripping the resources available for product development. The less successful cases missed opportunities to make trade-offs before product development started. By the time the gaps between requirements and resources were recognized and confronted, it was too late to materially change the requirements. Consequently, the only route left was for the developer to invest more resources than originally planned to meet the requirements.

Several Factors Enable Customer's Needs and Developer's Resources to Be Matched Before Program Launch

GAO found significant differences between the successful cases and those that experienced problems regarding (1) how systems engineering was employed, (2) how flexible customers and developers were, and (3) how balanced the roles of the developer and the customer were. Systems engineering is a disciplined process that translates customer needs into the specific capabilities that are needed to create the product, such as individual technologies and manufacturing processes. It is critical for identifying and resolving gaps between needs and resources and lays the factual foundation for pragmatic negotiations. When the product developer employed systems engineering before a new program started, the resultant gaps could be addressed through investments, alternate designs, and trade-offs. For example, Bombardier's systems engineering analysis for a new regional-sized jet showed that if the customer would accept a 3.7-percent reduction in cruise speed, existing propulsion technology could be used, greatly reducing risk. The customer agreed to the reduction. Flexibility was encouraged when the developer set a limit on how long it would allow product development to take but could credibly assure

customers that future versions of a product would meet many expectations deferred from the initial product. Finally, the developer and the customer were equal partners in setting product requirements; a new product was not begun unless both parties agreed to the requirements.

In the cases where the developers did not deliver the products as promised, little systems engineering had been done by the time requirements were set and the programs were launched. The bulk of systems engineering—including the identification of gaps between resources and requirements—was not done until well into product development. For example, it was 2 years after the Crusader's launch—after requirements were set and resource estimates made—that the developer concluded that a key propellant technology could not be developed within resources. Also, in these cases, the customers were relatively inflexible regarding requirements before the programs were launched. Even when the attempt was made to deliberately limit the length of the product development cycle—as in the case of the countermeasures program—the customer was unwilling to make compensating trade-offs in performance. Finally, the customer played the dominant role in setting requirements—a process that took over 4 years in one case—with comparatively little input from the product developer. In some cases, without having done systems engineering, the product developer was in a weak position to disagree with the requirements. In other cases, the product developer was forced to accept the requirements despite pointing out that resources were insufficient.

Characteristics of DOD's Acquisition Process Make It Hard to Match Needs and Resources Before Program Launch

In DOD, the mechanics of obtaining funding and getting approval to start an acquisition program dictate that events proceed in the following sequence: set requirements, obtain funding, launch program, perform systems engineering. This sequence places the knowledge that is needed to identify resource gaps and shape requirements after the program has been launched and resource estimates have been made. DOD does not typically sign contracts with product developers that conduct systems engineering until acquisition programs are started and funding is received. In turn, programs cannot be approved unless requirements have been set. By the time the systems engineering is started, customers' needs—as well as those of organizations within DOD and the Congress that approve and fund programs—have been set, making it difficult to change requirements. Adding resources—manifested by cost and schedule increases—then becomes the primary option for closing gaps.

DOD's process for setting requirements and justifying programs creates incentives for setting requirements that exceed available resources. For example, the intense competition to get programs approved and funded encourages requirements that will make the desired weapon system stand out from others. Also, DOD requirements setters are often motivated—not without reason—to aim for the most capability possible, given that it may be several years before they get another opportunity for a new weapon system of the same type. Further, they do not necessarily have confidence that DOD will be able to fund future, more capable versions of a weapon if they accept minimum capabilities on the initial version. Finally, the DOD customer is more willing to accept cost increases and schedule delays after program launch than a commercial customer. When these additional resources are provided after a program is launched, the incentive to let requirements drive resources up is reinforced.

DOD has recently adopted policies that could make it possible for a better matching of customer expectations and developer resources before program launch. These policies discourage programs from accepting unreasonable technical risks and identify ways such risks can be reduced before program launch. A primary way is the policies' expressed preference for an evolutionary approach to weapons development that calls for setting a reasonable—but not ultimate—requirement for an initial version of a weapon, with improvements to follow. By themselves, however, the policy changes do not materially alter the mechanics or the incentives that shape the process for setting requirements and justifying programs.

Recommendations for Executive Action

GAO recommends that the Secretary of Defense (1) require that systems engineering that is needed to evaluate the sufficiency of available resources be conducted before weapon system requirements are formalized, (2) reduce the pressures that encourage setting high and inflexible requirements to win the competition for program approval, and (3) require, as a condition for starting a new weapon system program, that sufficient evidence exists to show there is a match between a weapon system's requirements and the resources the program manager has to develop that weapon. These recommendations appear in full in chapter 5.

Agency Comments

DOD generally agreed with the report and its recommendations. A detailed discussion of DOD's comments appear in appendix I.

Introduction

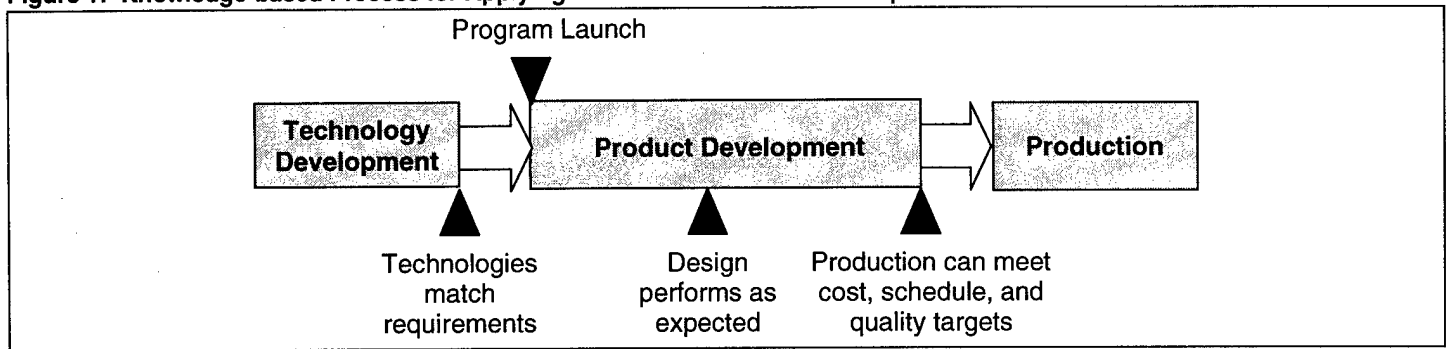
For several years, the Department of Defense (DOD) has expressed an urgent need to acquire new weapon systems to replace its force that it believes is becoming outdated and too costly to operate. DOD's annual weapon system investment has increased from about \$90 billion 3 years ago to almost \$100 billion for fiscal year 2001; over the next 5 years, DOD plans to spend about \$516 billion developing and acquiring weapon systems. DOD would like to get the most out of this investment, and it has set goals to develop new weapons in half the traditional time and within budget. Historically, DOD has not received a predictable return on its investment in major weapon systems as they have cost significantly more and taken much longer to complete than originally estimated. When one program runs into problems and needs more money than planned, it comes at the expense of delaying or canceling other programs, which reduces buying power and means less overall modernization. The ability to execute a program more predictably within cost and schedule estimates would lessen the need to offset cost increases by disrupting other programs. DOD recognizes that changes are necessary to its acquisition practices to achieve its modernization goals. Thus, it has advocated adopting the practices of leading commercial firms.

Our reviews over the past 20 years have likewise pointed to a need to adopt new practices. We have seen many of the same problems recur in weapon system programs—cost increases, schedule delays, and performance problems. On many occasions, we found that programs required more resources—time and money—than were estimated for demonstrating technologies, designing solutions, and providing more production capabilities in order to meet customer expectations. Because customer expectations for the system's performance were set when the decision was made to invest in the system, adding resources became the primary option for solving problems when they arose. Despite good intentions and some progress, our ongoing reviews of DOD's weapon system acquisitions show that these persistent problems remain. As a result, we undertook a body of work that examines weapon system acquisitions issues from a different, more cross-cutting perspective—one that draws lessons learned from the best commercial product development efforts to see if they can be applied to DOD weapon system developments. In past years, leading commercial firms have developed increasingly sophisticated products in significantly less time and at lower costs.

Our past work has shown that leading commercial firms expect their program managers to deliver high quality products on time and within budget. Thus, the firms have created an environment and adopted practices

that put their program managers in a good position to succeed in meeting these expectations. Collectively, these practices comprise a development process that is anchored in knowledge. The firms demand—and receive—specific knowledge about a new product at key junctures in the process, (see fig. 1).

Figure 1: Knowledge-based Process for Applying Best Practices to the Development of New Products



There is a synergy in this process, as the attainment of each successive knowledge point builds on the preceding one. Such a knowledge-based process is essential to commercial firms getting better—and predictable—cost, schedule, and performance outcomes. It enables decisionmakers to be reasonably certain about critical facets of the product under development when they need it. We have found that when DOD programs have employed similar practices, they also experience good outcomes. This knowledge can be broken down into three knowledge points:

- when a match is made between the customer's needs and the available technology;
- when the product's design meets performance requirements, and
- when the product can be produced within cost, schedule, and quality targets.

The most important knowledge point occurs at launch—the point at which the product developer makes a decision to commit (or invest) the resources necessary to develop a new product that will meet customer needs. This knowledge point makes it easier to reach the remaining two knowledge points at the right time. Successful programs are launched only when a product developer is confident that it has the resources—technology, engineering, and production knowledge, along with sufficient time, and money—to develop a product the customer wants. Significant

problems have occurred during development when programs were launched without this match.

We have reported on how a key resource of a developer—advanced technology—can and must be readied to meet product requirements at the time a product's development program is launched.¹ In this report, we address both sides of the match: how customer needs and product developer resources can be managed so that a product developer can predictably deliver a product the customer wants.

How Product Requirements Are Set Is Key to Program Outcomes

The decisions that are made in translating the ideas for a new product into actual features and characteristics dictate the amount of resources—knowledge, time, money, and capacity—that will be necessary to bring the product to market. Thus, they may be the most highly leveraged of all product development decisions. A product's requirements are based on customers' expectations and justify the developer's investment of resources to provide the desired capability. Requirements drive the amount of capital, time, expertise, and technologies the developer must invest. In the past, it has not been unusual for weapon system requirements to be set at such a high level that the initial estimate of the resources necessary to develop a responsive product proves insufficient, evidenced by cost growth and schedule slippage. The case to justify the requirements is often so stridently made that decisionmakers are in a relatively weak position to do anything other than find more resources.

For commercial firms and DOD, the basic process for formulating a product's requirements is the same. Each begins with understanding the customers' expectations. These expectations are then translated into product requirements that include the job the product is to perform, the functions or characteristics it is to possess, the practicality it must have, and its reliability. Typically, the first understanding of customer expectations exceeds what the developer can do within available resources, because the developer has a limited amount of resources at its disposal for product development. On one hand is knowledge—the technology and capabilities the developer has to engineer and manufacture the product. On the other hand is the time and money the developer has to develop additional knowledge, if need be, and to design, build, test, and

¹*Best Practices: Better Management of Technology Development Can Improve Weapon System Outcomes* (GAO/NSIAD-99-162, July 30, 1999).

deliver the product. It is not unusual for a customer to want a high-performing product that does not cost much or take too long to develop. Such an expectation may exceed the developer's technology or engineering expertise or may be more costly and time-consuming to create than the customer is willing to accept. The developer must stay within its means if the venture is to remain mutually beneficial. Table 1 characterizes the divergent interests of the customer and the product developer.

Table 1: Customer and Product Developer Interests in a Product's Development

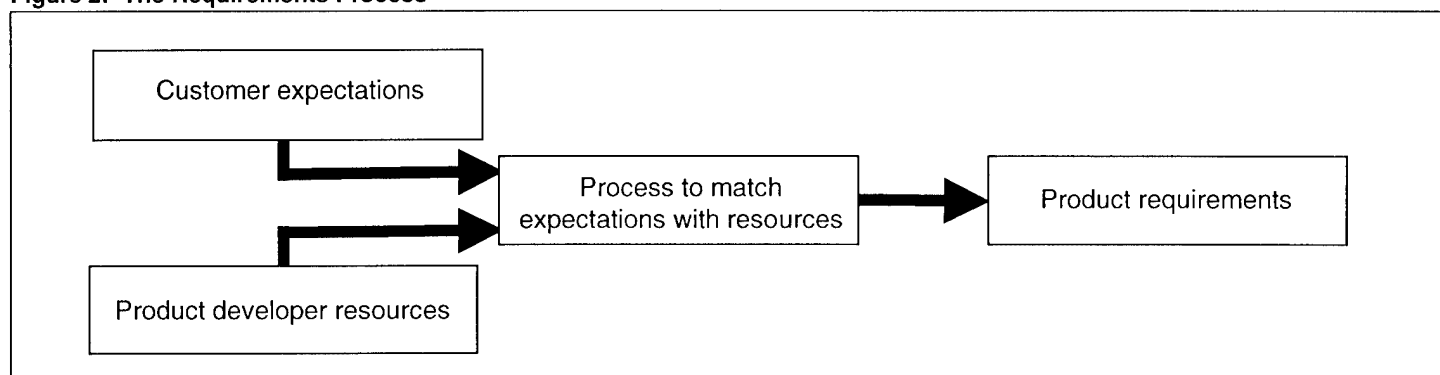
Customer wants	Product developer's resources
Performance: what the product should do. For example, what an aircraft's speed, range, fuel economy, reliability, and other features should be.	Technology: the technology that is needed to make the product function to a level necessary to meet the customer's wants.
Timing: when the customer wants the product.	Schedule: the amount of time that is needed to develop, design, test, and manufacture the product.
Pricing: what the product will cost. The customer must be able to afford the product.	Investment funds: the capital that is needed to pay for development, test, and manufacture of the product until revenue from sales begins.
	Expertise: the capabilities of the product developer in terms of engineering expertise, manufacturing capabilities, and production.

Given these different interests, a customer's wants and a product developer's available resources must be matched to form an achievable set of product requirements. On one hand, the product developer must develop and produce the product within the time frames the customer needs or the customer may find an alternative product or source. On the other hand, the customer must not demand a product that requires so much money or time to develop that it cannot be afforded or delivered when needed. There is a delicate balance that must be achieved between these two divergent interests before a product can be successfully developed and produced.

On all product developments, there is an attempt to match expectations with available resources to define the new product. A customer's expectations and a product developer's resources are more closely scrutinized during the matching process that attempts to bring the two together. The outcome is a set of product requirements that represent an

agreement that the product will meet the customer's wants and that the developer can deliver the product within acceptable cost and schedule estimates. The requirements then guide the development program. This basic requirements setting process is illustrated in figure 2.

Figure 2: The Requirements Process

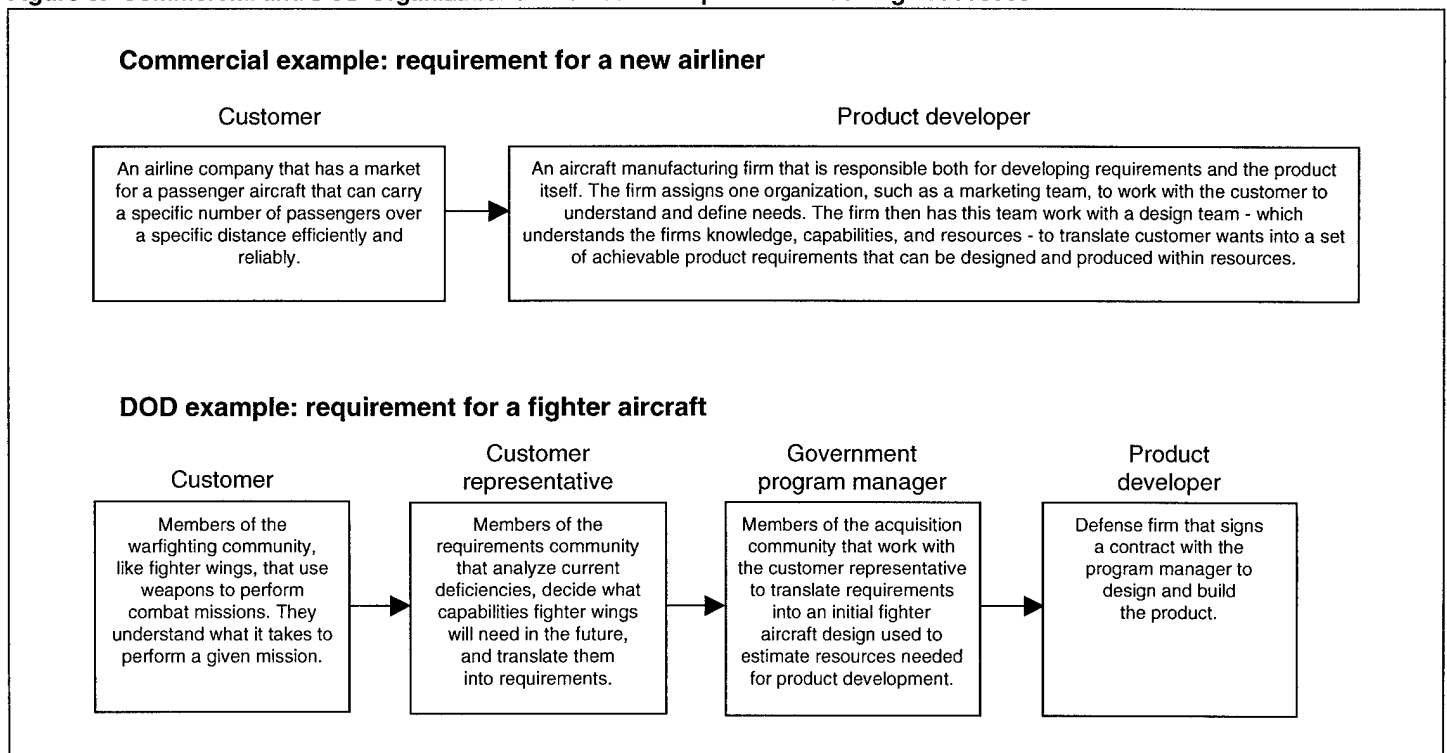


The process of translating general customer expectations into a specific set of product requirements involves information gathering, analysis, negotiation, and agreement. In the commercial process, the customer and the product developer negotiate requirements, matching expectations and available resources into a documented set of product requirements prior to committing resources to product development. During this negotiation, the customer's relatively unconstrained wants are often reduced to a set of performance characteristics that are achievable with available resources, yet still meet the customer's needs. The commercial process is a two-way communication between the customer and the product developer. For example, an airline company may want a certain speed to maximize revenue per passenger mile from a new aircraft. However, the product developer may determine that the resources to develop an aircraft with that speed are not available or must be increased dramatically. Both parties then work through an iterative process of trades and negotiation to settle on an aircraft with mutually acceptable performance and resource requirements.

The DOD process is somewhat more complex and involves communications among at least four major players. On one end is the customer, which is normally a military organization that belongs to a major fighting force. On the other end is the product developer, usually a defense firm that serves as the prime contractor for developing and producing the

weapon system. In between are two other players that actually negotiate needs and resources to arrive at product requirements. One is referred to as the user representative, which is an organization separate from the customer but represents the customer and negotiates on its behalf. The other player is the DOD program manager, a separate organization that, in essence, represents the product developer. Figure 3 illustrates how these different players interact in commercial and DOD requirement-setting processes.

Figure 3: Commercial and DOD Organizations Involved in Requirements Setting Processes



Both commercial and defense organizations are concerned about how much a product or weapon system is going to cost, how long it is going to take to build, what resources will be needed to build and maintain it, and whether it works properly. All of these concerns are translated into the product's requirements. Unlike the commercial process, the DOD product developer does not directly influence the product requirement prior to launching product development. Once requirements are formalized in what

DOD refers to as the Operational Requirements Document, they are turned over to the prime contractor, who actually begins product development.

Objectives, Scope, and Methodology

The Chairman and the Ranking Member, Subcommittee on Readiness and Management Support, Senate Committee on Armed Services, requested that we examine various aspects of the acquisition process to determine whether the application of best practices can improve program outcomes. To date, we have issued reports on advanced quality concepts, earned value management, management of a product from development to production, management of key suppliers, management of technology insertion, training, and management of test and evaluation (see related GAO products).

This report covers the beginning of the acquisition process: the management of product requirements. Our overall objective was to determine whether best practices offer methods to improve the way DOD sets product requirements within the framework of a knowledge-based product development process. Specifically, we assessed (1) the effect of the timing of the match between the customer's needs and the developer's resources on a product's cost and schedule; (2) the best practices for obtaining this match during the requirements setting process, compared with more traditional DOD practices; and (3) the progress made and challenges DOD faces in adopting best practices for setting requirements on individual weapon systems.

We follow a similar overall methodology for conducting best practices reviews in the area of weapon system development. We start by identifying individual aspects of weapon system development—in this report, the setting of requirements—that have been shown to be a significant and recurrent cause of problems. Our sources for such information include our many reviews of individual weapon systems; studies from other sources, such as the Defense Science Board; and discussions with defense experts, including past and current DOD officials, defense industry representatives, and analysts from private organizations that study defense issues. Before beginning a review of a particular topic, we confirm with DOD officials that the topic is one in which the potential for improvement is significant. Once we have identified the topic, we use a case study approach because case studies provide the in-depth knowledge needed to understand individual practices, how they affect program outcomes, and why they are adopted. In selecting case studies, we look for examples of excellent practices from leading commercial firms, examples of typical or traditional practices from

DOD, and where possible, DOD examples that exhibit excellent practices. In making our selections, we are careful to make sure that there is a link between the practices themselves and the outcomes of the programs.

To identify best practices for setting requirements on commercial products, we reviewed literature and spoke with industry and academic experts to find companies recognized for managing requirements to help deliver new products that were both quicker to market and more advanced than their predecessors. We identified three companies

- Caterpillar Construction and Mining Division, Decatur, Illinois;
- Bombardier Aerospace, Toronto, Canada; and
- Bethlehem Steel, Bethlehem, Pennsylvania

We visited each company, discussed the process used for setting requirements, and obtained an understanding of the overall process used with emphasis on those practices each felt were critical for success. We also met with individual program managers and discussed specific product development examples that further illustrated the process. During our discussions with the firms, we compared and contrasted the best practices with DOD's practices.

We developed nine case studies in total. These included two commercial case studies, one National Aeronautics and Space Administration (NASA) program that had received excellent results by disciplining its requirements-setting process, and six DOD weapon system programs that represented a mixture of traditional and best practices. We reviewed the requirements-setting process for all nine programs. For each program, we interviewed key managers and obtained documentation to determine (1) the process that was used to achieve the match between customer wants and resources to form the product's requirements, (2) the timing of this match and the tools used to achieve it, and (3) the extent to which the requirements setting process affected the program's product development outcome. Descriptions of the nine programs we reviewed follow.

Commercial

- Bombardier's BRJ-X, a commercial jet in development, designed to carry between 88 to 110 passengers. It bridges the gap between the current fleet of regional jets, 20 to 70 passenger capacity and the larger 111 to 170 passenger commercial airlines. The BRJ-X program was launched in the second quarter of 2000. The first aircraft is scheduled to be delivered

to airlines in late 2003. Bombardier estimates customers for 2,500 aircraft over the next 20 years.

- The Caterpillar 797 mining truck, the largest mining truck ever built. It can carry over 360 tons of ore, and features many patented innovations. Developed in response to mining companies' desire to reduce cost per ton of hauling ore in large-scale mining operations, Caterpillar launched the 797 program in 1997.

DOD

- The Air Force's Global Hawk, an unmanned aircraft that is intended to fly at altitudes as high as 65,000 feet and for as long as 40 hours to provide the Air Force with an intelligence, reconnaissance, and surveillance capability. The Air Force built five prototype technology demonstrators that were used to demonstrate the aircraft, and it plans to launch the product development program in 2001.
- The Army's Crusader artillery vehicle program, a self-propelled 155-millimeter howitzer and resupply vehicle. It is expected to be the first fully automated, computerized, and tracked artillery system. The Crusader development program began in 1994, and the howitzer is expected to start production in 2008. The development program is estimated to cost \$4.3 billion.
- The Army's Tactical Unmanned Aerial Vehicle, a short-range unmanned aircraft that is expected to provide the Army with day or night reconnaissance, surveillance, and target acquisition capability. The Army began development in March 1999. It plans to buy 44 systems starting in 2001. Each system includes three unmanned aircraft; a vehicle to carry the aircraft; two ground control stations mounted on vehicles; and launch, recovery, and support equipment pulled on trailers behind the vehicles. The cost to buy the 44 systems is estimated at \$430 million through 2004.
- The Navy's Radio Frequency Countermeasures system, an electronics warfare system that uses a jamming device called a techniques generator. It is carried onboard an aircraft to produce jamming signals that are transmitted by fiber optic cable to a towed device that acts as a decoy for the aircraft. The system is used to protect the aircraft from radar-controlled weapons like missiles and anti-aircraft artillery. It is a critical component of the Integrated Defensive Electronics Countermeasure System being developed for some Navy and Air Force aircraft. System development began in 1995 and is expected to cost over \$200 million. It is expected to enter production in 2002.

- The Army's Brilliant Anti-Armor Submunition program, referred to as BAT, an acoustic and infrared terminally guided submunition that searches for, detects, tracks and engages moving tanks and armored combat vehicles. Its mission is to provide deep attack against motorized rifle and tank divisions. The carrier for the submunition is the Army Tactical Missile System that is launched from the Multiple Launch Rocket System. The Army plans to buy 15,707 submunitions at a cost of \$2.5 billion.
- The Army's Comanche helicopter, a lightweight, twin engine, stealthy helicopter that is intended to replace the Army's OH-58 and AH-1 helicopters. The primary mission of the aircraft will be armed reconnaissance and attack. It is the Army's largest aviation acquisition program, with a projected total development and production cost of \$48 billion for 1,213 helicopters. The development program was launched in 1988, and production is expected to start in 2006.

NASA

- The Far Ultraviolet Spectroscopic Explorer (FUSE), a scientific telescope that is used for studying the origin and evolution of stars, galaxies, and planetary systems. The telescope is 18 feet tall and weighs 3,000 pounds. It was developed for NASA by the John Hopkins University. The FUSE program began in June 1996 and was completed in June 1999 at a cost of \$120 million.

We used information from our prior best practices work, including most of the information on the BAT and Comanche programs. Similarly, we gathered knowledge about many aspects of the product development processes, including the setting of requirements, from leading commercial firms in addition to the firms included in this report. During the past 4 years, we have gathered information on product development practices from 3M, Boeing Airplane Company, Chrysler Corporation, Ford Motor Company, Hughes Space and Communications, and Motorola. This information enabled us to develop an overall model to describe the general approach leading commercial firms take to developing new products.

We also met with experts in the area of setting product requirements from academia and participated in conferences and workshops with recognized leaders in the acquisition field to obtain information on how organizations were improving their acquisition processes. To obtain a general understanding of DOD's requirements setting process and improvement initiatives, we met with officials from the Office of the Secretary of

Defense; Army, Navy, and Air Force Headquarters; and the Joint Staff for the Joint Chiefs of Staff. We also had discussions with former DOD officials and industry experts about DOD acquisition policies and practices. With these officials we discussed the current process, initiatives and the applicability of best practices to DOD operations. In addition, we visited NASA to obtain information on their processes and practices for setting requirements for new product development programs.

We conducted our review from November 1999 through December 2000 in accordance with generally accepted government auditing standards.

Timely Matching of Requirements and Resources Is Critical to Product Development Outcomes

The point in time that a developer for a new product becomes justifiably confident that it has the resources—knowledge, capacity, time, and money—to develop a product that a customer wants is critical to the success of the development effort. Barring program cancellation, the match between resources and wants is eventually met on just about every product or weapon system development. A key distinction between successful products—those that perform as expected and are developed within estimated resources—and problematic products is when this match is achieved. Simply put, we found that when wants and resources were matched before a product development was started, the more likely the development was able to meet performance, cost, and schedule objectives. When this match took place later, programs encountered problems such as increased costs, schedule delays, and performance shortfalls.

For successful product or weapon system development program cases, trade-offs were made either in the design of the product or in the customer's expectations to avoid immature technologies or exotic components that threatened to outstrip the developer's resources. In the less successful cases, the opportunity to make such trade-offs before starting product development was missed either because gaps between expectations and resources were not identified or because customers were unwilling to reduce their expectations. When the divergence between customer expectations—which by then had become firm product requirements—and developer resources was recognized and confronted, decisionmakers were reluctant to materially change the requirements. Consequently, the developer had to invest more resources than originally planned to meet the requirements.

Early Matching of Customer Expectations and Developer's Resources Is Critical to Program Success

We found that the timing of the matching process—when the customer's expectations were successfully matched with the product developer's resources—significantly influenced the likely success of a product's development. After reviewing the process for defining product requirements for nine development programs, we found a relationship between when expectations were matched with available resources and when the cost and schedule predictions for the programs were achieved. This relationship is shown in table 2.

Chapter 2
Timely Matching of Requirements and
Resources Is Critical to Product
Development Outcomes

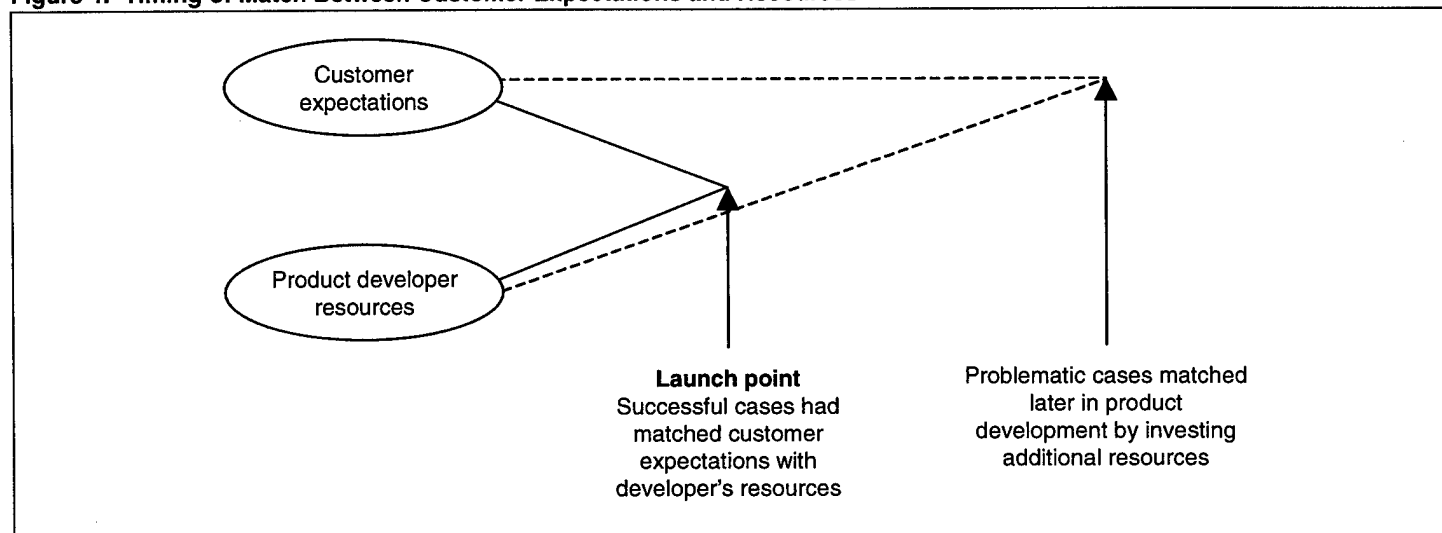
Table 2: Matching of Expectations to Resources and Product Development Outcomes

Programs	Expectations and resources adequately matched before launch	Product development cost growth	Product development schedule delays
Caterpillar 797 mining truck	Yes	5 percent	0 percent
NASA FUSE	Yes	20 percent	0 percent
Radio Frequency Countermeasures system	No	197 percent	23 percent
Crusader artillery vehicle	No	55 percent	26 percent
Comanche helicopter	No	127 percent	119 percent
Brilliant Anti-armor Submunition	No	99 percent	46 percent
Bombardier BRJ-X ^a	Yes	On target	On target
Tactical Unmanned Aerial Vehicle ^a	Yes	On target	On target
Global Hawk Unmanned Vehicle ^a	Yes	On target	On target

^a Specific cost and schedule data for the Tactical Unmanned Aerial Vehicle, Global Hawk Unmanned Aerial Vehicle, and Bombardier BRJ-X Regional jet were not included in the table because they had not been in the product development phase long enough to report actual cost and schedule variances. However, these programs had already avoided some of the problems experienced by the programs that did not match expectations and resources before launch. These programs were on target for meeting their objectives.

The more successful programs had matches before the commitment to launch the programs was made. In each case, the product developer had done the initial design of the product and ensured that only proven technologies, design features, and production processes would be used. This was accomplished by either making additional investments to demonstrate uncertainties such as new technology or by reducing the product's initial performance requirements. These steps maximized the knowledge content of the product and enabled the program manager to set cost and schedule estimates it could reasonably expect to meet. In contrast, the programs that did not have matches before launch did so during product development by the unplanned addition of resources. This contributed significantly to cost and schedule problems. Figure 4 illustrates the timing of the match between customer's expectations and a product developer's resources.

Figure 4: Timing of Match Between Customer Expectations and Resources



The programs in which expectations and resources were matched before product development started were in a good position to commit to cost and schedule estimates that were attainable. In those cases where expectations and resources were not matched before launch, cost and schedule estimates had to be made at the time of launch. Such estimates were necessarily made at levels consistent with the resources the product developer had available, under the assumption that either (1) no gaps existed between expectations and resources or (2) any gaps could be closed within projected resources. Because customer expectations regarding the performance of the product tended to become set when product development began, adding resources emerged as the primary option available to match expectations and resources. These resources (time and money) were typically needed for maturing technologies, developing design solutions, and providing more production capabilities. Perhaps more importantly, they were not estimated or planned for and often necessitated sacrifices in other needs, such as reducing the resources of other development programs.

Trade-offs Are Critical to Matching Customer Expectations With Developer Resources Before Starting Product Development

Caterpillar and Bombardier both matched customer expectations with available resources prior to setting product requirements and launching the products' development programs. In each case, there were differences between expectations and resources that necessitated trade-offs before requirements could be set and the product's development could be launched. For these cases, expectations and resources were negotiated so that the product's requirements could be achieved within available resources while still meeting the customers' critical needs. This allowed the firms to develop and deliver their products quickly and within acceptable cost limits, thereby maintaining their competitive advantage in their respective markets.

Caterpillar's 797 Mining Truck

To maintain the competitive advantage in its market, Caterpillar's board of directors believed it had to develop by the end of 1998 a new product that was sized to work efficiently with large loading shovels used in mining operations. This meant that Caterpillar's product development team would have about 18 months from the time the product development program was approved to develop and field the 797, a newly designed truck that could efficiently haul at least 360 tons of payload. According to Caterpillar, they met this date because they made trade-offs between the customers' expectations and the resources available before the product development program began. Figure 5 shows the 797 mining truck developed and figure 6 shows the history of the truck development.

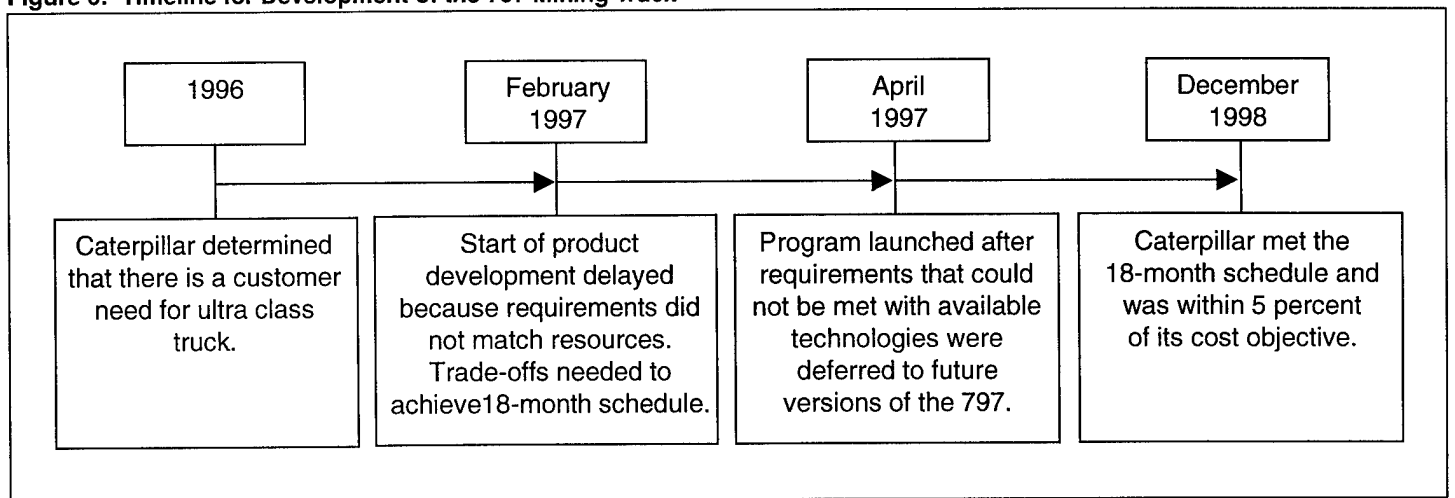
Figure 5: Caterpillar Mining Truck



Caterpillar developed the 797, a 360-ton capacity mining truck, in 18 months.

Source: Caterpillar, Inc.

Figure 6: Timeline for Development of the 797 Mining Truck



Examples of key trade-offs Caterpillar made to close gaps between customer expectations and its own resources were:

- deferring to the next product line, new prognostic technologies wanted by the customer that could assist in forecasting wear and tear to the truck, but were immature at the time product development started;
- selecting a twin-engine propulsion design to power the 797 rather than a single engine—despite its potential for lower operating costs—because it had not yet been developed and was therefore too much of a risk; and
- redesigning the wheel and transmission to avoid the need to develop new gears for the differential unit in the drivetrain, which avoided a costly and risky development effort that could have impacted the truck's development progress.

The Bombardier BRJ-X Jet

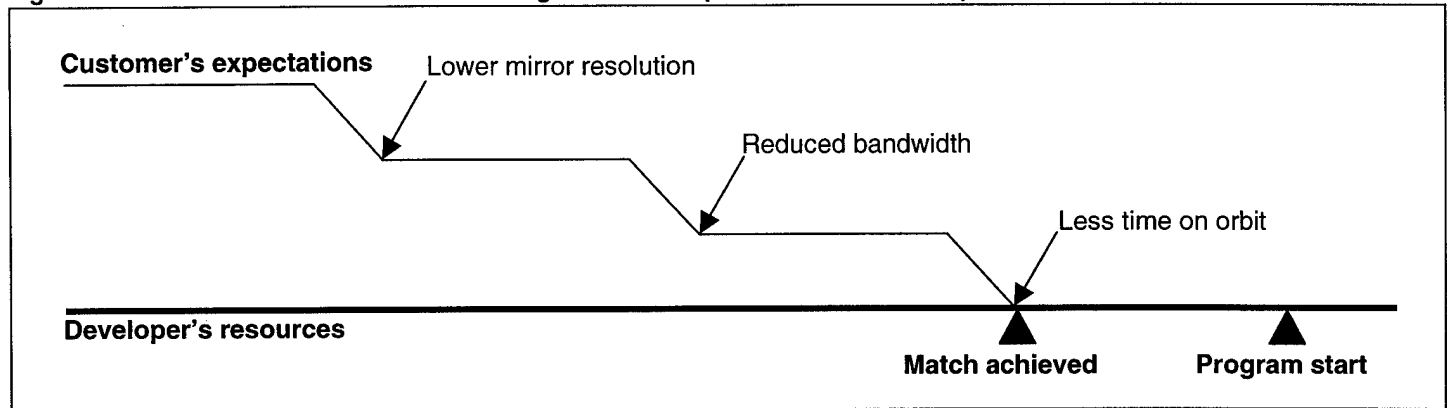
During the BRJ-X jet's concept definition phase, which preceded product development, Bombardier identified some customer expectations that its designers believed would put program cost and schedule at risk. The expectations were analyzed and trade-offs were made to make the design achievable within resources. For example, both airline customers and Bombardier wanted to use fly-by-wire flight control technology, which would replace heavy hydromechanical flight controls with lighter weight electronic controls, on the BRJ-X to reduce weight and lower fuel costs. However, Bombardier engineers had some concerns about the technology since it had never been integrated into a regional jet configuration before. Consequently, Bombardier decided to invest the time and money to demonstrate the technology on a surrogate business jet before making it a program requirement. Another trade-off was made after Bombardier determined that the desired speed would require design effort and features not fully proven out. The customers agreed that a slight reduction in speed would eliminate the design concerns yet still meet their expectations.

NASA's FUSE Program

FUSE is a telescope used to study the origin and evolution of certain elements in space to help determine the age and evolution of stars, galaxies, and planetary systems. The customer initially expressed expectations in terms of gathering precise images of light from these elements in space 24 hours per day. When NASA threatened to cancel the program because requirements were not achievable given available resources, FUSE program managers negotiated with customers and found they could still meet the basic expectations with reduced requirements for

a high-resolution mirror, bandwidth detection, and time on orbit; switching from a highly elliptical orbit to a low earth orbit (see fig. 7).

Figure 7: Effect of FUSE Trade-offs on Matching Customer Expectations with Developer's Resources



These reductions in requirements allowed the use of existing technologies such as a new grating technique to spread radiation into different wavelengths. Matching requirements to resources allowed FUSE to not only meet schedule targets and be within 20 percent of its cost objective but also a critical NASA need.

When Matching Did Not Occur Before Program Launch, Developers Were Forced to Add Unplanned Resources

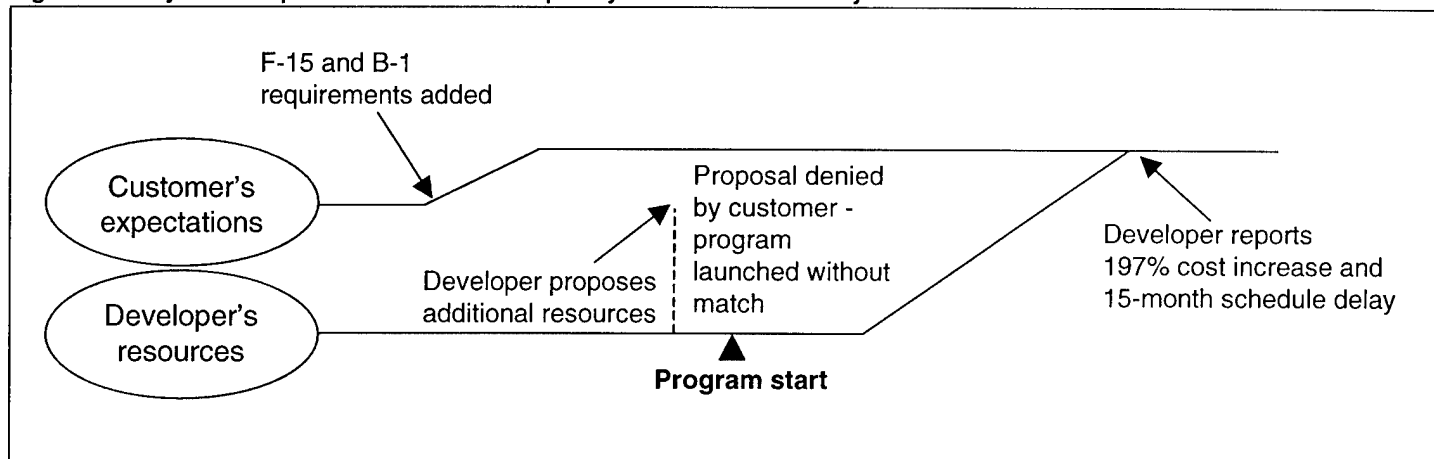
In cases where the customers' expectations were not matched with the developers' resources before product development began, the matches took place after opportunities to make trade-offs had passed. Because new programs had been approved with customer wants formally documented as requirements, the main avenue available to close gaps between requirements and resources was for the developers to invest more effort, time, and money to gain the knowledge and capacity needed to meet the requirements. This additional investment—manifested by cost increases and schedule delays—was not planned, which forced trade-offs or cuts to be made in other programs to free up the additional resources. In some cases, the developers may have had indications that there was a mismatch at the launch decision, but they were pressured to go forward anyway. In other cases, while the developers may not have enough knowledge to be confident that there was a match before launch, they were at a disadvantage to argue that there was not. DOD's Radio Frequency Countermeasures system and Comanche helicopter programs did not have matches before their product development programs were launched. In

fact, despite being several years into both programs, it is still uncertain whether this match has been reached.

Navy's Radio Frequency Countermeasures System

Customer expectations and developer resources were not matched on the Radio Frequency Countermeasures program when product development began in 1995. Essentially, the performance wanted by the customers exceeded the time, money, and technologies available to the product developer to develop an acceptable system. For example, a critical component is the fiber-optic towed decoy—a component, towed behind the aircraft in flight, which transmits electronic countermeasures. Before program launch, the requirement for the power to be transmitted from the towed decoy was nearly tripled because of a last minute addition to satisfy the Air Force's expectations for the F-15 fighter and the B-1 bomber. This was a demanding requirement that, according to the former program manager, required some technological invention. According to the manager, this was complicated by the customer's refusal to either reduce performance requirements or accept increases in time and cost to develop a product that would meet these requirements. The Navy chose to launch the program with this mismatch, recognizing that it added risk to the program. Figure 8 shows the timeline for the program.

Figure 8: Navy's Development of the Radio Frequency Countermeasures System



As the program proceeded, problems associated with the risk accompanying the mismatch turned into development problems, and the additional resources found to be unacceptable to the customer before launch were accepted as a necessity after launch. Consequently, the costs

rose from \$74 million to \$221 million and the development schedule was extended 15 months.

Comanche Helicopter

Customer expectations that became key requirements for the Comanche helicopter demanded several technologies that were still very immature when the Army decided to launch the program in 1988. For example, the integrated avionics and an advanced infrared night vision and targeting sensor were included on the program when they were still conceptual in nature. These advanced avionics systems were needed to meet the customer's "must-have" requirements for a very lightweight, stealthy, highly maneuverable, all-weather reconnaissance and attack helicopter. These technologies were also critical to meet cost and weight goals for the program. The Army launched the program despite the low readiness of the technologies, with the developer having limited design alternatives but believing that the needed technological invention could be accomplished within projected resources. At the time of launch, the Army estimated that product development would cost \$3.6 billion and last about 8 years. Due to problems that developed with these technologies and budgeting and other changes in the program, development is now estimated to take \$8.3 billion and 18 years—over 100-percent increases. The Army kept the customer's requirements essentially unchanged, electing to double the resources needed to meet them.

Several Factors Enable Customer Wants and Developer Resources to Be Matched Before Program Launch

The ability to match a customer's wants with resources before launching a development program is key to putting program managers in a better position to succeed. We found three factors that comprise this ability. First, developers employed systems engineering to identify gaps between resources and customer wants before committing to a new product development. Second, customers and product developers were flexible before launch. Leeway existed to reduce expectations, defer them to future programs, or to invest more resources up front to eliminate gaps between resources and expectations. Third, the roles and responsibilities of the customer and the product developer were balanced, with the product developer given the responsibility to determine or significantly influence product requirements. In cases where these factors were not present at program launch, product development began with imbalanced product requirements. Invariably, this imbalance favored meeting expectations at the expense of resources, putting the developers at a disadvantage to deliver the products within cost and schedule estimates.

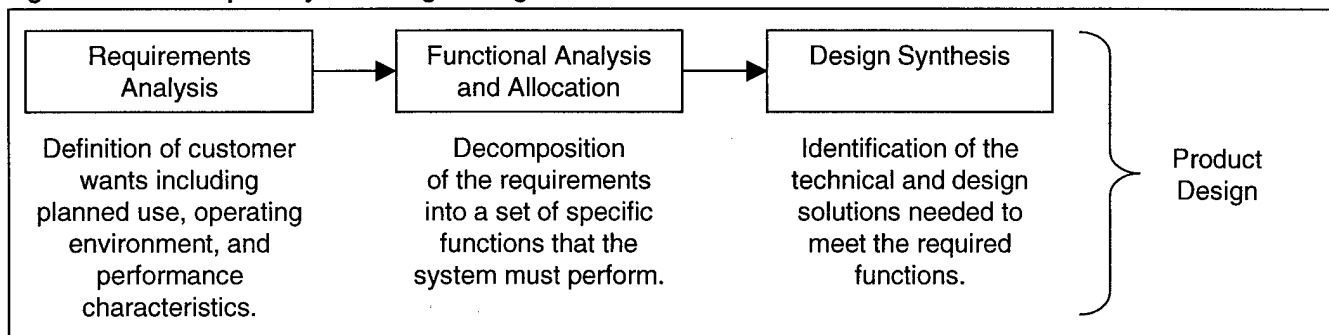
In the most successful cases, the effective interplay of these factors allowed the customers and product developers to arrive at a set of product requirements that could be developed within cost and schedule targets. Systems engineering provided knowledge necessary to translate customer wants into specific capabilities, enabling the developers to identify and resolve gaps before product development began. With systems engineering knowledge in hand, flexible requirements were essential to lowering risk through negotiations because knowledge alone did not produce trade-offs. Absent such flexibility, resources and wants could still be matched before product development began, but the options to resolving any gaps were limited to additional investments on the developers' part. Finally, with knowledge gained from systems engineering and flexible requirements as preconditions, successful product development programs benefited from an environment in which product developers and customers had balanced roles and shared responsibilities for setting product requirements.

Systems Engineering Tools Are Critical for Identifying Gaps Between Developer's Resources and Customer's Expectations

When product developers employed systems engineering before committing to product development, they were able to identify areas in which the customers' wants exceeded their resources. For those cases in which developers did not conduct sufficient systems engineering before committing to the new product development, they were weakened in their ability to identify gaps between their resources and expectations. These gaps were later revealed as unexpected problems that required invention, time, and money to resolve.

Systems engineering is a process that not only translates customer wants into specific capabilities, such as individual technologies and manufacturing processes, but also provides knowledge that enables a developer to identify and resolve gaps before product development begins. It is defined as a logical sequence of activities that transforms a customer want into specific product characteristics and functions and ultimately into a preferred design (see fig. 9). It is not necessarily the use of systems engineering in the development of a new product or weapon system, but when it is used that distinguishes it as a best practice.

Figure 9: Basic Steps in Systems Engineering Process

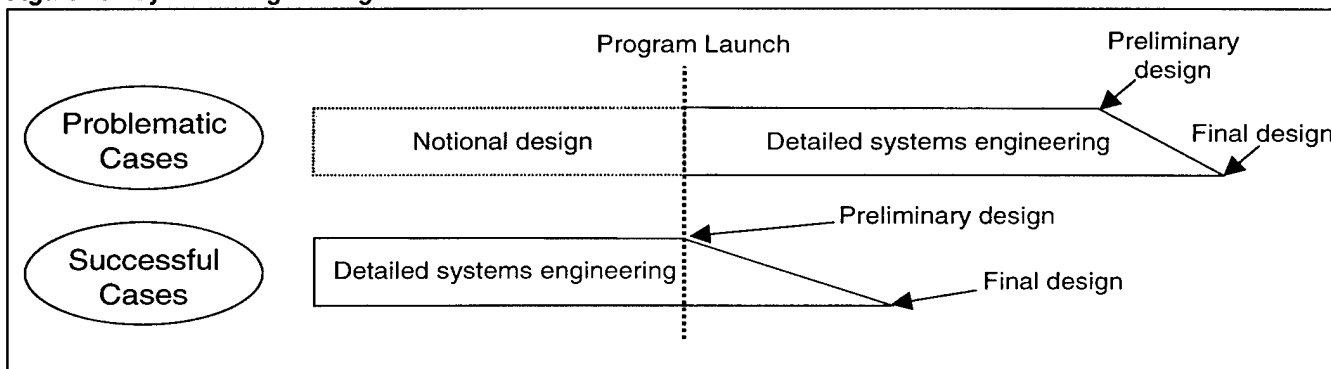


The systems engineering discipline enables the product developer to translate customer wants into specific product features for which requisite technological, software, engineering, and production capabilities can be identified. Once these capabilities are identified, a developer can assess its own capabilities to determine if gaps exist. It is critical for a developer to involve the right people—those with the affected areas of expertise—in this assessment. Gaps identified between what the customer's wants are and what the developer possesses then become the focus of analysis. Some gaps can be resolved by investments the developer makes, while others can

be closed by finding technical or design alternatives. Remaining gaps—those that represent capabilities the developer does not have or cannot get without increasing the price and timing of the product beyond what the customer will accept—must be resolved through trade-offs and negotiation.

During systems engineering, a product design progresses through at least three iterations. The first is a notional design—a general concept of what the product will look like and what it might be capable of that is unconstrained by resources. The second iteration is the first detailed design that enables a developer to compare its capabilities with the demands of the product. The third iteration is the final design, which captures improvements to the design generated by testing, analysis, and other forms of learning. These iterations can be seen in figure 10, which provides a general comparison of the amount of systems engineering accomplished in the successful and problematic cases prior to launching a product development program.

Figure 10: Systems Engineering Used for Successful and Problematic Cases



Successful Programs Used Systems Engineering Before Product Development Began

In each successful case, the product developer worked closely with the customer to understand its wants, which were often articulated in a bottom-line metric, such as cost per passenger mile for a commercial airplane. By the time the developer had committed to a product development program, it was well into its systems engineering process and had developed a preliminary design of the product. This process identified the gaps between resources and expectations, which could be then addressed through investments, alternate designs, and, ultimately, trade-offs. The knowledge produced by the process put the developer in a

good position to negotiate with the customer because consequences could be associated with attempts to meet those wants that exceeded the developer's capabilities. The process also involved the customer through periodic reviews and acceptance of the product's final design. According to some commercial representatives, systems engineering is a good investment to reduce risk, usually comprising a small percentage to the overall development cost of a new product. We found two commercial firms—Caterpillar and Bombardier Aerospace—and two DOD programs—the Army's Tactical Unmanned Aerial Vehicle and the Air Force's Global Hawk unmanned aerial vehicle—that employed fairly extensive systems engineering before they committed to product development.

Caterpillar's 797 Mining Truck

Caterpillar's New Product Introduction process calls for completing a significant amount of the systems engineering process during the concept phase for any new product before product development. It applied this process to its development of the 797 mining truck, a new product design. It spent significant time and effort prior to beginning product development establishing the customers' wants and closing the gap between them and available resources. Before committing to its development, Caterpillar gathered information from the mining companies about operating conditions and the cost per ton of ore hauled desired of the new truck that they would be willing to accept during the truck's lifetime. Caterpillar then made a preliminary determination of what the truck's performance requirements would have to be to meet these conditions and costs. For example, it determined that the truck's payload, or bed, would have to haul at least 360 tons, travel at certain speeds, and climb certain grades. This information served as the starting point for systems engineering to determine if the performance requirements for the 797 were achievable given Caterpillar's resources. Once these requirements were established, Caterpillar's engineers began an iterative systems engineering process to design a product that would meet the customers' wants and could be developed within funding, schedule, and resource targets. This process culminated in a specific product solution that matched requirements to resources before Caterpillar committed to product development.

The systems engineering process for the 797 forced key trade-offs between performance requirements and design solutions prior to commitment to product development. For example, to transmit the power from the engine to the rear wheels, the original design called for using very large differential gears. Upon reviewing that design, an experienced Caterpillar production engineer noted that no gear manufacturer made a gear that large and that to create such a production capability would be risky. Consequently, the

design engineers found an alternative that called for making incremental changes in the transmission and wheel designs, which enabled existing differential gears to be used. These design changes and the processes required to make the changes were demonstrated successfully prior to product development. Systems engineering also revealed risk on some of the new hydraulic technology for the 797 that would allow easier and more reliable unloading. Because this new technology had not been used in the field before, Caterpillar engineers demanded demonstrations and field tests of the technology before allowing it onto the 797 truck.

Bombardier's New Regional Jet

Bombardier set requirements for a new, larger family of regional jets that will carry up to 115 passengers—the BRJ-X series—using its Bombardier Engineering System. Beginning with an overall cost-per-passenger-mile target from the customer, Bombardier employed an iterative systems engineering process to make trade-offs between performance requirements—which were based on extensive market analysis—and available resources to arrive at requirements, design, and cost and schedule targets before committing to product development. The company plans to achieve nearly full knowledge of the product's design before it commits to product development. At launch, the product's performance requirements and its configuration will be frozen.

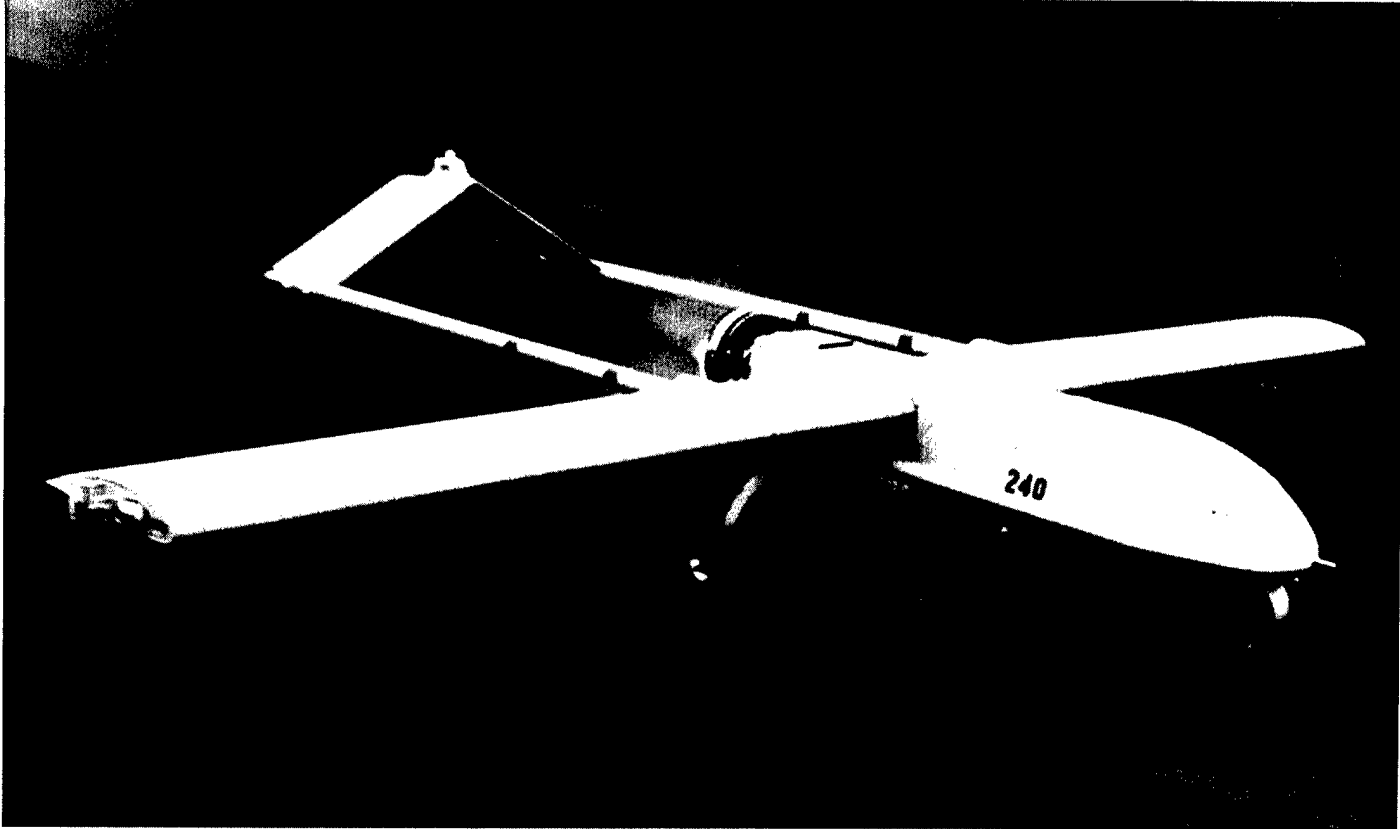
During Bombardier's trade study process, customer wants are thoroughly challenged by the firm's assessment of technology capability and readiness, as well as by manufacturing, producibility, logistics, and other implications of the product's features. During this process, engineers are cognizant that product success and profitability hinge on not only product features but also product price and quantity that market research has determined. This fact tempers decisions about the viability of key performance or design parameters. In other words, if Bombardier cannot produce and develop a product within a customer's price range, then the customer is not likely to buy it. Once this process is complete, Bombardier performs a detailed aircraft review, which results in a trade-off analysis. If this analysis suggests that key performance requirements—speed or range, for example—cannot be achieved within the established price and quantity, the requirements are changed. If product performance is reduced below the customer's minimum threshold, profit calculations are upset and the development program is not initiated.

Army's Tactical Unmanned
Aerial Vehicle

The Army's Tactical Unmanned Aerial Vehicle is a DOD program that used systems engineering to gather knowledge prior to starting development. The vehicle must meet the brigade commanders' need for a day or night, adverse weather, multisensor data collection system with improved communication with joint forces that provides real-time battle information and cannot be observed by the enemy. The program grew out of an Advanced Concept Technology Demonstration¹ program that was started in 1996 and completed in 1998. While the air vehicle that was flown and evaluated during this demonstration met most of the Army's close-range reconnaissance requirements, it did not meet all requirements and was canceled. Figure 11 shows the Army's Tactical Unmanned Aerial Vehicle.

¹ Advanced Concept Technology Demonstrations attempt to bring mature technologies together to meet an existing military need. They are managed by science and technology organizations and must demonstrate military utility before they can become acquisition programs.

Figure 11: Tactical Unmanned Aerial Vehicle



The Army used systems engineering to transform customer expectations into a set of achievable product requirements prior to program launch.

The technology demonstration provided the Army with knowledge about the achievability of the customers' requirements. The product developer built a prototype system that was used to identify gaps between what the customer wanted and what was achievable with resources. Through systems engineering, the developer transformed the wants into a set of performance requirements that led to the prototype's design. The Army used the results of the technology demonstration to define the customer's requirements that were geared toward obtaining a system that required minimal development, based largely on what was demonstrated. Because of the knowledge gained from systems engineering, the Army was able to stage a fly-off of four prototype designs within 9 months after the product development program began. The fly-off results provided additional knowledge to help match customer wants with the product developer's resources through further trades. The Tactical Unmanned Aerial Vehicle

that is now in development closely resembles the design that won that competition. Another program, the Air Force's Global Hawk, followed a similar path by conducting systems engineering and building prototype systems prior to starting its program.

Problems Arose When Only Limited Systems Engineering Was Done Prior to Launch

In the problematic cases, product developers had not progressed as far into the systems engineering process at the time the program was launched. In most of these cases, the product developers had only notional designs at that point—not thorough enough to translate expectations into specific functions against which resources could be compared. It was not until product development was underway that systems engineering was fully employed to create a preliminary product design. In each case, this occurred several years after the acquisition program was started. The lack of knowledge at the start of each program made well-informed trades between customer wants and developer resources difficult to see or make. Nonetheless, cost and schedule targets for each program were set based on available information. Problems that were discovered during product development and during the systems engineering process often resulted in the need for more time or money than had been estimated at program launch.

Two DOD programs we reviewed—the Radio Frequency Countermeasures system and the Crusader program—initiated a systems engineering process before product development; however, it was not extensive and performed by the eventual product developer hired to design the product and only resulted in a notional product design prior to the decision to commit to product development. The product developers did not gain significant knowledge about what was possible, given the availability of resources, until after the decision was made to commit the resources toward developing the product.

Navy's Radio Frequency Countermeasures System

The majority of the systems engineering by the Radio Frequency Countermeasures product developer—the defense firm that was awarded the development contract—was not done until after the Navy had launched the program. The knowledge used to match requirements with funding, schedule, and other resources was limited before the program was launched. The Navy did enough analysis—about 25 percent of systems engineering, according to the former program manager—to form a notional design of the system. The notional design was based on a top-level analysis of the functions, which was done primarily by the Navy's program office.

The Navy nonetheless considered this amount of knowledge sufficient to commit to product development.

The Navy entered product development assuming that a large number of the needed parts would be nondevelopmental items—items already used on products. The Navy estimated that 90 percent of the parts for one of the most critical subsystems, the techniques generator,² would be mature, readily available items. According to the program manager, it was not until the contractor hired to develop the system began the detailed systems engineering process that it discovered that only about 50 percent of those parts were still available. Many of the required parts had become obsolete and had to be replaced with redesigned or newly developed parts—revealing a gap between what was thought to be within the developer's capabilities and what the requirements were. As a result, problems with the assumptions made about the notional design by the Navy were discovered in product development, after resources had been determined and the fielding date had been established. This resulted in significant disruptions to planned cost and schedule; eventually affecting the product's fielding.

Army's Crusader Artillery Vehicle

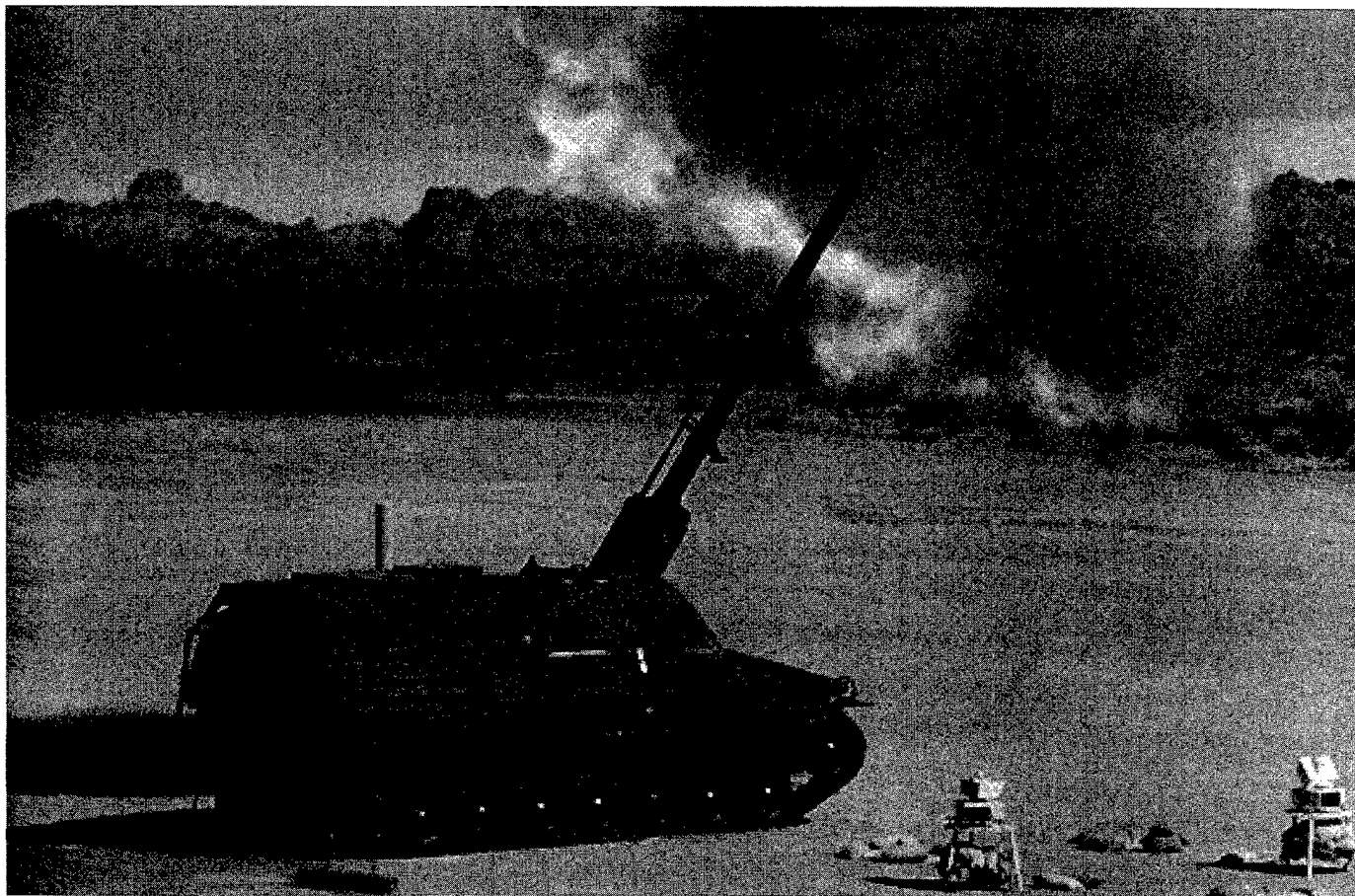
The Crusader artillery vehicle is another case in which systems engineering was not performed by the product developer, to a large extent, until after the acquisition program had been launched. The development program was launched based on a notional design done by the Army's program office, not extensive systems engineering done by the contractor that would design and build the product. Key to this notional design was the use of a liquid propellant—new technology—for firing weapon projectiles. Program officials stated that the optimal range that the Crusader is required to fire a weapon is still based on the use of this liquid propellant. The Army assessed various aspects of the risk of developing the liquid propellant technology and integrating it into the weapon system between low and moderately high. Nevertheless, on the basis of the notional design, the Army committed to launching product development.

After the program was launched in 1994, the product developer was awarded a contract to develop the Crusader. According to a program official, it took 2 years of systems engineering to determine if the requirements were feasible given established cost and schedule targets. In 1996, the product developer determined that the liquid propellant

² A jamming device carried onboard the aircraft produces jamming signals that are transmitted by fiber optic cable to the towed decoy for transmission.

technology was high risk in all aspects and that it would cost an additional \$500 million to develop. This was much more than originally estimated at the start of the program and represented a major resource gap. As a result, the Army elected to use a more traditional, less capable back-up—a solid propellant—to achieve a match between available resources and requirements. This decision may impact system performance since, according to program officials, the Crusader will probably not achieve its optimal firing range. The firing range and the liquid propellant were part of the reason for launching the program in the first place. Figure 12 shows the Crusader artillery vehicle.

Figure 12: Crusader Artillery Vehicle



It was not until 2 years after the Crusader development program was launched that the Army recognized a key technology could not be developed within available resources.

Flexibility in Setting Requirements Is Key to Closing Gaps Between Customer Expectations and Developer Resources

While knowledge is essential to identifying gaps between expectations and resources, it takes flexibility on the part of both the customer and the product developer to close the gaps. Flexibility represents the customer's ability and willingness to lower product expectations, coupled with the product developer's willingness and ability to invest more resources to reduce technical risks and other gaps before program start. Flexibility, when informed by systems engineering knowledge prior to program launch, was essential to lowering risk and reducing the cost and length of product development because knowledge alone does not produce trade-offs. Absent such flexibility, resources and wants can still be matched before starting product development, but the options to closing any gaps exposed by systems engineering are limited to additional investments on the developer's part. The scenario with the most potential for costly problems is one in which neither the requirements are flexible nor sufficient systems engineering has been done to reveal resource gaps before launch. Several of the DOD programs we reviewed that had significant problems in meeting product development objectives followed this scenario.

While there are instances in which flexibility on the part of the customer is inherent, such as for a unique product that has no predecessor, in most cases, potential customers for a new product already have expectations. In these cases, flexibility has to be fostered. We found two factors that fostered such flexibility before product development started. First, product development cycle times were limited. This forced product developers and customers to agree on requirements that were achievable within established time limits. Second, the developer enlisted the customer's trust through an evolutionary approach to product development, which relieved the customer of the pressure to want all needs met in a single product iteration. These factors made customers more willing to defer requirements that demanded more time or unproven technologies for succeeding versions of the product. In contrast, when these factors were not present and trade-offs were not made, there was an implicit decision to accept the risk of not having the product or the capability when needed.

Requirements Were Flexible Until Program Launch on Successful Cases

In successful cases, requirements were flexible until the decision was made to commit to product development because both customers and developers wanted to limit cycle time. This made it acceptable to reduce, eliminate, or defer some customer wants so that the product's requirements could be matched with the resources available to deliver the product within the

desired cycle time. The customer had incentives to trade off some wants, owing to the desire to get the product within cost and time predictions and to confidence that future versions of the product would meet many of those wants. The two commercial companies we visited exhibited these characteristics. In DOD, we found two programs that had exhibited this flexibility before launch.

Caterpillar's 797 Mining Truck

Because of mutual interest on the part of the product developer and the customer, Caterpillar's board of director's mandate for the new mining truck to be developed before the end of 1998 became a catalyst for flexibility in requirements and design decisions. For example, Caterpillar wanted to introduce new prognostic technology on the 797 that could significantly lower the cost of operating the truck—an expressed want of the customer. At the heart of this technology were monitoring sensors that could assist in forecasting wear and tear on the truck—such as on the powertrain, brakes, and tires—thereby allowing better maintenance management that would reduce how often components had to be replaced and increase the truck's life. However, Caterpillar engineers concluded that there was not enough time to make this technology mature enough to be included in the initial design if the 18-month delivery schedule was to be met. Despite the desire to have the sensors on the 797, the customer understood the need to make a trade-off and was willing to do without the sensor on the initial version if it meant getting the truck on time. As a result, Caterpillar deferred the technology, despite the increased performance it offered, because it would put other program resources—most importantly, schedule—at risk. The customer accepted this trade-off. The trade-off was made possible by Caterpillar's recognition of the risk, the customer's trust in the next generation of the truck, and the mutual desire to deliver the basic product on time and within cost.

Bombardier's New Regional Jet

Bombardier's goal is to limit cycle time on all product developments to 36 months. At the start of a new product's development process, decisionmakers ask, "What can we accomplish within 36 months?" Bombardier representatives explained that this forces them to have significant knowledge about a new product's cost and performance early in the process and is consistent with an evolutionary approach to product development. If a product's requirements force them to consider longer development time frames, they must consider a future generation of the product or a new and different product. This time frame played a role in the decision to reduce the BRJ-X customer's requirement for speed. The initial speed requirement, based on market research, was originally .81 mach. After subjecting the requirement to systems engineering, Bombardier's

engineers deduced that, while speeds of up to .78 mach could be achieved with current off-the-shelf propulsion technology, new and undemonstrated propulsion technology would be required to achieve .81 mach. After gaining additional knowledge through wind tunnel testing, the engineers concluded that to design and develop the needed propulsion and aerodynamics would create significant risk for the 36-month product development time frame.

Before launching the BRJ-X development program, Bombardier's marketing staff went back to the customers—over 30 airlines—and presented the information showing that the additional speed would require more development time and thus be more costly. On the strength of the analysis, the customers agreed that .78 mach would still meet their needs. In fact, they discovered that most European air traffic controllers would not allow the higher speed. Based on the agreement, Bombardier reduced the requirement to .78 mach, allowing the use of a low-risk propulsion system. The 36-month goal forced the developer and the customers to negotiate between the product's requirements and resources, while systems engineering provided the knowledge so that informed trade-offs could be made.

Air Force's Global Hawk and Army's Tactical Unmanned Aerial Vehicles

In two DOD cases that have met product development objectives so far — the Air Force's Global Hawk program and the Army's Tactical Unmanned Aerial Vehicle program—senior acquisition executives placed resource constraints on the programs and advocated evolutionary acquisitions, which provided the customers and product developers the incentives and the opportunity to cooperate and make mutually beneficial trade-offs. The Tactical Unmanned Aerial Vehicle had a schedule for first delivery of a system within 1-½ years after launch and the Army established an evolutionary acquisition strategy for the product to meet this schedule. This mandate was driven by a mutual agreement between senior executives from the Army's acquisition and requirement setting communities that the priority is to field it quickly. This agreement fostered a good relationship between the two communities that allowed a “no bells and whistles” approach to development.

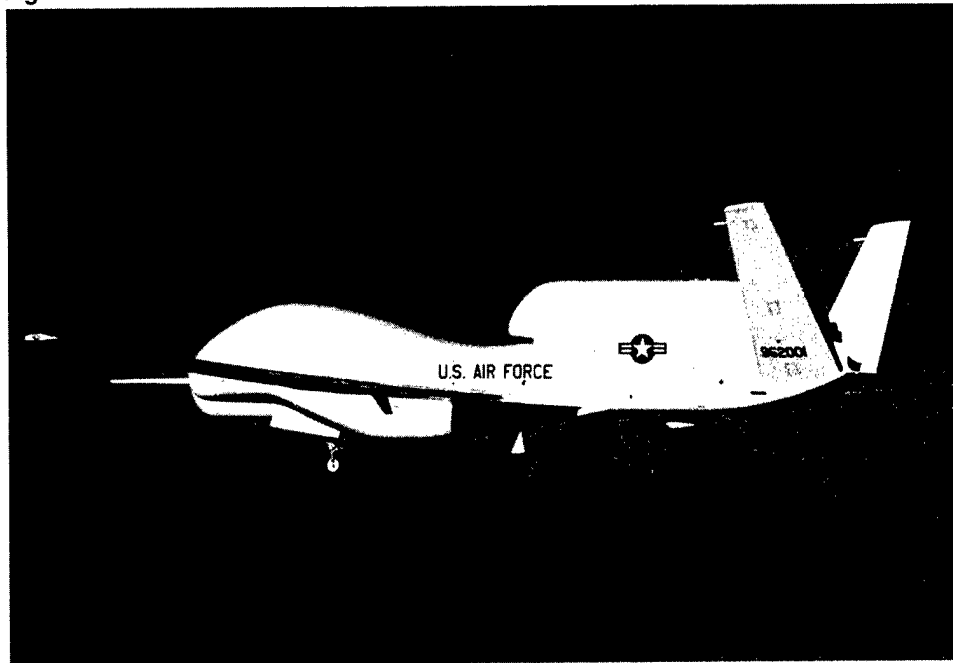
The product manager told us that using the guidance as a foundation, the customer agreed to collaborate on a basic list of key performance parameters as the only “must-have” requirements for the initial Tactical Unmanned Aerial Vehicle and define the remaining requirements as tradable against resources, such as cost and schedule. The requirements that were not key to the initial vehicle were grouped into three categories, each more important than the next, but none important enough to be added

to the initial vehicle if not achievable within the resources available to the developer. Product developers stated that several requirements would have been difficult to achieve without additional time and money to develop solutions. When they explained this to the customer and pointed out the associated high risks for achieving the requirements within the time frames, the customer was willing to defer these requirements to future versions of the system in order to meet the planned development schedule.

The requirement for the Tactical Unmanned Aerial Vehicle's imagery capabilities—that is, the electro-optic and infrared sensor systems that are used for observing targets—is a good example of this flexibility. The customer originally wanted the imagery to have at least a 90-percent probability of recognizing and identifying targets from an altitude of 6,000 to 8,000 feet. On the basis of a systems engineering analysis, the product developer concluded that this was not achievable with the technology available within the 1-½ year time frame and that more time and money would be required to develop technology that would meet the capability. As a result, the customer reduced the requirement to 70 percent, which was both technically feasible and still useful to the customer, and made 90 percent a goal that might be achieved in future generations.

A similar combination—a cost limitation and urgent customer need—led to flexible requirements on the Global Hawk unmanned aerial vehicle. A development cost limit set by DOD executives forced the customer and the program office to prioritize requirements into what could be achieved within the limit. Additionally, the customer, the United States Joint Forces Command, assessed the usefulness of the system and stated the basic capability tested during the Advanced Concept Technology Demonstration could provide utility today. This assessment increased the importance of quick delivery and forced the requirement setters and the product developer to look at an evolutionary approach to meeting their needs, planning for a basic capability in the first product line and more advanced capabilities added over time. Together, these constraints gave the program manager leverage in persuading the user to reduce or defer requirements. For example, the requirements manager wanted a more advanced imagery system in the first product line. However, the program manager pointed out to the requirements manager that the cost and time needed to include this capability would exceed the cost limit. In response, the requirements manager agreed to defer this capability to a later version of the product. Figure 13 shows the Global Hawk unmanned aerial vehicle.

Figure 13: Global Hawk Unmanned Aerial Vehicle



The Air Force has adopted an evolutionary acquisition strategy to match customer expectations with the developer's resources, enabling quicker delivery of the Global Hawk.

Less Successful Cases Maintained Inflexible Requirements Prior to Launch

On the weapon system programs that did not meet development objectives, the products' performance requirements were generally not flexible prior to launch—a condition compounded by the fact that systems engineering had not been done in time to reveal gaps between requirements and resources. The requirements demanded advanced technologies that were not yet proven or available. The matching of requirements with available resources was not done until well into the product development program. However, the requirements were not reduced. Instead, additional resources, including technologies, time, and money, had to be added. We have reported on the negative consequences of basing cost and schedule estimates on the hoped-for success of such technologies.³ Without the countervailing presence of systems engineering knowledge from the

³Best Practices: Successful Application to Weapon Acquisitions Requires Changes in DOD's Environment (GAO/NSIAD-98-56, Feb. 24, 1998). Best Practices: Better Management of Technology Development Can Improve Weapon System Outcomes (GAO/NSIAD-99-162, July 30, 1999).

product developer or the customer's acceptance of an evolutionary product development approach, flexibility was difficult to engender.

Army's Comanche Helicopter

In the Comanche program, initial requirements for attacking targets and performing other tasks, when combined with the desire for small size and light weight, called for a unique capability compared with existing helicopters. Meeting the size and weight requirements depended on new technologies such as advanced forward looking infrared and integrated avionics. Both size and weight were critical elements of a mission equipment package that was supposed to reduce the pilot's workload while improving aircraft performance in the areas of communications, targeting range, and pilot capabilities. The program office stated that at program launch the technologies were still conceptual in nature, needing an investment in time and funding before they would be mature enough to satisfy requirements. As a result, Comanche was expected to provide a quantum leap in product performance using new technologies that were not fully understood at the time the program began.

Not only did the customer consider the requirements that made these technologies necessary as not tradable, they were also confined by weight and cost restrictions placed on the program. The cumulative effect of several competing requirements—low cost, reduced weight, long range, and increased lethality—resulted in solutions that relied on advanced technologies. For example, a more mature target sensing technology that might have met performance requirements was rejected because it weighed too much. The Army decided to launch the program despite the significant lack of knowledge about the needed technologies, leaving a mismatch between requirements and available resources, and chose to develop the new technologies during the product development program. This action placed the burden of maturing technologies onto the program manager during product development. Difficulties encountered maturing these technologies to meet unyielding user requirements contributed, in part, to the program's significant cost and schedule increases.

Army's Crusader Artillery Vehicle

The Army's Crusader program also had competing requirements that—when taken together—resulted in an inflexible system solution. Requirements for firing range, accuracy, rate of fire, lethality, and resupply remained inflexible prior to program launch. Similar to the Comanche program, this inflexibility limited the technical solutions that could meet the requirements and forced the program to be launched with immature technologies. Many of these technologies—such as the automated ammunition loading and handling system and the actively cooled cannon

barrel—were considered technological firsts for U.S. artillery systems. As a result, the Crusader program is expected to take over 14 years and cost over \$4 billion to develop.

Army's Brilliant Anti-armor Submunition

The BAT program also had inflexible requirements that exceeded available resources at the start of the program. The BAT operational concept is based on a need to locate targets from great distances using advanced sensor technologies, which are then required to guide the weapon to closer ranges, where the submunition would engage the target. The acoustic target technology was the most important technology needed to meet the weapon's performance requirements, and the contractor proposed a weapon concept based on it. The Army accepted the concept and drafted performance requirements based on the acoustic technology. In this case, there was limited flexibility to negotiate trade-offs between requirements and resources given the small margin of error for a munition to hit the target. Consequently, the key to matching requirements with resources depended on committing the necessary resources to close gaps after the program was launched.

At the start of product development, the cost and schedule targets for BAT's development were set without knowledge about the feasibility of the performance requirements. While the requirements were based on a specific technology, it was not mature enough for inclusion onto a product. In fact, the technology was still being defined in paper studies. The Army did not prototype this technology until almost 6 years after the program was launched. During its product development program, the BAT experienced significant development cost and schedule increases. Program officials attribute these increases, at least in part, to unknowns about the new technologies. Because requirements remained inflexible, the product developer was forced to add resources to achieve a match between the two.

Balance in the Roles of the Customer and Product Developer Makes for Effective Trade-offs

With knowledge gained from systems engineering and flexible requirements as preconditions, successful product development programs benefited from an environment in which product developers and customers had balanced roles and shared responsibilities for setting product requirements. In two successful cases, product managers were responsible for both (1) translating customer wants into product requirements and (2) developing and delivering the products within available resources. This dual responsibility allowed them to make reasonable trade-offs between

performance requirements and resources prior to committing to product development. In two other successful cases, requirement setters and product developers had equal roles in establishing and changing requirements, using knowledge from systems engineering as a guide. In unsuccessful cases, there was no parity in decision-making between the requirement setter and the product developer; the requirement setter held the upper hand by controlling the requirements without being bound by cost and schedule considerations or the developer's resources.

**Successful Programs
Benefited From Parity in
Decision-making Between
Customer and Developer**

In the successful commercial cases we examined, the product developer had ultimate responsibility for defining the product's requirements but worked intimately with the customers to understand their needs. The firms established an environment that teamed customer representatives with product development engineers in setting mutually agreeable product requirements. Representatives from one commercial firm told us that they feel responsible for understanding a customer's operations better than the customer does. They achieve this through their marketing people. Once the marketing staff understands a customer's wants, they can work with the design and production engineers to develop a product solution that will meet the customer's needs and can be met with company resources. The product manager makes final decisions on the product's requirements, but is mindful of the fact that a dissatisfied customer will not buy the product.

Caterpillar's 797 Mining Truck

An example of how this parity in decision-making worked is the Caterpillar 797 mining truck engine. To meet the customers' needs, the engine had to produce at least 3,400 horsepower. For maintenance and serviceability reasons, some mining companies wanted a single engine to produce this power, which Caterpillar's marketing staff translated into a requirement. However, Caterpillar did not have such an engine and its systems engineering analysis showed that a new single-engine design could not be matured and demonstrated within the 18-month cycle time limit. Thus, product developers proposed a twin-engine design that met the horsepower requirement but used an existing engine. Caterpillar's customer representatives presented this proposal to the customers, as well as their position that the firm could either deliver the truck powered by twin engines in 18 months or take longer to deliver a single engine truck—but not both. Most customers accepted the proposal and the position.

Bombardier's New Regional Jet

Similar parity in decision-making was evident concerning Bombardier's fly-by-wire technology. The airlines wanted fly-by-wire on the BRJ-X aircraft because of the benefits. The benefits, which Bombardier's systems

engineering confirmed included 96 percent fewer parts and 1,250 fewer pounds than hydromechanical controls. These benefits would reduce engine power requirements, saving about 3 percent of fuel capacity and reducing the need for maintenance significantly. All of these savings responded directly to the airlines' performance needs. However, because this technology had never been integrated onto a regional jet before, Bombardier's product development engineers believed it to be risky. Also, since the workforce of regional jet pilots had never used fly-by-wire, they would have to be trained on how to use it, and system engineers who had the authority to accept or reject the technology would not commit to including the technology unless it was demonstrated first. Bombardier closed the technology gap by demonstrating it on an existing aircraft. At that point, Bombardier was confident in including fly-by-wire in the product requirements for the BRJ-X.

Less Successful Cases Did
Not Have Parity Between
the Requirement Setter and
the Product Developer

In two less successful cases, the customer set the product requirements with comparatively little input from the product developer. These programs were initiated with cost and schedule estimates that were, for the most part, based on the customer's requirements and a notional design. The product developer was not an equal partner in setting product requirements and had to launch programs without requisite resources.

Navy's Radio Frequency
Countermeasures System

Before product development began, the program manager for the Radio Frequency Countermeasures system had been working with the F/A-18 E/F customers to match its needs with available resources. The program manager told us that both parties believed they had a good match because the technology was mature. Also, both parties agreed that an approximately 5-½ year development cycle would deliver the desired product. However, prior to program launch, as part of the normal process used for approving product requirements, the proposed Navy requirements were distributed to the other services. The Air Force became interested in the program and requested that its needs for the F-15 and B-1 be combined with the Navy's to develop a common system. The Air Force's requirements were much more demanding than the Navy's because more power was needed to generate the electronic countermeasures⁴ for the F-15, a less stealthy aircraft than the F/A-18 E/F. These additional needs created a technology gap that required either more time or trade-offs.

The product developer analyzed the technology gaps and determined that, given projected time and money, the effort required to meet them would take close to 7 years. The Navy customer would not agree to the additional time and insisted that the product developer deliver a product to meet the expanded needs within the original 5-½ year time frame. The customers, in sole control of requirements setting, thus firmed the product requirements. The program manager informed us that he had little decision-making authority in the matter and was compelled to accept the customers' schedule. The result was an imbalance between product requirements and resources, which also resulted in cost and schedule increases. Because of the delays in developing the system, the Navy plans to incorporate a less effective substitute onto the F/A-18 until the product is ready. These aircraft will have to be retrofitted with the system when it becomes available—a costly and inefficient process. Ultimately, the trade-offs that were unpalatable before launch became unavoidable after launch.

Army's Comanche Helicopter

Parity between the requirement setter and the product developer did not exist on the Comanche program. As discussed previously, the Comanche product development program included immature avionics technologies

⁴ Electronic countermeasures involve the jamming and deceiving of the enemy's electronic devices, such as a radar or communications system, by sending an electronic signal that reduces or prevents their usefulness. Because of the more traditional design of the F-15, it required the Radio Frequency Countermeasures system to produce as much as 2 to 3 times more amplified power than that needed for the F/A-18.

that were needed to meet demanding and inflexible performance requirements. These technologies represented significant gaps between what the customer wanted and what the program office could confidently deliver given the resources available. Prompted by concerns about the time needed to advance the necessary technologies, the program manager proposed trading off some requirements. However, requirements managers informed us they were unwilling to accept trade-offs and that they believed the program manager was too risk averse. Consequently, the program was launched with the requirements intact, despite the program manager's concerns, and, cost and schedule estimates for its development have doubled.

Characteristics of DOD's Acquisition Process Make It Hard to Match Expectations and Resources Before Program Launch

Within DOD's traditional acquisition process, it is difficult to employ systems engineering in making trade-offs, maintain flexibility in customer expectations, and put the product developers in a balanced position relative to the customers. As a result, customer needs—however legitimate—are translated into product requirements that make unreasonable demands on available resources. This pattern is perpetuated because resources are generally added later during product development to close any gaps between requirements and resources. The mechanics of obtaining funding and getting approval to start an acquisition program dictate that events proceed in the following sequence: set requirements, obtain funding, launch program, and perform systems engineering. This sequence places the knowledge that is needed to identify resource gaps—and the power that it gives to the product developer—at a disadvantage to shape requirements and improve program outcomes. Other aspects of the process reward behaviors that can put pressure on requirements, making them less flexible and more difficult to meet. For example, the services must clearly differentiate a new weapon's performance characteristics from alternatives to successfully compete for funding, encouraging detailed cost and schedule estimates to be made with little knowledge from systems engineering. The weapon system programs that did match requirements and resources before launch—the Tactical Unmanned Aerial Vehicle and the Global Hawk—represented departures from this process that benefited greatly from the intervention and protection of top-level individuals.

DOD has recently changed the requirements setting and acquisition processes to better reflect best commercial practices. Specifically, DOD has revised its policy for approving new development programs by providing more latitude for technology maturation and other knowledge-generating activities to take place before a program is launched. The acquisition policy also supports the evolutionary development approach as the preferred method of product development. In addition, DOD has revised its policy for developing requirements, calling for a staged or stepped approach that will dovetail with evolutionary acquisitions. By itself, however, the policy can do little to foster the early matching of customer wants with developer resources because the mechanics of obtaining funding and the pressures on requirements setters are unchanged. The incentives of the process, unlike policy, are more likely to be seen in decisions made on the funding and approval of individual programs.

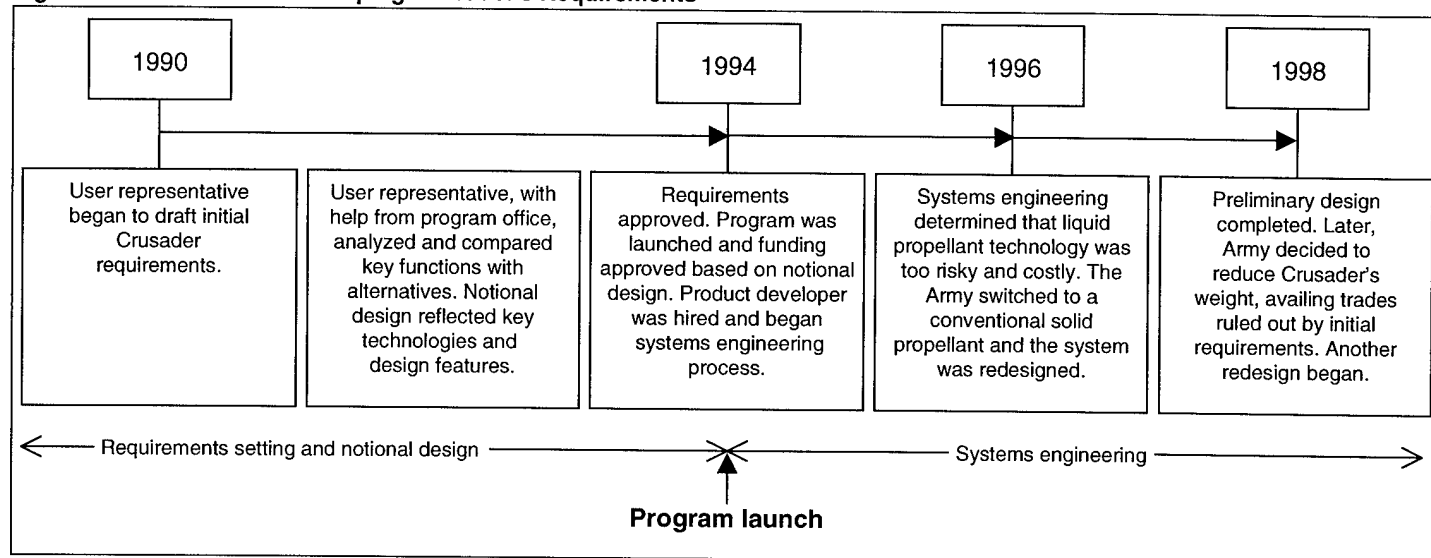
Current Process Puts Requirements Setting and Systems Engineering on Opposite Sides of the Launch Decision

DOD's acquisition process makes it difficult to know what resources will be needed to meet requirements before launching a program. Within this process, systems engineering does not take place until a program has been launched and cost and schedule targets have been set. One reason for this is that DOD does not typically sign contracts with product developers, who are responsible for systems engineering, until after the requirements have been written. Once an acquisition program is approved and product development is funded, a product developer can begin systems engineering and gaps between requirements and resources can be identified. However, this process does not yield knowledge about the requirements' achievability until well into product development. Even when requirements are in draft at the time of launch, they are hard to change because user representatives have already invested significant effort in preparing them. This sequence of events—setting requirements, launching an acquisition program, contracting with a product developer, and conducting systems engineering—narrows the options for closing gaps primarily to increasing cost and schedule estimates.

DOD's process for setting requirements can begin many years before a program is launched, and it can be several years after the program is launched before systems engineering knowledge is obtained. The time period from the start of the definition of the user's needs to the arrival of systems engineering knowledge that often uncovers gaps can approach 10 years in some instances. More than 30 organizations within the requirements community may have a hand in determining a weapon system's performance requirements before a contractor with systems engineering expertise can identify the gaps between requirements and available resources. This process means the "doability" of the requirements is often not known with certainty until well into product development or until a significant percentage of funds planned to develop the system has been invested. By this point in time, customers' expectations have been set, making it difficult to change requirements if gaps between requirements and available resources are found.

The process used to set requirements and begin development on the Army's Crusader program provides an example that illustrates the mechanics of the process (see fig. 14).

Figure 14: Timeline for Developing Crusader's Requirements



The user's representative for the Crusader (the Army's Training and Doctrine Command artillery school at Fort Sill, Oklahoma) began drafting the performance requirements for the Crusader in 1990. The process to define the requirements took approximately 4 years. During this time, the user representative framed the needed features of the Crusader and conducted exhaustive analyses and trade studies to identify the optimal point to set a specific requirement. Also, as required by DOD acquisition policy, the user representative analyzed a notional Crusader that met these requirements against other alternatives, such as improved versions of existing artillery systems. The result of these analyses was a set of requirements from the user representative and notional design prepared by the Army program office. In 1994, the requirements for the Crusader system were approved, the acquisition program was launched and funded, and program cost and schedule targets were baselined.

By this time, key features of the Crusader were defined. For example, the Crusader would have to use liquid propellant—a revolutionary technology—to propel the projectiles far enough to meet the optimal range requirements. Also, because the Crusader was required to stay on the firing line during rearming and refueling, it would have to have an armored and automated resupply vehicle to keep the resupply crews protected.

After the program was launched, the Army entered into a contract with United Defense Limited Partnership to develop the Crusader. Over the next

4 years, the firm applied systems engineering practices to the requirements in order to develop a preliminary design. During this process, the firm had to make trade-offs in order to develop a design that could stay within resources. By 1996—2 years into product development and 6 years since the need for the Crusader was identified and determined—United Defense Limited Partnership concluded that resources needed to develop a liquid propellant technology were not available. The firm's only option was to accept a less capable technology—a conventional solid propellant, increasing the risk that the Crusader's firing range requirement may not be achieved. According to Crusader officials, United Defense Limited Partnership did not develop a good preliminary design of the system until 1998 or about 8 years after the user representative began the requirements setting process.

Incentives of Current Process Create Pressure on Product Requirements

Several factors in the DOD environment create incentives to set requirements high and to resist trade-offs. The competitive nature of the process to justify a new program puts great pressure for a potential weapon's requirements to stand out. Unlike the commercial environment, the user representatives are separate from both the customer and the product developer, and thus play a unique role that has different interests. Once user representatives get a set of requirements through the very difficult and lengthy process of approval before a program can be launched, they are understandably reluctant to change them. Finally, the DOD customer—unlike its commercial counterpart—is more tolerant of schedule delays and cost increases.

Pressures on the Requirements-setting Process

The competition within DOD to win funding and get approval to start a new program is intense; establishing the basic need and writing requirements is perhaps the most important step in the process. This creates strong incentives for requirements setters to write performance requirements that will make their particular weapon system stand out from existing or alternative systems. Much of the requirement-setting activity prior to initiating a program is devoted to proving the superior cost-effectiveness of the preferred system over others, with less consideration given to the resources that will be needed to develop the system. If user representatives do not write requirements that will withstand scrutiny and prevail over alternatives, the program could be killed and no capability is gained for the customer. Costly, labor-intensive studies, such as analyses of alternatives, are done to determine the best possible solution to meet the user's needs and to beat the competition. At the same time, overall DOD funding

constraints put a high priority on affordability, making it important for program sponsors to provide cost estimates that will fit within the funding constraints. Instead of forcing trade-offs, challenging performance requirements, when coupled with other constraints, such as cost or light weight, can drive product developers to pursue exotic solutions and technologies that, in theory, could do it all.

To simplify requirements and foster trade-offs, DOD has adopted the practice of identifying only a limited number of key performance parameters—"must-haves" for the customer—for each weapon system. This practice may help to prioritize requirements. However, if the parameters are not informed by systems engineering, given the pressures inherent in the process, they still result in unrealistic demands made of existing resources. For example, the Army's Crusader program had only five key performance parameters, including characteristics such as rate-of-fire, range, and speed, but they were dependent on about 500 other subordinate performance requirements that were defined before systems engineering was done by the product developer.

The unique role of the requirement setter in DOD's acquisition process can also put pressure on requirements. DOD's requirement setters are outside of the acquisition community and often represent an operational function such as air combat, artillery, or armor. They are not the actual user like an operating air wing or Army brigade, but serve as a representative of the user. Unlike the commercial world, where a customer's wants are represented by someone within the product developer's organization, DOD's requirement setters are, for the most part, separate and independent of the customer, program manager, and the product developer. A user representative can work directly with DOD science and technology organizations and defense firms to obtain information about new technology, and thus may be less willing to defer to a program manager's advice on these issues. Also, while a customer is focused on current problems and near-term performance, a user representative tries to look at longer term needs. In fact, the fear that DOD may not procure another such system for several years creates incentives for user representatives to reach for the most capability possible because they do not know when or if they will get another opportunity to develop and acquire the next weapon system.

The Comanche helicopter program is a good example of these pressures at work. The Comanche was initiated in the early 1980s as a family of lightweight, multipurpose helicopters whose operation and support costs

would be 50 percent less than the Vietnam-era fleet. The program was originally expected to offer as good a technical performance as possible within clearly stated—and low—unit cost goals. The requirements were simple at the start. However, once the requirement setting process began, the program emerged as it is today—a threat-based program to yield the next-generation, high-performance helicopter—at a cost significantly higher than the existing Apache. It was justified as being faster, stealthier and smaller than the Apache helicopter. Resource gaps were identified after the program was launched, when the product developer began to obtain knowledge through systems engineering and technology development about what it would take to meet the requirements.

Leadership in the Army has called for a transformation in Army forces and equipment to a lighter, more mobile force that can be deployed more quickly and easily. The impact this change is having on Crusader's requirements further illustrates how DOD incentives can drive requirements and ultimately impact program outcomes. The preliminary Crusader design—which met all key requirements—was considered too heavy for the new, lighter force. In fact, the Army Chief of Staff said he would like to have the Crusader's weight reduced to the point that twice as many vehicles could be moved with the same amount of transport aircraft. With the program's future at stake, the user representative, program manager, and product developer are working together to reduce the overall design weight of the system from 55 to 38 tons. Because of this new priority, previously untraded requirements—such as degree of crew protection, time on the firing line, and the need for tracked vehicles—are now being examined to see if they can be reduced to save weight.

A specific Crusader requirement is illustrative. In developing the original set of requirements, the user representatives determined that the Crusader's effectiveness would be maximized if the Crusader could avoid having to leave its battle station to reload and refuel. To meet this requirement, the resupply vehicle would have to reload and refuel the howitzer at the battle station. This requirement necessitated that the resupply vehicle be armored, tracked, and fully automated so that the crew would not be exposed to enemy fire. This not only made for a more effective howitzer but also distinguished the Crusader from other candidates. In looking for weight reductions, the Army is considering pulling at least some of the howitzers off station to reload and refuel. If it relaxes that requirement, the resupply vehicle and crew can do its work under safer conditions. In turn, the vehicle would not have to be as heavily armored, automated, or tracked. In fact, the Army is considering using

existing trucks, which are far lighter and less expensive than a new resupply vehicle. In our view, the changed circumstances of the Crusader program—past the approval gate, a product developer deep into systems engineering, and a top level mandate to reduce weight—created incentives to make requirements trade-offs that were not acceptable before.

**Calcification and Customer
Acceptance Do Not
Encourage Trade-offs**

Once established, system requirements undergo incredible scrutiny and review by a myriad of interests within DOD's process. For example, the Crusader draft requirements were circulated to approximately 30 organizations throughout the Army, other services, operational commands, and the development community for review. This process yielded 943 comments. To incorporate or otherwise dispose of each comment, a joint working group with representatives from all of the reviewing organizations was established. The group incorporated 702 of the 943 comments into the requirements, the cumulative effect of which was to add, rather than to trade, requirements. As one official stated "it is generally not the practice to reduce or eliminate requirements but to add more to appease a particular party." This lengthy and cumbersome review process tends to calcify weapon system requirements before product development begins and knowledge from systems engineering can be obtained.

The practice of breaching cost and schedule objectives to meet difficult requirements would not persist without a customer's cooperation. Unlike commercial customers, DOD customers tend to be tolerant of cost overruns and delays in order to get a high-performance weapon system. Traditionally, customers have been willing to wait long periods of time for a highly desirable system that they feel will provide them the longest lasting capability. They would rather wait for the most desirable system to be developed than accept a less capable system, thinking that they may not get the opportunity to acquire a new or modified system in the future. Again, the Comanche program provides insight. At the time the program was started, the Army expected to receive the first operational helicopter in 1996. The development program has encountered delays; some related to weight, cost, and performance requirements that demanded immature technologies. However, the Army has chosen to keep the requirements generally intact and to do without the helicopter instead of fielding a less capable system more quickly. The Army now expects to have an initial operational capability in 2006, 10 years after the initial target date.

More Successful Weapon System Programs Have Departed From the Normal Process

The two DOD programs we examined—Tactical Unmanned Aerial Vehicle and Global Hawk—that set requirements in a way that approximates best commercial practices were departures from DOD's normal process. Specifically, (1) their origins as Advanced Concept Technology Demonstrations enabled them to hire a product developer much earlier than is traditionally the case and (2) they benefited greatly from the personal intervention of service and DOD executives who created and enforced conditions that were conducive to making trade-offs between wants and resources. Other new programs, such as the Joint Strike Fighter program, showed that traditional incentives to speed a program along still existed and could increase risk in product development.

The Advanced Concept Technology Demonstrations, for the Tactical Unmanned Aerial Vehicle and the Global Hawk, showed the feasibility of developing a system that could do what the customer wanted before a commitment to product development was made. The sequence of events leading to program launch on each of these programs was similar to those of successful commercial firms. The demonstrations involved the customer, user representative, program manager, and product developer in a more integrated fashion than is normally the case. Moreover, by building prototypes for the demonstrations, the product developers had to conduct a significant amount of systems engineering before the programs were launched. Consequently, the demonstrations provided valuable knowledge that allowed the customer, user representative, and product manager to define a set of product requirements that could be met within resources. Most importantly, the demonstrations were conducted before program launch, before cost and schedule targets were set.

Both programs had unusual intervention by top-level individuals that set resource constraints and encouraged evolutionary acquisition strategies. On the Tactical Unmanned Aerial Vehicle program, the top military acquisition executive personally met with the head of the user representative's organization and struck an agreement that the product was to be fielded in stages, with the first stage being a very basic system. This agreement had the effect of establishing mutual interest in the same program outcome and shielded the program from criticism by either community. The personal involvement of the Under Secretary of Defense for Acquisition, Technology, and Logistics helped set the stage for Global Hawk's evolutionary approach to meeting requirements. The Under Secretary insisted on an initial capability that could be developed within a fixed budget while providing the flexibility to defer other requirements to

succeeding versions. In both cases, this top-level intervention allowed requirements to be flexible and gave the product developers parity with the requirements setters in influencing requirements. Equally important, we believe the intervention signaled support for the programs, which eased some of the pressures that normally accompany efforts to get programs approved. In each case, while there was a potential for success, it came not so much from a well-established process but from exceptional behavior from senior-level leaders. If, for some reason, leadership or priorities change, the process may not ensure success.

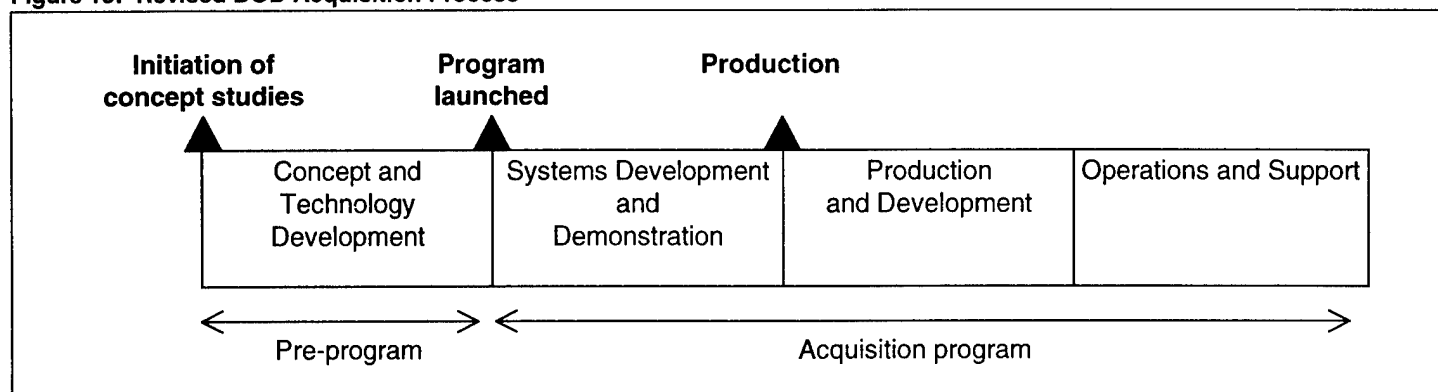
Constructive Changes in DOD's Policy Not Enough to Match Customer Expectations With Developers' Resources

While DOD has taken steps that could help it more efficiently acquire its weapons, these steps have not substantively changed the mechanics or incentives of the requirements setting process. While the revised acquisition policy provides opportunities for improvement, it is not specific about when to match wants and resources. In fact, the sequence of events—setting requirements, obtaining funding, launching an acquisition program, and conducting systems engineering—remains essentially the same as before the revision. Recent experiences with the Global Hawk and the Joint Strike Fighter programs indicate that traditional pressures on the requirements process are still strong.

Recent DOD Policy Revisions Are Supportive of Best Practices

DOD has recently revised its policies for operation of the defense acquisition and requirements setting processes. The acquisition policy reflects best commercial practices and emphasizes better use of evolutionary acquisitions, more reliance on mature technology, and reduced cycle times and costs. It recognizes shorter acquisition cycle times as critical to making the best use of advanced technologies and evolutionary requirements as a way to reduce cycle times. The Under Secretary of Defense for Acquisition, Technology, and Logistics issued related guidance stating that DOD's objective will be to achieve acquisition cycle times—from program start to initial fielding—no longer than 5 to 7 years. The revised acquisition policy also states a clear preference for evolutionary acquisitions over "single step to full capability" acquisitions. DOD also revised its acquisition process, which is now four phases: (1) concept and technology development, (2) system development and demonstration, (3) production and deployment, and (4) operations and support (see fig. 15). In addition, guidance that directs the requirements setting process was revised to include an emphasis on the use of time-phased performance requirements in support of evolutionary acquisitions.

Figure 15: Revised DOD Acquisition Process



The decision to launch a program would normally take place between the first and second phases. The revised policy states that the decision is dependent on three factors: technology maturity, validated requirements, and funding. Assuming that technology is found to be mature, at the start of the system demonstration and development phase, the policy requires the weapon's requirements to be formally approved and full funding to be provided for the remainder of the program. This is the point at which a program manager would commit to performance, cost, and schedule estimates and DOD would commit to provide that level of resources. DOD later would award contracts to product developers to conduct the majority of systems engineering necessary for designing and building the product. In that regard, little has changed under this revised approach. It is still difficult to know what resources will be needed to meet a set of requirements before making the decision to launch the program.

Pressures on Requirements Are Still Powerful

While DOD policy encourages evolutionary acquisition approaches, it will not be successful if traditional incentives for setting high and inflexible requirements persist. Recent developments on the Global Hawk program indicate the continuing pressure programs face to increase requirements. The initial Global Hawk system provides a capability for high altitude reconnaissance that the customer has stated is acceptable for meeting its short-term needs. Future generations would add capabilities to match the U-2—a manned reconnaissance airplane—as technology, money, and time become available. The Air Force had embarked on an evolutionary acquisition that defines the first generation of the Global Hawk based on the system already demonstrated with performance, supportability, and producibility enhancements. However, the Air Combat Command, the user representative, indicated that it would accept nothing short of the same

capability found in the current U-2, despite the customer's views. The Command did not have confidence that the evolutionary approach would receive the support and resources to attain the U-2's capabilities in future generations. As a result of pressure from the user representative, the Air Force proposed a revised acquisition strategy that while still evolutionary in nature, accelerated the inclusion of advanced technologies onto the aircraft to provide U-2 capabilities sooner. In December 2000, the Deputy Secretary of Defense elected not to approve the revised acquisition strategy at this time. While we did not review the revised approach in detail, it did appear risk had been added to the program as requirements increased and resources changed.

The Joint Strike Fighter program is another example in which traditional incentives can result in decisions contrary to best practices. While DOD has designated the Joint Strike Fighter as a flagship program for acquisition reform, it is now 4 years into its acquisition program and has not yet achieved a match between requirements and resources—particularly in the form of the technologies needed. By best practice standards, none of the fighter's critical technology areas that the program office has identified are expected to be at readiness levels acceptable for entry into the engineering and manufacturing development phase, which is scheduled for 2001. Reminiscent of the Comanche, numerous conflicting demands that the fighter achieve high performance and low costs have resulted in requirements that must be satisfied with several technical advances. The requirements have also proven to be relatively inflexible. As we reported¹ in May 2000, delaying this phase of the program until technologies are mature would improve the chances that the Joint Strike Fighter will be fielded as planned. However, despite not having the requisite knowledge for the technologies, DOD has deemed the risks manageable and proposes to proceed with the program as planned. Such a decision reinforces traditional incentives and increases the likelihood for future problems.

¹ *Joint Strike Fighter Acquisition: Development Schedule Should Be Changed to Reduce Risks* (GAO/NSIAD-00-74, May 9, 2000).

Conclusions and Recommendations for Executive Action

Conclusions

Managing the setting of a product's requirements in a way that matches the customer's needs with the developer's resources is critical for a successful product development. This kind of success—delivering weapons that meet needs within predicted costs and time frames—is essential if DOD is to get what it wants from its huge modernization investment. The best practices for balancing needs and resources before committing to a new product or weapon system development are to (1) conduct systems engineering to illuminate what has to be done to match the wants with the resources; (2) establish fixed cycle times for an initial product within an overall evolutionary approach to foster flexibility needed to make key trade-offs; and (3) maintain parity between requirement setters and product developers when translating customer needs into product requirements. These practices provide for identifying gaps between wants and resources as well as solutions—whether by trading off needs or investing more resources—*before* setting requirements and starting development.

The environment for commercial products provides incentives that encourage these practices. Like DOD, commercial customers have an initial advantage in that they have high expectations of a new product, they do not have unlimited time and money, and ultimately, their needs have to be met. While firms are motivated to offer a customer a product that meets these needs, they are keenly aware that promising more than they can deliver will ultimately disappoint the customer. Consequently, leading firms consciously attempt to manage customer expectations and put themselves in a good position to negotiate a reasonable set of product requirements. They do this in several ways. First, because they are investing their own resources to develop the product, they are at liberty to conduct systems engineering early—an investment they consider small relative to the overall cost of developing a product. Second, they have a proven track record for delivering products on time and making promised improvements to succeeding versions of the product. Third, they play a prominent role in setting and agreeing to product requirements. Together, these factors help create the credibility, confidence, and trust that are essential to maintaining the flexibility needed to match their resources with the customer's needs before launching a new product development.

Within DOD's traditional acquisition process it is difficult to gain knowledge and maintain flexibility in requirements prior to committing resources to an acquisition program. As a result, customer needs are translated into product requirements that often make unreasonable

demands on available resources. There are several reasons for setting weapon system requirements this way. Some are the following:

- The mechanics of the program approval and funding process force a sequence of events that keeps a product developer relatively uninvolved in shaping requirements, compared with best practices, causing product development to begin with cost and schedule targets untempered by systems engineering knowledge.
- Unique or demanding requirements can help gain approval to fund a new program because aiming too low can result in losing out to other programs, thus denying any new capabilities.
- There is some mistrust in an evolutionary approach, specifically regarding whether future improvements will be approved; consequently, attempting to reach for the full capability in a single step can be seen as a safer course of action.
- The challenging and long process to get requirements approved hardens requirements setters against trade-offs—in fact, the process of getting a requirement approved can actually encourage additions to garner support.
- Unlike the commercial world, DOD customers have proven to be tolerant of cost and schedule increases once a program is underway.

Seen in this light, while the pattern of weapon system requirements outstripping planned resources is inefficient, it is not irrational; within the DOD environment, this approach is successful in starting programs that eventually provide superior capabilities. This approach also has negative consequences. First, the additional time and money that must be invested after launch still yield the same capability called for by the original requirements, effectively lowering the buying power of the investment. Second, the unplanned nature of the additional investment generally requires weapon system quantities to be lowered or money to be taken from other programs. Third, when a requirements setter is unwilling to make trade-offs before launch but later elects to accept delivery delays to meet those requirements, the implicit trade-off is to have the customer do without any of the new capability for a longer period of time. The challenge in adopting best practices, therefore, is to make them rational—that is, critical for success—in the DOD environment. Meeting this challenge will take changes in both the mechanics and the incentives of the requirements setting and program approval processes.

DOD's recently revised policies could make it possible for a better matching of customer needs and developer resources before program

launch. While these policies are sound and merit support, they retain the mechanics of the old policies. Namely, requirements must be set before a program can be approved and a program must be approved before the money can be obtained to pay the product developer to conduct systems engineering. Such mechanics deny the knowledge needed to match wants with resources before starting a program. Similarly, the new policies must overcome the still extant pressures brought to bear on requirements setters to aim high and become inflexible. It took unique circumstances—starting as Advanced Concept Technology Demonstrations and enjoying the personal intervention of top DOD executives—to create the incentives on the Global Hawk and Tactical Unmanned Aerial Vehicle programs for making the trade-offs needed to match needs with resources. Even so, the Global Hawk is struggling with pressures to reverse some of the trade-offs and raise requirements. Other programs, such as the Joint Strike Fighter, have requirements that outstrip resources, despite efforts to keep requirements flexible and to treat the price of the aircraft as a requirement.

Recommendations for Executive Action

To realign the mechanics of the requirements setting and program approval processes to bring more knowledge into the process of setting requirements, we recommend that the Secretary of Defense require that the systems engineering needed to evaluate the sufficiency of available resources—knowledge, time, money, and capacity—be conducted in time to help identify and make the critical trade-offs that precede the formalization of requirements. One option is to allow the award of well-defined systems engineering contracts to prospective product developers—contractors—before the system development and demonstration phase.

To realign the incentives of the requirements setting and program approval processes with the need to match available resources, we recommend that the Secretary of Defense:

- Reduce the pressures put on user representatives to set requirements high to win the competition for program approval. One way to reduce these pressures, drawing on the experiences of the Tactical Unmanned Aerial Vehicle and Global Hawk, is to have higher level officials in the services and DOD decide on the type of weapon system that is needed to meet a valid need before the requirements setters begin detailed work on framing a specific solution. Making such a decision earlier in the process would ease the pressure on to set overly demanding and

inflexible requirements that will crush alternatives and win program approval.

- Require, as a condition for starting the system development and demonstration phase for a weapon system—program launch—that sufficient evidence exists to show there is a match between a weapon system's requirements and the resources the program manager has to develop that weapon. Based on our current and past work on the best practices of leading commercial firms, there is a key tool the Secretary can use to define what resources DOD is willing to apply—establishing limits on the time it takes to complete system development, such as not to exceed 5 years. Further, having a formal agreement among the requirements setters, program managers, and resource providers on development and delivery of the required product would emulate the best practice of establishing accountability for subsequent actions that stray from the agreement.

Agency Comments and Our Evaluation

DOD concurred with a draft of this report and its recommendations and agreed that the requirements process needs to be better informed by systems engineering in order to allow for the timely leveling of user needs and developer solutions. It noted that the recently revised acquisition policy takes the first steps in this new direction with guidance for evolutionary acquisitions and the identification of knowledge points in the acquisition process, but agreed that more progress needs to be made. Specifically, DOD recognized that more knowledge in the setting of requirements and the potential ability of the producer to meet those requirements would provide a greater understanding of the time, cost, and potential success of a program. DOD also recognized that the systems development and demonstration phase can begin with a higher level definition of requirements (that is, a higher level than the Operational Requirements Document), which can be used by the requirements-setter and the program manager, after some systems engineering work is done, to facilitate trade-offs earlier and relieve some of the pressure on Operational Requirements Document. Finally, DOD stated that the Acquisition Program Baseline should require signatures from both the user and the resource sponsor prior to program initiation signifying agreement that there is sufficient evidence—such as determined by systems engineering, demonstration of technology maturity, and adequacy of funding—that a match between requirements and resources has been made.

Comments From the Department of Defense



ACQUISITION AND
TECHNOLOGY

PRINCIPAL DEPUTY UNDER SECRETARY OF DEFENSE
3015 DEFENSE PENTAGON
WASHINGTON, DC 20301-3015



FEB 8 2001

Ms. Katherine U. Schinasi
Director, Acquisition and Sourcing Management
U.S. General Accounting Office
Washington, DC 20548

Dear Ms. Schinasi:

This is the Department of Defense (DoD) response to the General Accounting Office (GAO) draft report, "BEST PRACTICES: Better Matching of Needs and Resources Will Lead to Better Weapon System Outcomes," dated December 22, 2000 (GAO Code 707454/OSD Case 3022). The Department concurs with the GAO draft report and agrees with the recommendation of the need to level requirements, resources, and time-lines. The recently revised 5000 process helps in that regard by fixing the development side of the leveling -- evolutionary acquisition, identifying knowledge points, etc.

The GAO is also correct, however, that we still do this within the context of requirements to resources to systems engineering. The Department needs to correct that to allow the final setting of requirements and resources to be completed only after some systems engineering is done. This way, the program manager has a greater ability to negotiate with the requirements and resource communities. The first steps in this new direction have already been taken with the recent 5000 rewrite, but, as GAO points out, more progress needs to be made. The Department welcomes the GAO's recommendations and our specific responses to these recommendations are included herein as an enclosure.

Thank you for the opportunity to review and comment on the report. The professionalism and the level of cooperation between my staff and yours are greatly appreciated and we look forward to working with your staff again in the future.

Sincerely,

Dave Oliver

Enclosure:
As Stated



**GAO DRAFT REPORT - DATED DECEMBER 22, 2000
GAO CODE 7074541OSD CASE 3022**

**"BEST PRACTICES: BETTER MATCHING OF NEEDS AND RESOURCES WILL
LEAD TO
BETTER WEAPON SYSTEM OUTCOMES"**

DEPARTMENT OF DEFENSE COMMENTS TO THE RECOMMENDATIONS

RECOMMENDATION 1: The GAO noted that to realign the mechanics of the requirements setting and program approval process to bring more knowledge into the process of setting requirements, the GAO recommended that the Secretary of Defense require that the systems engineering needed to evaluate the sufficiency of available resources--knowledge, time, money, and capacity--be conducted in time to help identify and make the critical tradeoffs that precede the formalization of requirements. The GAO noted that one option the Secretary could consider for advancing the timing of systems engineering is allowing the award of well-defined systems engineering contracts to prospective product developers--contractors--before the system development and demonstration phase. (p. 51/Draft Report)

DOD RESPONSE: Concur. The Department agrees that the requirements process needs to be informed through systems engineering in order to allow for the leveling of user needs and developer solutions. In fact, our changes to the requirements process (in CJCSI 3170.01A) and the acquisition process (in DoDI 5000.2) support this recommendation by encouraging the development of technologies and components before the beginning of system development and the creation of an Operational Requirements Document (ORD). Also, our current Analysis of Alternatives methodology includes systems engineering tasks such as requirements and functional analysis/allocation. However, more needs to be done. For example, systems development and demonstration can begin with higher level "requirements" that define needed capabilities (e.g., a statement of operational capabilities approved by the JROC) then negotiate schedule, funding, and performance requirements through interaction with the program manager and the requirements generator so that those capabilities can be translated into firm requirements that would be captured in an operational requirements document. We recognize that more knowledge in the setting of requirements and the potential ability of a producer to meet those requirements would provide a greater understanding of the time, cost, and potential success of a program.

RECOMMENDATION 2: The GAO noted that to realign the incentives of the requirements-setting and program approval processes with the need to match available resources, the GAO recommended that the Secretary of Defense reduce the pressures put on user representatives to set requirements high to win the competition for program approval.

Now on pp. 11 and 67.

Now on pp. 11 and 67.

The GAO noted that one way to reduce these pressures, drawing on the experiences of the Tactical Unmanned Aerial Vehicle (TUAV) and Global Hawk, is to have higher level officials in the Services and DOD make the decision on the type of weapon system needed to meet a valid need before the requirements setters begin detailed work on framing a specific solution. Making such a decision earlier in the process would ease the pressure on setting overly demanding and inflexible requirements that crush alternatives and win program approval. (p. 51/Draft Report)

DOD RESPONSE: Concur. The Department believes the recommendation can be accomplished by using a requirements document such as the mission need statement, that defines needed capabilities that would be translated into an operational requirements document (ORD) after some systems engineering work is done (as discussed in the response to recommendation 1). Use of a higher level more general requirements document to facilitate tradeoffs earlier would improve this process and relieve some of the pressure on the ORD. Weighing the advantages and disadvantages of trading cost and performance to meet the general requirements can be guided by the principles of "Cost as an Independent Variable."

RECOMMENDATION 3: The GAO noted that to realign the incentives of the requirements-setting and program approval processes with the need to match available resources, the GAO recommended that the Secretary of Defense require, as a condition for starting the system development and demonstration phase for a weapon system--program launch--that sufficient evidence exists to show there is a match between a weapon system's requirements and the resources the program manager has to develop that weapon.

Now on pp. 11 and 68.

Based on the GAO current and past work on the best practices of leading commercial firms, there is a key tool the Secretary can use to help define what resources the Department is willing to apply--establishing limits on the time it takes to complete system development, such as not to exceed 5 years. Further, having a formal agreement between the requirements setters, program managers, and resource providers on development and delivery of the required product would emulate the best practice of establishing accountability for subsequent actions that stray from the agreement. (p. 51/Draft Report)

DOD RESPONSE: Concur. The Department agrees that there should be an agreement between the user, the developer, and the resource sponsor in which all sign up to the requirement, time-line, and costs. The need to match requirements to available resources is obvious and essential for program success. Currently, the Acquisition Program Baseline (APB) is used as an agreement within the acquisition chain-of-command on resources, schedule, and performance. Both the user and resource sponsor concur in that baseline. The user and resource sponsor's agreement could be made more formal with the requirement for their signatures on the APB. Further, the APB should contain sufficient evidence that a match between requirements and resources has been made, such as demonstration of technology maturity, results of systems engineering, and the adequacy of available funding to cover acquisition costs.

The recently revised CJCSI 3170.01A and DoDI 5000.2 both require that costs be addressed as part of the development of the operational requirement. This was done to provide a better match between resources and requirements. We have not established a hard and fast rule about length of time for system development, because length of time is very dependent on the type of system. However, the USD(AT&L) memorandum forwarding the revised DoD 5000 documents does address a planning horizon of five to seven years for translation of a mission need into a fielded system. Also, we are tracking cycle-time as part of our GPRA metrics with an internal stretch goal of reducing cycle-time in general from an average of 132 months to 66 months.

GAO Staff Acknowledgments

Acknowledgments

Paul Francis, Matthew Lea, Michael Sullivan, and Katrina Taylor made key contributions to this report.

Related GAO Products

Best Practices: A More Constructive Test Approach Is Key to Better Weapon System Outcomes (GAO/NSIAD-00-199, July 31, 2000).

Defense Acquisition: Employing Best Practices Can Shape Better Weapon System Decisions (GAO/T-NSIAD-00-137, Apr. 26, 2000).

Best Practices: DOD Training Can Do More to Help Weapon System Program Implement Best Practices (GAO/NSIAD-99-206, Aug. 16, 1999).

Best Practices: Better Management of Technology Development Can Improve Weapon System Outcomes (GAO/NSIAD-99-162, July 30, 1999).

Defense Acquisitions: Best Commercial Practices Can Improve Program Outcomes (GAO/T-NSIAD-99-116, Mar. 17, 1999).

Defense Acquisition: Improved Program Outcomes Are Possible (GAO/T-NSIAD-98-123, Mar. 17, 1998).

Best Practices: DOD Can Help Suppliers Contribute More to Weapon System Programs (GAO/NSIAD-98-87, Mar. 17, 1998).

Best Practices: Successful Application to Weapon Acquisition Requires Changes in DOD's Environment (GAO/NSIAD-98-56, Feb. 24, 1998).

Major Acquisitions: Significant Changes Underway in DOD's Earned Value Management Process (GAO/NSIAD-97-108, May 5, 1997).

Best Practices: Commercial Quality Assurance Practices Offer Improvements for DOD (GAO/NSIAD-96-162, Aug. 26, 1996).

Ordering Information

The first copy of each GAO report is free. Additional copies of reports are \$2 each. A check or money order should be made out to the Superintendent of Documents. VISA and MasterCard credit cards are accepted, also.

Orders for 100 or more copies to be mailed to a single address are discounted 25 percent.

Orders by mail:
U.S. General Accounting Office
P.O. Box 37050
Washington, DC 20013

Orders by visiting:
Room 1100
700 4th St. NW (corner of 4th and G Sts. NW)
U.S. General Accounting Office
Washington, DC

Orders by phone:
(202) 512-6000
fax: (202) 512-6061
TDD (202) 512-2537

Each day, GAO issues a list of newly available reports and testimony. To receive facsimile copies of the daily list or any list from the past 30 days, please call (202) 512-6000 using a touchtone phone. A recorded menu will provide information on how to obtain these lists.

Orders by Internet:
For information on how to access GAO reports on the Internet, send an e-mail message with "info" in the body to:

info@www.gao.gov

or visit GAO's World Wide Web home page at:

<http://www.gao.gov>

To Report Fraud, Waste, or Abuse in Federal Programs

Contact one:

- Web site: <http://www.gao.gov/fraudnet/fraudnet.htm>
- e-mail: fraudnet@gao.gov
- 1-800-424-5454 (automated answering system)