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The **Military-Industrial** Complex

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From the Chairman and Executive Editor

It is my pleasure to note several changes to the masthead of the *Defense Acquisition Research Journal*. First, on May 25, 2012, the Senate confirmed Frank Kendall and Katrina McFarland as Under Secretary of Defense for Acquisition, Technology and Logistics, and Assistant Secretary of Defense for Acquisition, respectively. McFarland leaves behind a distinguished tenure as President of the Defense Acquisition University (DAU), a position now filled on an acting basis by Dr. James McMichael.

The other change is the appointment of Dr. Mary Redshaw as Deputy Executive Editor. Dr. Redshaw, who is also the Deputy Director of Research at DAU, brings 21 years of uniformed military service and two decades of public and private experience supporting the military and federal government. Welcome aboard!

This issue's theme "The Military-Industrial Complex" is taken from the term popularized by President Dwight Eisenhower in his farewell address on January 17, 1961. Although he used the phrase in a cautionary sense—"we must guard against the acquisition of unwarranted influence ... by the military-industrial complex"—the close link between military and industrial strength has long been recognized as an essential ingredient in a nation's strategic capability.

The first article, "The Jeep at 70" by Brian Duddy, reflects the lessons learned from the cooperative development between the U.S. Army and several automobile manufacturers to create the iconic vehicle that carried Eisenhower and millions of other warfighters across every continent. Thomas R. Edison and Andre Murphy, in their article "A New

Look at Enablers and Barriers to Performance Based Life Cycle Product Support (PBL) Implementation," look at the enablers and barriers for creating and sustaining effective military-industrial logistics partnerships.

The article "Running with Scissors" by Bryan Riley has the distinction of winning the DAU 2011 Award for Excellence in Research and Writing at the Industrial College of the Armed Forces (ICAF), now renamed the Dwight D. Eisenhower School for National Security and Resource Strategy (The Eisenhower School) under the National Defense University. Riley's article is a cautionary tale of the risks to the military-industrial complex in the face of expected U.S. defense budget cuts.

The last two articles provide some rays of hope in these otherwise gloomy scenarios. Chad Dacus' article suggests that the cost and schedule risks associated with immature technologies and integration can be mitigated using a more holistic means of measuring system technology readiness. Mark Pflanz and his coauthors describe successes and lessons learned in applying early systems engineering concepts to the development of the Joint Light Tactical Vehicle program.

In this issue, John Schank adds to our understanding of how defense acquisition works (and sometimes doesn't work) overseas, in his review of the book *The Collins Class Submarine Story: Steel, Spies, and Spin*. Finally, we take the opportunity to thank all the reviewers of the *ARJ* articles for the year 2012.

Dr. Larrie D. Ferreiro
Executive Editor
Defense ARJ

Dr. Mary Redshaw
Deputy Executive Editor

The Defense Acquisition University (DAU) welcomes the appointment of Dr. Mary Redshaw as Deputy Executive Editor of the *Defense Acquisition Research Journal* and Deputy Director of Research at DAU. She brings 21 years of uniformed military service and two decades of public and private experience supporting the military and federal government. Dr. Redshaw has a broad and varied background from which to draw in her new collateral duty as Deputy Executive Editor for the *Defense Acquisition Research Journal* through such varied assignments as editor of the *Pioneers' Progress* (1989–1991) and as a contributing editor and chapter author for the *Systems Engineering Handbook* published in 2006 by the International Council on Systems Engineering (INCOSE).

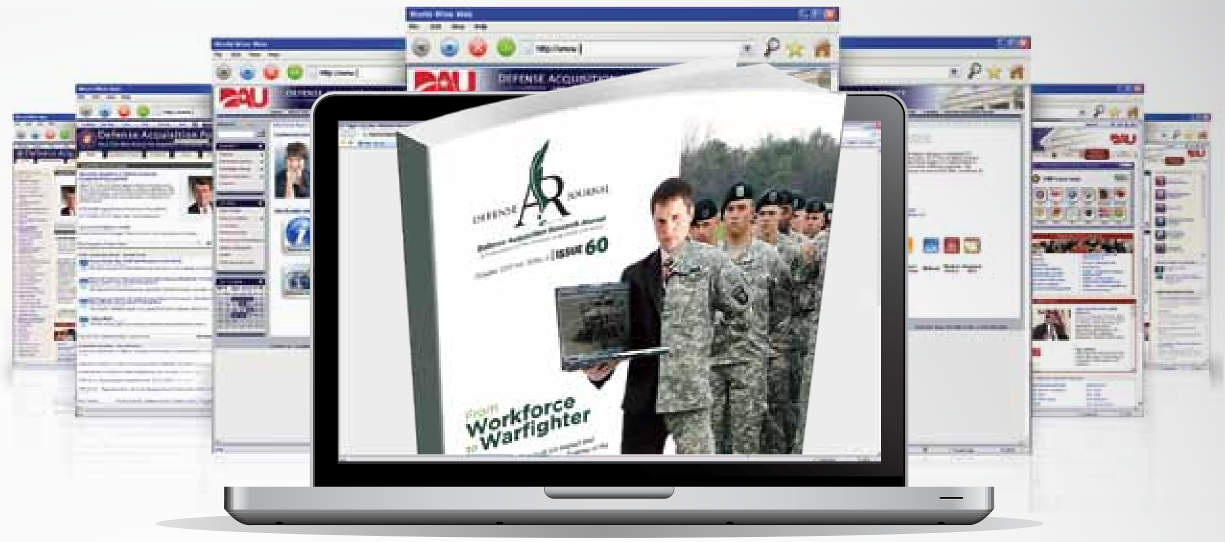
Her military career included assignments as communications technician, surface warfare officer, naval flight officer, and aerospace engineering duty officer. She became the first woman in the U.S. Navy's history to achieve warfare qualifications in both surface and aviation operations. As an acquisition professional whose career spanned military and civilian assignments, Dr. Redshaw was instrumental in milestone decisions for multiple items of user equipment in the Navy's Global Positioning System Program Office and for the ACAT IC Joint Standoff Weapon.

After retiring from active duty in 1994, she supported or led research and acquisition programs for the Defense Advanced Research Projects Agency, Office of the Secretary of Defense (Health Affairs), and the Naval Air Systems Command before accepting a position with the DAU faculty in 2003. At DAU, Dr. Redshaw developed DAU's online Level II Systems Engineering Course, receiving accolades for her efforts from the highest levels of DAU and the Office of the Under Secretary of Defense for Acquisition, Technology and Logistics.

A proponent of life-long learning, Dr. Redshaw earned an undergraduate degree in Engineering Science; graduate degrees in Aeronautical Engineering, Business Administration, and National Resource Strategy; and advanced degrees in Engineering Management (PhD) and Educational Leadership (EdD). She completed DoD's Senior Acquisition Course while attending the Industrial College of the Armed Forces at National Defense University as well as the former 20-week Program Management Course and the current Level IV Program Manager's Course (PMT 401) at the Defense Systems Management College (DSMC).

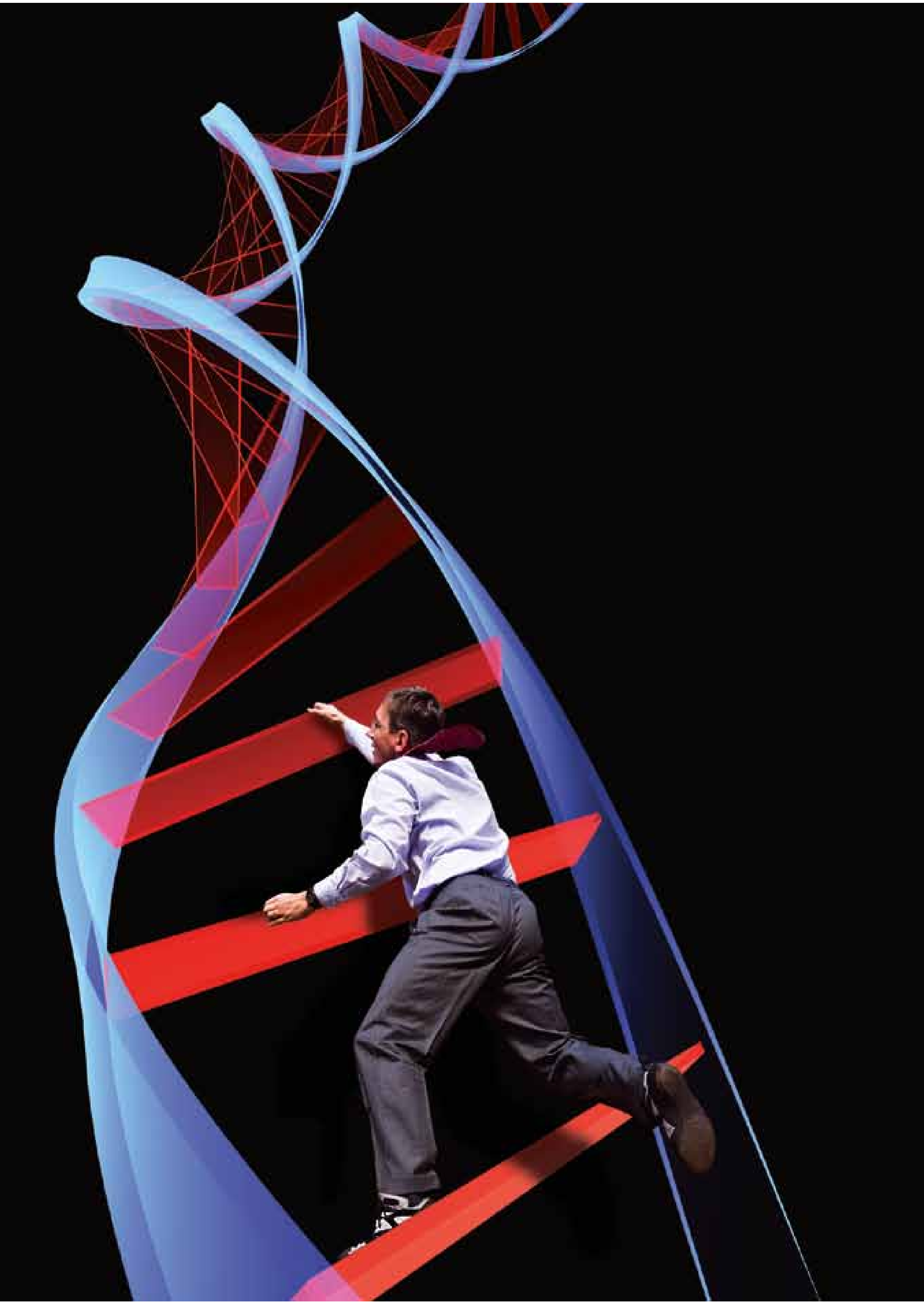
Dr. Redshaw is Level III certified in program management, systems engineering, and test and evaluation. Additionally she achieved certification through two prominent international associations as a Project Management Professional and a Certified Systems Engineering Professional.

Dr. Redshaw will continue to serve in her current capacity within the Executive Program Management Center, DSMC, a DAU business unit co-located with the university's headquarters at Fort Belvoir, Virginia.



Workforce
Warfighter

Better Buying Power



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- The competition is open to anyone interested in the DoD acquisition system and is not limited to government or contractor personnel.
- Employees of the federal government (including military personnel) are encouraged to compete and are eligible for cash awards unless the paper was researched or written as part of the employee's official duties or was done on government time. If the research effort is performed as part of official duties or on government time, the employee is eligible for a non-cash prize, i.e., certificate and donation of cash prize to a Combined Federal Campaign-registered charity of winner's choice.
- First prize is $1,000. Second prize is $500.
- The format of the paper must be in accordance with guidelines for articles submitted for the *Defense Acquisition Research Journal.*
- Papers are to be submitted to the DAU Director of Research: research@dau.mil.
- Papers will be evaluated by a panel selected by the DAUAA Board of Directors and the DAU Director of Research.
- Award winners will present their papers at the DAU Acquisition Community Training Symposium, Tuesday, April 9, 2013, at the DAU Fort Belvoir Campus.
- Papers must be submitted by December 1, 2012, and awards will be announced in January 2013.

DAU Center for Defense Acquisition Research

Research Agenda 2012–2013

The Defense Acquisition Research Agenda is intended to make researchers aware of the topics that are, or should be, of particular concern to the broader defense acquisition community throughout the government, academic, and industrial sectors. The purpose of conducting research in these areas is to provide solid, empirically based findings to create a broad body of knowledge that can inform the development of policies, procedures, and processes in defense acquisition, and to help shape the thought leadership for the acquisition community. Each issue of the *Defense ARJ* will include a different selection of research topics from the overall agenda, which is at: *http://www.dau.mil/research/Pages/researchareas.aspx*

Effects of industrial base

- What are the effects on program cost, schedule, and performance of having more or fewer competitors? What measures are there to determine these effects?
- What means are there (or can be developed) to measure the breadth and depth of the industrial base in various sectors, that goes beyond simple head-count of providers?
- Has the change in industrial base resulted in actual change in output? How is that measured?

Competitive contracting

- Commercial industry often cultivates long-term, exclusive (noncompetitive) supply chain relationships. Does this model have any application to defense acquisition? Under what conditions/circumstances?
- What is the effect on program cost, schedule, and performance of awards based on varying levels of competition: 1. "Effective" competition (two or more offers); 2. "Ineffective Competition" (only one offer received in response to competitive solicitation); 3. Split awards vs. winner take all; and 4. Sole source.

Comparative studies

- Compare the industrial policies of military acquisition in different nations and the policy impacts on acquisition outcomes.
- Compare the cost and contract performance of highly regulated public utilities with nonregulated "natural monopolies," e.g., military satellites, warship building.
- Compare contracting/competition practices between DoD and complex, custom-built commercial products (e.g., offshore oil platforms).
- Compare program cost performance in various market sectors: highly competitive (multiple offerors), limited (two of three offerors), monopoly.
- Compare the cost and contract performance of military acquisition programs in nations having single "purple" acquisition organizations with those having Service-level acquisition agencies.

Acquisition of services

- What means are there (or can be developed) to measure the efficiency and effectiveness of service contractors?
- What means are there (or can be developed) to evaluate and compare incentives for small business to participate in service contracts?
- What means are there (or can be developed) to evaluate and compare services that the government outsources with those kept in-house? Can they be used to evaluate "inherently governmental" functions?
- Are there insights from other sectors that can inform how we measure acquisition of services?
- Are there insights from the private sector that can inform how we measure supply chain management?

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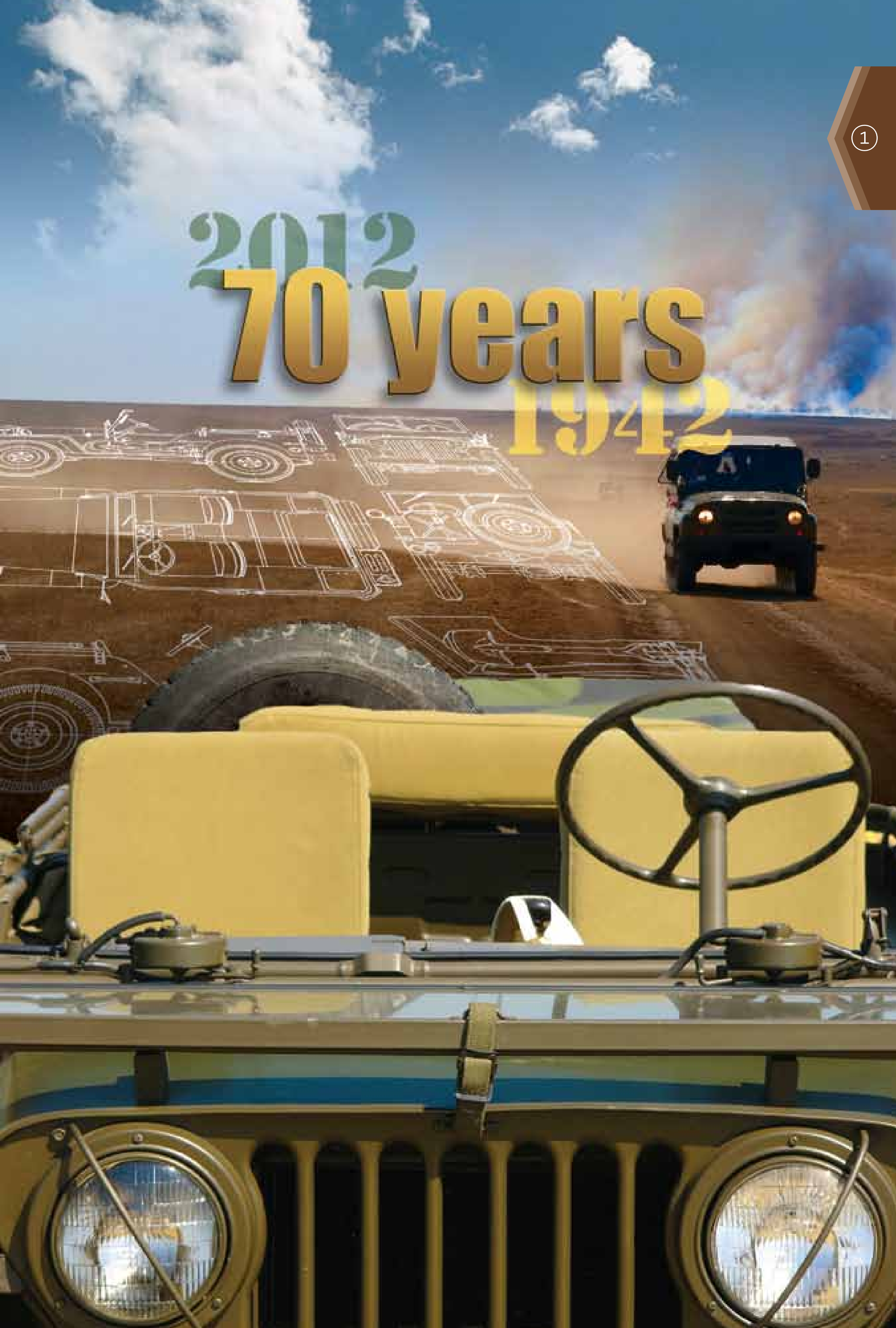
Keywords: *Jeep, Mass Production, Requirements Development, Government-Industry Partnership, Automotive Design*

The Jeep at 70: *A Defense Acquisition Success Story*

Brian J. Duddy

The successful development of the jeep during World War II (WWII) was a long process of requirements development, testing, and experimentation of small reconnaissance cars, and incorporation of lessons learned from WWI transport vehicles. The jeep prototype was initially developed by American Bantam Company, but later designs by Willys-Overland and Ford were also evaluated during the acquisition process. Changes in laws and procurement procedures also impacted execution of the jeep development program. Eventually, a single vehicle design was standardized and produced during the war, primarily by Willys-Overland, but also by Ford. The design of the jeep has endured as an acquisition success story. Lessons learned from the jeep development can still be applied to systems acquisition programs today.

image designed by Diane Fleischer »



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The enormously successful vehicle we know today as the "jeep" was born out of requirements developed by the U.S. Army prior to World War II (WWII). From a small company and simple beginnings came one of the iconic symbols of WWII and arguably one of the most enduring automotive designs of all time. The successful development of the jeep demonstrates the need for requirements harmonization, and the mass production and longevity of the design demonstrates the application of thoughtful, long-range manufacturing planning. In this follow-up case study to the P-51 *Mustang* (Haggerty & Wood, 2010), we look at how the jeep design was created and what set it on the course to become the vehicle with the longest production run in U.S. history.

The overall requirement for the vehicle that became the jeep followed the demise of the horse as a method of military transport and reconnaissance. Following WWI, the world's armies focused their energies on the development of petrol-powered vehicles of all types. In the United States, the Army was interested in a vehicle that could replace both the horse and the motorcycle in the scout, reconnaissance, communication, and liaison roles as well as a vehicle large enough to carry the heavy weapons and ammunition required by infantry companies.

Army Requirements Develop

The lean interwar years 1919–1939 were a time of experimentation in the new concepts of mechanized warfare. The Army was searching for a solution to its vehicle requirements during a time of dynamic change. Wars of the future would likely be more mobile than the trench warfare of WWI, and armies would require a wide range of mechanized forces. Initially, the Army's need was for a vehicle that would have a low silhouette, be able to carry a one- or two-man crew and a machine gun with ample ammunition. It had to have speed, toughness, and a useful payload. The vehicle also needed to have good ground clearance and cross-country mobility as it was envisioned that it would travel off-road more often than not. The Army sponsored limited evaluations of a number of existing light vehicles to find a suitable solution to its requirements. Several tracked vehicles were tried at Aberdeen Proving Ground, but they proved to be unsuitable. The Army even evaluated a radical two-man powered cart developed by Army personnel. The low-slung vehicle was equipped with a machine gun and nicknamed "The Belly Flopper." Although this extensive experimentation and testing did not ultimately produce a vehicle for the Army, it served to refine the requirements for the light reconnaissance car.

In 1938 and again in 1939, the Pennsylvania National Guard used a few small open-topped sedans built by the American Bantam Car Company as utility vehicles during training exercises. Bantam specialized in small, inexpensive cars and they performed reasonably well in these evaluations. Based on the results of these exercises and using the Bantam design as a departure point, the Army solidified its need for a reconnaissance car. It took many of the ideas and design concepts that emerged from the various trials and demonstrations and merged them into a single set of general requirements (Denfeld & Fry, 1973).

At this point there was some internal disagreement within the Army regarding the management of the vehicle program. In the pre-WWII era, acquisition of transport vehicles was the responsibility of the Quartermaster Corps. Acquisition of tactical and combat vehicles was the responsibility of the Ordnance Corps; the new vehicle had the potential to fill several different roles, both tactical and nontactical (Rifkind, 1943). Although the vehicle was initially conceived as a general purpose commercial vehicle without armor, it had the potential to evolve into a vehicle that could serve in several roles in the combat forces. The Army resolved the situation by appointing an Ordnance Technical Committee to lead the program—headed by the Ordnance Corps, but with representatives from the Infantry, Cavalry, and Quartermaster branches (Denfeld & Fry, 1973).

The Ordnance Technical Committee was charged with developing a specification for the vehicle that would satisfy the needs of all the using branches. This required difficult compromises on specific vehicle features and characteristics desired by each branch. Committee members had to balance such needs as durability and cross-country capability with the desire for a vehicle that had a low profile, good fuel economy, and adequate carrying capacity. It was a challenge to synthesize all these needs into a vehicle design that was also affordable and producible. With much effort, eventually a single specification resulted in May 1940 and was forwarded to the Assistant Secretary of War for approval. The Quartermaster General directed the Motor Transport Procurement Branch to initiate purchase of the vehicle that would fulfill this specification (Rifkind, 1943).

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Detailed Specifications for the New Vehicle

The details of the reconnaissance car specification drawn up by the Technical Committee were as follows: The $\frac{1}{4}$-ton vehicle had to have 4-wheel drive, a maximum weight of 1,200 pounds, a useful load of 600 pounds, a maximum height of 36 inches, and a wheelbase of 75 inches. The body style was to be rectangular with bucket seats and a fold-down windshield. Performance requirements included a minimum top speed of 50 mph and a minimum sustained speed of 3 mph.

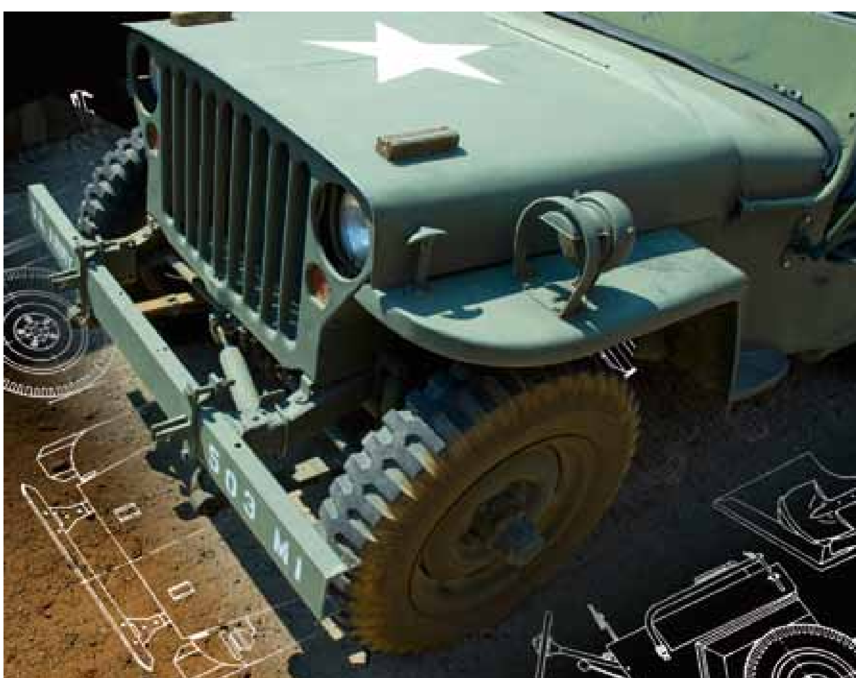
As soon as the requirements were formalized, a small group of Army officers and civilians visited the Bantam factory in Butler, Pennsylvania, to further test Bantam vehicles and discuss the concept of the new military car with the Bantam development group (Denfeld & Fry, 1973; Rifkind, 1943). The results of this meeting allowed the Army to continue to refine the specifications and even sketch a rough outline of what the new vehicle should look like. Thus, by working with industry the Army had arrived at a set of requirements that was simple, functional—and most importantly—achievable (Denfeld & Fry, 1973).

On June 27, 1940, the Ordnance Technical Committee issued its final recommendations for a $\frac{1}{4}$-ton, 4x4 truck. (The term 4x4 meant the vehicle had four wheels, all of which were powered.) The vehicle maximum weight was now raised to 1,300 pounds with a 600-pound payload, and the wheel base was increased to 80 inches (Probst, 1976; Wells, 1946; Vanderveen, 1971; Denfeld & Fry, 1973). To keep the design simple, the Army intended for manufacturers to use several common pieces of military vehicle equipment already available such as tail lights and towing pintles. The Army sent invitations to bid on 70 "pilot" trucks or sample models to 135 manufacturers. Bidding instructions mandated that the first pilot model should be delivered to Camp Holabird in Baltimore in 49 days. It was one of the first examples of "try-before-buy" ever used by the Army, which prior to WWII had been directed to purchase commercial off-the-shelf trucks almost exclusively (Thomson & Mayo, 1960).

As the vehicle development evolved, changes were also occurring in the way the Army acquired equipment. These changes were intended to help speed the process for procuring large amounts of materiel in the event of a crisis. Many in the U.S. Government feared war was near and such process changes would be required to get equipment to the field as fast as possible versus waiting for firms to submit bids. One of the most significant changes occurred in July 1940 when Congress passed Public

Law 703, which allowed the Services to negotiate contracts directly with firms of their own choosing rather than compete programs and award contracts to the lowest bidder (Thomson & Mayo, 1960).

Out of 135 companies invited to bid on the vehicle contract, only two submitted proposals: American Bantam and Willys-Overland Motors. However, only Bantam affirmed it could deliver a vehicle in the tight timeframe specified by the Army. Willys underbid Bantam on per-vehicle cost, but responded that they could not have a prototype ready for 75 days. On July 25, 1940, under the new negotiated procurement law, the Army and Bantam signed the contract for delivery of the pilot vehicles within the 49-day window (Denfeld & Fry, 1973).



The First Jeep is Delivered

Like the NA-73X/P-51 story, the prototype machine that would eventually mature into the jeep was completed in record time. As Bantam engineers started work on August 1, 1940, they knew that meeting both the delivery date and the specifications would be extremely difficult. As the design solidified, it emerged that one requirement in particular—vehicle weight of only 1,300 pounds—would not be achievable in the short

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term. But the Bantam team was experienced enough in the design of small automobiles to know that none of the other competitors could likely build a vehicle that size and that robust, which still fit into the weight envelope. Undaunted, they pressed on with their design. Working around the clock, Bantam completed the prototype and company executives drove the vehicle directly from the factory in Butler to Camp Holabird, its first long-distance trip. On September 23, they made it through the gate at Holabird with only 30 minutes to spare on their 49-day deadline.

The Bantam vehicle, as delivered, weighed in at 1,840 pounds and was powered by a 45hp Continental engine. Since the vehicle was able to successfully complete a series of strenuous tests at Holabird, the Army representatives believed that the maximum weight target could be reconsidered. Both the Bantam and Army engineers knew that as the design matured, strengthening the chassis and body for rough service would result in an increase in the vehicle empty weight. The addition of extra required equipment would also render the 1,300-pound target unrealistic. In lieu of a strict numerical weight objective, the Army performance objective was still for a few soldiers to be able to manhandle the vehicle should it get stuck in the mud, sand, or snow. Eventually, the Army accepted weight growth as inevitable as long as that performance requirement could be met (Wells, 1946). The focus then shifted to the automotive performance of the vehicle as more critical to its success than its weight. In some ways, the jeep development employed the modern concepts of evolutionary acquisition, incremental development, and systems engineering.

Since it was extremely satisfied with the prototype, the Army gave the go-ahead to Bantam to initiate production of the other 70 pilot vehicles based on that design, but incorporating some design changes and improvements that resulted from the early testing of the prototype. These changes were to improve both performance and reliability. The testing at Holabird was an early example of what we would call today Test, Analyze, and Fix or Reliability Development/Growth Testing. The first series of the improved vehicles were delivered to the Army in December 1940 and were known as "Bantam Reconnaissance Cars" (BRC).

While Bantam was moving ahead with the production of its truck, Willys was still in the competition for Army contracts. Both Willys' personnel and engineers from Ford Motor Company had been present when the Bantam pilot was delivered to Camp Holabird, so the company had advanced knowledge of what the competing vehicle looked like. It even had the opportunity to make sketches of the Bantam vehicle. The Army later responded to charges that this represented unfair competition by saying that the pilot model was government property and that they wanted to make it available in order to develop multiple sources for production of the cars (Denfeld & Fry, 1973; Jeudy & Tararine, 1981).

Like the Bantam team, Willys' engineers also knew achieving or beating the maximum weight requirement specified by the Army would be difficult using existing technology. Using the Bantam pilot design as a starting point, Willys' designers set out to develop a car roughly fitting the other Army specifications, but incorporating an engine of their own design that they considered more suitable for the mission the Army had in mind for the vehicle (Denfeld & Fry, 1973). The Willys prototype arrived at Camp Holabird on November 11, 1940—also overweight at 2,400 pounds, but with a powerful 65hp engine. With the two prototypes in place, the Army decided its earlier weight goal should be revised upward, but it still kept a goal in place to force the industry to consider weight and weight savings as its designs matured.

A third bidder was also now in the race—Ford. The Ford Company had decided to enter the competition with its own small vehicle design incorporating an existing 46hp tractor engine. The lure of commercial business was too strong for Ford to stay out of the vehicle competition, and it was also encouraged by the Army to consider participation (Denfeld & Fry, 1973). All three companies now sensed that this rugged off-road vehicle concept had the potential to grow beyond a military application. No vehicle like it existed in the civilian world—"sport-utility vehicles" were decades away—and the promise of extensive commercial, particularly agricultural, sales awaited the company that could successfully secure the Army contracts. The Ford prototype, called the "GP," was delivered to the Army on November 23, 1940. The Army now had three competing designs to evaluate. This presented both a technical and a manufacturing challenge: how to select the best vehicle design for the mission ***and*** ensure that it could be produced in quantities sufficient for the needs of a world-wide conflict.

Mass Production Dilemma

The key concern in getting the jeep design to the field was the issue of mass production capacity. Although Bantam had produced and refined the original design, the Army believed the small company was in no posi-

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tion to produce the rate and number of vehicles the Quartermaster Corps believed they would need for wartime requirements (Thomson & Mayo, 1960; Jeudy & Tararine, 1986; Zaloga, 2005). During WWI, the Army had to employ a dizzying array of vehicles to meet urgent wartime needs and they wanted to avoid that in the future; thus, the goal of standardization underpinned the strategy for the Army vehicle fleet in the 1940s (Thomson & Mayo, 1960). Logistics planners did not want to repeat the problem of provisioning spare parts and support equipment for multiple vehicle types and multiple manufacturers.

One encouraging fact was that the designs of all three prototype reconnaissance cars were similar—a steel frame and sheet metal body. It was within the capability of each of the three manufacturers to produce them since they were in some ways simpler than the civilian passenger cars they were already building. The central issue was more one of production capacity than complexity, and there were a significant number of subcontractor components in each vehicle, particularly the drive train.

Bantam, even by its own admission, was on the ropes. Sales of its civilian vehicles were very modest—1,225 in 1939 and only 800 in 1940. By the time of the jeep design and competition, it had no operating capital and only 15 people in its engineering department (Domer, 1976). As a result, the Army looked on Bantam as high risk regarding its capacity for producing the thousands of vehicles that would be needed for a global war. Army planners initially estimated they would need 11,800 reconnaissance cars by mid-1941 (Zaloga, 2005).

Consequently, Army acquisition personnel faced a significant dilemma—do they stay with the company that had successfully pioneered and built the vehicle they wanted, or abandon it in favor of a company or companies that could produce the quantity they would need (Thomson & Mayo, 1960)? Willys was a larger company than Bantam, but still not as large and well-resourced as Ford. The situation was further complicated by the fact that by the end of 1940, three viable yet clearly different design/prototypes existed from Bantam, Willys, and Ford. If only one was to be selected for high-rate production to meet the goal of standardization, which design would it be? All three vehicles had their own peculiar strengths and weaknesses, and no single design was clearly superior, but at least they all met the minimum Army requirements.

The Army decided to solve each problem in turn. First to be settled was the design issue, although the plan that resulted also had the secondary goal of surfacing potential production shortfalls. To move the design forward, a contract would go to all three manufacturers for 500 vehicles each. This quantity was thought to be sufficient for each interested Army branch to test the vehicles thoroughly in an operational environment and provide feedback on the competing designs. After some internal disagreements within the Army, this plan was revised to procure all 1,500 vehicles from Bantam on the grounds that only its prototype had met the first delivery requirement and had successfully completed all the initial testing, which the Willys and Ford models had yet to do. This plan was revised a second time in November 1940 to acquiring 1,500 cars with contracts to all three manufacturers, subject to approval of each company's prototype model. In consideration of the new procurement law now on the books, these were negotiated contracts not competitive bids (Thomson & Mayo, 1960).

All three manufacturers then set out to produce what in today's acquisition lexicon would be "low rate initial production" quantities. In the end, all three companies had trouble meeting delivery schedules because of a production problem at the Spicer Company, which was the source for the axles for all three vehicle designs. Indeed, the availability of axles and related equipment was a major production bottleneck for a number of military truck designs during WWII, since all-wheel drive was not a feature offered on civilian vehicles and the only users of specialized gear components and constant velocity joints were military trucks. Shortfalls in these components bedeviled the Army for many months in the early part of WWII (Thomson & Mayo, 1960). The availability of these components is an example of a critical technology crucial to the supply chain that drove both the system performance and the total production capacity of more than one Army truck system.

Operational Testing Results—A Further Dilemma

When these initial production vehicles reached the field, they were extensively tested by the Army with the objective of selecting the best design that would move to the next phase of high-volume production. The operational testing focused mainly on performance since the bodies of all three vehicles were similar—the Willys and Ford models having been copied from the original Bantam design. The weight of each vehicle had steadily grown, reinforcing what certain Bantam and Army engineers knew was the case in practice—vehicles tend to get heavier, not lighter. That is still true today as all the prototypes for the JLTV exceeded the desired transport weight of 15,629 pounds by several hundred to a thousand pounds (Beidel, 2011). Thus, the jeep vehicle weight limit increase over time is very similar to today's use of the threshold and goal/objective values in Performance Based Acquisition.

In the performance area, the Willys "MA" models with their 4-cylinder, "Go Devil" engine were clearly superior (Jeudy & Tararine, 1986; Denfeld & Fry, 1973). The Willys vehicles also had the best acceleration and cross-country performance. The Bantam models were notable for their superior fuel economy, steering, and braking, which was attributed to Bantam's focus on keeping the weight of the vehicle as low as possible. The Ford vehicle came in third in the competition, but it did have some features that the Army liked over the other two such as the front-end design, gear lever, handbrake, and passenger comfort. So the testing, while useful, did not resolve the dilemma of how to arrive at a single, standardized design.

The Army leadership saw only two alternatives to resolve this dilemma: (a) design a new vehicle combining all the desirable features of all three existing designs, or (b) take the best design of the three existing and graft on to it, as far as possible, the most desirable features of the other two (Cowdery, 1986; Denfeld & Fry, 1973). The first approach was rejected because of the time required to literally "go back to the drawing board" and design a new vehicle. At that time—mid-1944—the urgency of getting vehicles into the field fast was becoming the driving requirement. So the Army, through the Quartermaster Corps (QMC), would have to award a single contract for a "combined" design.

The contract award decision itself then became controversial. Initially, the QMC wanted to award the production contract to Ford. Although its vehicle came in last in the competition, it was seen as being the lowest risk to produce the required number of vehicles on time. This acquisition approach was vetoed by the government's Office of Production Management (OPM), which argued that, at a minimum, the contract should go to either Willys or Bantam as the vehicle designs submitted by the two companies were superior and both had met their earlier contract requirements (Thomson & Mayo, 1960; Denfeld & Fry, 1973). The Willys vehicle also had the lowest unit price. The OPM also argued all along that having more than one source qualified to produce the cars would be advantageous in the long run, particularly if war loomed on the horizon. The positions of all three companies, the Roosevelt administration, and the Army resulted in a messy dispute, which even played out in the contemporary press. As a result of this controversy, the Army was forced to relent on the Ford contract plan, and on July 23, 1941, the QMC awarded a full-rate production contract to Willys for 16,000 identical jeeps at a unit price of $739.00, with an initial delivery date of January 1942. This contract award reflects what we would consider today as "Best Value" for the government.

A Legend is Born

The task that remained was to synthesize the advantageous characteristics of the three competing vehicles into a single vehicle configuration that the Willys team was to use as the production design. After the contract award to Willys, the Army convened its own team to finalize the features of the vehicle using the Willys MA as the new baseline configuration. The Army engineers also had to ensure inclusion of other standardized military vehicle equipment into the final configuration. The design that resulted, the Willys MB "¼-ton, 4x4 utility," was broadly the Willys body, chassis, engine, and drive train with a Ford front end and grille. This configuration would become the standard for more than 640,000 WWII jeeps—an iconic design that would last 70 plus years and spawn an entire new class of civilian vehicle. The jeeps that were provided to U.S. and Allied forces during the war were an instant success. A vehicle originally designed for use by the Combat Arms branch was adopted and used by all the Services. In fact, the vehicle was so versatile in a number of roles and in all theaters of the war that its reputation grew well beyond anything the original designers could have imagined. Although its programmatic beginnings were rocky, the little car quickly became an overnight operational success story and an instant hit with G.I.'s.

What became of the original three companies? As forecast by the OPM, as soon as the United States became involved in WWII, a second source was needed to produce the jeep in addition to those being produced by Willys, which eventually produced 362,000 MB models. That second-source contract went to Ford, which by the end of 1945, co-produced 277,000 of its own version of the Willys MB. The Ford version, the GPW, differed in only the smallest details from the Willys and allowed the Army to achieve the standardization and production volume it desired. Bantam, however, lost out completely on subsequent Army jeep contracts, producing a total of only 2,600 vehicles, many of which went to Allied nations. Congressional hearings were eventually held on the controversy of who had "invented" the jeep, and Bantam was vindicated by the judgment of the U.S. Government that the wartime design was based on its initial prototype and intellectual property (Rifkind, 1943). This victory did not help the company financially. Although Bantam did produce trailers for the jeep during the war, the company did not survive much past 1945. In truth, the jeep design was a product of a massive team effort, including all three manufacturers as well as Army engineers, both military and civilian (Vanderveen, 1971; Wells, 1946; Hogan, 1941).

Newer models of the Willys jeeps "soldiered on" in the U.S. military until the Vietnam War when they were gradually replaced with a new vehicle design—the Ford M151 MUTT. Production of civilian jeeps began immediately after WWII. Although based on newer technology, the M151 owed much of its design to its predecessors, the Bantam BRC and the Willys MB. The jeep was a design for the ages and one that will seemingly never go out of style. Today's contemporary civilian model, the Jeep Wrangler, still maintains many of the design features of the $\frac{1}{4}$-ton 4x4 reconnaissance car of WWII. Its design longevity has made it a true defense acquisition success story.

Lessons Learned

The lessons learned from the development and production of the jeep are many. Surely the first and most significant is the importance of government and industry partnerships to work together to satisfy operational requirements. As the Army, Bantam, and Willys evaluated the maturity of the reconnaissance car design, they grew to understand the "art of the possible." The Army involvement in the jeep development functioned in ways similar to the Department of Defense (DoD)'s current Integrated Product and Process Development/Integrated Product Team environment and the Joint Capabilities Integration and Development System process. Developing requirements that are simple, functional, and achievable is a good model for the JLTV program.

A second key lesson is impact of sound production planning on the eventual deployment and sustainment of the system. The Army knew that multiple sources would be required to supply the jeeps for wartime needs. Although the methods it used to ensure multiple sources were criticized, in the end its strategy was validated as the production from both Willys and Ford provided sufficient quantities of a standardized vehicle for not only the United States, but many Allied nations. The operational testing at Camp Holabird and other locations surfaced reliability problems on the early vehicles, which would later be corrected in full-rate production versions.

A third enduring lesson is keeping designs realistic and having the courage to prioritize or revise requirements in light of common sense and the results of operational testing. The weight limit on the jeep imposed by the Army was revised based on technological and operational realities, but was maintained to avoid too many "ornaments" being added to the design. The development and production of the jeep followed an approach similar to DoD's current Performance Based Acquisition process.

Dilemmas in defense acquisition will always arise, but by taking some lessons from history, those dilemmas can be successfully resolved.

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A New Look at Enablers and Barriers to Performance Based Life Cycle Product Support (PBL) Implementation

Thomas R. Edison and Andre Murphy

Efficient and effective product support development and implementation are not simple. Increasingly, more focus is being placed on how to deliver cost-wise and effective product support. In an environment of Better Buying Power—greater efficiency and productivity in defense spending—a need to better understand and implement product support that is performance outcome-based is not only prescribed, but prudent. PBL can provide desired performance based product support. A 2005 study unearthed perceived PBL enablers and barriers. This article is a byproduct of 2011 research contrasting the 2005 study's PBL barriers and enablers. Through survey of the acquisition workforce, data were collected on 15 PBL implementation factors. This article discusses current working perceptions that either encourage or impede PBL implementation.

image designed by Diane Fleischer »

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The acronym "PBL" has changed. Its definition now corresponds to Performance Based Life Cycle Product Support vice Performance Based Logistics—but has the scope and function of PBL really changed? Indeed, the objective of the PBL name change was to broaden the context of how, why, when, and who would implement and manage PBL. Rightfully so, policy makers thought it prudent to redefine the initiative to make it clear that PBL is not just a tool for the logistician, but now includes other program areas of responsibility such as system engineers, contract specialists, etc.

The work of various roles required with the implementation of PBL is broader than what was initially envisioned, and PBL has become a more significant enabler to greater product support capability throughout the Department of Defense (DoD). PBL should no longer be viewed as solely outcome-focused on an end product, nor from just the perspective of supporting the logistics support elements. PBL needs to be considered throughout the entire life cycle and as an enabler to forge a more effective product support strategy throughout the product's entire life cycle—from "must have it" (initial requirement) to "rust has it" (final disposal).

But changing PBL and how it is implemented and managed obviously takes more than a name change from the stroke of a pen. Has PBL really changed over the years since it was embraced in earnest in the late 1990s? Specifically, has the PBL environment changed—have barriers and/or enablers been transformed for PBL so it can be implemented more successfully throughout DoD? At the day's end, do we really understand PBL? Have perceptions of PBL being too expensive, requiring greater funding, or being too complicated to implement in terms of developing proper contractual incentives/awards or partnering agreements, changed? Have Services' viewpoints of PBL changed? Have some of the barriers and enablers to PBL's effective and efficient implementation changed over the last 5–10 years?

The research analyzed the current perceptions of PBL through the eyes of approximately 300 plus military, civilian government, and contractor personnel working primarily in program management and logistics. The respondents were asked to rate 15 factors as to whether they believed a factor was a barrier or an enabler to PBL implementation. They also rated how significant they believed each factor impacted PBL implementation in their program on a scale from 1 (minimal) to 4 (very significant). They were asked other related questions to determine if they had accomplished a Business Case Analysis on their program and what the overall effect was on their program's cost, schedule, and performance from implementing PBL.

Over 600 defense acquisition professionals had an opportunity to participate in the online posted survey. The invited respondent pool consisted of selected graduates of Defense Acquisition University (DAU) acquisition courses (e.g., LOG 235/236 and LOG 350) and other identified personnel that were known to have knowledge and experience in implementing PBL within DoD. Of the identified personnel that were invited to participate in the survey, approximately 50 percent participated in the survey. These writings will explore and discuss information gathered from those 300 plus PBL implementers on whether the effects of PBL barriers and enablers have changed. But before we discuss more on PBL perceptions, we should first understand where we have been to know where we need to go. A synthesis of recent writings is provided to underscore the discussion of perceived changes in PBL implementation enablers and barriers.

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PBL Yesterday and Today

Much has been written (Canaday, 2010; DeVries, 2005; Fowler, 2009; Fowler, 2010; Geary, Koster, Randall, & Haynie, 2010; Kobren, 2009; Miller, 2008; Omings, 2010), spoken, and taught regarding PBL—not only about its advantages, but also about what prevents it from being fully embraced and effectively implemented by all the Services.

Since PBL is becoming a growing practice within industry and DoD, the literature discussed herein will leverage both bodies of knowledge within industry and government. Before the discussion begins, we should level the playing field with a common understanding and concise definition of PBL. As Kobren (2009) asserts, PBL is about performance. It is about readiness. It is also about enabling mission accomplishment and ensuring the warfighter has weapon systems that are available, reliable, and supportable when and where required. PBL is part of a long tradition of contracting for performance. Since its inception, PBL has continued to evolve. The shift toward Integrated Logistics Support attempted to wrap together the distinct logistics elements into a coordinated approach, but there was still the disjointed acquisition versus sustainment support issues and the lack of a linkage between supportability measures and warfighter needs (DeVries, 2005). Fowler (2009), then Assistant Deputy Under Secretary of Defense for Materiel Readiness, believes the time is coming to rebrand the sustainment approach. The rebranding effort should include an emphasis on re-integrating complete life-cycle sustainment into programs.

Clearly, product support, while primarily a logistics and sustainment function, is not actually synonymous with the fundamental aspect of logistics. To that point, product support encompasses materiel management, distribution, technical data management, maintenance, training, cataloging, configuration management, engineering support, repair parts management, failure reporting and analysis, and reliability growth (DoD, 2009). To further this point, Canady (2010) talks about how PBL remains the preferred method for weapon systems sustainment. However, defense officials are scrutinizing PBL strategies such as those on the C-17, pressing for lower costs, better proof of savings, and more government control of long-term sustainment options.

Geary et al. (2010) inform us that effective product support requires contributions from both the public and private sectors. A significant challenge over the course of the next decade, particularly in today's acquisition environment of declining financial resources combined with project deficits and undiminished operational demands, is creating a more effective, unified, and fiscally prudent industrial integration strategy for product support. They also highlight some of the real DoD innovators and enablers in deploying PBL effectively and why they were successful. Some of the highlighted key enablers to PBL's success were: integrated partnerships, incentive strategies, a culture of innovative teams, shared visions on objectives/metrics/incentives, and shared common grounds on win-win scenarios between industry and government.

In government, PBL has garnered mixed reviews and outcomes. A few organizations have implemented support strategies under the guise of a performance outcome-based strategy only to discover the product support was a hybrid version of a transactional arrangement. Department of Defense Directive 5000.01 (2007) requires that program managers develop and implement performance outcome-based logistics strategies that optimize total system availability while minimizing cost and the logistics footprint. But, more than we would like to think, organizations proceed at their own peril by not conducting an initial business case analysis to determine their potential Return On Investment associated with their product support decision. Fortunately, there are true successful ventures that evidence those attributes and objectives sought with PBL implementation (Beggs, Seymour, & Ertel, 2005).

Miller (2008) identifies an ingredient required for a successful PBL undertaking. Stated plainly: Get on with the work of sourcing the best possible product support results for the warfighter given statutes and regulations governing your options. Find the most cost-effective means of supporting warfighters. He further states, the research is clear that, properly done, PBL can be an important part of the solution. He also highlights several barriers and enablers that affect PBL implementation—similar to those explored in this article. He identifies funding, regulations, BCAs, and several other misperceptions driven by a misunderstanding or lack of experience working with PBL.

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Former Deputy Under Secretary of Defense for Materiel Readiness Randy Fowler wrote in his 2010 work, *Future of Product Support*, that among critics there remains a strong consensus that an outcome-based, performance-oriented product support strategy is a worthy objective. As much as any other organizational construct to date, Fowler touches on the situation of defense leadership. On the one hand, transforming product support will require not only strong leadership in DoD, but also an open-minded, reform-driven DoD-congressional partnership and a collaborative DoD-industry relationship to realize PBL's objectives. The national security and economic environments dictate tough-minded acquisition reform and logistics transformation. On the other hand, the challenges of affordability constraints; the need to upgrade systems, processes, and infrastructure; and a continuing, persistent operations tempo prescribe a clear need for DoD implementation of an integrated plan to address product support across the defense enterprise—like PBL.

Fowler (2010) also suggests that PBL will only succeed when driven from the topmost levels in the program or organization. One can surmise only top-level managers have the breadth of perspective and authority needed to see the entire process from start to finish. An effective pro-

ponent of PBL must be part visionary, part communicator, and part leg breaker. Program managers are charged with ensuring the development and implementation of performance outcome-based strategies that strive for a more cost-effective weapon systems support approach and a balanced use of public-private partnerships. Program managers and logisticians must be open to contrasting product support strategies to experience those benefits PBL can afford a weapon system.

Omings (2010) offers, in certain circles, that PBL has been viewed as a business fad and is derided in much the same fashion as Total Quality Management and Lean Six Sigma when those concepts were first espoused—misconceptions on their true value. He highlights that it is true that these methods are not a panacea, but time has shown that when applied under the right circumstances, they can provide powerful results.

One final point about Fowler's discussion on the future of product support should be noted: Fowler, like Kobren and Geary et al., understands the role of a product support strategy such as PBL where it is crucial to our national interest to ensure that product support achieves a level of performance equal to its importance. Customer or warfighter requirements, not internal values, should guide the product support manager's performance or decisions. They must replace old ways of thinking with new ideals and expectations associated with letting the old paradigms go. These include replacing perfectionist ways of thinking with experimental thinking, and getting-it-just-right credos with making-it-better credos.

A recurring theme among authors is the importance of positive preconditions for PBL success: senior management and sponsorship, realistic requirements and expectations, empowered and collaborative product support integrators, strategic context for efficiency growth, shared vision, sound supply chain management practices, and appropriate people participating full-time with a sufficient budget. Some also identify negative preconditions related to PBL: wrong sponsor (leader for the job), cost-cutting focus, narrow technical focus, and do-it-to-me attitudes. Some authors assert that, to turn around negative conditions, we must educate the workforce on PBL and do something small first.

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PBL Perceptions Discovered

What do we truly understand about the current workforce's perceptions of PBL? What are some of the known or perceived PBL implementation and management conundrums facing program management practitioners?

The objective of the study was to gather information from senior DoD leadership on factors that could be enhanced to help reduce identified barriers or factors that would enable more effective PBL implementation. The study examined the perceived effects of 15 factors relating to PBL implementation—whether they were a barrier or enabler and the relative importance of these factors for carrying out the product support strategy. The genesis of factors used in this and the previous study was based on literature searches, numerous PBL briefings from the Services, various conference minutes, and informed identification of what is perceived to be an appropriate set of factors for study—the most prevalent barriers and enablers that were impacting PBL implementation efforts.

Figure 1 shows the factors and definitions that were rated on the survey by each of the 300 plus respondents. Respondents were provided the option to rate a neutrally or unbiased (no predisposition to being an enabler or barrier) worded factor as either a barrier or an enabler.

The method used to determine a factor's specific rating score and whether a factor was a barrier (negative rating score) or an enabler (positive rating score) was to multiply the ranking (either positive or negative 1, 2, 3, or 4 based on the respondent's selection on the survey) by the total number (votes) of respondents that selected that ranking.

Information was obtained suggestive of current thinking regarding these 15 factors as to their effects on PBL implementation—the main objective of the survey. Ten factors were determined by respondents to be enablers (positive rating scores) to implementation while 5 were determined to be barriers (negative rating scores). In particular, Warfighters' Perspective had the highest rated score as an enabler with a score of 323. Five factors (Performance Metrics, Total Life Cycle Systems Management [TLCSM], Strategic Alliances/Partnerships, Supply Chain Management [SCM], and Performance Based [PB] Contracting) were next in the positive rankings (enablers) with similar scores ranging from 217 (Metrics and TLCSM) to 193 for PB Contracting. Four other

FIGURE 1. FACTORS, DEFINITIONS, AND SURVEY RESPONDENTS' PERCEPTIONS (BARRIERS VS. ENABLERS)

1.	**BARRIER: Funding.** Working capital fund, colors of $, expiring $
2.	**BARRIER: Statutory-Regulatory Requirements.** Title 10, Core, DoDI 5000.02, Service policies
3.	**BARRIER: Cultural Paradigms.** Organic vs. Contractor Logistics Support (CLS), parts management vs. performance management
4.	**BARRIER: Existing Infrastructure or Organization.** Management, oversight/review, structures/processes
5.	**BARRIER: Technical Data (TD) Rights.** Ownership of technical data package, access to technical data
6.	**ENABLER: PBL Awareness/Training.** Formal DAU training, in-house/on-the-job training, personnel skills
7.	**ENABLER: Incentives/Awards.** Award/incentive fees, administration of innovative contracts/agreements
8.	**ENABLER: Supply Chain Management (SCM).** End-to-end customer support, enterprise integration
9.	**ENABLER: Strategic Alliances/Partnerships.** Depot partnering, joint ventures
10.	**ENABLER: Performance Based (PB) Contracting.** Incentive/award fees, innovative contracts
11.	**ENABLER: Performance Metrics.** Information systems, variations, trends
12.	**ENABLER: Total Life Cycle Support Management (TLCSM).** PM's TLC product support responsibility
13.	**ENABLER: Adoption of Commercial Off the Shelf (COTS).** Commercial practices/procedures, products, subsystems
14.	**ENABLER: Total Ownership Cost (TOC).** Cost accounting, reporting, tracking
15.	**ENABLER: Warfighters' Perspectives.** Readiness, affordability, combat requirements

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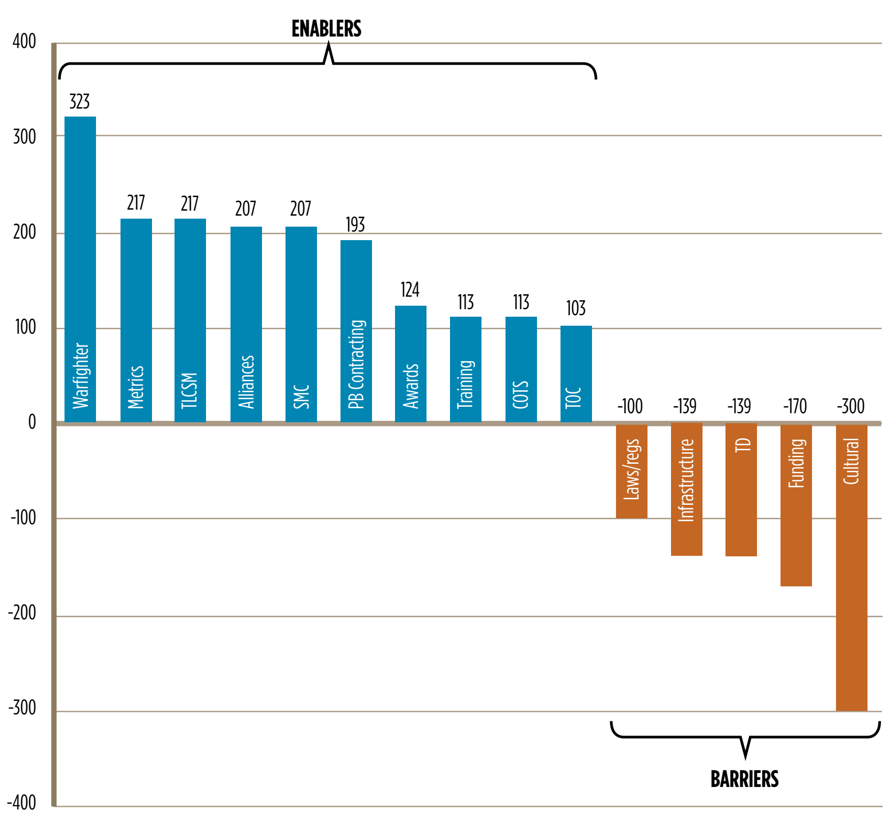
enablers were close in their positive rating scores (124 to 103): Incentives/Awards, PBL Awareness/Training, Adoption of COTS, and Total Ownership Cost (TOC).

Cultural Paradigms was the highest rated barrier (negative ranking score of -300). This was significantly above the second place barrier of Funding with -170. The next three negative rated factors (barriers) were grouped together from -139 to -100. Collectively, raw scores for the four grouped barrier factors—Funding, Technical Data [TD] Rights, Existing Infrastructure or Organization, and Statutory-Regulatory Requirements—were so similar that little can be interpreted about their relative different effects on PBL without further or a more granular analysis.

The graphic (Figure 2) displays the rating scores and relative differences or similarity of the barriers and enablers.

FIGURE 2. ENABLERS/BARRIERS RELATIVE COMPARISONS



The survey data analyses determined that from the initial 15 factors, 10 were enablers and 5 were barriers to PBL implementation. This distribution of factors was considered significant since in the previous study in 2005 by DeVries 7 factors were considered to be enablers while 7 others were considered to be barriers. An additional factor of Warfighters' Perspective was included in this study that was not rated in 2005. Specifically, PBL Training and Incentives/Awards had previously (2005) been identified as a barrier. The 2011 study determined they were enablers. Even though these two factors (Training and Incentives) were rated in the lower 30 percent of the enablers in 2011, it is suggestive that respondents did not perceive these two ranked factors to be barriers as they were categorized in the 2005 survey. This highlighted the reason for allowing the respondents to determine by their ratings whether a factor was a barrier or an enabler.

The results highlighted that of the 15 factors rated on the questionnaire, only 5 were identified as barriers. Ten were identified as enablers—3 more than in the 2005 study. More factors are now (2011) considered to be enablers to PBL implementation than previously identified in 2005. Perceptions in 2011 may be that PBL is not as difficult to implement and more factors are considered to be aids or enablers to its successful implementation.

As highlighted in figure 1, respondents considered the Warfighter's Perspectives to be the most important positive factor (enabler) facilitating PBL implementation. This matches the commonly accepted theory that the warfighter is normally assumed to be one of the most critical elements or factors to a program's overall success. The success of PBL implementation is no different—the Warfighters' Perspectives factor is highlighted in this research data as being critical to a program's success.

Respondents considered Cultural Paradigms a significant challenge (barrier) to PBL implementation. Cultural paradigms are normally assumed to be among the most serious impediments or hindering factors to a program's ability to accept change or accomplish a challenging issue within the program. The success of PBL implementation is no different—Cultural Paradigms must be overcome if a program or PBL is to succeed in the complex DoD environment. In relationship to PBL implementation, Cultural Paradigms being rated the highest is not surprising given that culture is the most challenging factor to overcome in any significant change, especially when these new concepts or changes

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are viewed as threats. Many government personnel consider PBL as a threat because of a common misperception that it is a synonym for contractor logistics support (CLS) or "contracting out support." The aforementioned information is vital for any program to consider when attempting implementation of different business practices like performance based incentives.

As seen through the eyes or viewpoint of the respondents, clearly the Warfighters' Perspectives factor had a positive effect on PBL implementation. Respondents report that if they were able to determine and maintain a warfighter's point of view, they had a greater ability to effectively implement PBL. Clearly, these respondents are sending an important message to potential implementers of PBL—if you want to effectively implement PBL you need to understand and maintain the Warfighters' Perspectives. This point of view is a normal, commonly accepted theory, but one that is not always supported with empirical data.

The study also revealed that the same can be said for Cultural Paradigms; it had a perceived significant effect on PBL—but as a barrier. Like the Warfighters' Perspectives factor, the Cultural Paradigms factor has a significant effect on PBL implementation. The Cultural Paradigms factor is perceived as a significant barrier and must be reduced or eliminated if PBL is going to be more successful. Specific paradigms were not detailed within the survey; however, some commonly known paradigms consider PBL as another way of buying CLS, as too expensive to incorporate and manage, and not as flexible in terms of providing needed product support. PBL can be a valued-added game changer such as public-private partnerships, where potentially the best of entities (industry and government) collaborate to meet warfighter requirements. To move beyond cultural impediments requires hard work to change old ways of thinking. As discussed earlier in this article, customer or warfighter requirements, not internal values, should guide the product support manager's performance or decisions. They must replace old ways of thinking with new theories and expectations associated with letting the old paradigms go. If DoD is to effectively implement PBL, then the acquisition and sustainment workforce education and training needs to continue the reduction of cultural maladies that impede the ability to implement a viable PBL solution.

Results and Discussion

The **Warfighters' Perspectives** are perceived by senior program management practitioners to be the most vital enabling factor to ensuring PBL is effectively and efficiently implemented—a result suggestive of the 2011 study. In all future endeavors, any plan to deploy PBL as a viable product support strategy should include the warfighters and their critical perspectives if PBL is to be successfully implemented.

PBL Awareness/Training and Incentives/Awards should be considered effective enablers to PBL implementation and need to be fully embraced by the Services and the Office of the Secretary of Defense. The 2011 survey indicated that current respondents consider these factors (Figure 1) to be vital to the success of PBL. They were rated as barriers in 2005; conversely, they have been shown in the 2011 study to be effective enablers, and need to be leveraged as such. Continued attention should also be placed on ensuring that incentive-based contracts are properly managed by DoD and the Services' contracting agencies. PBL training should also be continued through development of additional courses and Continuous Learning Modules by DAU and other DoD training agencies. Senior leaders should also attend similar courses and related conferences/symposiums—especially in light of the Cultural Paradigms factor discussed next, which was considered to be the most significant PBL barrier.

Cultural Paradigms should be addressed very carefully by all PBL implementers. This factor was identified by respondents as the major barrier to successful PBL deployment. DoD leadership must address this fact and ensure that PBL training is provided so all involved understand more clearly what is at stake (more affordable product support, increased readiness, or enhanced efficiencies). Additionally, they should understand what the cultural impediments are to PBL's acceptance as an effective means to ensure greater product support and mission effectiveness. Continued promulgation of success stories that highlight the true capabilities of PBL should be shared throughout the Services—along with how and who have been most successful in implementing PBL. Specific attention should be placed on removing cultural impediments. In particular, future training should include awareness of related cultural impediments and techniques for reducing these impediments. The target audience for this type of training would be senior program managers, systems engineers, contract specialists, and logisticians.

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Additional emphasis should be placed on enhancing all the identified 10 enablers. Conversely, efforts should be placed on reducing the effects of the 5 identified barriers. Besides the Warfighters' Perspectives, the policy responses to five other factors (Strategic Alliances/Partnerships, Supply Chain Management, Performance Metrics, TLCSM, and PB Contracting) are likely to yield large benefits. Besides focusing on Cultural Paradigms, the four grouped items identified as barriers (Funding, TD Rights, Existing Infrastructure or Organization, and Statutory-Regulatory Requirements) should be treated as opportunities for mitigation efforts to reduce their undesired effects on successful PBL implementation.

Conclusions

The 2011 survey identified 10 critical PBL enablers that should be enhanced; it also identified 5 barriers that should be minimized in PBL implementation. The results of this study have applications to successful implementation of PBL throughout DoD and the commercial-industrial workplace.

To restate, the research provided the following results:

- The single most significant enabling factor for PBL was maintaining the Warfighters' Perspectives in the 2011 study.
- The top barrier to PBL was Cultural Paradigms in the 2011 survey.
- Warfighters' Perspectives (2011) replaced Performance Metrics from the 2005 study as the most significant enabler.
- Cultural Paradigms (2011) replaced Funding from the 2005 study as the most significant barrier.
- Two barriers from the 2005 study were determined to be enablers in the 2011 study (PBL Awareness/Training and Incentives/Awards).

Future research similar to this effort should ensure or include the participation of other disciplines such as systems engineers, testers, contract specialists, and business cost estimators and financial managers, to view perceptions about PBL through a "larger aperture" or perspective. Additionally, analyses should be conducted with the existing data to determine if survey respondents expressed different perceptions between functional career areas, e.g., do all supply specialists have a different perception of the effect training has on PBL implementation vs. program managers? It should also be highlighted that the survey did not specifically question respondents on whether their perceptions of PBL implementation were reflecting their opinions on each factor's effect on PBL implementation under current practices and policies, or if their opinions reflected each factor's effect regardless of current practices. This is an important consideration when one is considering the causes of implementing PBL. Is implementation affected more by specific program or project-unique PBL policies or practices, or by the general DoD/Office of the Secretary of Defense policies and procedures effects on PBL? Clearly, more research is required on the current dynamic topic of PBL .

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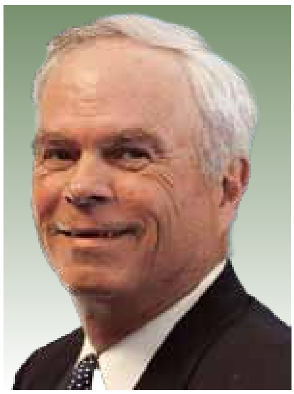
Author Biographies



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Keywords: *Defense Industry, Defense Budget Cuts, Federal Deficit*

Running With Scissors: *Defense Budget Cuts and Potential Industry Responses*

Bryan A. Riley

Nearly everyone can relate to the experience of seeing a dangerous sequence of events unfold. A well-intentioned action is followed by a subtle misstep. Add in a measure of unpredictability, and quickly the sequence starts to diverge. In these situations, a reasonable person mentally fast-forwards to anticipate the possible outcome. It is that quick mind's eye picture that spurs action. It prompts intervention. Building on the analysis and recommendations presented in this article, the author makes the case that it is possible for both the U.S. Department of Defense and the U.S. defense industry to mitigate the dangerous downside risk of anticipated defense budget cuts.

image designed by Diane Fleischer »

Nearly everyone can relate to the experience of seeing a dangerous sequence of events begin to unfold. A well-intentioned action is followed by a subtle misstep. Add in a measure of unpredictability, and quickly the sequence starts to diverge. In these situations, a reasonable person mentally fast-forwards to anticipate the possible outcome. It is that quick mind's eye picture that spurs action. It prompts intervention.

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As unexpected as it may appear, recent debates on the U.S. defense budget hold many of these same concerns. Reducing federal deficit spending is a well-intentioned action, but the method of achieving that objective is a source of great risk. A subtle misstep and the sequence of events could quickly accelerate—with the cascading effects growing beyond even the most diligent efforts to avoid a wildly negative outcome.

To help develop this thought, the following discussion addresses six key questions.

- Where are we in the sequence of events?
- What is likely to happen next?
- How will industry respond?
- What are the impacts on acquisition?
- Are specific scenarios already in motion?
- What can be done?

Within this context, the thesis of this article is simply stated. Even though current U.S. defense budgets remain strong, actions by the U.S. defense industry in response to anticipated spending cuts may result in increased risk, decreased readiness, and ultimately degradation of the nation's defense industry at large.

It is this potentially dangerous scenario that characterizes the current discussion of expected U.S. defense budget cuts. Intervention is possible. First, stop running—then slowly put down the scissors.

3

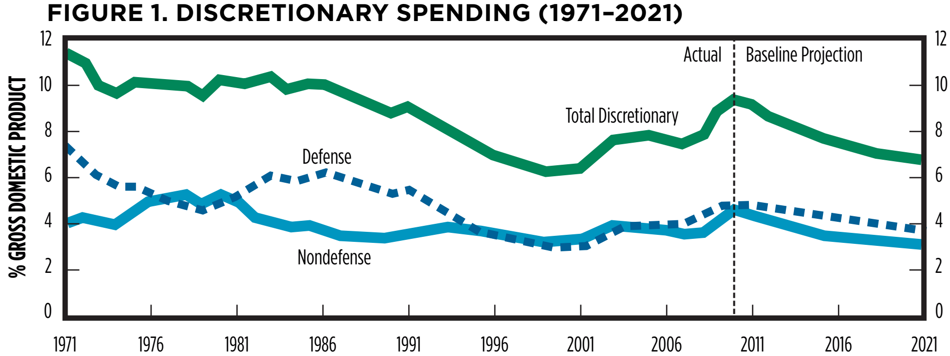
Where Are We in the Sequence of Events?

Current U.S. federal deficit spending is well documented—as is the rapidly increasing federal debt. In developing a baseline for the discussion of defense budget reductions, a short summary of past, current, and anticipated federal spending is useful and informative. To this end, the following section outlines the key issues of discretionary federal expenditures, defense spending, and military procurement budgets.

In 2010, defense expenditures accounted for slightly more than half of federal discretionary spending at $689 billion, including the cost of overseas contingency operations (OCO) in Iraq and Afghanistan (Congressional Budget Office [CBO], 2011b, p. 69). The January 2011 baseline CBO data (Figure 1) predicted a decline in both defense and nondefense discretionary expenditures starting in 2010, and continuing through 2021 as a percentage of Gross Domestic Product (GDP). Based on this forecast, discretionary spending was anticipated to fall from 9.3 percent of total U.S. GDP in 2010 to 6.7 percent by 2021 (CBO, 2011b, p. 71).

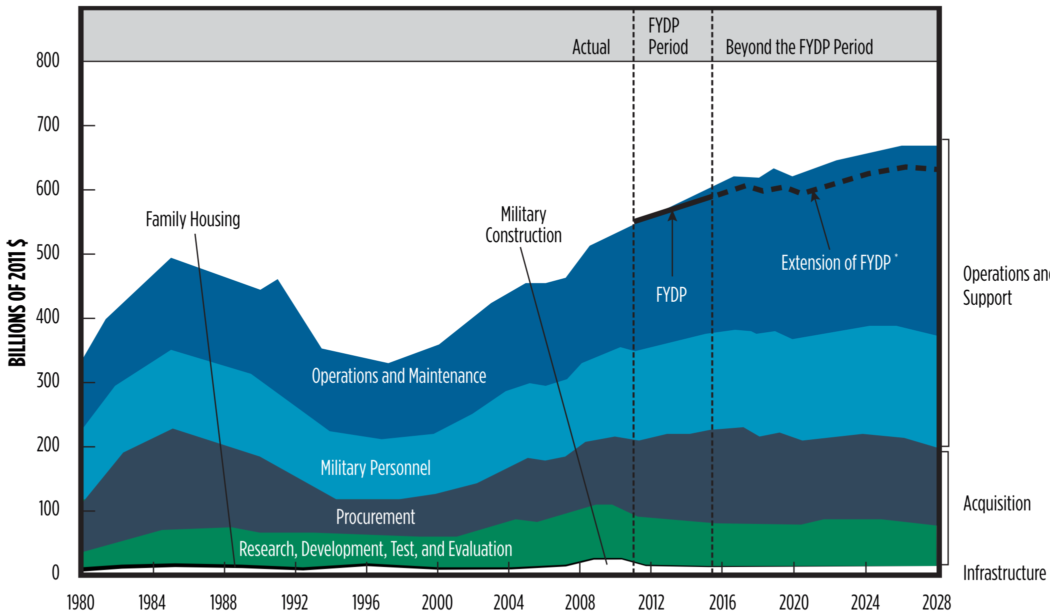
Using January 2011 data for defense spending (Figure 1), the CBO forecasted base budget growth in 2011 dollars continuing through 2028 with an anticipated expenditures forecast using the current Future Years Defense Program (FYDP) data shown in Figure 2. The CBO analysis included forecasts for the five primary budget categories of defense spending: (a) military construction, (b) research, development, test, and evaluation, (c) procurement, (d) military personnel, and (e) operations and maintenance.

FIGURE 1. DISCRETIONARY SPENDING (1971–2021)



Source: Congressional Budget Office (as of January 2011).

FIGURE 2. COSTS OF DoD'S PLANS FOR ITS BASE BUDGET, BY APPROPRIATION CATEGORY

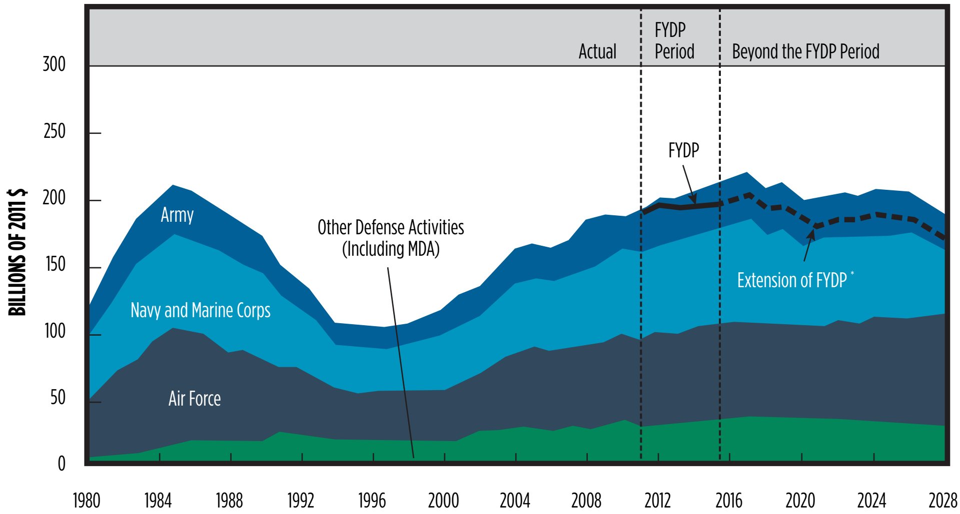


Notes. Adapted from "Reducing the Deficit: Spending and Revenue Options," published by the Congressional Budget Office, March 2011. Each category shows the CBO projection of the base budget, which incorporates costs that are consistent with the Department of Defense (DoD)'s past experience. The amounts shown for the FYDP and the extension of the FYDP are the totals for all categories. Base-budget data include supplemental funding prior to 2002. FYDP period = 2011 to 2015, the years for which DoD's plans are fully specified.

*The extension of the FYDP extends DoD's plans and uses DoD's estimates of costs if they are available and cost factors based on the broader U.S. economy if estimates by DoD are not available.

In February 2011, the CBO reported U.S. defense acquisition spending from 1980 and forecasted anticipated defense acquisition spending through 2028. According to the CBO, 2011 acquisition costs would account for 34 percent of total defense spending (excluding OCO costs). Based on the current FYDP, the CBO forecasted defense acquisition will grow from its 2011 level of $189 billion to $218 billion in 2017 before starting a modest decline (CBO, 2011b, p. 19) as indicated in Figure 3.

FIGURE 3. COSTS OF DoD'S BASE BUDGET ACQUISITION PLANS, BY DoD COMPONENT



Notes. Adapted from "Long-term Implications of the 2011 Future Years Defense Program," published by the Congressional Budget Office, February 2011. Each category shows the CBO projection of the base budget, which incorporates costs that are consistent with the Department of Defense (DoD)'s past experience. Base-budget data include supplemental funding prior to 2002. The amounts shown for the FYDP and the extension of the FYDP are the totals for all components. FYDP period = 2011 to 2015, the years for which the DoD's plans are fully specified. MDA = Missile Defense Agency.

*The extension of the FYDP extends DoD's plans and uses DoD's estimates of costs if they are available and cost factors based on the broader U.S. economy if estimates by DoD are not available.

Before completing this background discussion, it is important to note two additional considerations. First, from 2001 through 2011, almost $1.2 trillion has been appropriated for the cost of overseas contingency operations. Significant uncertainty exists in forecasting future operational expenditures; for purposes of the following discussion, OCO funding is not included unless specifically noted. Second, as experienced in 2011, the fiscal year federal budget may not receive timely approval by the U.S. Congress. In this case, through a series of continuing resolutions, defense spending is limited to prior-year funding levels. In recent statements, former Secretary of Defense Robert Gates warned that the impact of continuing resolutions "may soon turn into a crisis" (Gates, 2011). For this discussion, the anticipated effects are not included unless specifically noted.

By starting with this summary of federal discretionary spending, it is now possible to better characterize defense acquisition spending in the context of future budget reductions. This serves to answer the opening question—where are we in the sequence of events?

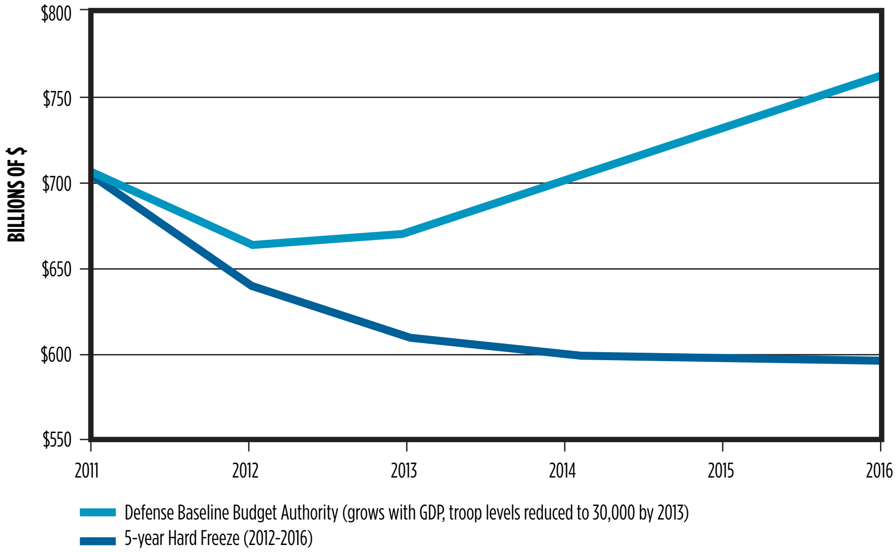
3

What is Likely to Happen Next?

Building on the federal expenditure summary presented in the previous section, the following discussion summarizes a set of budget reviews and policy opinions affecting the U.S. federal budget. In particular, this outline compares recommendations from recent congressional committees, federal agencies, and think-tank organizations.

In November of 2010, former Senate Budget Committee Chairman Pete Domenici and former White House budget director Alice Rivlin led a bipartisan study to deliver a set of broad recommendations that addressed federal spending as well as government revenues. The goal of their recommendation was to balance the federal budget by 2014 and stabilize the national debt below 60 percent of GDP by 2020. As part of the strategy, defense spending would be frozen at current levels for 5 years and then capped at the GDP growth rate. In further detail, savings would come from reductions in military force structure, acquisition, intelligence operations, personnel costs, and current efficiency efforts already underway. Shown in Figure 4, the net effect of these decisions would reduce defense spending to approximately 3 percent of U.S. GDP by 2020 (Domenici & Rivlin, 2010).

FIGURE 4. DEFENSE DISCRETIONARY BUDGET AUTHORITY: BASELINE v. BIPARTISAN PLAN



In December of 2010, a team led by Senator Alan Simpson and former White House Chief of Staff Erskine Bowles presented their recommendations. The team developed a set of actions to generate approximately $4 trillion in deficit reductions through 2020. Their strategy focused on balancing the federal budget by 2015 and reducing the federal debt to 60 percent of GDP by 2023, and 40 percent by 2035. Beginning in 2012, all discretionary spending would be capped at 2011 levels. Defense spend-

FIGURE 5. DISCRETIONARY SPENDING LEVELS (2012–2020)

Commission Proposal	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2012-2015**	**2012-2020**
Total	1,098*	1,043	1,050	1,061	1,072	1,084	1,095	1,106	1,117	4,251	9,724
Security	688*	654	658	665	672	679	686	693	700	2,664	6,095
Non-security	410*	389	393	396	400	405	409	413	417	1,587	3,630
President's Request	1,180	1,196	1,229	1,266	1,293	1,324	1,359	1,397	1,442	4,872	11,686
CBO baseline	1,143	1,164	1,191	1,222	1,257	1,290	1,323	1,357	1,390	4,720	11,337
Dollar amount below President	84*	153	179	205	221	240	264	291	325	622	1,963
Percentage below President's request	7.1%	12.8%	14.6%	16.2%	17.1%	18.1%	19.4%	20.8%	22.5%	12.8%	16.8%
Outlay savings	60	113	152	183	205	226	247	272	302	508	1,760

* *Note:* Levels will be set by the current Congress rather than the statutory caps; the 2012 levels will be at or below the final 2011 levels. $1,098 represents a 12-month Continuing Resolution as a default, but the actual number could differ significantly.

ing would be combined with other categories of related discretionary spending to be managed and reduced as a broader category of security spending (National Commission, 2010) shown in Figure 5.

In March 2011, the CBO released a set of 105 options to help guide the discussion of deficit reduction through potential changes to federal spending and revenue policies. Options addressed both mandatory as well as discretionary spending with significant detail devoted to federal revenue and tax policy. On defense expenditures, the CBO developed three potential scenarios beginning in 2012: (a) limit growth in defense spending to 1.4 percent per year to realize a reduction of $286 billion by 2021, (b) freeze defense spending at 2011 levels to generate $611 billion in savings by 2021, and (c) reduce defense spending by 1 percent annually from 2011 levels to achieve $862 billion in reductions by 2021. Looking at options that focus specifically on acquisition programs, the CBO outlined potential reductions of $38 billion by 2016 through cancellations, deferrals, and force reductions (CBO, 2011a).

Next, turning to the think-tank groups, a wide range of assessments and recommendations exists. The Center for Strategic and International Studies echoed the concerns raised in the prior sections and argued that the coming decline in defense spending will require a much more involved strategic threat assessment to establish military funding priorities (Berteau, 2009). The Center for Strategic Budgetary Assessments emphasized the need for the U.S. Department of Defense to respond to the upcoming levels of budget austerity by "accepting some risks and divesting of lower priority programs and capabilities" (Harrison, 2011). As expected, additional recommendations spanned the range of conservative, moderate, and liberal advocacy consistent with groups such as the Cato Institute, Heritage Foundation, Brookings Institute, Teal Group, and the Center for American Progress.

From this brief summary, contemporary thinking points to a consensus that current levels of federal spending are not sustainable. In particular, there is a consistent emphasis on the need to curb discretionary spending—defense expenditures in particular. This forms the response to the second key question—what is likely to happen next?

How Will Industry Respond?

In an uncertain environment, industry is likely to respond by reducing investments, diversifying its market base, and restructuring its business operations.

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First, when at risk of declining future demand, business can respond quickly by reducing investment in two categories: capital expenditures and research and development. These actions are often viewed by investors as positive near-term strategies since cost avoidance is typically realized on the company's balance sheet as improved operating margins and/or dividends are returned to shareholders. Unfortunately, severe reductions in either capital investment or company-funded research and development are not sustainable in a competitive business environment. The long-term negative impact is felt by both the company and its customers.

Reasonable levels of capital investment are necessary to sustain the infrastructure and systems required for manufacturing and operating activities. In most cases, gaining efficiencies and realizing cost savings require increasing levels of capital investment. The business case for these investments requires significant long-term returns to justify the expenditures. In an uncertain environment, the business case rationale often does not support increasing investment. Moreover, capital expenditures become more difficult to justify, and less capital is invested in the business. In the case of ongoing production, this scenario results in increasing cost pressure as facilities and equipment continue to age, and support systems are not updated with improved processes or technology.

Similar to capital investment, company-funded research and development is likely to decline. While the impact of capital investment is more visible, the impact of research and development is less tangible. With confidence in anticipated demand and future requirements, industry invests in the development of technologies to compete for upcoming contracts. Absent that future opportunity, businesses will not emphasize research and development over other, more pressing financial needs. This may result in a near-term benefit to the industry as resources are applied in other areas, but the long-term impact to technology development can be severe. With declining investment, future capabilities will require longer development timelines. Longer timelines introduce both cost and performance risk. Viewed together, these factors combine to form a growing disincentive to launch new programs that require significant advances in research and development. Much like reductions in capital investment, the cycle quickly begins to develop into a strongly negative feedback loop.

Second, industry will likely respond by aggressively seeking to diversify both its customer and product base. While the leading U.S. defense companies are involved with contracts that span across Service branches, much of the defense industry is focused on providing specific capabilities, systems, and technologies that serve a very narrow customer group. For those companies, the downside risk is significant as budget cuts take place. To counter this, companies will seek to diversify across Service branches as well as outside of the Defense Department, and into other areas such as the State Department and Homeland Security. However, the most likely diversification opportunity lies in competing for potential Foreign Military Sales (FMS). As U.S. military forces draw down from current combat operations, the stated objective is to develop the capacity of foreign governments to provide for their own security and defense. This marks a clear opportunity for the U.S. defense industry to diversify its customer base through FMS.

In an environment of declining defense spending, U.S. industry will also seek to diversify its products and services offerings. As demand has grown quickly over the past decade, some defense companies have developed into providers of specialized products or services. This pattern is neither unnatural nor unhealthy in the short-term, but it does introduce sizeable downside risk as demand begins to decline. One example of this pattern is the result of rapid growth in demand for unmanned systems. While many providers have maintained a broad set of capabilities for aircraft, ground, and underwater systems, the demand for specific capabilities has narrowed the market base. In addition, during a period of increasing demand, some companies across the defense industry have struggled to leverage opportunities to capture services and support contracts while quickly expanding to meet production contracts. Declining production demand will free-up capacity that could be applied toward future services and support opportunities.

Third, the U.S. defense industry will look to restructure itself as defense budgets decline. During the industry downturn in the early 1990s after the collapse of the Soviet Union, the U.S. defense industry saw a number of large-scale consolidations. Northrop merged with Grumman

Aerospace, Lockheed with Martin Marietta, and Boeing with McDonnell Douglas. Other companies divested some of their core operations such as General Dynamics' divestiture of its military aircraft business to Lockheed Martin. Others such as Raytheon purchased lower tier companies including Hughes and E-Systems to build a much broader business portfolio centered around systems technology. This particular industry response will be fueled by the recent economic recovery leaving companies with sizeable cash reserves.

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As described in this section, industry is likely to react to anticipated reductions in defense spending by reducing investment, diversifying its business base, and restructuring its operations. This characterizes the response to the third question—how will industry respond?

What Are the Impacts on Acquisition?

The impact of anticipated reductions in U.S. defense spending will be seen in acquisition scope, structure, and competition.

First, the scope of acquisition will change. Driven by high operational tempo during the past 10 years, U.S. military acquisition has focused on satisfying the needs of the ongoing conflicts in Iraq and Afghanistan. New weapon systems have been developed and deployed such as the unmanned Predator drone and the Mine-Resistant Ambush Protected vehicle. Declining budgets will shift the focus of defense acquisition away from new capabilities to more modest upgrades and derivatives of weapon systems within the current U.S. military inventory. Support and services contracts will transition to organic resources as U.S. forces draw down from their current deployments. However, the most severe acquisition impacts are likely to come from program deferrals through reduced production rates, reductions through decreased unit quantities, and—in the extreme case—program terminations.

Second, the structure of acquisition will change. Expanding defense budgets have accommodated a wide range of acquisition structures, from single-year fixed-price contracts for combat support and supplies to large scale cost-reimbursable development programs. As defense budgets decline, pressures will increase to reduce acquisition costs by restructuring existing contracts. Multiyear contracts will transition to single-year, cost-plus contracts will convert to fixed-price, and block quantity purchases will reissue as individual unit quantity contracts with priced options. While this approach is likely to meet the near-term goal of reducing current year acquisition costs, the net effect will likely drive increasing unit costs. This scenario risks sparking the dangerous iteration loop experienced in recent years where budget pressures force reductions in quantities and/or production rates, which in turn drive higher unit costs. History has been particularly unkind to programs caught in this acquisition scenario.

Third, the competition for acquisition will change. During the recent environment of increasing demand, the limiting constraint has often been industry capacity. For U.S. defense companies, this has created a very attractive advantage where demand in many cases exceeded supply. However, as demand declines, the result will likely be improved pricing for the U.S. military as companies begin to trade operating margins for continued revenues. This pattern will be particularly strong in product classes requiring high fixed costs and significant capital investments such as aircraft and shipbuilding. In some cases, the growing pressures will result in companies divesting unprofitable operations or even choosing to close down certain business lines. Compounding this effect, global defense budgets are also expected to decline. As international demand decreases, foreign competition for U.S. military acquisition will intensify. EADS, BAE, and others will increase their already growing search for opportunities in the U.S. defense market.

So for acquisition, three areas of impact are most likely: scope, structure, and competition. These categories help address the fourth question—what are the impacts on acquisition?

Are Specific Scenarios Already in Motion?

Applying the concepts developed throughout the previous sections, it is now possible to develop a case study using the top largest U.S. defense companies: Lockheed Martin, Boeing Defense, Northrop Grumman, General Dynamics, and Raytheon. To establish a baseline comparison, the following discussion uses data compiled from U.S. Securities and Exchange Commission 10-K Reports for the 2001 to 2010 reporting periods, summarized in Figure 6.

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FIGURE 6. U.S. SECURITIES & EXCHANGE COMMISSION 10-K REPORTS (2001–2010 REPORTING PERIODS)

		2001	2002	2003
General Dynamics				
Annual Revenue	$B,USD	$23.990	$26.578	$31.824
Annual Operating Earnings	$B,USD	$0.833	$1.158	$2.019
Annual Operating Margin	% Annual Revenue	3.5%	4.4%	6.3%
Capital Expenditure	% Annual Revenue	~	2.5%	2.2%
Research & Development	% Annual Revenue	~	~	~
Boeing (Defense)				
Annual Revenue	$B,USD	$22.815	$24.957	$27.361
Annual Operating Earnings	$B,USD	$1.965	$2.009	$0.766
Annual Operating Margin	% Annual Revenue	8.6%	8.0%	2.8%
Capital Expenditure	% Annual Revenue	2.6%	2.2%	1.4%
Research & Development	% Annual Revenue	2.3%	2.0%	2.1%
Northrop Grumman				
Annual Revenue	$B,USD	$13.558	$17.206	$26.206
Annual Operating Earnings	$B,USD	$1.004	$1.391	$1.538
Annual Operating Margin	% Annual Revenue	7.4%	8.1%	5.9%
Capital Expenditure	% Annual Revenue	2.9%	3.1%	2.4%
Research & Development	% Annual Revenue	2.5%	1.6%	1.6%
General Dynamics				
Annual Revenue	$B,USD	$12.163	$13.829	$16.617
Annual Operating Earnings	$B,USD	$1.485	$1.582	$1.467
Annual Operating Margin	% Annual Revenue	12.2%	11.4%	8.8%
Capital Expenditure	% Annual Revenue	2.9%	1.9%	1.3%
Research & Development	% Annual Revenue	1.7%	1.8%	1.7%
Raytheon				
Annual Revenue	$B,USD	$16.867	$16.760	$18.109
Annual Operating Earnings	$B,USD	$0.759	$1.754	$1.316
Annual Operating Margin	% Annual Revenue	4.5%	10.5%	7.3%
Capital Expenditure	% Annual Revenue	2.7%	2.7%	2.4%
Research & Development	% Annual Revenue	2.7%	2.7%	2.7%

2004	2005	2006	2007	2008	2009	2010
General Dynamics continued						
$35.526	$37.213	$39.620	$41.862	$42.731	$45.189	$45.803
$2.089	$2.986	$3.953	$4.527	$5.131	$4.466	$4.097
5.9%	8.0%	10.0%	10.8%	12.0%	9.9%	8.9%
2.2%	2.3%	2.3%	2.2%	2.2%	1.9%	1.8%
~	1.7%	1.6%	1.6%	1.6%	1.6%	1.4%
Boeing (Defense) continued						
$30.465	$30.791	$32.439	$32.080	$32.047	$33.661	$31.943
$2.925	$3.890	$3.032	$3.440	$3.232	$3.299	$2.875
9.6%	12.6%	9.3%	10.7%	10.1%	9.8%	9.0%
0.7%	1.4%	1.0%	0.7%	0.8%	0.8%	0.7%
1.8%	1.9%	1.7%	1.7%	1.9%	2.3%	2.4%
Northrop Grumman continued						
$29.853	$30.721	$30.148	$32.018	$33.887	$33.755	$34.757
$2.006	$2.178	$2.454	$3.006	-$0.111	$2.483	$3.070
6.7%	7.1%	8.1%	9.4%	-0.3%	7.4%	8.8%
2.3%	2.7%	2.4%	2.1%	2.0%	1.9%	2.2%
1.7%	1.7%	1.9%	1.7%	1.7%	1.8%	1.7%
General Dynamics continued						
$19.178	$21.244	$24.063	$27.240	$29.300	$31.981	$32.466
$1.941	$2.197	$2.625	$3.113	$3.653	$3.675	$3.945
10.1%	10.3%	10.9%	11.4%	12.5%	11.5%	12.2%
1.4%	1.2%	1.4%	1.7%	1.7%	1.2%	1.1%
1.7%	1.6%	1.6%	1.6%	1.6%	1.6%	1.6%
Raytheon continued						
$20.245	$21.894	$20.291	$21.301	$23.174	$24.881	$25.183
$1.388	$1.687	$1.840	$2.328	$2.596	$3.042	$2.607
6.9%	7.7%	9.1%	10.9%	11.2%	12.2%	10.4%
1.8%	1.4%	1.4%	1.5%	1.3%	1.1%	1.3%
2.4%	2.0%	2.3%	2.4%	2.2%	2.3%	2.5%

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FIGURE 7. REVENUES OF TOP U.S. DEFENSE FIRMS OVER LAST DECADE

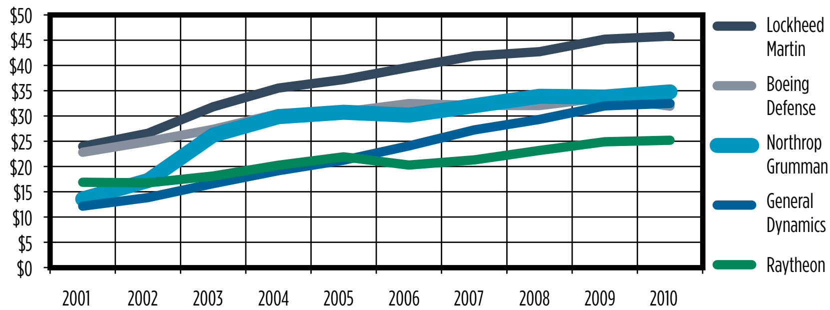
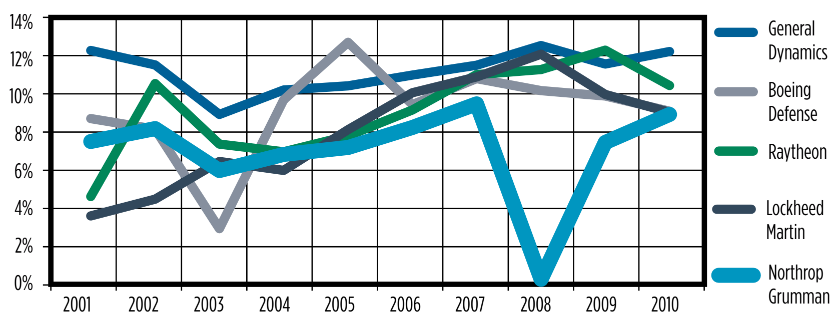


FIGURE 8. COMPARISON OF ANNUAL OPERATING MARGINS OF TOP U.S. DEFENSE FIRMS OVER LAST DECADE



Looking first at revenues in Figure 7, each of the top U.S. Defense firms experienced significant sales growth during the last decade. In particular, General Dynamics and Northrop Grumman saw annual revenues more than double.

In contrast to the steady increase in annual revenues, a comparison of annual operating margins shown in Figure 8 is more unstable. Two features to note: In 2003, Boeing-Defense recorded a one-time charge of $1.7 billion against its space launch and orbital systems division, which drove the company's performance down to 2.8 percent for the year. In 2008, Northrop Grumman announced a $2.5 billion write-off against its shipbuilding business that resulted in a net loss of –$111 million for the reporting year (The Boeing Company et al., 2001–2010).

FIGURE 9. ANNUAL RESEARCH AND DEVELOPMENT EXPENDITURES, PERCENTAGE OF ANNUAL REVENUES FOR TOP FIVE U.S. DEFENSE FIRMS (2001–2010)

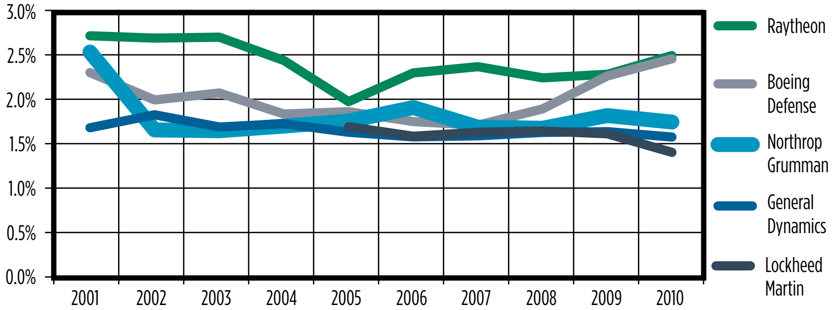
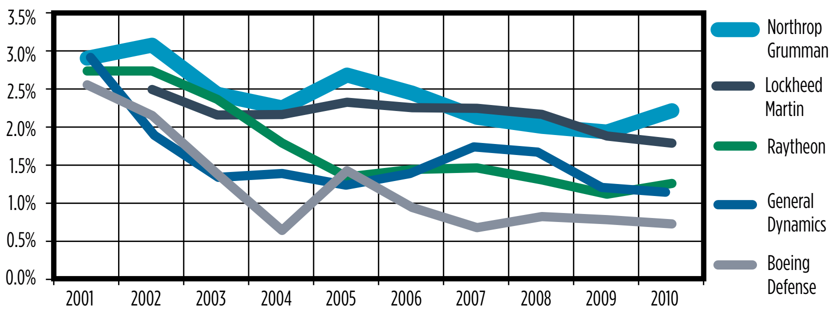


FIGURE 10. ANNUAL CAPITAL EXPENDITURES, PERCENTAGE OF ANNUAL REVENUES FOR TOP FIVE U.S. DEFENSE FIRMS (2001–2010)



Next, applying the framework developed for likely industry responses, it is helpful to compare research and development expenditures along with capital investments. For the top five U.S. defense firms, Figures 9 and 10 show the data from 2001 through 2010 as a percentage of annual revenues.

From the data, research and development expenses are fairly constant, with Boeing Defense indicating a noticeable increase in investment over the past three reporting years. However, capital expenditures for the top defense companies show a clear downward trend. This downward trend is led by Boeing Defense, the same company that indicated stronger recent investment in research and development.

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FIGURE 11. SEC DATA COMPILED FOR NORTHROP GRUMMAN BUSINESS SEGMENTS (2001–2010)

		2001	2002	2003
Northrop Grumman (Business Segments)				
Annual Revenue	$B,USD	$3.00	$3.27	$6.62
Annual Operating Earnings	$M,USD	$258	$331	$573
Annual Operating Margin	% Annual Revenue	8.60%	10.10%	8.70%
Electronics				
Annual Revenue	$B,USD	$4.72	$5.34	$6.04
Annual Operating Earnings	$M,USD	$359	$435	$590
Annual Operating Margin	% Annual Revenue	7.60%	8.10%	9.80%
Information Systems				
Annual Revenue	$B,USD	$3.78	$4.24	$8.87
Annual Operating Earnings	$M,USD	$170	$249	$539
Annual Operating Margin	% Annual Revenue	4.50%	5.90%	6.10%
Shipbuilding				
Annual Revenue	$B,USD	$1.88	$4.71	$5.45
Annual Operating Earnings	$M,USD	$19	$306	$295
Annual Operating Margin	% Annual Revenue	1.00%	6.50%	5.40%
Technical Services (Omitted from Comparison Charts - Segment Operations Started in 2004)				
Annual Revenue	$B,USD			
Annual Operating Earnings	$M,USD			
Annual Operating Margin	% Annual Revenue			

While this simple comparison is not conclusive, it is indicative of the industry response of reduced investment presented in the financial performance data of the top five U.S. defense companies.

Next, data available in the 10-K annual reports help provide examples of the need for diversification. In 2010, Lockheed Martin reported 84 percent of the company's net revenues from the U.S. Government, with 15 percent of revenues from FMS. Also in 2010, Boeing Defense reported 87 percent of revenues from contracts to the U.S. Government, and Northrop Grumman's U.S. Government sales were 92 percent of 2010 revenues. General Dynamics reported 72 percent of revenues from the U.S. Government, and Raytheon reported 88 percent of total sales

2004	2005	2006	2007	2008	2009	2010
Northrop Grumman (Business Segments) continued						
$8.01	$9.01	$8.85	$8.20	$9.84	$10.42	$10.91
$634	$729	$844	$852	$417	$1,071	$1,256
7.90%	8.10%	9.50%	10.40%	4.20%	10.30%	11.50%
Electronics continued						
$6.42	$6.64	$6.58	$6.91	$7.09	$7.67	$7.61
$670	$710	$744	$813	$952	$969	$1,023
10.40%	10.70%	11.30%	11.80%	13.40%	12.60%	13.40%
Information Systems continued						
$10.00	$10.62	$9.11	$10.42	$10.16	$8.61	$8.40
$622	$736	$823	$895	$813	$631	$756
6.20%	6.90%	9.00%	8.60%	8.00%	7.30%	9.00%
Shipbuilding continued						
$6.25	$5.79	$5.32	$5.79	$6.15	$6.21	$6.72
$389	$241	$393	$538	($2,307)	$299	$325
6.20%	4.20%	7.40%	9.30%	-37.50%	4.80%	4.80%
Technical Services (Omitted from Comparison Charts - Segment Operations Started in 2004) continued						
$0.23	$0.04	$1.79	$2.18	$2.30	$2.78	$3.23
($3)	($17)	$110	$120	$121	$161	$206
-1.30%	-40.50%	6.10%	5.50%	5.30%	5.80%	6.40%

(The Boeing Company et al., 2001–2010). Just looking at the most recent 2010 reporting period, financial performance of the top U.S. defense companies is clearly at significant risk as defense budgets decline. Diversification will likely be a key industry response.

Turning next to restructuring, the initial set of comparisons over the past 10 years ranks Northrop Grumman as third in annual revenues and last in annual operating margins. Narrowing the focus, performance data for each of Northrop Grumman's business segments indicate potential industry responses. Figure 11 summarizes Northrop Grumman's business segment performance from 2001–2010, and Figures 12 and 13 compare annual revenues and operating margins.

FIGURE 12. ANNUAL REVENUES OF NORTHROP GRUMMAN'S BUSINESS SEGMENTS (2001–2010)

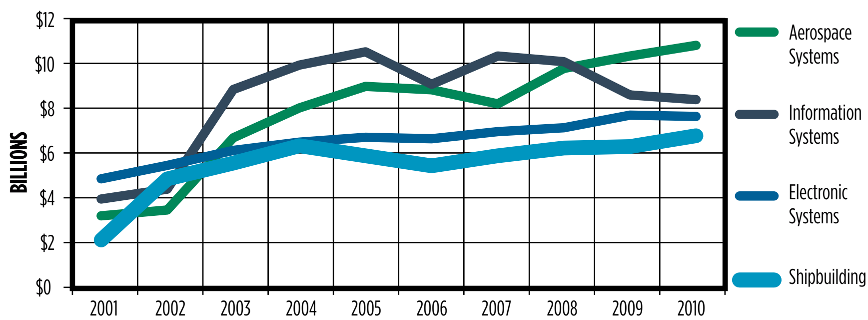
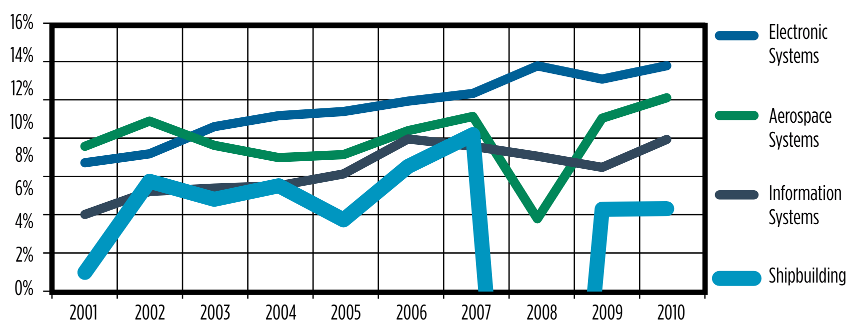


FIGURE 13. ANNUAL OPERATING MARGINS OF NORTHROP GRUMMAN'S BUSINESS SEGMENTS (2001–2010)



Based on these comparisons, Northrop Grumman shipbuilding lags the company's other business segments in both revenues and operating margins, with shipbuilding reflecting the sizeable impact of the $2.5 billion charge taken in 2008. This likely helps provide important context to the company's announcement in 2010 that it intended to spin off its shipbuilding business (The Boeing Company et al., 2001–2010). While only a singular example, this serves to highlight the active industry response of restructuring.

Using the information developed in this short case study, the response is positive to the fifth key question—are specific scenarios already in motion?

What Can Be Done?

Fortunately, much can be done to counter the downside risk of a declining U.S. defense budget. The following section outlines several recommendations to mitigate the risk to the U.S. military as well as the U.S. defense industry.

The first recommendation is to enact an aggressive incentive program focused on business investment. Current plans for accelerated capital depreciation credit align very well with this recommendation. Since the financial rationale for capital expenditures is driven by how quickly a company can recover its investment, an accelerated depreciation credit has a significant positive effect through taxation benefit. In addition, an increased research and development tax credit should also be enacted to better align financial incentives with the strategic benefit of investment by U.S. defense companies in future technologies. It is important to note that the public policy dimension of this recommendation will be a considerable challenge. Even as the global economy recovers, U.S. lawmakers will struggle to balance the strategic benefits of policies such as these with the need to sustain or increase federal tax revenues. This recommendation will help counter industry's likely response of reducing investment.

The second recommendation addresses potential restructuring of the U.S. defense industry by updating federal policy guidance and processes. The downturn during the 1990s spurred a series of consolidation actions across the defense industry, with the majority of these activities resulting in mergers or acquisitions. As a result, the overwhelming majority of today's federal policies focus on antitrust and competitive concerns. Similarly, reform efforts related to the Committee on Foreign Investment in the United States pushed the balance-point further away from beneficial foreign ownership of businesses that provide capabilities to the U.S. military. As the global economy has changed during the past decade, these policies have become increasingly out of date (Department of Defense, 1996). Further complicating the concern, a number of different federal departments and agencies are responsible for areas of the review and approval process. From the Department of Justice to the Securities and Exchange Commission, no clear process owner exists. In addition to updating the policies involved, clear process ownership should be established. This recommendation is essential to successfully managing the likely industry response of restructuring (Department of Defense, 2003).

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The third recommendation is to accelerate current reform efforts related to U.S. export controls. Much like the industry restructuring policies outlined previously, military export controls have not kept pace with changes in the global environment. In August of 2009, the White House initiated a review to identify needed export reforms, but the basic issues and struggles remain. Oversight and authority for export controls continue to be redundant and—in the assessment of the Government Accountability Office (GAO)—overly restrictive and ineffective (GAO, 2010). In some cases, the real effect on U.S. defense companies is an inability to compete for FMS opportunities, while European or Asian companies expand their global market share. As the U.S. defense industry seeks to diversify both its customer and product base, more effective and better balanced export requirements will be key to this strategy.

The fourth recommendation emphasizes the importance of continued open and proactive communication. Through formal statements and even informal remarks, Department of Defense officials can signal to industry what actions it will support as well as what actions it will not. As an example, in February of 2011 former Under Secretary of Defense Ashton Carter delivered timely guidance to industry by stating that the Department of Defense would support consolidation of second- and third-tier suppliers, but not first-tier defense companies. For businesses diligently working to develop strategies for declining defense budgets, this level of openness is essential (Carter, 2011). The costs to evaluate and formally propose a potential merger or acquisition are significant. The least favorable outcome is for industry to invest the resources only to have the federal government determine that the proposal is not in its best interest. Clear, open, and proactive communication is key.

In summary, this set of recommendations focuses on investment incentives, industrial review policies, export reforms, and proactive communication. Combined together, these form an effective response to the sixth question—what can be done?

Conclusions

Mirroring the structure developed at the beginning of this discussion, the following section addresses each of the opening questions.

Where are we in the sequence of events? It would be comforting to describe how the United States is still very early in the timeline and how a wide range of options remains open to policy makers. However, the reality is that more than a decade of federal deficit spending and the resulting increase in the national debt has crossed the point of crisis. Simple options are no longer available.

What is likely to happen next? Prior to release of the President's 2012 budget, expectations centered on the need for a series of strategic commitments to responsibly draw down federal expenditures while increasing revenues. Now, growing consensus opinion points to a near-term scenario requiring dramatic cuts in federal spending that include sharp reductions in discretionary expenditures focused on the U.S. defense budget.

How will industry respond? Based on the discussion, three likely scenarios for industry's response emerge: reduced investment, diversification, and restructuring. Near-term response to uncertainty will impact capital investment as well as research and development spending. Companies will also pursue opportunities to diversify their customer base as well as their range of products and services. As industry adjusts to declining future demand, many businesses will choose to restructure through acquisitions, divestiture, or mergers. In some cases, companies may choose to no longer compete for U.S. defense business.

What are the impacts on acquisition? The impact of declining U.S. defense budgets will be seen in acquisition scope, structure, and competition. Scope will transition from a focus on wartime supply and rapid development to much more modest upgrades and reset activities. Structure will transition from a broad mix of contract types to a more narrow set of shorter duration, fixed-price, limited-quantity contracts. Competition will increase significantly both in depth and breadth as U.S. companies begin to trade operating margins for continued revenues, and international companies increase efforts to compete for U.S. defense contracts.

Are specific scenarios already in motion? Researching the top five U.S. defense firms, elements of the predicted industry response clearly exist. Investment in areas such as capital expenditure is in decline. In particular, Boeing Defense has reduced its rate of capital investment by over half during the past decade. Diversification is underway as companies compete for FMS opportunities. Many examples of restructuring exist to include acquisitions, divestitures, and proposed mergers.

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What can be done? Four policy recommendations hold particular promise. First, the federal government should provide financial incentives for business investment through increased tax credit for research and development as well as capital investments. Second, the policies that govern the restructuring of U.S. defense companies should be consolidated and updated to include beneficial foreign investment. Third, the current effort to revise U.S. export controls should be accelerated to enable market diversification of U.S. defense companies through foreign military sales. Fourth, the Department of Defense should increase its use of industry forums, public statements, and other communication channels to signal its intentions as companies develop their response strategies.

Closing Comments

Building on the analysis and recommendations presented in this discussion, it is possible for both the U.S. Department of Defense and the U.S. defense industry to mitigate the dangerous downside risk of anticipated defense budget cuts.

Intervention *is* possible.

Now, stop running—and slowly put down the scissors.

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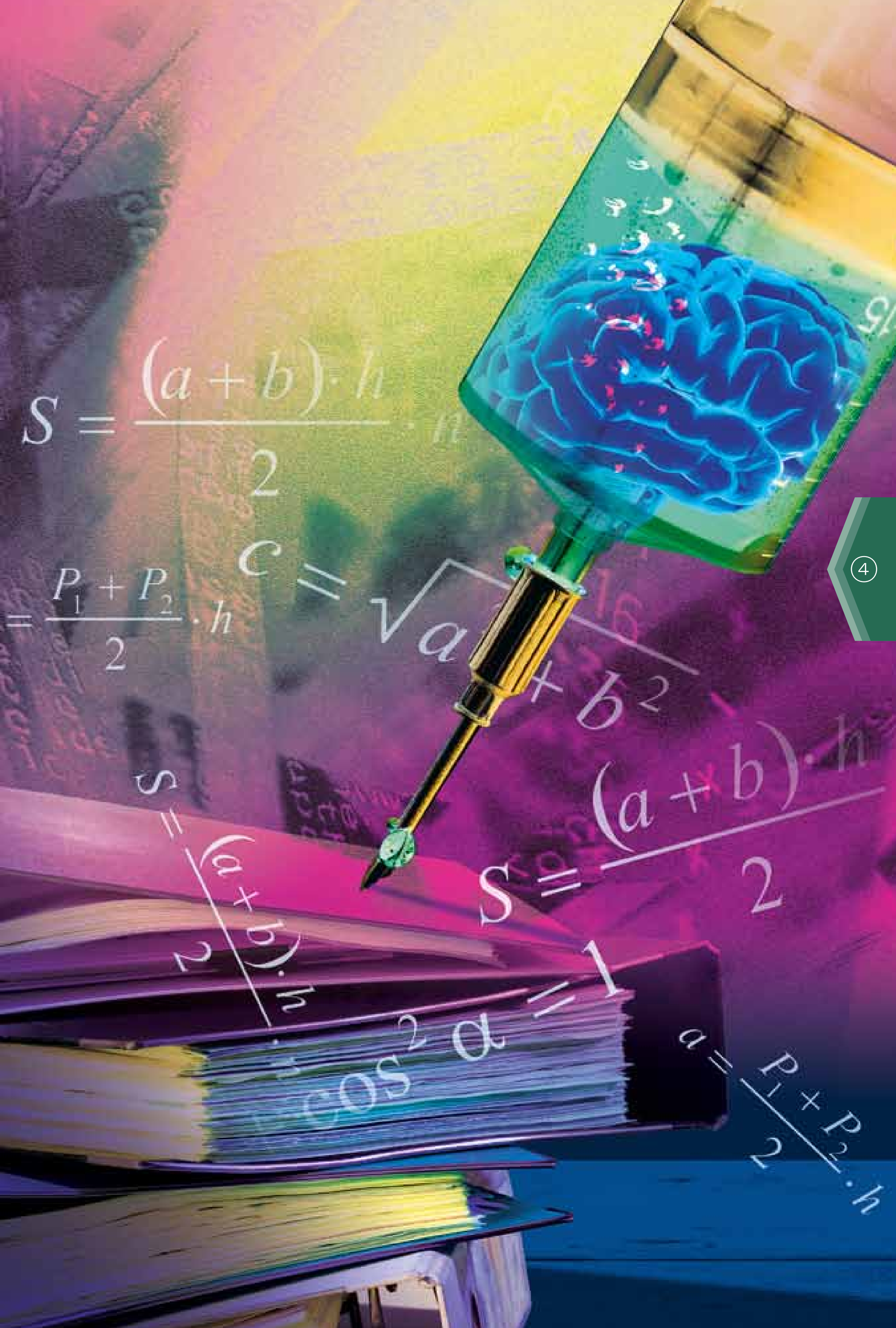
Keywords: *Capability Development, Competitive Prototyping, Knowledge Points, Early Systems Engineering*

Applying Early Systems Engineering: *Injecting Knowledge into the Capability Development Process*

Mark Pflanz, Chris Yunker, Friedrich N. Wehrli, and Douglas Edwards

A common problem in defense acquisition is the difficulty in ensuring that the required capabilities stated in capability development documents are technically feasible, affordable, and available through mature technologies. This problem is driven by a lack of knowledge on both the capability developer and program manager teams. Addressing this knowledge gap requires a new approach to capability development, where knowledge gained early in the process is injected into the capability development process in a rigorous way. This article describes that new technical approach along with lessons learned on two large acquisition programs. Key tenets include the use of pre-planned knowledge points as a vehicle for expanded collaboration between program managers and capability developers, and early use of systems engineering fundamentals.

image designed by Diane Fleischer »



The current capability development environment includes a host of challenges: the need for increasingly capable systems, often with greater complexity; time constraints and the resultant pressure on rapid delivery of new capabilities; and increased cost pressures. As new capabilities are developed, the threat and operational environment continues to adapt, often necessitating midstream changes to requirements or other aspects of the capability. Mandatory requirements to satisfy larger DoD policy goals must also be addressed. These challenges are made more difficult by a lack of knowledge on the part of the capability developer as well as the program management teams regarding technology maturity, technical feasibility, and affordability. This situation makes it difficult to reconcile requirements stated in capability development documents, with the 'state of the possible' in terms of feasibility and cost. The purpose of this article is to outline a technical approach to addressing these problems. Key tenets of this approach are use of pre-planned Knowledge Points as a vehicle for expanded collaboration between the capability and program managers (PM), and early use of systems engineering fundamentals in the capability development process.

This approach has been demonstrated on the Joint Light Tactical Vehicle (JLTV) program throughout the Technology Development (TD) Phase (over 36 months until its Joint Requirements Oversight Council [JROC] approval), and based on that success is now being implemented on the Marine Corps Amphibious Combat Vehicle program. Although these programs remain in development, the purpose of this article is to describe a technical approach that has shown promise for those PMs opting to apply the techniques and lessons learned described herein to their own programs.

Background

In September 2007, then Under Secretary of Defense for Acquisition, Technology and Logistics (USD[AT&L]) John Young directed that all acquisition programs requiring USD(AT&L) approval include competitive, technically mature prototyping from two or more industry teams through Milestone B. Programs requiring USD(AT&L) approval are typically the largest, most expensive, and most complex (Young, 2007). Competitive prototyping was later incorporated into Department of Defense Instruction 5000.02. Secretary Young directed this policy to address the problem of large weapon system programs being initiated with an inadequate understanding of technical risk, without firm requirements, and with a weak foundation for estimating developmental and procurement costs. This situation results in an unacceptable number of programs not meeting performance, cost, or schedule requirements. The JLTV program was the first ACAT 1D program to apply this directive. This competitive prototyping paradigm in the TD phase offers capability developers a unique opportunity, but confers a responsibility for a technically sound capability development approach.

As foreshadowed by implementation of the Joint Capabilities Integration and Development System (JCIDS) by DoD in 2003, this new approach to capability development involves early use of systems engineering and technical analyses to supplement the existing operational analysis techniques currently used in capability development activities. To meet their responsibilities in the acquisition process, capability developers must make capability trade-off decisions based on the performance of industry in meeting the requirements, cost, and risk. The involvement of industry prototypes at significant investment make close PM and capability developer collaboration essential to understanding the TD phase results and translating that knowledge into decisions that guide the new capability documentation.

As draft requirements are provided to industry to begin design, the capability developer must remain actively engaged in the design reviews for informed trade-off decisions. Exercising their leadership in establishing the foundational requirements, the capability developer must remain active in framing and observing the results of early key testing to make informed judgments about industry's success in meeting the requirements.

As design, fabrication, and test takes place, the operational relevance, feasibility, and cost of some requirements will be clear, but the best combination will not. Because the design of a system includes a series of trade-offs, indicators and issues on the more critical decisions of best balance in cost versus performance will not be clear-cut. The indicators will manifest themselves piecemeal at various points in design and test, and the capability developers use the systems engineering framework to orient and correctly place indicators in a logical decision series leading to a sound capability statement. Informed capability decision making requires understanding the basics of technical issues and using that understanding to supplement user expertise to state a feasible capability. The capability developers own the requirement, but the results of a competitive prototyping TD phase will, by definition, produce changes to the draft Capability Development Document (CDD) used at the start of the TD phase. To truly 'own' the CDD, capability developers need to be conversant in the basics of the technical issues uncovered in the TD phase to resolve and state the best expression of feasible and useful capabilities in the draft CDD. Gaining a working understanding of the technical issues involved in capability decisions will require access to technical resources, discussed later in this article.

A 'Knowledge Point'-Based Approach

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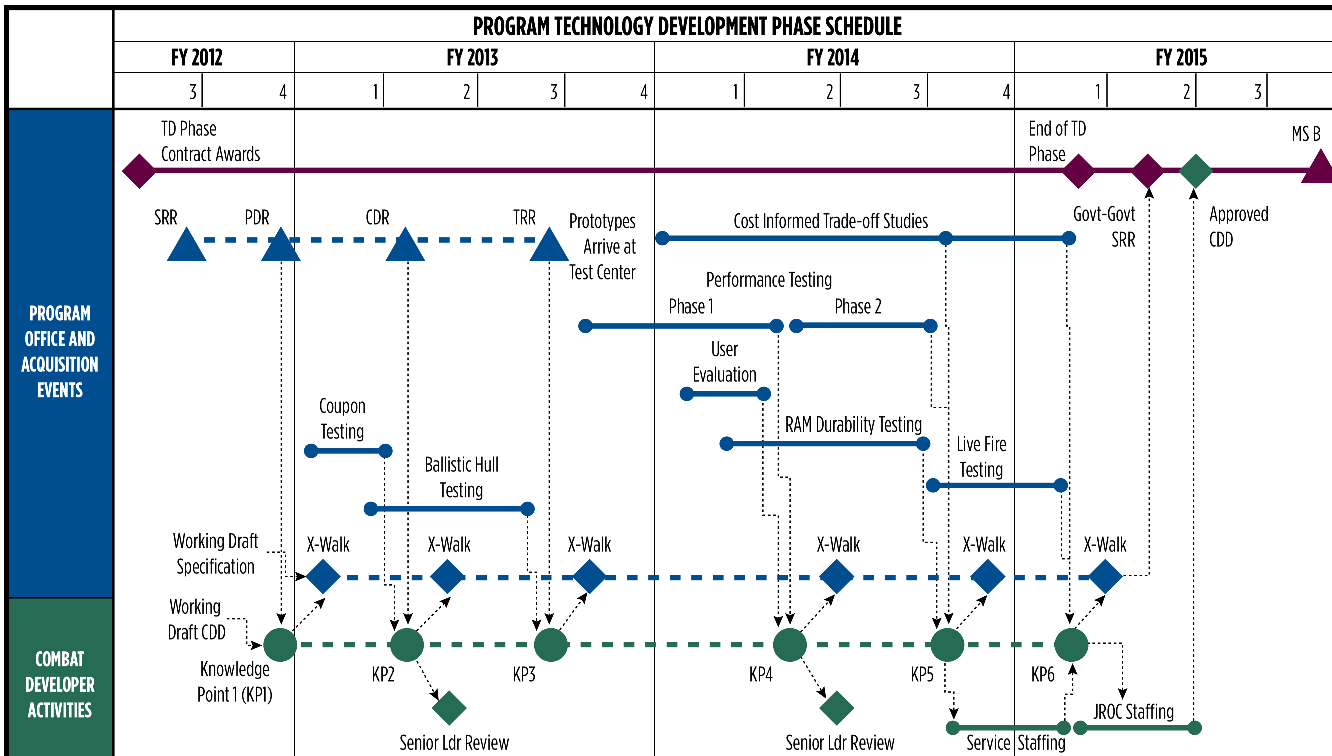
Competitive prototyping provides an immense array of valuable information based on the success of the competing industry teams in meeting performance, schedule, and cost as outlined in the TD phase initiating requirements. The primary goal of the capability developer during this phase is to translate knowledge gained in the TD phase into a technically achievable, operationally relevant, and affordable set of required capabilities documented in a revised CDD. Abstractly, the capability developers could revise the CDD using knowledge of the TD phase in one of two ways: incrementally, or with a 'big bang' at the end. The big-bang approach presumes an extremely high level of ability in translating all of this information and getting it right in a single change. Alternatively, the capability developers can play an active role in TD activities, incrementally updating the CDD at pre-planned intervals, based on major events in the TD phase where key information elements are expected to be available. Incrementally is preferred for a number of reasons. First, comprehensively capturing all necessary changes is difficult over the course of the TD phase: organizations often lose focus. Second, the more revisions done at a single point, the more difficult it is to manage. The more potential changes that occur simultaneously, the greater the need for analysis resources, which can be more efficiently used over time. Finally, an incremental approach allows capability developers to identify an issue, establish an analysis team, conduct the analysis, and reflect the recommendation in a rigorous manner.

We next introduce a new term, Knowledge Point (KP), as an approach to address these issues. A KP is a pre-determined, event-based CDD review where accumulated knowledge is injected into the CDD, updating the requirements based on analysis or test results . The main idea is to translate information gained at key points during the TD phase into actionable knowledge to refine the CDD and system specification. The incremental approach is event-driven and tied to targeted information gaps. For a major program, the capability developer may conduct four to eight KPs, depending on the depth and complexity of the initiative and the length of the TD phase activities. The number of KPs will be driven by the number of key events triggering a KP and the amount of time available. As time decreases, fewer KPs may be practicable or multiple key events may be combined into a single KP. Events that trigger a KP review include: industry design reviews (Preliminary Design Review, Critical Design Review, etc.); the conclusion of major test phases (ballistic hull testing, performance testing, etc.); and the conclusion of major analysis activities (Analysis of Alternatives [AoA], Trade Studies, etc.). Figure 1 displays this sequence of events. KPs are capability decision briefs that assess the information available to revise the CDD. The major result of each KP is a revised CDD with associated analysis products supporting the decisions made at that KP. A secondary result of KPs is to initiate analysis activities to address the problems raised at a particular KP. Such analyses and trade studies are then due at a future KP for implementation in the CDD. To reduce confusion and ensure transparency, the capability developers only update the CDD at KPs, not in between.

In planning a KP approach, the capability developers should identify and carefully consider key knowledge gaps associated with the initiative. Which key requirements are considered high risk? What are the system boundaries? When are cost projections and affordability estimates available? The program manager has a responsibility to assist the capability developer in identifying these knowledge gaps. In a well-designed program, information about these knowledge gaps will be addressed by the TD phase events planned by the program manager. For example, feasible protection requirements are addressed in live fire testing; feasible reliability is assessed in durability testing; weight is assessed in design reviews and upon prototype arrival at test centers. Where knowledge gaps are not addressed, the capability developers must work with the program manager to get these key knowledge gaps addressed in the planned activities. The capability developers must also consider when this information is available with respect to the CDD development timeline, and work with the testing and cost authorities to ensure that their products are available early enough to influence the CDD refinement activities. Stove-piped delivery of test results and cost estimates that are not avail-

FIGURE 1. PLANNING A KNOWLEDGE POINT-BASED APPROACH



Notes. SRR = System Requirements Review; PDR = Preliminary Design Review; CDR = Critical Design Review; TRR = Test Readiness Review.

able until very late in the TD phase will not support the CDD decision timeline. Collaboration is required to sequence test activities and cost analysis activities to address key concerns early using interim reports.

Implementing a KP-based approach to incrementally refining the CDD provides several key benefits. First, it provides a framework upon which PMs can base their own plans, synchronizing the overall effort. Specification development activities can base their development plans from the KP timeline. The AoA and cost analysis teams can use specific KPs as a data cut-off point. Key tests can be scheduled to ensure results are available to inform the CDD. Importantly, this approach ensures transparency in how analysis and test results are used to drive key CDD decisions. Second, all CDD decisions are implemented in an open KP format with key stakeholders present. Transparency eliminates confusion, allowing sequential decisions by the systems engineering, test, or cost organizations to proceed with the best information about the intent of the decision and the constraints under which it was made. Third, a knowledge point, incremental approach allows for the full impact of a decision to be clarified or revisited as the phase progresses. To summarize, having a series of KPs supports a deliberate analytical process in which issues are sequentially identified and framed with assumptions, analyses are conducted, and recommended solutions are then presented to leadership for decisions and recorded in the newest CDD draft.

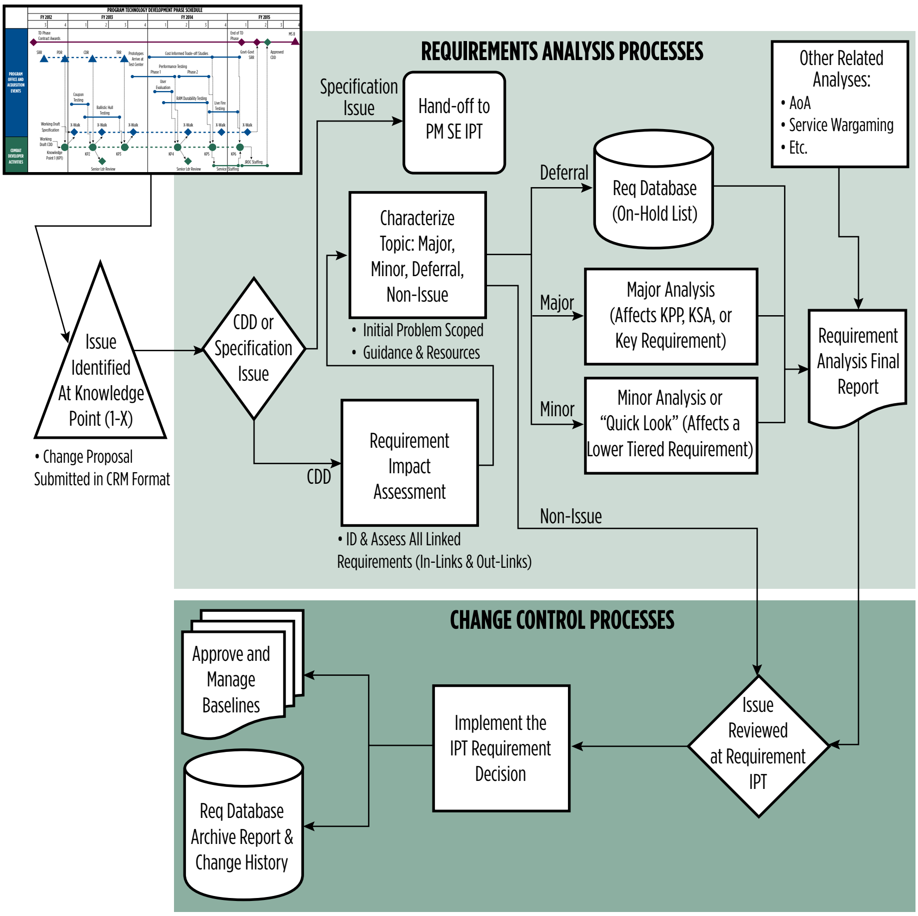
Executing A Typical Knowledge Point

The capability developers must own the KP process. Each KP event should be structured as a decision brief with defined decision authority. Decision authority is discussed in more detail later in this article. The Requirements Integrated Product Team leading up to each KP is the place for detailed discussions and development of recommended positions on each issue, allowing the KP to be focused on the 'so what' of key analysis or test results. The agenda of each KP can include updates of ongoing studies, but is effective when focused on a final results briefing of completed analyses ready for decision. While large groups tend to complicate decision making, KP attendees should include all the key stakeholders for stable decisions, ensuring transparency. Two stakeholders, the PM and lead systems engineer, hold special prominence at KP reviews as they hold the most accurate assessments of technical feasibility, maturity, and cost and schedule risk. The capability developer plans, coordinates, and leads the analysis activities, often relying on the PM or other technical expert to assist in the conduct of each analysis activity. When analysis and test activities are ready for presentation, the capability developer and technical experts collaborate in presenting the material at the KP. Later in this article, we discuss access to technical resources, which is a key enabler of sound capability development decisions.

Each KP should include success criteria to assist in communicating with stakeholders the focus of each KP event. The results of the KP should be summarized in a Memorandum for Record (MFR) stored in a location accessible to those who need to reference it. The capability developers and PMs will reorganize their efforts after each KP to ensure they are correctly aligned with the overall direction of the capability development effort based on the decisions made at the KP. Therefore, the KP and its results must be accessible. External agencies will also seek to minimize disruptions to a program, and can use KPs as key interface points with which to engage a program.

Well in advance of each KP, the capability developers provide a draft copy of the CDD with which stakeholders are invited to generate comments. Using a standardized format, such as the existing JROC Knowledge Management Decision Support Comment Resolution Matrix is recommended for simplicity. Comments from the stakeholders should be returned with sufficient time (approximately 2 weeks) prior to the KP event to allow time for background work to be conducted on each comment. The capability development team takes each change recommendation and conducts an impact (traceability) assessment to determine which related CDD attributes would be affected by the change. Each comment is characterized as a 'non-issue,' 'major analysis,' 'minor analysis,' or a 'deferral.' Changes that didn't require analysis (i.e., could be accepted or rejected without further effort) are characterized as 'non-issues.' Changes where insufficient data exist or where the answer will be available at a defined future event (such as a test) are characterized as 'deferral' and are deferred until the correct data are available. Changes proposed to critical requirements or requiring further analysis are characterized as major analyses. Changes requiring further analysis and proposed to lower tiered, non-KPP requirements are characterized as minor analyses. Once comments requiring analysis are characterized the study objectives are determined, and guidance and resources are assigned (Figure 2).

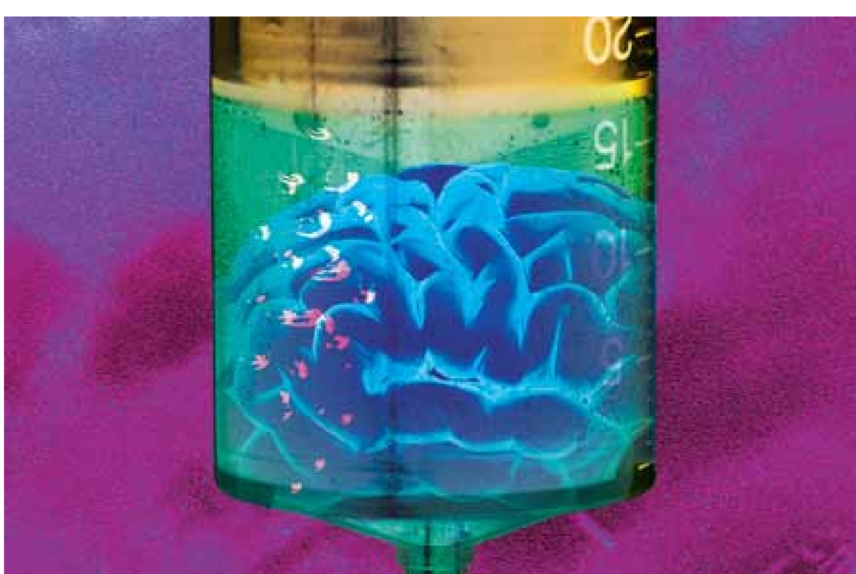
FIGURE 2. EXECUTING THE KNOWLEDGE POINT MACRO PROCESS



Once the background work is completed, the results are published 3 days prior as a read-ahead for the KP. This allows participants to arrive knowing all of the salient issues and understanding the decisions needed at the KP. The background work reflects the recommended 'going-in' positions at the KP. However, no decisions are made except at the KP to ensure transparency. At the KP, each proposed change with supporting analysis is reviewed, and the CDD decision authority adjudicates the proposed changes after receiving input from key stakeholders. Those changes adjudicated as major analyses, minor analyses, or deferrals are tagged as 'on-hold' and tracked in the requirements management database. Decisions on each proposed change are made only at KPs when the analysis is complete, not necessarily when the proposed change is first submitted.

KPs should include the use of metrics and culminate in a decision to either publish a revised CDD or publish an erratum. This provides a quantitative snapshot regarding requirements uncertainty, detailing what studies have been closed and implemented, as well as which are outstanding. It reflects how many change proposals are being submitted at a given time and helps assess relative success at dealing effectively with the complete set of proposed changes.

Key to sound decision making is the rigorous use of analysis and test results to underpin every activity and decision. Deferring decisions until sufficient information is available is preferable to changing an attribute or CDD section multiple times. Reliance on test results and technical analyses moderates the influence of any one stakeholder group. While not always easy, making CDD decisions only at the KP is key to maintaining transparency and critical to reinforcing the goal of always underpinning every CDD change based on analysis or test results. The results of each KP should be communicated throughout the capability developer and PM organizations to ensure everyone understands how these decisions affect their own work. This can be accomplished via an MFR summarizing



the KP outcomes. Publishing an MFR ensures only one (vice multiple) interpretations of a decision made, which is especially important if the KP decision is to publish an errata, rather than an updated draft CDD.

For key requirements, the decision authority for a CDD change is typically the capability development senior leadership. Therefore, following select KPs with a General Officer—or SES-level senior leadership review—is useful to validate key decisions. For example, a senior leader review can be used to validate the Key Performance Parameter (KPP) or to validate a key trade-off decision with far-reaching effects. This ensures that the Service leadership remains engaged in the capability development initiative, and can serve as a forum to reconcile differences that could not be resolved at the action officer level. However, to preclude schedule slip, these reviews should be scheduled in advance. Additionally, the scheduling of senior leader reviews should balance their availability and authority with the substance of the issues being reviewed.

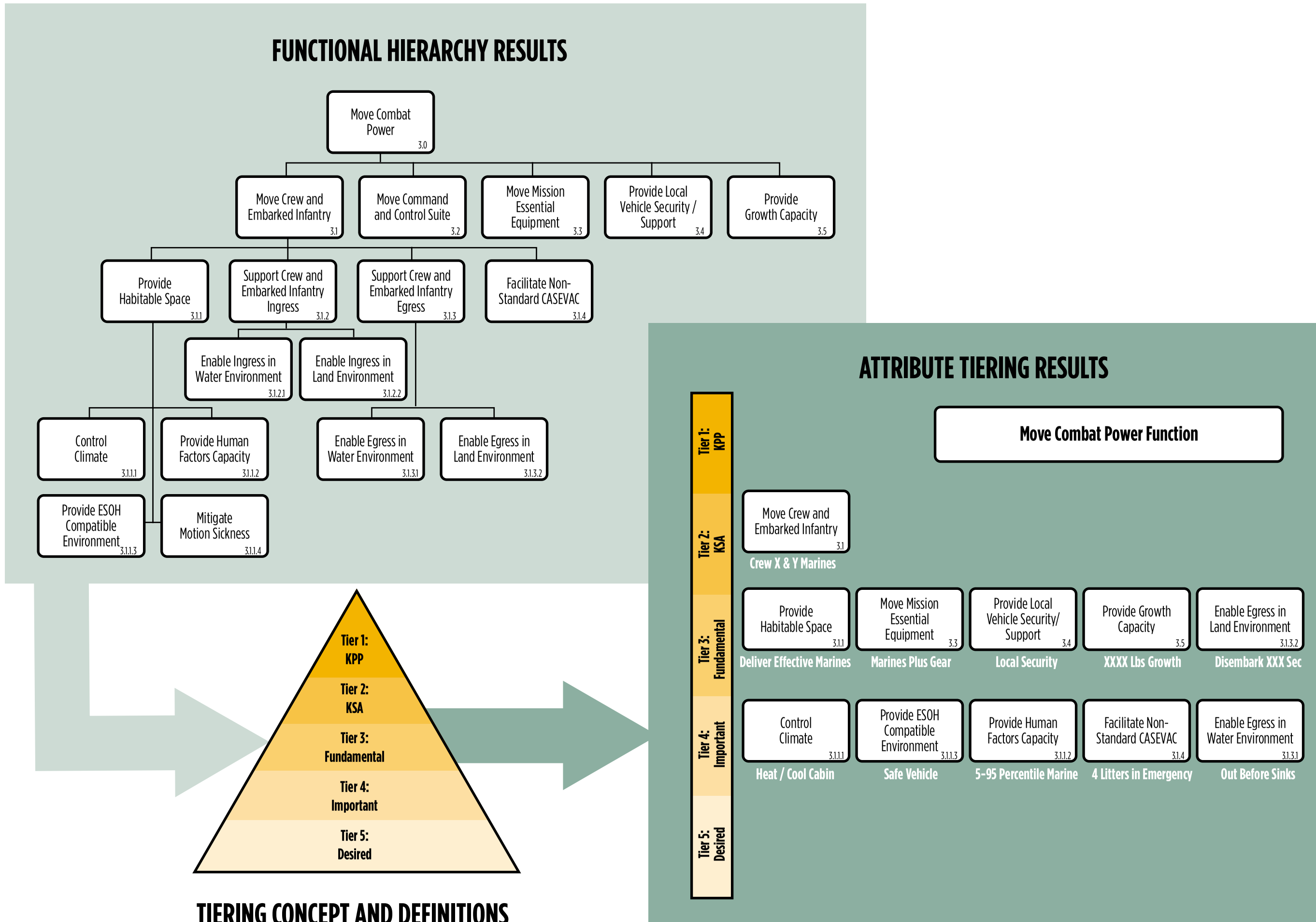
Early Use of Systems Engineering Fundamentals

Early use of systems engineering fundamentals is essential to successfully implementing a KP-based capability development approach. Key tenets include: (a) determine the plan upfront; (b) application of best practices; (c) enterprise-level use of requirements management software; (d) access to technical resources; (e) integrating test results; and (f) early and ongoing cost integration.

A comprehensive technical plan is essential during the TD phase: our warfighters depend on us, and a significant amount of taxpayer money is involved in any TD phase initiative. The plan should address the timing, events, and execution of various KPs and the knowledge gaps they seek to resolve. It should address what roles and responsibilities various organizations will play in terms of issue identification, analysis, decision authority, and closure. Given that potentially a lot of changes to a CDD and systems specification can occur, how will these changes be tracked, managed, and burned down? How will analyses initiated at a given KP be tracked and managed? Decision authority is especially important. At each KP, the lead capability developers should make CDD-relevant decisions after hearing the key points of stakeholders, with special attention paid to the PM and lead systems engineer. Certain key decisions, such as regarding a KPP, should be validated following select KPs at a senior leader review. All of these decisions are re-validated as the CDD moves through Service and Joint staffing as well as during key acquisition meetings such as the Defense Advisory Boards. Finally, the plan should address how software will be used in the process for key activities like requirements management, test integration, and include how any classified aspects will be handled. While many of these are simple, they must be documented to ensure common understanding given the number of people involved in a large program. Some decisions are not at all simple and require forethought and planning. All of these decisions and the resulting plan should be documented in the Requirements Management and Analysis Plan (RMAP) and signed by each of the lead capability developers and PMs. Implementing this plan, including the sections described below, requires an investment of resources by the capability developer in terms of people and funding, and a commitment to the processes it describes. For the capability developer, this may require one to three additional staff members to execute this process, depending on the status of the program. No additional staff is needed for the PM. To keep the RMAP from growing stale, it can be reviewed at each KP to determine if changes should be made in the plan. A copy of the technical plan used to execute the KP process on JTLV (Pflanz & Clark, 2009) is available through the Defense Technical Information Center (DTIC) Online Access Controlled as accession SURVIAC-SV-33264.

Best practices in systems engineering, as taught at the Defense Acquisition University, must continue to make their way into capability development activities. This principle aligns with the general guidance of the JCIDS as described in Chairman Joint Chiefs of Staff Instruction 3170. However, certain aspects are particularly important and worth elaboration. First, the attributes in the CDD should include decomposition and relative prioritization (Figure 3). Decomposition is important because it describes how a top-level capability, such as a KPP, is supported by lower level capabilities. A functional hierarchy can be developed to support decomposition using existing systems engineering techniques. When doing the impact assessment during the KP process, this decomposition can be used to support the impact (traceability) analysis to determine what other requirements are affected by a single attribute change. Relative prioritization is equally important. It can be used to inform trade-off decisions during the KP process to preclude lower level attributes from causing undue performance or cost risk to high-priority capability, such as a KPP. Relative priority also can be flowed down into the system specification. Relative priority can be established by assessing an attribute's 'depth' in the functional

FIGURE 3. DECOMPOSITION AND TIERING THE CDD ATTRIBUTES



Notes. EOSH = Environmental & Occupational Safety & Health; CASEVAC = Casualty Evacuation hierarchy and through subject matter expertise. Relative priority can be reflected using a set of tiers, where the definition for each tier is clearly defined (Figure 3). It is essential that industry understand the relative priority of the requirements for it to make sensible trade-off decisions when building prototypes. While the CDD is important, the warfighter ends up receiving what industry builds, and industry will build to the system specification, not the CDD. Therefore, conducting a series of CDDs to system specification crosswalks is absolutely essential to success. These crosswalks should verify that each attribute is completely and accurately decomposed, and that there are no requirements in the system specification without a parent in the CDD. The results of these series of crosswalks should be agreed to by senior leadership at a formal review prior to strategic points in the acquisition process. This is critical to ensuring the system specification is a sufficient and accurate representation of warfighter needs stated in the CDD.

Enterprise-level use of requirements management software is a key enabler to rigorous execution of the KP process. IBM's DOORS© is one popular software package. The increased demands on performance, complexity, and costs of systems now being developed require tight coupling between operational requirements stated in the CDD, system requirements stated in the specification, and test results. All of the requirements documents, such as the CDD and system specification, need to be resident in a single database with controlled access for authorized staff among capability developers, PMs, and testers. Since capability developers and PMs will often be geographically separated, this may require a networked tool to allow all data to reside on a single database. The more often the CDD is updated, the more frequently all of those ripple effects will flow down toward related and child-level documents. While it may be physically possible to manage a CDD in MS Word, doing so is not recommended. Changes will get lost or misapplied. The program office will have difficulty in tracing requirements and decomposing requirements as they change.

Access to technical resources is also essential to effective execution of the KP process. A large-scale capability development effort will include a wide variety of technical aspects. No one organization or individual can be expected to provide technical expertise across the spectrum. Establishing a working relationship and ensuring access to technical experts in the government are essential to success. The government has established centers of excellence in almost every area of science and engineering relevant to weapon systems development and should be included where possible. By resourcing these agencies to conduct analyses to support capability development, capability developers get access to the best minds in government who are already ‘past the learning curve’ on the particular issue at hand. Importantly, a capability development effort should establish a standing Whole Systems Trade Study (WSTS) group. The WSTS group focuses on whether the KPPs and other key requirements are achievable at the whole system level. An example of one such group is the U.S. Army Tank Automotive Research, Development and Engineering Center, Advanced Concepts Lab (TARDEC ACL). On the JLTV program, the TARDEC ACL served as a WSTS Group by building full computer models of a government design for JLTV, and also analyzing industry designs as they matured. They analyzed whole system achievability, as well as manipulating designs to answer ‘what if’ questions. The WSTS group government designs were also used as alternatives in the AoA, and portions of the WSTS group participated in the AoA. For JLTV, the WSTS Group was especially important in the decision to increase the JLTV underbody protection requirements and determine which other system requirements must be traded. Here, the computer models proved invaluable to underpinning this key protection decision.

Integrating test results is a key enabler of effectively executing the KP process. The test results must show that the current requirements stated in a CDD for a program at Milestone B are achievable; or where modified from the delivered prototypes, they are estimated as achievable by a credible expert authority or analytical modeling result. Assessing test results is difficult because it involves a complex mapping of multiple prototype test results used to assess achievability and the fact that requirements often changed during execution of the KPs. Collaboration of the testers, systems engineers, and capability developers is required to sufficiently translate the test information into actionable knowledge that can be applied in the CDD.

Test results are traditionally available at the end of testing, and therefore the end of the TD phase. This is not compatible with a competitive prototyping TD phase where the requirements are periodically updated as described previously. However, a prioritized test schedule can be developed using phases where test results are available at the end of each phase. KPs can be tied to the timing of each test phase. If done in priority order, the most important CDD attributes are verified first, with lower importance attributes varied as the testing progresses. There will be important exceptions to this rule. For example, durability testing typically involves long durations; therefore, reliability and certain sustainment attributes cannot be verified until late in the phase. However, these exceptions can be dealt with while still verifying as many key attributes as early as possible.

The purpose of the TD phase is to "get the requirements 'right'"; therefore, a logical consequence of the TD phase is changed requirements. Where possible, the test plans should be modified to reflect new changes to the CDD at a prior KP. For example, if a KPP changes or the mission profile changes in time to be reflected in testing, then the program will benefit from testing to the new requirement vice the old requirement. Not passing a modified requirement (to which industry did not design toward) does not necessarily invalidate the new requirement; however, it does increase the level of uncertainty in the achievability of that attribute. Finally, it is essential for capability developers to be present at certain key test events to collect the 'right' take-aways from the test and to ensure that the testing is in accordance with the implicit vision and explicit attributes of the CDD.

Early integration of cost estimates is the last key enabler to the KP process. Test results and delivered prototypes may demonstrate achievability, but not affordability. Correlating cost estimates from prototype work to affordability estimates requires early integration of the cost estimating profession. This requires several key activities. First is establishing a cost threshold beyond which the system is at risk of not being affordable; in the case of JLTV, this meant establishing cost as a Key System Attribute. Second is to correlate cost-driving requirements with the relative priority of requirements. Using a cost-informed trade-off assessment, the capability developer must be prepared to make difficult trade-off decisions to ensure low-priority, cost-driving requirements do not price the capability above the affordability cutline. Typically, these cost trade-off decisions require the participation of senior leaders. This integration of cost analysis is similar in scope to the DoD's Better Buying Power Initiative (https://dap.dau.mil/bbp) where cost analyses are used to inform systems engineering trade-off decisions to meet an affordability target.

Conclusions

This article described a new approach to capability development in the DoD's new competitive prototyping guidance for the TD phase. It focused on how the draft requirement is refined through a series of KPs, enabled by early use of systems engineering fundamentals. By following the ideas established in this approach, future programs can tailor their application based on program peculiarities; however, the common principles described here will endure regardless of scope or application.

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Keywords: *Acquisition, Technology Readiness Levels, System Readiness Levels, Science and Technology*

Improving Acquisition Outcomes Through Simple System Technology Readiness Metrics

Chad L. Dacus

This article advocates the use of simple technology readiness metrics that focus on system-wide technological maturity. Current DoD practice is to set guidelines for the maturity of individual system components, but the statistical evidence provided in this article demonstrates that more holistic metrics should be adopted. A simple system technology readiness metric is proposed and evaluated based on historical cost and schedule performance, and is shown to be potentially quite useful in avoiding poor acquisition outcomes. Finally, the policy implications of implementing a decision rule based on the metric are explored in depth, and the DoD is advised to pursue and encourage applied research for the development of more comprehensive technology readiness metrics.

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The discovery process in defense acquisition is expensive and time-consuming. If the Department of Defense (DoD) is too optimistic in what technologies it believes U.S. defense contractors can master in a timely fashion, taxpayers will be subject to large cost overruns, and warfighters will go without more effective weaponry for much longer than expected. Congress has attempted to reduce this risk by codifying minimum technology maturity levels for program elements before they can be included in a program of record. To further reduce these risks, minimum technology maturity levels should be enforced for the program in its entirety rather than focusing exclusively on its individual components. Indeed, empirical evidence gleaned from an evaluation of the effect of Technology Readiness Levels (TRL) on system cost overruns and schedule slips strongly supports taking a more holistic view of technology maturity. To put the magnitude of possible savings in perspective, a potentially avoidable additional cost overrun of 40 percent through the procurement phase for a **single** 'typical' $2.5 million Major Defense Acquisition Program (MDAP) results in $1 billion in additional outlays. The DoD should stop reaching for elusive technologies in its programs of record, but it should continue to retain and even enhance its technology leader status through strengthening its science and technology programs.

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The Services face a problem familiar to commercial interests in high-technology sectors: the development and fielding of appropriate technologies to satisfy customers' demands. The connection of technology to system requirements is clear—higher levels of technology generally allow the satisfaction of more demanding requirements. However, more advanced technologies can take much more time and money to develop, so trade-offs have to be made in a resource-constrained world.

TRLs describe the state of a critical technology element's development. The National Aeronautics and Space Administration developed the TRL methodology in 1974 (Banke, 2011). The DoD adopted the TRL framework, and it is now partially codified in regulations applying to all MDAPs. Title 10 United States Code (U.S.C.) Section 2366b requires the Milestone Decision Authority to verify that "the technology in the [major defense acquisition] program has been demonstrated in a relevant environment" before receiving Milestone B approval. A technology readiness assessment consists of classifying each critical technology element into one of nine technology readiness categories according to its technological maturity. The DoD uses the following scale (DoD, 2009):

- TRL 1: Basic principles observed and reported
- TRL 2: Technology concept and/or application formulated
- TRL 3: Analytical and experimental proof of concept
- TRL 4: Component validation in a laboratory
- TRL 5: Component validation in a relevant environment
- TRL 6: Subsystem model or prototype demonstration in a relevant environment
- TRL 7: System prototype demonstration in an operational environment
- TRL 8: Actual system completed and qualified through test and demonstration
- TRL 9: Actual system proven through successful mission operations

As is clear from Title 10's language, system components must achieve TRL 6 before reaching Milestone B. Although not codified in the U.S.C., TRL 7 or higher is the expected state of technology maturity at Milestone C. In addition, some programs use technology readiness assessments as an integral part of their risk assessment and risk reduction strategy (DoD, 2009). Since production begins after the Milestone C decision, a strong argument can be made that testing and integration should be complete—rendering TRL 8 the more appropriate standard.

The technological maturity of a system's critical components has long been recognized as a key determinant of weapon systems outcomes (General Accounting Office, 1999). If significant technological advances are required during design and manufacturing development, the program will be very susceptible to extended cycle times, higher unit costs, management changes, and funding volatility. In addition, these outcomes will provoke deleterious second-order effects such as smaller buys and technological obsolescence of more mature system components. Technological obsolescence can then lead to requirements creep. It is easy to see how a vicious cycle could take hold and even lead to a program's

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cancellation. Expanding technology readiness metrics by including a simple indicator of system readiness will allow program leadership to effectively control risk at both the individual technology element level and at the system level.

As mentioned previously, the U.S.C. requires an overall minimum TRL of 6 for critical technology elements. The Government Accountability Office (GAO) has recommended that technologies included in a product's design reach TRL 7 before being turned over to the product development manager (GAO, 2009). In addition to reinforcing the GAO's position, empirical analyses of Selected Acquisition Reports (SAR) and a system's TRLs support including an additional metric that takes a more comprehensive view of technological maturity.

Research Methods

The quantities of interest for this analysis are the percentage change from the earliest available estimated Program Acquisition Unit Cost (PAUC) to the current estimated PAUC and the actual schedule slippage, in months, as of the last published SAR. TRLs were taken from Defense Acquisition Executive Risk Summaries when these numbers became available starting in March 2007. All systems included in the sample had reached Milestone B by the time TRLs were collected. To exploit recently available technology readiness data, programs were selected for inclusion in the sample if Milestone B approval occurred after January 1, 2000. Programs reaching Milestone B before 2000 were very likely to have TRLs of 8 or better for every critical technology element by the time TRL data became available in 2007, so the additional data would not be particularly informative.

While a minimum TRL is prescribed by law at Milestone B, the raw number of critical technology elements with TRLs below 8 has not been identified as a major risk factor. For the purposes of this analysis, when a critical technology element's TRL reaches 8, technology risk has been effectively eliminated. To keep the focus on shortfalls in technology and because of mathematical necessity, the candidate explanatory variables were stated with the difference between a critical technology element's TRL and a TRL of 8 as the basic building block. In mathematical notation, this shortfall can be found quite simply by computing:

i-th critical technology element's TRL shortfall = $8 - TRL_i$

For example, the minimum TRL of 6 that is codified in the U.S.C. can be written interchangeably as

$$\min TRL_i = 6 \text{ or}$$

$$\max(8 - TRL_i) = 2$$

The same principle can be applied for all critical technology elements with TRLs less than or equal to 8. Armed with the insight that both the number and magnitude of technology shortfalls are important, the candidate explanatory variables containing TRL information that were considered are listed in Table 1.

TABLE 1. CANDIDATE EXPLANATORY VARIABLES

Quantity Measured	Mathematical Specification
Number of Technology Issues	$N = \text{Count}(8 - TRL_i) > 0$
Number and Severity of Issues	$Sum = \sum_{i=1}^{N} (8 - TRL_i)$
Number/Weighted Severity of Issues	$SS = \sum_{i=1}^{N} (8 - TRL_i)^2$
Maximum Technology Shortfall	$Max = \text{Max}(8 - TRL_i)$

The sum of the squared TRL shortfalls, or *SS*, merits additional explanation. Clearly, advancing from a TRL of 5 to a TRL of 6 may not require the same amount of effort as advancing from a TRL of 6 to TRL 7. That is, there is no reason to believe TRLs were designed as a linear scale. Squaring the TRL shortfall allows more serious shortfalls to be weighted much more heavily than minor shortfalls. The effect of squaring is pronounced—a shortfall of two units in the TRL scale is weighted four times more heavily than a shortfall of one. A shortfall of three is considered to be a major weakness and is given a weight nine times higher than a shortfall of one to reflect its relative seriousness.

These candidate variables and combinations of them were regressed against the number of months the system is or is projected to be behind Acquisition Program Baseline (APB) schedule and the ratio of current estimated PAUC to the earliest available comparable estimate of PAUC. To preserve the simplicity of the model and to keep the number of decision rules to a minimum, a variable or combination of variables was evaluated according to its ability to explain both schedule slippages and the percentage change in estimated PAUC. In addition to evaluating the effects of various technology maturity metrics, several other explanatory variables were incorporated in models to assess their relative value in explaining acquisition outcomes. These covariates, and whether each variable helped explain acquisition outcomes, are listed in Table 2.

TABLE 2. OTHER VARIABLES CONSIDERED AND THEIR EXPLANATORY VALUES

Independent Variable	Explanatory Value
Service	No
Months Since Milestone B	Yes
Type of Commodity	No
Prime Contractor	No
Cost Variance Causes	Yes
Program Size	No

The rationale for the consideration of most of these covariates is straightforward. The lead Service, the type of commodity being acquired, and the prime contractor were included to determine whether acquisition outcomes differed systematically because of the personnel involved in running the program or the fundamental nature of the acquisition itself. None of these were found to be useful in explaining acquisition outcomes when any TRL variable was also included in the model. A program's size, measured by its estimated total acquisition cost, was considered because expenditure could be a good proxy for complexity, so larger programs may be intrinsically more difficult to gauge. No statistical evidence was found to support this conjecture. Finally, sources of cost variance identified in the SAR were introduced in various models to determine whether one particular type of error was particularly influential in explaining acquisition outcomes. Even though information on these variables is obviously collected after the fact, they can still shed light on the consequences of misjudging a program early in its development. One of these indicator variables was found to be useful in explaining each acquisition outcome. Obviously, the presence of these variables compromises the predictive value of the statistical models presented in the next section, and for this reason they were not included once a decision rule was formulated. The number of months that have passed since a program satisfied Milestone B has been included to determine whether overruns intensify or dissipate as more of the program is executed.

Results

In explaining schedule slips, the model that explained the most variance while maintaining parsimony included the sum of the TRL shortfalls, the number of months since the program passed Milestone B, and an indicator variable that denotes that estimation error contributed to the cost variance that has occurred to date. The statistical results for this model are displayed in Table 3.

TABLE 3. SCHEDULE SLIPPAGE REGRESSION RESULTS

Variable	Estimate (Standard Error)
Constant	-11.50 (6.41)
TRL Sum	1.54** (0.29)
Months Since MS B	0.125* (0.06)
Estimating Error	10.57* (4.06)

Note. $R^2 = 0.55$, N = 50, * P-value < 0.05, ** P-value < 0.001

Estimated Schedule Slippage Model

$$\text{Slippage} = a(Sum) + b(Months\ Since\ MS\ B) + c(Estimating) + d$$

The model explains more than half of the variation in schedule slips. The model's explanatory value strongly suggests that any decision rule regarding minimum technology readiness should incorporate the sum of technology readiness shortfalls. The results also reveal that schedule slippage worsens as the time since Milestone B increases, and that cost estimating errors that understate program expense contribute to schedule overruns. This probably occurs because unpleasant cost surprises lead to the stretching of program timelines to meet each calendar year's budget targets. To evaluate the proposed technology readiness rule's value, the model's efficacy in explaining cost ratio was also investigated. As the results in Table 4 illustrate, a similar model also works well in explaining cost overruns.

TABLE 4. COST OVERRUN REGRESSION RESULTS

Variable	Estimate (Standard Error)
Constant	-22.17 (12.95)
TRL Sum	3.56** (0.77)
Months Since MS B	0.19 (0.14)
TRL SUM* Months Since MS B	-0.02* (0.01)
Schedule Error	19.19* (8.55)

Note. $R^2 = 0.53$, N = 49, * P-value < 0.05, ** P-value < 0.001

Estimated Cost Overrun Model

$$\text{Overrun} = a(\textit{Sum}) + b(\textit{Months Since MS B}) + c(\textit{Sum* Months Since MS B}) + d(\textit{Schedule}) + f$$

In addition to explaining more than half of the variation in schedule slippage, the model also explains over half of the variation in cost overruns. Once again, the sum of TRL shortfalls is highly influential in explaining the acquisition outcome. Cost overruns tend to increase in severity as time passes, but strangely, the interaction between the sum of TRL shortfalls and the number of months since Milestone B has a negative sign. This means that the effects of the sum of TRL shortfalls diminish somewhat as time passes. However, evaluating the results from both regressions, clearly the sum of TRL shortfalls is the most useful of the variables considered in explaining cost and schedule overruns.

To illustrate the results in more concrete terms, a notional decision rule can be specified and applied to the systems in the sample. The most discriminating decision rule in this sample predicts that systems with a sum of TRL shortfalls above 10 or a maximum technology shortfall of 3 will cost significantly more than expected and will experience a longer cycle time than was previously expected. The currently codified standard of no maximum technology shortfall of 3 or higher was included because it is useful and highly unlikely to be eliminated. The average results for this rule are summarized in Table 5. It is especially noteworthy that the mean overrun for both acquisition outcomes was found to be substantially higher in violating programs versus no violating programs. The differences were found to be statistically significant at the 1 percent level for schedule and at the 5 percent level for cost.

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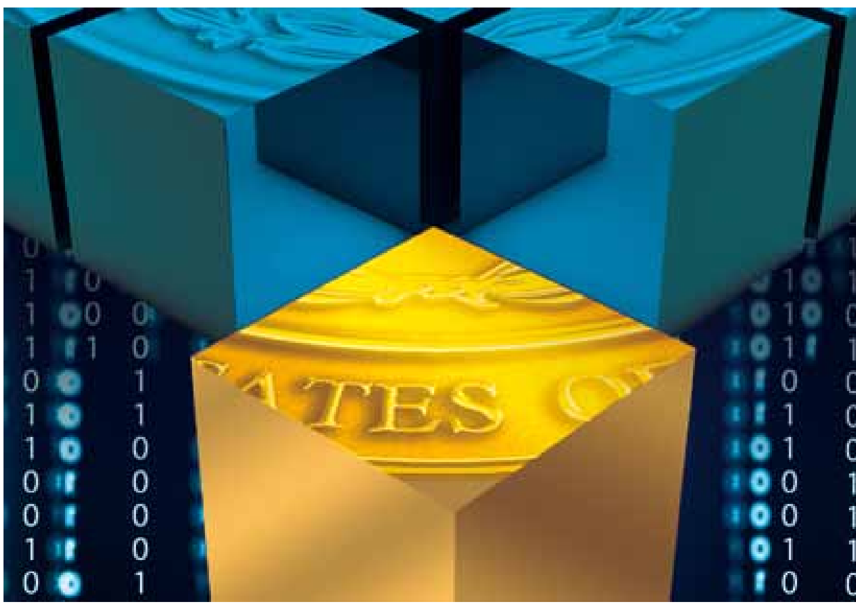
TABLE 5. APPLICATION OF THE PROPOSED DECISION RULE

Quantity of Interest	No Violation	Violation
Mean Months Behind Schedule**	7.7 mos.	31.2 mos.
Mean Percentage Cost Overrun*	3.2%	35.5%

Note. * P-value < 0.05, ** P-value < 0.01

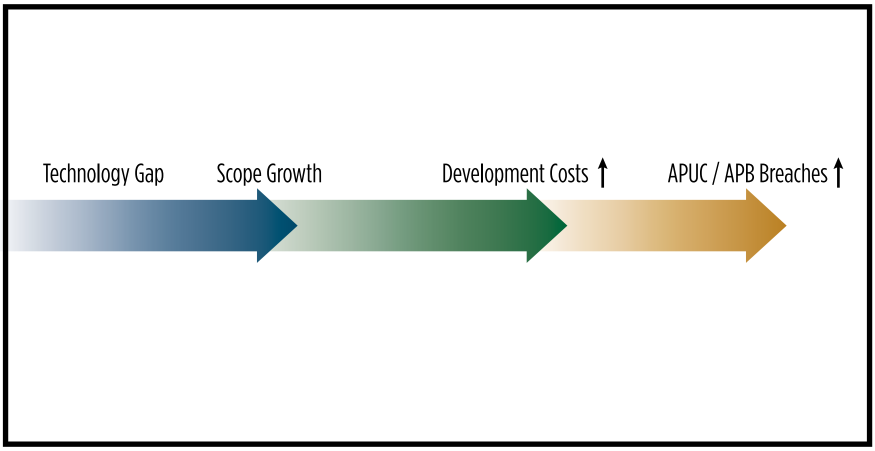
The impact of the rule is stark—an average difference in schedule overrun of over 23.5 months and 32 percent higher relative costs. In fact, it is reasonable to conclude that systems that do not violate this decision rule perform, on average, almost as expected with respect to cost, and systems that violate the rule generally have problems that will lead to multiple Nunn-McCurdy and APB breaches.



Possible Mechanisms of Cost and Schedule Growth

Although a causal link between large technology gaps and cost and schedule overruns has not been established statistically, identifying an intuitively appealing mechanism that could be causing these effects would help satisfy us that these are probably not spurious results. Dan Davis speculated that low TRLs might cause more scope growth during development, and showed that scope growth was highly statistically significant in explaining development cost growth (Davis, 2010). Furthermore, a quick analysis of a recently published GAO report reveals that increases in Research and Development (R&D) costs are strongly correlated with rising estimated procurement costs (GAO, 2011). Complexity could be driving cost growth throughout a program's development and production phases. This mechanism may be equally valid for explaining systems that have multiple schedule overruns. Using a sample of 70 systems with current SARs, development cost increases led to statistically significant increases in the number of APB schedule breaches, the probability of multiple breaches, and the probability of an APB breach after Milestone C. Therefore, there is statistical evidence that a large technology gap could, through the mechanism of scope growth during the development phase, eventually contribute to systemic cost and schedule issues throughout a system's acquisition cycle. A program that gets into trouble early stays in trouble, and one way to virtually ensure a troubled system is to tackle too large a technology gap. The figure shown here summarizes the mechanism graphically.

FIGURE. HYPOTHESIZED MECHANISM OF SYSTEMIC COST AND SCHEDULE GROWTH



Now that the predictive power of this decision rule for recent systems has been established, what general guidelines for implementing it should apply? If the rule is violated, the decision maker has three options: (a) take measures to bring the program into compliance with the rule, (b) cancel or delay the program, or (c) assume the risks associated with large technology gaps without mitigating them. The implications of the last two options are clear, so the emphasis in this article will be on the first option.

If the system technology readiness gap exceeds upper tolerance levels such as the one specified in the previous section, partially closing the gap by substituting more mature technologies could pay considerable dividends. Of course, for some systems such substitution would not be possible, but when feasible, it is highly recommended. Experienced systems engineers would work with science and technology professionals and cost estimators to make the most cost-effective trades. As the cost and schedule performance of the DoD acquisition system improves, these collaborative efforts could potentially be instrumental in demonstrating the worth of systems engineering. As the DoD learns more about cost and schedule performance at various technology readiness gaps, the technology readiness decision rule can be modified to reflect actual experience.

Analyses of Alternatives (AoA) could play an important role in identifying potentially useful technology substitutions. Through DoD Instruction 5000.02, defense leaders have mandated the performance of an AoA before Milestone A. An AoA is specifically intended to be the analytical foundation for arriving at the correct materiel solution when one is required. In addition, AoAs are to offer an assessment of the critical technology elements that make up each potential materiel solution. However, as the GAO has found, many AoAs do not provide a robust set of alternatives at the system level—much less at the critical technology element level. The DoD concurred with the GAO's recommendations for improvement, so it is possible that AoAs are improving as this is being written (GAO, 2009). The DoD must prioritize the funding of AoAs, provide useful feedback to those who perform the analysis, and emphasize analysis at the critical technology element level. Perhaps most importantly, the DoD should require that an "80 percent solution" and a low-budget option are identified and analyzed at both the system and critical technology element level (Defense Science Board, 2009). The DoD must deter the use of an AoA merely to "support a predetermined solution" (GAO, 2007).

System Technology Readiness Gaps

Including an additional metric in technology readiness assessments could help facilitate the efforts of systems engineers and program managers in making technology trade-offs. Toward that end, John Mankins has proposed adding Research and Development Degree of Difficulty ($R\&D^3$) to technology readiness assessments (Mankins, 2002). Mankins created five $R\&D^3$ classifications that depend on how many parallel paths of discovery researchers believe are necessary to ensure a reasonable probability of successful discovery. It is likely that the number of parallel paths required will be positively correlated with total early development costs. Therefore, this approach could also facilitate and standardize the participation of cost estimators. By requiring researchers to submit R&D^3 classifications for each critical technology element and then asking cost estimators to provide a ballpark estimate for development costs based on the size of the total technology gap and the R&D^3 classification, systems engineers and program managers will be armed with the information they need to make reasonably informed technology trade-offs. Of course, this metric could be helpful in cost estimation without trade-offs (option (c) at the end of the previous section) and could be used to help understand the risks involved in developing systems with relatively large technology gaps. Although this recommendation almost certainly requires additional cost-estimating staff, it is likely these additional staff members will pay for themselves by providing useful information on how to save money. Because these estimates would be ballpark estimates, they would not require the level of analysis needed later in the cycle, and the number of new estimators would probably not be prohibitive. Where possible, we have refrained from making recommendations that require an up-front investment of increasingly scarce resources, but here it is highly advisable to take the long view.

Although the approach of evaluating TRLs in isolation would be a substantial improvement over existing practice, the long-term potential of technology readiness assessments that consider interfaces between components has greater potential and should be pursued. Recently, researchers have made progress in defining technology maturity metrics that incorporate the interface between critical technology elements (Sauser, Ramirez-Marquez, Verma, & Gove, 2008). Two technology maturity metrics have been advanced in the systems engineering literature: the interface readiness level (IRL) and the system readiness level (SRL). As their names suggest, IRLs measure the readiness of technology that enables interoperability of two critical technology elements, and the SRL is an aggregate number that incorporates both TRLs and IRLs. Theoretically, SRLs should be the ideal end state—allowing systems engineers to evaluate the contribution of each critical technology element to the functioning of the entire system at the press of a button. However, SRLs are a concept in its infancy, and much work needs to be done before transitioning to this technology readiness metric.

Multiple measurement issues arise when attempting to calculate an SRL (Kujawski, 2010). In the end, objections to the calculation of SRLs amount to concerns over mixing arbitrary subjective rating scales and then aggregating the results. While these objections are well-founded, there is no reason why IRLs cannot be considered in assessing system technological readiness with the eventual goal being more comprehensive metrics for technology readiness assessment.

IRLs could be used in several ways without mixing the two rating scales. First, minimum IRL guidelines could be set and considered when making technology trades. In addition, overall IRL technology gaps could be assessed and used to motivate technical substitution as we proposed with TRLs. Finally, IRLs should play an important role in system cost estimation. With all of these potentially worthwhile applications associated with IRLs, the DoD should devote the necessary resources to fully understanding the contribution of the interfaces to overall system technology readiness and applying the IRL concept to its complex systems.

Although calculation of credible overall SRLs may be quite a few years off, useful information on a system's interfaces could be reported in a modest amount of time. While guidelines that incorporate IRLs are being developed, the DoD can use decision rules similar to those proposed in the preceding discussion. Eventually, the DoD should be able to report a single SRL and be able to make trades based on contributions to overall system technological readiness.

Implications for Science and Technology

The most obvious and potentially important implication of deferring the use of relatively immature technologies in system development relates to the allocation of funding between Science and Technology (S&T) and programs of record. If less R&D funding is to be spent after a system acquisition becomes a program of record, more funding should naturally be diverted to S&T. This is not a new idea—as far back as 2000, the Defense Science Board recommended that S&T budget requests be increased to almost 3 percent of the total DoD budget submission (Morrow, 2000). In 2003, Under Secretary of Defense for Acquisition, Technology, and Logistics Pete Aldridge set the same target for S&T funding; and in 2007, the Pentagon's Director, Defense Research and Engineering John Young argued that the department's S&T funding should be 3 percent of the DoD's total budget (Davey, 2003; Chow, Silberglitt, & Hiromoto, 2009).

An increase in S&T's share of DoD funding flies in the face of current trends. In fiscal year 2000, S&T accounted for approximately 3 percent of DoD's budget (Morrow, 2000). In the proposed fiscal year 2013 budget, S&T has slipped to 2.26 percent of DoD's allocation (DoD, 2011). In the extraordinarily tight budget climate expected for the foreseeable future, reversing this trend of decreasing S&T funding as a percentage of the DoD budget will be very challenging. To gradually raise S&T's share of total funding, the DoD could implement a 'reinvestment' policy. That is, as cost performance improves from insisting on smaller technology maturity gaps in programs of record, the DoD could earmark a portion of the realized savings for use in basic and applied research. Since total defense S&T funding is less than 12 percent of DoD procurement funding, demonstrating the plausibility of such a reinvestment strategy is trivial (Office of the Under Secretary, 2012). If the DoD has enough discipline to accomplish this ramp-up in S&T funding, the Services' technological edge will not be diminished to an unacceptable degree over the long haul despite obvious short-term sacrifices implied by some of these recommendations.

If the DoD increases the intensity of its S&T efforts, the Services must decide how to prioritize new R&D projects that will become possible with the newly available resources. RAND researchers working on behalf of the Army have made progress in this area, and the Air Force and Navy could profit from adopting some of their recommendations. In the most general terms, the algorithm they developed maximizes the number of technology objectives prospective projects satisfy while minimizing total life-cycle costs (Chow et al., 2009). While the algorithm considers neither cycle time nor discovery risk at this time, the general approach holds promise and has been under development and revision since 2002.

Conclusions

A new way of assessing a system's TRLs has been demonstrated to be quite useful in explaining cost and schedule overruns. In particular, this research shows that larger total technology gaps, as measured by the sum of the TRL shortfalls, lead to drastically increased costs throughout the system's useful life and to more frequent and sizable schedule slips. Since the size of the total technology gap is a key driver, reducing the technology gap by making technology substitutions where possible can mitigate these risks. First and foremost, the DoD should enforce present guidelines and stop allowing critical technology elements with TRLs below 6 to be included in a program after Milestone B. Further, using a simple rule of thumb that aggregates a system's critical technology element readiness gaps could significantly improve acquisition outcomes, but DoD should eventually develop more comprehensive technology readiness metrics that have the potential to reduce technology risk even further. To implement these recommendations, the DoD must put the right professionals in place—skilled systems engineers, cost estimators, and researchers are vital to this roadmap's success. Finally, the DoD should increase S&T funding as savings are realized from informed technology substitutions.

5

Author Biography

Dr. Chad Dacus is a Defense Analyst-Economist at the Air Force Research Institute (AFRI). Before joining the AFRI staff, Dr. Dacus worked for the Center for Naval Analyses as a field representative to U.S. Fleet Forces Command. His current research interests include defense acquisition, economics and strategy, and cyberspace risk modeling. He holds a PhD in Economics from Rice University and an MS in Statistics from Texas A&M University.

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5

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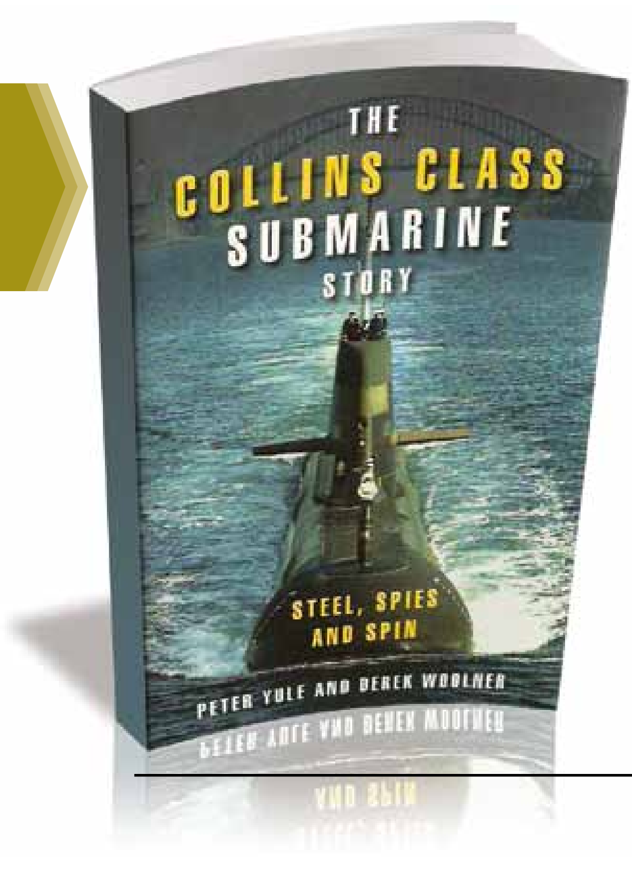

Featured Book

The Collins Class Submarine Story: Steel, Spies, and Spin

Author(s):
Peter Yule and Derek Woolner

Publisher:
Cambridge, Cambridge University Press

Copyright Date:
2008

ISBN:
978-0521868945

Hard/Softcover:
Hardcover, 402 pages

Reviewed by:
John F. Schank, Senior Operations Research Analyst, RAND Corporation

Review:

The Royal Australian Navy (RAN) operated submarines built and supported by Great Britain for much of the 20th century. As the RAN's British-built *Oberon* class submarines were reaching their mid-life point in the early 1980s, the RAN was finding it difficult and expensive to support the desired operational availability of their submarine fleet. In this environment, and with much debate and deliberation, Australia decided that the new submarines needed to replace the *Oberon* boats would be built in Australia. The resulting *Collins* class submarine program was the largest, most expensive, and most controversial military project undertaken by Australia's defense community.

The authors of this superb history of the *Collins* class program thoroughly describe the numerous players, their intentions, and their interactions during the 20 years from the beginnings of the program to the delivery of the sixth and final submarine in the class. The program produced not only one of the largest and most capable diesel submarines in the world, it also created a new national industry. However, it was marked with technical difficulties and political intervention. As the authors state, "It is a story of heroes and villains, grand passions, intrigue, lies, spies and backstabbing" (p. xviii).

The authors tell their story in four parts:

- The early years of debate on whether Australia could actually build submarines, followed by the solicitation and awarding of a design and construction contract to an alliance of several companies. Acquisition professionals will find informative the process used to set requirements, the contracting structure, and the interactions between the buyer and the seller.

- The first few years of design and construction, when enthusiasm and newness created an atmosphere of cooperation and progress. However, there were several issues arising between the corporations involved in the prime contractor partnership. The design developed by the Swedish shipbuilder, Kockums, was based on a Swedish Navy boat whose operational capabilities were very different from those desired by Australia. Technical problems began to emerge, especially in the combat system, and construction lagged. Acquisition professionals will benefit from the description of the combat system contract environment as well as the creation of a new cooperative venture and a green-field shipyard.

- A several-year period when the bloom fell off the rose. This period was marked by increasing technical problems and construction delays. The public's perception of the program problems was inflamed by several disparaging media articles. The original partnership changed dramatically as Australia assumed the ownership of the Australian Submarine Corporation (ASC). Acquisition professionals will find enlightening the process through which the contracting arrangements changed and the recognition that the government had substantially underestimated the risks in undertaking such a complex program for the first time.

- The last several years of the program when the *Collins* submarines finally became operationally capable with the help of the United States Navy. Problems during this time period switched from designing and building the submarines to providing the logistics support needed to attain operational goals. This problem persists today as marked by new studies seeking to identify the inherent problems in supporting the *Collins* class submarines and the future costs needed to keep the boats operationally ready during the second halves of their operational lives.

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