UNITED STATES AIR FORCE SPACE COMMAND

Volume 6, Number 1

HIGH FRONTIER

THE JOURNAL FOR SPACE, CYBERSPACE, & MISSILE PROFESSIONALS

INSIDE:

- Air Force Space Acquisition
- Getting it Right: Lessons from Failed Space Acquisitions
- Acquiring Space Systems in an Uncertain Future: The Introduction of Value-Centric Acquisition
- The Cyberspace-Development Dogfight: Tightening the Acquisitions Turn Circle

SPACE ACQUISITION

Headquarters
Air Force
Space Command
Peterson Air Force Base, Colorado

Published by a private firm in no way connected with the US Air Force, under exclusive written contract with Air Force Space Command. This command funded Air Force journal is an authorized publication for members of the United States military Services. The views and opinions expressed in this journal are those of the authors alone and do not necessarily reflect those of the United States Department of Defense, the United States Air Force, or any other government agency.

Editorial content is edited, prepared, and provided by the *High Frontier* staff. All photographs are Air Force photographs unless otherwise indicated.

High Frontier, Air Force Space Command's space professional journal, is published quarterly. The journal provides a scholarly forum for professionals to exchange knowledge and ideas on space-related issues throughout the space community. The journal focuses primarily on Air Force and Department of Defense space programs; however, the *High Frontier* staff welcomes submissions from within the space community. Comments, inquiries, and article submissions should be sent to AFSPC.PAI@peterson.af.mil. They can also be mailed to:

AFSPC/PA
150 Vandenberg St. Ste 1105
Peterson AFB, CO 80914
Telephone: (719) 554-3731
Fax: (719) 554-6013

For more information on space professional development please visit:
http://www.afspc.af.mil

To subscribe:
Hard copy: nsage@sgis.com
Digital copy: http://www.af.mil/subscribe

Cover: Air Force Space Command's mission is to provide an integrated constellation of space and cyberspace capabilities at the speed of need.

HIGH FRONTIER

The Journal for Space, Cyberspace, & Missile Professionals

November 2009 Volume 6, Number 1

Contents

Introduction

General C. Robert Kehler . . . 2

Senior Leader Perspective

Air Force Space Acquisition
Mr. Gary E. Payton . . . 3

Applying the Lessons of Acquisition Success in the Next Generation Electro-Optical Program
Maj Gen Ellen M. Pawlikowski . . . 5

Requirements Generation: The Crucial First Step to Delivering Warfighter Capability
Col Jay A. Moody . . . 7

Space Acquisition - Space and Missile Systems Center

***Forward**: Space and Missile Systems Center "Building the Future of Military Space Today"*
Lt Gen John T. "Tom" Sheridan . . . 10

Getting it Right: Lessons from Failed Space Acquisitions
Mr. Douglas Loverro . . . 12

Mission Assurance: "Baking In" Mission Success
Col David Swanson, Dr. Sumner Matsunaga et al. . . . 15

PMAG: The Relentless Pursuit of Program Management Excellence
Col Mun H. Kwon . . . 18

Keys to Acquisition Success
Ms. Catherine J. Steele . . . 22

Space Acquisition

Firth Principles
Dr. Robert L. Butterworth . . . 29

Regaining Credibility: Making Nuclear Sustainment a Model of Excellence
Col James D. Fisher . . . 32

Acquisition Education for Space Warriors
Dr. Brian K. Anderson . . . 35

Acquiring Space Systems in an Uncertain Future: The Introduction of Value-Centric Acquisition
Dr. Owen C. Brown and Mr. Paul Eremenko . . . 37

The Cyberspace-Development Dogfight: Tightening the Acquisitions Turn Circle
Maj Matt Larkowski, Dr. Robert F. Mills et al. . . . 44

Is Acquiring Space Systems a Wicked Problem?
Maj Nick J. Martin . . . 50

Industry Perspective

Ten Rules for Common Sense Space Acquisition
Maj Gen Thomas D. Taverney, retired and Col James D. Rendleman, retired . . . 53

Legislative Perspective

Weapon Systems Acquisition Reform Act
Maj Jung H. Ha . . . 66

Book Review

Arms and Innovation: Entrepreneurship and Alliances in the Twenty-First-Century Defense Industry
Mr. Edward T. White . . . 70

Next Issue: *International Space*

Acquiring Space Systems in an Uncertain Future: The Introduction of Value-Centric Acquisition

Dr. Owen C. Brown
Chief Technology Officer, Kinsey Technical Services, Inc.
Chantilly, Virginia

Mr. Paul Eremenko
Program Manager, Tactical Technology Office
Defense Advanced Research Projects Agency
Arlington, Virginia

…Pentagon planners may blithely assume away all uncertainty and essentially bet that the future they forecast is the one that will emerge. In this case the US military will be very well prepared—for the predicted future. But history shows that militaries are often wrong when they put too many eggs in one basket.[1]
~ Dr. Andrew Krepinevich

In an ideal world we would have a crystal ball. Using it we could foretell all future threats: all requirements would be known well in advance, and systems would be built to meet those needs with the requisite acquisition timelines. In the magical sphere, we would see future technical challenges faced in building space systems, and we could visualize the disruptive capabilities that would be deployable in the coming years. Failures would be predictable and designed away or new processes created to avert catastrophic consequences. Space system cost would be estimated to high precision. The entire cycle of planning, procuring, budgeting, and execution would run like clockwork. Risk would vanish. In summary, there would be no uncertainty.

Such a crystal ball is fantasy of course. Uncertainty has always been an unavoidable and inexorable fact of existence: to make matters worse, the ambiguity of the future will only accelerate. In a networked world of well educated benevolent *and* malevolent people and intelligent machines, uncertainty now increases at an increasing rate. In this, the 21st century, linear change has given way to jumps, or substantial discontinuities that ultimately shape our world. Elements under our main control in the acquisition framework—namely the space systems we build—have become so complex that great uncertainty exists in their successful procurement and operation.

Given we cannot *predict* the future, we are left with only one alternative: we must *prepare* for a future of uncertainty for the entire life cycle of all military systems. This impetus is particularly strong for space systems, which are high-value assets with lengthy development timelines, and which cannot be easily accessed for the duration of their operational life. The inevitability of an uncertain future *does not* mean that we throw up our hands, and simply wait to react to future shocks (eschewing the planning process). It *does* mean that we must explore a variety of potential futures (including very ambiguous ones), and create strategies and policies, as well as technical and architectural solutions that provide hedges for a variety of circumstances that could occur. In our domain, the manifestation of such an approach will be the acquisition of *flexible* and *robust* space systems. Flexibility will provide options for change throughout a space system's lifecycle (to include conceptualization, design, build, launch, and operations). Robustness will further enable our space assets to operate, as planned, through a variety of threatening environments. Today our space systems are notoriously inflexible and lack the robustness to survive in a variety of stressing scenarios, including programmatic ones. Requirements changes and technology readiness impediments can break these systems. The ability to rapidly scale, evolve, adapt, or maintain on-orbit space system assets (although demonstrated to a degree) has not yet been accepted or demanded for the national space architecture. Worse still, the complexity of our space systems creates a brittleness that threatens their successful deployment, regardless of the time spent developing them. We continue to be held hostage to a "one strike and you're out" architecture. After five decades, why have space systems not evolved to meet the demands of change? We argue that it is the current acquisition framework, one that rewards cost minimization for a fixed set of requirements, which leads us to build inflexible and non-robust systems. These systems and the process used to deliver them are, in themselves, a clear and present danger in a world of uncertainty. The counter to this cost-centric approach is the development and integration of what we call a *value-centric acquisition* framework. This value-centric model provides a rational and *quantitative* framework for trading flexibility, cost, performance, and risk. Using this methodology, tools are provided to decision makers which allow them to plan appropriately for an uncertain future, constrained only by the resources made available to them.[2]

The Status Quo: Cost Centric Acquisition

McNamara's lasting systems legacy was the Planning, Programming, and Budgeting System (PPBS)…. It was a laudable approach to solve industrial era system complexity, which sought to match a complex analytical tool to the growing complex programs needed for defense in the early 1960's…. Unfortunately Department of Defense is still using this method forty years after its introduction. The rudimentary understanding of the complexities of the Information Age is its chief failing today…[3]
~ CDR Gregory Glaros, Office of Force Transformation

Before we describe value-centric acquisition, it is important to understand the historical development of today's cost-centric practices. This history begins with the 1960 appointment of the late Mr. Robert S. McNamara as secretary of defense, which brought about the most radical re-thinking of government procurement practices that had ever been undertaken. McNamara had started his career teaching analytical approaches to business decision-making at the Harvard Business School. During World War II; he worked for (then) Maj Gen Curtis LeMay analyzing the effectiveness of various bombers and helping systematically coordinate the allies' global bombing campaign. In 1946, McNamara joined the Ford Motor Company with a group of other young quantitative analysts—the so-called "Whiz Kids"—from General LeMay's staff. For the next 14 years, McNamara held various senior management positions at Ford, culminating in his ascent to the firm's presidency. His time at the auto maker is, perhaps, best remembered by the prescient admonition to his engineers: "Put in value, not cost."[4] McNamara emerged as an ardent advocate of safety, fuel efficiency, and reliability, while the prevailing wisdom in the industry (and among much of the rest of Ford's managers and engineers) favored size, chrome, and horsepower. Thirty four days after being named the company's president, McNamara accepted an offer from President-elect John F. Kennedy to run the Pentagon.

Nearly simultaneously with McNamara's appointment as Secretary of Defense Charles J. Hitch, an economist at the RAND Corporation, published a report (and later book) titled *The Economics of Defense in the Nuclear Age*.[5] The work was a summary of economic techniques applied to defense planning. Its major contribution was an extensive treatment of the application of economic tools to defense decision-making, particularly in the realm of procurement. It was the Harvard economist Mr. John Kenneth Galbraith who—having originally recommended McNamara to Kennedy for the Pentagon job—encouraged McNamara to read the book and meet with Hitch.[6] McNamara was enamored. Hitch's work formalized many of the ideas that McNamara had practiced and advocated for years. In January 1961, Hitch was appointed assistant secretary of defense (comptroller) and charged with architecting a new budgeting system for the Pentagon: enforcing the philosophy of his RAND work, he instituted what came to be known as PPBS in the course of a mere six months in 1961—in time to apply it to the fiscal year 1963 defense budget submission.[7]

In a 1965 retrospective on PPBS, Hitch described the resultant process of the system:

> Thus, the problem of allocating resources within the Department of Defense itself involves the choosing of doctrines, weapons, equipment, and so forth, so as to get the most defense out any given level of available resources or, what is logically equivalent, to achieve a given level of defense at the least cost.… Approaching the problem from the second point of view—achieving a given level of defense at the least cost, *which is the way Secretary McNamara prefers to look at the problem* [emphasis added]—we work in terms of marginal products and marginal costs in order to help the top decision-maker choose the appropriate level of resources.[8]

So, in the end, the analysis used in the PPBS process to determine the "best" system (in our specific case space systems) has a foundation on minimizing cost for a fixed set of requirements. As described in a previous *High Frontier Journal* article by Dr. Owen C. Brown and Mr. Naresh Shah,[9] the relevant result of this philosophy is the procurement of large, monolithic, and relatively long-lived space systems: Decision makers respond to increased marginal cost by increasing the scale of spacecraft to maximize the overall capability/cost quotient, and increasing lifetime to minimize amortized annual costs.[10] In a perfect world of no uncertainty (or certainty of the uncertainty) this is an appropriate decision. The scars of real world experience illustrate the true problems of this approach. These space systems, which (because of their complexity) take years to design and build, are designed to meet requirements based on the today's threat forecasts. With constantly changing threat environments, requirements change during the design and build phase. The result is redesign, which costs time and money for a large, tightly coupled system. Once launched, there is little hope the capability of a space system can be adapted to a new threat. Carrying multiple payloads, it takes a delay with only one of those payloads to delay the entire program and hence result in cost-overruns. Putting all eggs in one basket, the failure of a launch results in incredible setback—the same is true of a potential on-orbit attack or debris collision. All of these examples imply risk—but there is also little opportunity. New technologies advance at a breakneck pace. For the most part, technology growth is exponential, following Moore's law (more or less). But, technologies can also be disruptive, ushering in unpredicted capability in what seems to be overnight. These new technologies sit waiting for literally a decade or more, on the shelf, before being integrated into the next block of spacecraft or new spacecraft series to take advantage of them (the reverse, of course, is also true: some spacecraft may wait around a decade for a new technology to be matured).

There are possible technologies and architectures that can limit the risk and enhance the opportunities in space systems discussed here. These approaches include:

- Distribution, such as building multiple smaller satellites that provide the same capability as a large one.
- Modularization—already adopted to a significant extent in new naval and aircraft architectures and being developed for satellites at the Air Force Research Laboratory—provides a plug-n-play approach for payloads and other components.[11]
- On-orbit servicing—demonstrated autonomously in Defense Advanced Research Projects Agency's (DARPA) Orbital Express demonstration—allows the means to upgrade and maintain space systems.[12]

DARPA's System F6 fractionated spacecraft program combines the strategies of distribution, modularization, and servicing into a single architecture, creating "virtual spacecraft" made up of free flying, wirelessly networked elements.[13] These newer approaches to spacecraft lifecycle management all have the hallmark of flexibility: by adopting these solutions, options would be provided to decision makers to change a space system, relatively rapidly, at any time in the lifecycle. Likewise, they offer greater robustness, as replacement strategies can be employed more rapidly, plus there is resiliency (graceful degradation) in the event of failure. The challenge is that the cost-centric acquisition framework provides no incentives for the development of flexible systems, and also makes it difficult to fully measure the impact of robustness features on cost and benefits. For a fixed set of requirements, flexible systems most probably cost more (assuming no or little uncertainty) than the conventional counterpart, and therefore are disadvantaged in a cost-centric analysis of alternatives. Of course, one could "require" flexibility. But how would such flexibility be measured and specified? What are the units of flexibility? Does that flexibility curtail capability or add to it? What will that flexibility cost? How much should one be willing to pay for it? Several single function spacecraft cost more than a multi-payload monolith, but are less prone to catastrophic loss of all capability: is this approach "worth it"? These are the pertinent questions that would be asked in the systems analysis required by Planning, Programming, Budgeting, and Execution System (PPBES), and rightly so. At present, there are no tools provided in the decision making process to make appropriate trades in flexibility, cost, risk, and performance. Value-centric acquisition principles, if adopted, could change that problem.

A New Approach: Value Centric Acquisition

I will never get to know the unknown since, by definition, it is unknown. However, I can always guess how it might affect me, and I should base my decisions around that.[14]

~ Nassim Nicholas Taleb

We introduce here the notion that the acquisition of space systems should be based on cost-benefit analyses firmly rooted in the metric of *net present value* (NPV)—and hence our approach is deemed "value centric acquisition." NPV, a measure used in making daily investment decisions in the business sector, is simply the *value* of a project, less its cost, over the lifecycle of the project. Inflows (value) and outflows (cost) are both measured in dollar units. Out-year net values are *discounted*. This technique accounts for a simple law of finance: a dollar received tomorrow is worth less (now) than one received today.[15] This follows from the notion that there is a time value of money. Put another way, there are opportunity costs for waiting for a valuable commodity. We then introduce a second element into this acquisition model—uncertainty. The lifecycle of a space system can be viewed as a series of uncertain events: the performance over time with the system is fully dependent on the interaction of these events. In this model, each key event has a possible distribution of outcomes. For example, a threat capability may slightly change with a probability of 15 percent, or dramatically change with a probability of 60 percent. Likewise, it may be predicted in pre-Phase A that the delivery of a TRL-3 payload has a 5 percent chance of occurring within one month of schedule, and a 80 percent chance of occurring two years late.[16] A launch may have a 98 percent chance of success. A specific hostile space event may have a 50 percent chance of taking place, conditioned on a regional conflict taking place. All such events can be modeled in a simulation.[17] If any options (such as the option to upgrade a system in-orbit) have been built in, they can be exercised in the simulation when the model determines an event has occurred which acts as a "tripwire" for that change. At the end of a single simulation run, a lifecycle cost and value (and hence a NPV) for a given system design will result. After another simulation run, events will take place in different fashion (because of the random nature of events) resulting in a different lifecycle cost and value (either better or worse than the previous). Through execution of many, many simulations, a distribution of possible outcome in cost and value will be accumulated.[18] The range of possible outcomes is representative of the uncertainty in cost and value which is intrinsically based on the forecast of many possible futures.

Placing value on a space asset requires a pricing scheme for its services. Presently, most space systems are purchased on a cost-plus basis, but this provides little information of their true value to the stakeholder.[19] But, current value based pricing models exist for many commercial space products (as a market exists), many of which are purchased by the government. Commercial communications bandwidth is valued and purchased on a per bit basis: the authors have previously conducted a NPV analysis of a satcom service for monolithic and fractionated architectures using reasonable market rates and demand variations.[20] Satellite imagery is sold commercially on the basis of image resolution. These value models could serve as an initial basis for the dollarization of equivalent military capability. Valuation of other space system products currently not offered on a commercial market has been performed: In a cost-benefits analysis conducted by National Oceanic and Atmospheric Administration for the Geostationary Operational Environmental Satellite Block R, the present value of the data products delivered by both payloads (imager and sounder) was calculated. Recognized as a lower bound in the estimates, the monetized benefits came from many stakeholder categories, including aviation (e.g., cost savings by reducing weather delays) and agriculture (e.g., frost mitigation). Benefits of other systems (e.g., GPS, reconnaissance missions) might prove more difficult to quantify in dollar terms, but techniques based on stakeholder interviews exist which can develop value relationships with capabilities.[21] Seemingly more elusive still are space systems designed to support others: in this case the value of such systems is derived specifically from the value of those systems supported.

Using the net value approach, with uncertainty modeled, many new insights arise during the analysis of alternative architectures and systems design of the most promising ones. Specifically:

1. **Flexibility is measurable and can be traded with cost.** In today's acquisition framework, flexibility has no units, and therefore measures of effectiveness are elusive and arbitrary. In an analysis of alternatives for example, flexibility may be given a qualitative score, such as "high" or "low." This score is typically somehow weighted and analyzed, apart from the base system capability scoring, and then added as part of the total score. But, in value-centric analysis with uncertainty modeled, flexibility is quantifiable *in dollar terms*. With flexibility, the capability of the system (hence its value) can be maintained and even increased once a change is made to the system. Say for example we build in the flexibility for a communications satellite to have its computer upgraded on-orbit. We can forecast today that a new computer may have twice the processing speed in three years. In this scenario, as-

sume that if this old computer is exchanged with the new one, the spacecraft can use an advanced signal processing algorithm that increases its bandwidth by 50 percent; hence, if value grows directly with bandwidth, the value of the system increases 50 percent at that time. In this case, the value of flexibility is the net value added to the system over its remaining lifetime because of the added bandwidth capacity. In this example, there would be added cost for serviceability, and it comes in two forms. First, adding the capability of servicing will add additional fixed cost to the spacecraft. Second is the cost of the actual servicing mission, but this cost would be optional—one could decide not to upgrade, and live with the system as is for the entire life of the system. Thus, from this approach it can be seen that flexibility value, measured in dollars, can be traded with cost. Note two other important features of flexibility that this example points out. First, the value of flexibility—which is measured apart from the cost—is *derived* from the value of an underlying asset. In this brief example, the value of flexibility is specifically derived from the value of communications capability. Many trades are currently done (incorrectly) with flexibility as a score separate from baseline capability: but, without capability, flexibility is worthless. Secondly, this example demonstrates that flexibility implies a choice: it is the right, but not the obligation, to exercise change in the future. This delineation is the formal definition of an *option*—like a stock option, where the owner has the right, but not the obligation to purchase stock in the future. Stock options have true monetary value, a value that can be determined using analysis that looks at the value of the underlying asset (the stock in this case) and the probability of future events changing the value of the asset (more often referred to as volatility). A body of academic work was started at Massachusetts Institute of Technology several years ago using options analysis to value space system flexibility by former Air Force Chief Scientist Dan Hastings (now the dean of undergraduate education and a professor in the Department of Aeronautics and Astronautics).[22] This work continues to serve as motivation for the acquisition philosophy amplified in this article.[23]

2. **Alternatives can be traded against one another based on value, cost, and *quantifiable risk*.** Risk analysis and management is based today on the use of the infamous tricolor (red, yellow, green) risk chart. The value-centric approach embraced here allows risk to be quantified—where risk is now the downside *variance in potential outcomes of cost* (and similarly, the value variance, specifically upside value, is a measure of opportunity). Thus, not only can alternatives be traded on a basis of possible net value, but also risk (to net value). In this context, many categories of robustness—such as resiliency and survivability—become quantifiable elements that limit risk throughout the lifecycle. A new feature introduced is that the risk tolerance or aversion of the relevant stakeholders can be explicitly and quantitatively incorporated into architectural decision-making, for example, the extent to which one might distribute or fractionate a system, and so forth. This is very similar to the way in which any investor of mutual funds chooses a plan—it is based not only on expected increase in value, but also the risk of the investment. Note that using the uncertainty analysis approach, managers can play a much more active and controlling role in the risk management process: a tool is now available that provides insights into how programmatic and design decisions quantitatively impact uncertainty in outcomes. Thus, changes in program philosophy or design can be analyzed in terms of the quantitative impact they have on program risk. This insight should undoubtedly lead to a further embrace of a portfolio of approaches that appropriately balance cost, value, and risk, including alternate architectures that are non-conventional (e.g., ground based solutions).
3. **The value of responsiveness is quantifiable and can be traded with cost and capability.** Discounting future cash flows in the NPV based analysis reveals the higher value of a capability when it is received sooner. Often we hear of the "70 percent solution" as the prototype of an approach that can get a space system (confidently) delivered sooner and less expensively than the total (100 percent solution). The NPV approach will allow the 70 percent and 100 percent system solutions to be compared equitably, with distinct value metrics provided to determine the benefit of one approach versus the other.
4. **A better measure of both cost and value uncertainty can be made, and therefore confidence in predictions can be much higher.** One of the key tenets of the net value approach is to utilize uncertainty in key events to forecast possible outcomes. Thus, both cost and value estimates yielded in the net value analysis are not discrete numbers, but rather are random variables contained within a probability distribution. Most conventional cost estimates performed today are given probability distributions, but the practice that leads to these estimates is specious. Current cost analysis uncertainty estimates are based on the uncertainty *in the cost estimating relationships that are derived from curve fits of programs in the past*. The more optimal approach described is to base uncertainty on costs *based on the forecast uncertainty of key events for the actual program in the future*.[24] The enormous advantage this approach provides is that the stakeholder now can quantify the impact of trade decisions on possible cost growth, as well as value growth (which would be a function of the flexibility built into the system!). This uncertainty analysis process also is used for the launch and operations phase of programs, which can be important in quantifying the *robustness* of architecture. A distributed satellite approach using multiple launch vehicles, for example, has been shown to be more robust to possible launch failures, as compared to a monolithic system launched on a single launch vehicle.[25] The latter "all eggs in one basket" approach means significant value is lost should the launch fail. If a replacement is built, additional cost is incurred,

and the value of the replacement is diminished because of the delay (accounted for in the discounting process). A distributed approach results in only partial reduction of capability, the impact of which if fully quantifiable in the value centric analysis. Of course, this effect needs to be traded with the extra potential costs of the distributed approach, which most probably would exceed that of the monolithic architecture *if everything goes right*. This same analytical approach also is suitable for the studying the impact of survivability and resiliency of systems in a threat environment.

Before ending this present discussion, we must note one of the much-touted reforms of the 1990s to the defense procurement process—that of "best-value" contracting, whereby more than just the cost of a system (for a given level of performance) is considered in procurement decisions; specifically, the alternative that offers the "best value to the government" is selected.[26] Unfortunately, while a good idea in principle, this particular acquisition reform fell far short of the mark. The impetus behind best best-value contracting was to provide an incentive scheme for rewarding systems that had desirable non-performance and non-cost attributes such as quality and schedule. In performing systems analyses or in making source selection decisions, these additional attributes are combined—either quantitatively or qualitatively—using an arbitrary weighting scheme to evaluate alternative systems.

There are at least two problems that compromise the merits of this approach. First, attributes such as flexibility and robustness, for which no commonly accepted definitions much less quantitative metrics are available (within the current acquisition framework) are still universally excluded. Second, the arbitrary weighting scheme provides no assurances that optimal balance between cost, performance, and other system attributes is attained. In fact, by imposing an ambiguous "best value" criterion in place of a clear and quantitative (albeit sub-optimal) minimum-cost one, the designer's ability to optimize the system is compromised. While the procurer undoubtedly has some conception of his relative weighting of the attributes, this is treated as private information by the procurement process (i.e., it is not disclosed to the performers proposing alternate system designs), they do not provide a viable metric for design optimization.[27] The value-based source selection criterion which we advocate here is much different than this existing "best value" paradigm by revealing quantitative measures of value and cost, based on design decisions.

Integration into the Planning, Programming, Budgeting, and Execution System—What Would Hitch Think?

Our proposal to use value centric analysis in space acquisition is modest in its scope but dramatic in its ramifications. We do not purport to supplant the half-century of wisdom that has accrued in what is today PPBES. We seek only to replace the criterion for selecting among alternatives for effecting a particular capability that nominally takes place during the programming activity. At the same time, comparable changes would need to take place in the criteria employed during execution, specifically in source selection, contract execution, and effects analysis.

So what would the creator of PPBS, Charles Hitch, think of this value centric approach, as opposed to the cost centric approach he advocated in writing 45 years ago? If one returns to the principal document that Hitch authored 50 years ago, which catalyzed his appointment to the Pentagon, answers can be found. In *The Economics of Defense in the Nuclear Age*, Hitch wrote, "In principle, the criterion we want is clear enough, the optimal system is the one which yields the greatest excess of positive values (objectives) over negative values (resources used up, or costs)." This articulated an identical criterion to the one that we have advocated here—net value. "But," Hitch continued, "this clear-cut ideal solution is seldom a practical possibility in military problems. Objective and costs usually have no common measure: there is no generally acceptable way to subtract dollars spent or aircraft lost from enemy targets destroyed. Moreover … there may be multiple objectives or multiple costs that are incommensurable."[28] Hence, Hitch was presented with two issues in implementing a value based approach. First, he understood the difficulty in monetizing capability. Second, there are "incommensurable" criteria that are likewise difficult to quantify. We have suggested approaches here that tackle the issue of monetization. In fact, space systems can be much easier to dollarize than other military systems, as commercial analogues exist for many capabilities. Flexibility and robustness seem to be difficult to quantify and to compare with cost, but the uncertainty analyses introduced here tackles that problem. Therefore, we believe that value-centric acquisition conforms more closely than cost minimization to Hitch's original thesis, and even to McNamara's admonition to his Ford Engineers, "Put in value, not cost."

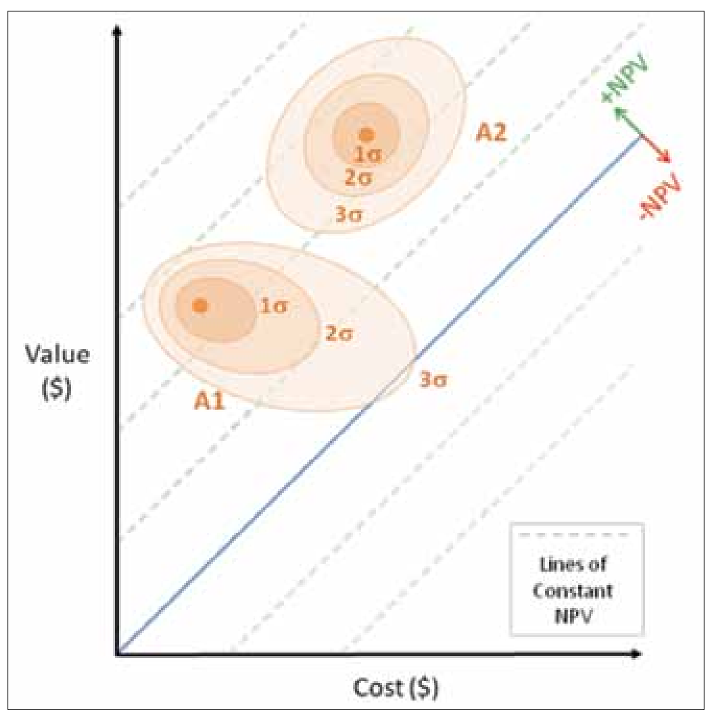

Figure 1. Plot comparing the cost and value distributions of two hypothetical space system architectures (A1 and A2).

A Brief Example of the Value-Centric Approach

NPV analysis, including an acknowledgement of the possible variation in cost and value inherent because of uncertain events, is the fundamental tenet of value-centric acquisition approach. An example is provided here to provide a better grasp of the concept. Figure 1 provides a notional depiction of a NPV comparison of two hypothetical space architectures. The horizontal axis of the graph is cost, in dollars. The vertical axis is value, also in dollars. Lines of equal NPV are shown as dashed lines for reference. The bold green line represents the points of zero NPV for all costs (the "break even" solution); all points above the green line have greater value than cost, and all points below the green line have greater cost than value. Architecture 1 (A1) is representative of a tightly coupled, complex, (but typically "cheaper") monolithic system, whereas Architecture 2 (A2) is representative of a distributed system. Both systems are designed to have the same initial baseline capability. Uncertainty ellipses are shown for A1 and A2 representing 1-sigma, 2-sigma, and 3-sigma confidence levels (equivalent to 66 percent, 95 percent, and 99.7 percent confidence levels, respectively). The first obvious behavior of uncertainty profiles is that A1 has a much larger range of levels in cost as compared to A2. This is a feature symptomatic of the monolithic approach where all eggs have been placed in one basket, and therefore all value is potentially spoiled at once (for example, a launch failure results in total loss of capability). Next note that the uncertainty profile of A1 goes down and to the right. In the case of total failures, the only path to recovery is to start over, which adds costs, but delays availability. With discounting, the value decreases. The effect is the same for delays in integration and test due to component delays etc. Hence, as cost builds, value decreases. For A2, the cost spread is reduced, and in fact, a large percentage of possible A2 costs lie in the same region of possible costs for A1. Fundamentally, this is the result of distribution: a loss or delay in one element does not result in total loss of the system: it is more robust. A2 also demonstrates a behavior in uncertainty profiles that as cost increases, so does value. This would be attributable to the value of flexibility. For example, a distributed system can be scaled—elements can be added as demanded to increase capability. Hypothetically, new elements can be added much more quickly with newer technologies. Is the increased value worth the added cost? In this case, note that as more costly solutions are chosen for A2, in general the NPV increases (as the solutions move to higher NPV lines). Thus, in this case, flexibility is worth the added cost. This approach is totally different from the conventional cost-centric deterministic approach: most likely a specific cost for each architecture would be determined for a notional case, with A1 showing the least cost in the "perfect world" scenario. Although this example is purely hypothetical, it is consistent with results obtained from four separate contractors who performed value-centric analyses of fractionated versus monolithic architectures in the first phase of DARPA's System F6 program.[29, 30, 31]

Conclusion

…In preparing for battle I have always found that plans are useless but planning is indispensable.

~ Dwight D. Eisenhower

We have introduced the concept of value-centric acquisition as a possible path to improved decision making in today's dynamic world. Rather than providing a crystal ball that allows us to better predict the future, value-centric acquisition acknowledges uncertainty, and provides a quantification of risk and opportunity, which are functions of programmatic and design decisions. Put another way, both flexibility and robustness—the prescriptions to uncertainty—become measurable units and can be traded with cost and performance. In this approach, we resist the technocratic urge to conclude that a few formulas will lead to perfection in plans and execution. We instead acknowledge the complexity of systems and the unpredictability of events: in the process we provide a technique that allows decision makers to determine a system's possible distribution of costs and benefits in a world of potential futures. The key to our approach is the introduction of the net value metric, which is an analogue to NPV in widespread employment for private-sector decision-making. We fully understand that our military space systems are not built to make money—but they are built to provide value to the warfighter. Our net value approach provides a new toolset that will provide the best assurance (and insurance) that our men and women in harm's way have the capability they need, when they need it. In fact, this approach may usher in more rapidly capability the warfighter had no idea could exist. In essence, our approach is a return to the gain-minus-cost formulation which the founders of PPBS, McNamara, and Hitch, rejected due to the problem of incommensurables. A half-century of progress in microeconomics, finance, and decision theory has placed it firmly within the realm of solvability.

Notes:

1 Andrew F. Krepinevich, *Seven Deadly Scenarios*, Bantam Books, February 2009.

2 A detailed description of the value-centric framework contained in this article is forthcoming in Owen Brown and Paul Eremenko, *Value-Based Decision-Making for Defense* (Cambridge University Press, 2010) (in draft).

3 Gregory Glaros, "Real Options for Defense," *Transformation Trends*, 6 June 2003.

4 Richard A. Johnson, "The Outsider," *Invention and Technology Magazine* 23, no. 1 (Summer 2007).

5 Charles J. Hitch and Roland N. McKean, *The Economics of Defense in the Nuclear Age*, Report No. R-346, (RAND Corporation, Santa Monica, CA, 1960). Later published in book form under the same title by (Harvard University Press: Cambridge, MA, 1961).

6 Alex Abella, *Soldiers of Reason: The RAND Corporation and the Rise of the American Empire* (Harcourt Trade, 2008), 135.

7 Charles J. Hitch, *Decision-Making for Defense* (University of California Press: Berkeley, CA, 1965), 29.

8 Ibid., 52.

9 Naresh Shah and Owen Brown, "Fractionated Satellites: Changing the Future of Risk and Opportunity for Space Systems," *High Frontier Journal* 5, no. 1 (November 2008).

10 Owen Brown, Paul Collopy, and Paul Eremenko, "Value-Centric Design Methodologies for Fractionated Spacecraft: Progress Summary from Phase 1 of the DARPA System F6 Program," paper presented, AIAA Space 2009 Conference and Exposition, Pasadena, CA, 14-17 September 2009.

[11] Jim Lyke, "Packaging, Plug-and-play, Modularity and the Impact of Wires," paper presented, CANEUS 2007, Dallas, TX, 28 March 2007.

[12] Owen Brown, Fred Kennedy, and Wade Pulliam, "DARPA's Space History," *Success Stories in Satellite Systems* (American Institute of Aeronautics and Astronautics, 2009) chapter 16.

[13] Owen Brown, Paul Eremenko, "The Value Proposition for Fractionated Space Architectures," paper presented, AIAA-2006-7506, AIAA Space 2006, San Jose, California, 19-21 September 2006.

[14] Nassim Taleb, *The Black Swan: The Impact of the Highly Improbable* (Random House, 2007), 210.

[15] OMB Circular No. A-94, "Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs."

[16] Delivery time as a function of TRL has indeed been modeled. See Gregory Dubos, Joseph Saleh, and Robert Braun, "Technology Readiness Level, Schedule Risk and Slippage in Spacecraft Design: Date Analysis and Modeling," paper presented, AIAA 2007-6020, Space 2007 Conference and Exposition, September 2007, Long Beach, CA.

[17] Disagreements of course can arise on the uncertainty distributions of the key events: we propose that what is most important is not to be certain of the uncertainties, but rather understand the sensitivity of outcomes to a range of possible inputs.

[18] This more specifically is an example of a Monte Carlo simulation process.

[19] The other problem with this valuation strategy is that it would by default result in a positive net present value for all choices, and all choices would have net present values in the same range, more or less.

[20] Owen Brown, Paul Eremenko, and C. Roberts, "Cost-Benefit Analysis of a Notional Fractionated SATCOM Architecture," paper presented, AIAA-2006-5328, 24th AIAA International Communications Satellite Systems Conference, San Diego, California, 11-14 June 2006.

[21] One such method of overcoming the problem of valuing non-market based attributes comes from the field of decision theory. See, for example, John vonNeumann and Oskar Morgenstern, *Theory of Games and Economic Behavior* (Princeton University Press, 1947); Ralph Keeney and Howard Raiffa, *Decisions with Multiple Objectives: Preferences and Value Trade-Offs* (Cambridge University Press: Cambridge, UK, 1993).

[22] See, for example, Joseph Saleh et al., "Flexibility and the Value of On-Orbit Servicing: New Customer-Centric Perspective," *Journal of Spacecraft and Rockets* 40, no. 2 (March-April 2003), 279-291; Rania Hassan et al. "Value-at-Risk Analysis for Real Options in Complex Engineered Systems," working paper, MIT Engineering Systems Division, ESD-WP-2005-03, 2005.

[23] Some have vociferously objected to the use of the options framework in the context of procurement planning, given the recent failure of derivative vehicles in the sub-prime loan crisis. We reject these notions. The chief lesson from this crisis is that models used to value derivatives should be well understood, and uncertainty properly acknowledged in the model inputs. Equity markets have not disposed of hedging strategies because of the recent financial meltdown, and rely on them especially in today's volatile economy.

[24] Of course, there are assumptions that must be made in predicting the possible outcomes of key events.

[25] Owen Brown, "Reducing Risk of Large Scale Space Systems Using a Modular Architecture," paper presented, Aerospace Corporation Space Systems Engineering and Risk Management Symposium, Manhattan Beach, CA, 2004.

[26] The Federal Acquisition Regulations (FAR) § 15.302.

[27] FARs require only that the relative importance of source selection factors be stated, i.e., that they be ordered from most- to least-important and that a "state[ment] whether all evaluation factors other than cost or price, when combined, are significantly more important than, approximately equal to, or significantly less important than cost or price" be made. FAR §§ 15.101-1, 15.304(d)-(e). Thus, no actual quantitative weightings of the KPIs need be supplied to the offerors.29

[28] Charles J. Hitch and Roland N. McKean, *The Economics of Defense in the Nuclear Age*, Report No. R-346, (RAND Corporation: Santa Monica, CA, 1960), 120.

[29] Dragos Maciuca et al., "A Modular, High-Fidelity Tool to Model the Utility of Fractionated Space Systems," paper presented, AIAA Space 2009 Conference and Exposition, Pasadena, CA, 14-17 September 2009.

[30] David McCormick et al., "Analyzing Fractionated Satellite Architectures Using RAFTIMATE—A Boeing Tool for Value-Centric Design," paper presented, AIAA Space 2009 Conference and Exposition, Pasadena, CA, 14-17 September 2009.

[31] E. Eichenberg-Bicknell et al.,"Using a Value-centric Tool Framework to Optimize Lifecycle Cost, Value, and Risk of Spacecraft Architectures," paper presented, AIAA Space 2009 Conference and Exposition, Pasadena, CA, 14-17 September 2009.

The views, opinions, and/or findings contained in this article/presentation are those of the author/presenter and should not be interpreted as representing the official views or policies, either expressed or implied, of the Defense Advanced Research Projects Agency or the Department of Defense.

Dr. Owen C. Brown (BS, Engineering Science, Loyola College Baltimore; MS and PhD, Aeronautical and Astronautical Engineering, Stanford University) is the chief technology officer for Kinsey Technical Services, Inc. He recently completed six years of service as a program manager in the Tactical Technology Office (TTO) at the Defense Advanced Research Projects Agency (DARPA) in Arlington, Virgina. He was the program manager for the design, integration, test, launch, and demonstration of the joint DARPA, Air Force, and Navy Microsatellite Technology Experiment. He conceived the fractionated spacecraft approach, and managed the first phase of the System F6 program. Dr. Brown served on active duty in the US Navy from 1984 to 1990 as a nuclear trained submarine officer; he was assigned to the fast attack submarines USS Flying Fish (SSN 673) and USS Sturgeon (SSN 637) in a variety of engineering and operations positions. At Stanford he acted as a teaching assistant for graduate propulsion courses, and was a research assistant at the NASA Ames Research Center. He was employed at Space Systems/Loral in Palo Alto, California for seven years as a spacecraft reliability, propulsion, and systems engineer. From 2001 to 2003 he served with Booz Allen Hamilton as a technical consultant to DARPA/TTO for space programs. He led technical efforts for the Rapid Access Small Cargo Affordable Launch program in this position. Dr. Brown transitioned to a retired status in the Navy Reserve with the rank of commander after 20 years of combined active and reserve duty. He is the author of many technical papers, and has acted as a distinguished lecturer for the American Institute of Aeronautics and Astronautics on space history and aerospace topics.

Mr. Paul Eremenko (BS, Aeronautics and Astronautics, MIT; MS, Aeronautics, Caltech; JD, Law, Georgetown) is a program manager in the Tactical Technology Office of the Defense Advanced Research Projects Agency (DARPA). His primary area of focus is on developing technological solutions to the challenges of design and procurement of defense and aerospace systems of rapidly increasing complexity; he is interested in novel architectures, technologies, design flows, tools, verification approaches, and acquisition methodologies. He is also the current program manager for the System F6 fractionated spacecraft demonstrator effort. Prior to joining DARPA, Mr. Eremenko was a strategy consultant with the Global Aerospace and Defense practice of Booz Allen Hamilton. He began his career as an aircraft design engineer at the Charles Stark Draper Laboratory and subsequently as the lead project engineer on the GoldenEye-100 unmanned aerial vehicle at Aurora Flight Sciences.