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Transforming the Acquisition Enterprise: A Framework for Analysis and a Case Study of Ship Acquisition

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ABSTRACT

The acquisition of public sector complex systems is time-consuming, very expensive, and rife with uncertainties. The enterprise associated with acquisition is an excellent candidate for transformation—fundamental change to achieve substantially higher levels of value. This paper argues that choosing among alternative transformation initiatives should be based on an enterprise-wide perspective as well as systematic economic valuation of the alternative investments. An options-based methodology for assessing the economic value of alternative initiatives is presented and illustrated in the context of military ship building. © 2007 Wiley Periodicals, Inc. Syst Eng 10: 99–117, 2007

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1. INTRODUCTION

Enterprises that acquire public sector complex systems face serious cost challenges. Costs of military platforms (e.g., ships), space platforms (e.g., space stations), and

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transportation systems (e.g., airports) have increased enormously in the past few decades, far beyond inflation during this period. Consequently, the public sector enterprises that acquire these systems anticipate buying fewer of them. This tends to sacrifice needed capabilities as well as exacerbate the cost challenges.

This paper addresses the question of assessing the economic value of investments to transform the overall acquisition enterprise and ameliorate these problems. The model of the enterprise adopted includes political entities (e.g., Congress), government agencies (e.g., the military services), contracting companies (e.g., defense contractors), workforce organizations (e.g., unions), development and construction facilities (e.g., ship yards), and suppliers to facilities. Use of the model to frame transformation initiatives and assess their economic value is illustrated in the context of military shipbuilding.

A portfolio management approach is outlined that enables understanding and balancing the returns and risks associated with alternative investments. Investments of interest include rationalizing of authorization and acquisition processes, streamlining of acquisition policies and practices, accelerating bid and proposal processes, modifying work processes and procedures, redesigning incentive and reward systems, and, of course, investments in improving systems themselves. The methodology presented enables assessing the returns and risks associated with particular transformation initiatives.

This paper proceeds as follows. First, we discuss the history of acquisition reform and identify past failures. The characteristics of these failures serve as the motivation for the approach presented in the paper. Next, we present a conceptual model of the acquisition enterprise that serves as the context within which to consider any potential efforts to fundamentally change the enterprise. We then outline a portfolio approach that allows us to compare potential transformation efforts in terms of risk and return. This facilitates a methodical approach to selecting among proposed initiatives.

Using this overall framework for analysis, we present a method to evaluate the return and risk for each transformation proposal. In particular, we advocate the use of options analysis over traditional discounted cash flow methods to properly capture the risk mitigation effects of staging typical of government projects. We introduce the use of price indexing as a means of overcoming the lack of monetary value attached to government acquisitions. Finally, we use Monte Carlo simulation to capture the risk inherent to any reform effort. We demonstrate the methods developed with a notional example.

2. BACKGROUND

To an extent, we are addressing the question of the economic value of reforming acquisition. To place our approach in context, it is valuable to understand the effects of previous reform efforts and the current state of research on the acquisition enterprise itself. Our emphasis in this section is on defense acquisition.

2.1. Acquisition Reform

The defense acquisition enterprise is unique; it operates with public funds, with primarily one buyer, little competition, contracts signed years in advance based on cost estimates, and decisions made in complex stages by multiple organizations. The process is infused with disparate goals and objectives: to have the highest performing technology at the lowest price possible in the fastest amount of time; to ensure the defense industry and related economies remain solvent; and to encourage small business, minority contractors, and women-owned businesses [Cancian, 1995]. The number of participants in the acquisition enterprise is large, and they have different goals and measures of success. There appears to be little agreement on what needs to be reformed, let alone how to fix it.

Historically, reforms have been enacted for primarily two reasons: increasing complexity of the technologies involved and individual corruption and abuse for monetary gain. Excesses in time and cost, or deficits in performance, are some of the more obvious outward signs that reform is warranted. But these are just symptoms, and it is instructive to elucidate the contributing factors. First, is the government acquiring the right systems to meet its needs, and second, is it acquiring those systems well?

The first question addresses the agility of the acquisition enterprise. With an ever-changing world, the actions of both adversaries and allies can alter the efficacy of military systems both deployed and under development with little warning. Consequently, a program could be run with perfect efficiency and achieve all of its performance objectives, yet the resulting systems could be useless upon completion. While this does not constitute a failure in the traditional sense, a lack of agility in the acquisition system means that resources continue to be expended on a program even after it is recognized that it is no longer viable.

The second question addresses the efficiency of the acquisition process. That is, assuming that the mission is sound, does the acquisition enterprise deliver systems in the most cost effective way possible? This category includes most of the issues one typically associates with acquisition failings including excessive oversight, lack of competition, political interference, requirements creep, and the inclusion of immature technologies. Issues with acquisition efficiency are linked to the structure of the acquisition process as well as the discipline with which the process is implemented.

With acquisition it is sometimes difficult to define a failure since even troubled programs often result in the acquisition of something. However, in hindsight at least, it is not always the case that the right weapon was acquired to address the right threat. Further, the costs of acquired systems often far exceed original projections, and the desired capability is often provided much later than originally planned. These are the factors that determine the effectiveness of acquisition. History has shown that not all acquisition efforts are successful with regard to these factors. These phenomena can be better illustrated by providing some examples.

Loss of Mission occurs when the threat that was to have been addressed by the system is no longer viable, or a new type of threat emerges. One such example is the B-70 Valkyrie. The Valkyrie was intended to be a high-altitude, Mach 3+ strategic bomber. However, concerns over the aircraft's vulnerability to surface-to-air missiles as well as the increasing dominance of ICBMs in the nuclear strike role lead both the Eisenhower and Kennedy administrations to question its military viability. Eventually, the program was transformed into a research program, the XB-70. Another example of loss of mission is the Drone Anti Submarine Helicopter (DASH). It was originally developed as an expendable antisubmarine platform. However, since submarines were not a significant threat during the Vietnam War, the DASH program was canceled in 1969. Both of these examples illustrate a lack of agility in the acquisition process in that resources were redeployed long after the changing threat had been identified.

Process Failure can cause the cancellation of programs as well. For example, the M247 Sergeant York DIVAD (Division Air Defense gun) was born of the Army's need for a replacement for the ageing M163 20mm Vulcan A/A gun and M48 Chaparral missile system. Despite the fact that the system utilized as much off-the-shelf technology as possible, when the first production vehicles were delivered in late 1983, there were many performance deficits, including issues with the fire control system, clutter handling, turret traverse rate, and ECCM suite. Consequently, in December 1986 after about 50 vehicles had been produced, the entire program was terminated. Of course, most acquisition process problems do not lead to cancellation. Many acquisition programs deliver highly capable systems, but only after delays and cost overruns. An example of such is the F-22 Raptor. Considered one of the most technologically advanced aircraft in the world, it is also one of the most expensive. The program began with the award of the Advanced Tactical Fighter Demonstration/Validation contract in 1986 and achieved Initial Operational Capability in 2005. The inclusion of many advanced technologies such as advanced avionics and low-observable materials helped contribute to the long duration and high cost of the program.

These and many other instances have driven desires for acquisition reform. However, past reform efforts have been less than fully successful, as shown by Drezner et al. [1993]. They reported that reform initiatives from 1960 to 1990 did not reduce cost growth on 197 defense programs. In fact, the average cost growth on these programs was 20% and did not change significantly for 30 years. Christensen, Searle, and Vickery [1999] reaffirmed this conclusion and also found that initiatives based on the specific recommendations of the Packard Commission did not reduce the average cost overrun experienced (as a percent of costs) on 269 completed defense acquisition contracts evaluated over an 8-year period (1988–1995). Actually, cost performance experienced on development contracts and on contracts managed by the Air Force worsened significantly.

In part, this lack of reform success can be attributed to one or more of the causes discussed above. Since the 1980s, the military threat has changed from full-scale thermonuclear war to domestic terrorism, information warfare, and asymmetric warfare. Not only are weapons programs designed for a Cold War threat not always appropriate, but the entire system of acquisition has become too slow to adapt to emerging threats. Performance and politics still have an impact, but the rate of technological change has advanced so rapidly that weapon systems can become obsolete before they leave the design stage. In response, the Department of Defense has attempted large scale, fundamental change in all facets of its operation.

Former Secretary of Defense Donald Rumsfeld made the comprehensive transformation of the Department of Defense a priority during his tenure. While he departed in November 2006, the current Defense Secretary Robert Gates indicated that he shares Rumsfeld's vision of military transformation, centered around a lighter, more mobile force that heavily relies on technology.

Beyond transforming how it pursues military engagement, the DoD has begun transforming its acquisition process to create more efficient and effective ways to acquire goods and services faster, better, and cheaper [DAU, 2005]. The exponential rate of technological advance combined with the availability of new technologies on the commercial market has added a sense of urgency to the acquisition environment. DoD would like to access these advances before adversaries can use them against the United States.

A good example of the type of change sought is the pursuit of evolutionary acquisition strategies that rely on spiral development processes. This approach focuses on providing the warfighter with an initial capability (that may not be the final capability) as a tradeoff for earlier delivery, flexibility, affordability, and risk reduction. The capabilities delivered are provided over a shorter period of time, followed by subsequent increments of capability over time that incorporate the latest technology and flexibility to reach the full capability of the system [Apte, 2005].

In the recent Defense Science Board summer study on transformation [DSB, 2006], it was recommended that the Undersecretary of Defense (AT&L) "should renew efforts to remove barriers that prevent the entry of non-traditional companies to the Defense business and Defense access to commercial technology, attacking the myriad rules, regulations, and practices that limit the use of OTA, Part 12, and other programs to reach beyond traditional defense companies." (p. 33). The study goes on to recommend intense integration with global and commercial supply chains, as well as transforming the export license process.

This brief review shows that acquisition reform has long been sought and the results are mixed, at best. While the call for reform is persistent, these findings raise the question of whether it is possible to transform the acquisition enterprise and to have the varied stakeholders agree to any extent that the process has actually improved. This issue leads to the question of what is known about the fundamental nature of acquisition. This matter is addressed in the following brief review of the current state of acquisition research.

2.2. Acquisition Research

A quick review of recent acquisition research topics indicates a tendency to concentrate on single-issue concepts such as outsourcing, contractors, leasing, privatization, contingency contracting, performance measurement and financial management. Considering the 2004–2006 Annual Conferences on Acquisition Research, topics covered included:

- Acquisition avenues such as market-based acquisition, capabilities-based acquisition, competitive sourcing, and outsourcing
- Acquisition issues such as program management, performance management, and business process reengineering
- Financially oriented topics such as financial management, total cost of ownership, and real option models.

Further, acquisition policy in general was, of course, a recurring theme. While improving the performance and/or judging the effectiveness of each of these topics is worthwhile, it is also important to study the overall acquisition enterprise as an integrated and interactive complex system.

Currently, however, only limited acquisition research is being conducted—primarily by internal DoD organizations, such as the Naval Postgraduate School, Defense Acquisition University, Air Force Institute of Technology, and DoD FFRDC's (e.g., RAND and LMI). Although these research projects offer valuable assessments of current practices and suggestions for improvements, the results are often limited in scope and may only address one specific problem at a time; often replicate previous or parallel work; and generally have limited general application. These efforts constitute only a fraction of the effort that is warranted by the size, complexity, and changing nature of DoD's acquisition challenges. They are not a substitute for disciplined, replicable academic research [Gansler and Lucyshyn, 2005].

No significant reform effort has addressed this issue at the broad enterprise level. Viewing the challenges of the acquisition process from a broad systems-oriented perspective provides an opportunity to understand where change can be leveraged and the economic value of change. We do not claim that this will obviate the impacts of changing threats and technologies, or political forces. However, we will show how rather modest changes of the acquisition process can have enormous economic benefits. We intend this paper as a first step towards showing the economic value of more agile and efficient acquisition processes.

3. THE ACQUISITION ENTERPRISE

There are a variety of economic, political, and social arguments for why acquisition reform has not provided the benefits envisioned. As noted above, our sense is that the lack of a broad view of acquisition has made it difficult to articulate and estimate the economic benefits of acquisition process changes. Further, the lack of a broader view has limited abilities to estimate the increased value of the systems acquired using new processes. This section provides the needed broader view.

3.1. Acquisition Life Cycle

Figure 1 depicts the Defense Acquisition Management Framework provided in the Defense Directive 5000.1 [DoD, 2003]. This process provides both the context for transformation of acquisition and an opportunity, in itself, for transformation. In fact, the ways in which the many stakeholders in the acquisition enterprise exercise this process strongly affect the time, costs, and uncertainties associated with the acquisition of complex systems. In light of the past and current Secretary of Defense's stated transformation priorities, this process would seem to be a good candidate for fundamental change.

3.2. Example of Shipbuilding

Consider the enterprise of military shipbuilding. This enterprise is facing serious cost challenges. Shipbuilding costs have increased enormously in the past three decades, far beyond inflation during this period. It certainly can reasonably be argued that these more expensive ships are much more capable than earlier ships. Thus, you may need fewer ships. It is quite possible, however, that increased costs will cause the number of ships you can buy to decrease faster than new capabilities reduce the number of ships needed. Thus, these cost challenges cannot be dismissed. This situation raises the question of where investments in shipbuilding should be focused. In this paper, we describe a method for assessing the economic value of transforming acquisition processes and use the example of the shipbuilding enterprise to illustrate this method.

As indicated in Figure 2, the enterprise of interest includes a set of stakeholders and issues much broader than those directly associated with the ships of interest. Congress, the armed services, defense contractors, and workforce organizations have significant impact on the returns and risks associated with alternative investments. These stakeholders affect the ship building enterprise in a variety of ways:

- Congressional Interests & Mandates, e.g., Jobs & Other Economic Interests
- Service Interests & Oversights, e.g., Procedures, Documentation, & Reviews
- Incentives & Rewards for Contractors, e.g., Cost-Plus vs. Firm Fixed Price
- Lack of Market-Based Competition, e.g., Hiring & Retention Problems
- Aging Workforce & Lack of Attraction of Jobs, e.g., Outsourcing Limitations, Underutilization of Capacity

The example stakeholders in Figure 2 and their varied interests tend to introduce significant uncertainties into the enterprise. Figure 3 provides a characterization of sources of uncertainty. Clearly, the various stakeholders have significant impacts on uncertainties in terms of both magnitudes and timing of returns. Such uncertainties strongly impact the value of potential investments in ships themselves, as well as investments in improved processes for acquiring ships. At an extreme, if the probability of any ships being acquired is very low, then returns on investments in shipbuilding are unlikely.

3.3. Military vs. Commercial Ships

There have, in recent years, been many studies of best commercial practices in manufacturing and assembly, e.g., Lean and Six Sigma, and attempts to adopt these practices for military shipbuilding. The goal has been to reduce the costs and time required for ship production. These initiatives have had positive impacts. However, there are important differences between military and commercial ships [Birkler et al., 2005]:

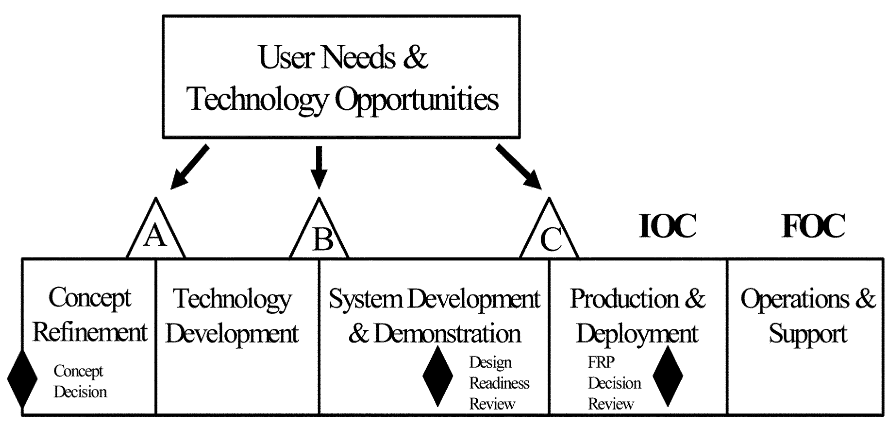

Figure 1. Defense acquisition management framework.

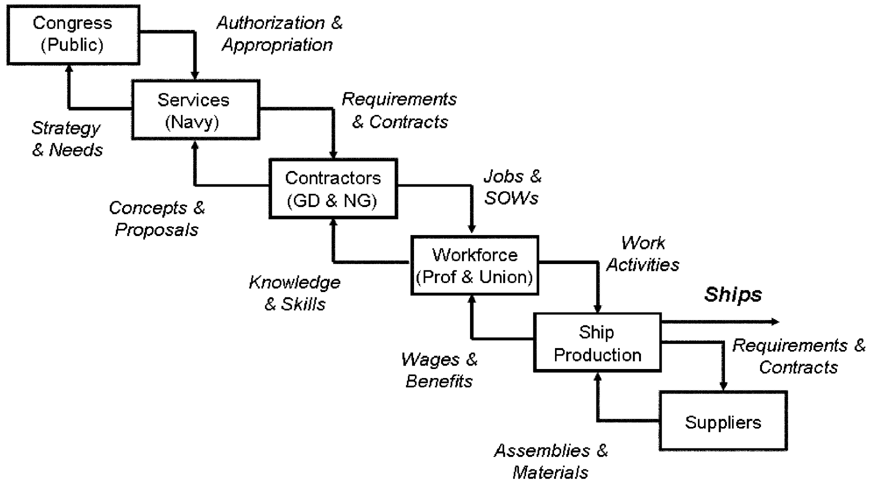

Figure 2. The overall shipbuilding enterprise.

- Ship Size & Complexity—Slower Design
  - Commercial: Large & Relatively Simple
  - Military: Complex & Relatively Small
- Acquisition Process—Slower Buying
  - Commercial Simpler Than Congressional/Military
- Design & Construction—Slower Production
  - Commercial: Large Steel Boxes with Simple Systems
  - Military: High Density of Integrated, Sophisticated Equipment
- Workforce Character—More Expensive People
  - Commercial: Mostly Blue Collar Workers
  - Military: Much More Engineering Support

Thus, the two types of platforms are much more different than they first appear. A simple indicator is the percent of the cost of the ship due to hull construction. This percentage is much higher for commercial ships. For military ships, costs are more driven by the equipment on the ship than the ship itself. Consequently, commercial shipbuilding "best practices" are in many respects inapplicable to military shipbuilding, especially for naval combatant vessels. This is not to deny that some subset of commercial "best practices" can be transferred to military shipbuilding, but these are unlikely to dramatically reduce military shipbuilding costs.

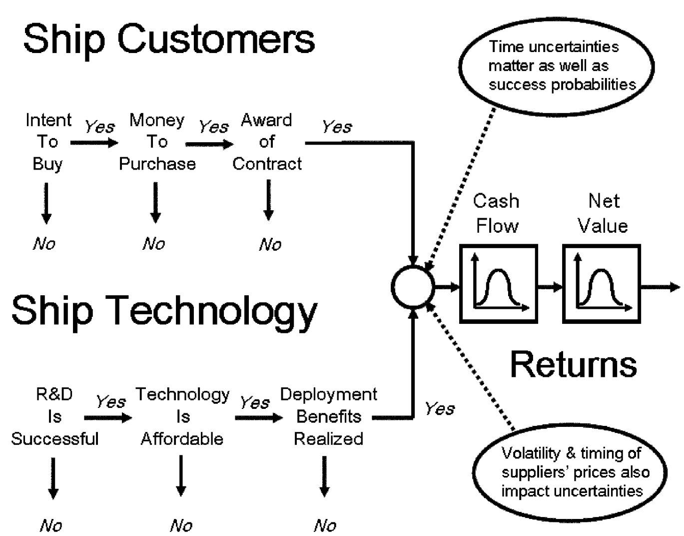

Figure 3. Sources of uncertainty in ship building.

3.4. Enterprise Transformation

If adoption of commercial practices is not the "silver bullet" that will provide ships faster and cheaper, how then can this objective be achieved? Considering Figures 2 and 3, there are many opportunities for fundamental change beyond the ship itself. We suggest that the overall ship building enterprise needs to be transformed.

Enterprise transformation is driven by experienced and/or expected value deficiencies and is enabled by changes of work processes [Rouse, 2005a, 2005b, 2006]. By "work," we mean any relevant activities pursued by any of the actors in Figure 2. Thus, changes might be affected in organizational processes for policy, authorization, appropriation, acquisition, development and deployment, or of technical processes for design, production, operations, maintenance, and repair. Work processes may be changed to increase value (e.g., capabilities/dollar) and/or decrease time, costs, and uncertainties.

Thus, for example, we might accelerate the processes associated with authorization, appropriation, requirements, and contracts, while also decreasing the uncertainties surrounding these processes (e.g., number of ships acquired). These changes will impact the magnitude and timing of expected cash flows. In particular, costs savings due to such streamlining will be larger and realized more quickly. The next section of this paper addresses valuation of such changes to assure that investing in these changes provides returns in excess of the costs of change.

Notice that the examples of change just discussed do not necessarily result in the acquisition of a different ship than what would have been obtained in the slower, more uncertain way. This portends one of the major conclusions of this paper—if we want ships significantly faster and cheaper, we have to change the way we buy them. Investments in process changes can greatly enhance the value of investments in the product—in this case, ships—due to decreased time and uncertainty.

It is important to note that decreasing time and uncertainty also tends to affect more than just the magnitude and timing of cash flows. Accelerating processes usually decreases "requirements creep" because there is a smaller time window within which technologies can change and key stakeholders can change and/or change their minds. Further, decreased time often results in decreased costs due to their being fewer calendar days over which labor costs can be charged.

We hasten to note that these impacts will reduce opportunities for rescoping needed capabilities (e.g., changing missions and requirements), intensity of oversight (e.g., number of development reviews), and workforce sustainment (e.g., number of person-hours per ship). In this paper, we show how to assess the economic value of such changes. To the extent that these additional considerations drive ship acquisition, then we would have to conclude that acquiring needed military capabilities faster and cheaper is not the overarching goal.

Employing the methodology described in this paper, one can assess the economic value of alternative transformation initiatives. This is particularly important in the public sector where, as discussed earlier, there is an abundance of transformation initiatives. Most of these initiatives make sense. However, it is difficult to choose those few initiatives deserving of major investment without some means of assessing the relative value of alternative initiatives. The methodology presented here provides such a means.

4. PORTFOLIO MANAGEMENT APPROACH

As was stated previously, our objective is to evaluate transformation opportunities as investments. Unfortunately, financially valuing any changes to a government organization presents some challenges that are particular to the government context. First, the benefits of government investments are usually nonmonetary. We do not typically assign monetary value to such government services as national defense or law enforcement. Thus, valuing any change in the provided level of such services is difficult at best.

Second, government acquisition decisions directly impact the performance of its supplier base. For defense contractors in particular, the U.S. government is the most important and sometimes only customer, and production decisions greatly influence the efficiency at which they operate. Thus, we cannot assume that the government can acquire systems at the market price since its decisions effectively dictate the market price.

Third, the diversity of the government's stakeholders makes the assessment of risk attitudes difficult. In traditional investment analysis, risk attitudes are typically encapsulated in a discount rate drawn from the financial markets. For a publicly traded company, this is generally considered to be a sufficient proxy for the risk attitudes of its shareholders. Conceptually, this is inapplicable to the government context since the government is not a profit-generating firm. If we cannot employ the financial markets to assess risk attitudes, the next logical tool would be utility theory. Again the nature of the government's stakeholders precludes this option. It would be virtually impossible to capture the risk attitudes of all relevant stakeholders, and further-more, it would reduce interpretability. It is unlikely that concerned parties would accept a utility score as justification for a major investment or reform.

Our approach addresses each of these challenges in the following manner. First, we quantify the return from any acquisition reform as a change in the government's buying power. If, for example, a change in acquisition procedures reduces the cost to acquire a particular system, the buying power of the government has increased since it can now get more for the same amount of money. This is analogous to how inflation is measured, and, thus, we could consider that an increase in buying power after a reform is the same has having more money in today's prereform dollars. This transforms the return on our investment into monetary terms and overcomes the first challenge.

Second, we utilize a production function to capture the impact of the government procurement rates on the efficiency of the producer. A production function allows us to include economies of scale, and the production of military systems in particular tends to exhibit increasing returns to scale. This means that as the size of the production run increases, the unit cost drops. This effect can be attributed to sharing overhead, more efficient use of resources, workforce learning, etc. and is sometimes referred to as a learning curve. Thus, the application of a production function allows us to consider a common situation faced by the government. Rising costs force the government to reduce the quantity procured. This means that the contractor must spread fixed costs over fewer units and use more inefficient means of production. Consequently, the unit costs increase further, and the government must buy an even smaller quantity.

Third, we account for risk attitudes by evaluating an investment in terms of both the expected return as well as the uncertainty in the return. We then place each investment option into a portfolio, and allow decision-makers to explicitly trade off risk and return. To do so, we consider two possible metrics for expected return, Net Present Value (NPV) and Net Option Value (NOV), the latter being appropriate when investments are staged with intervening decision points for continued investment. As for uncertainty in the return, we propose two risk measures, the probability of a loss and the conditional expected loss. The probability of a loss is self-explanatory, but the conditional expected loss is defined as the expected loss assuming that one occurs. These are both characterizations of the downside risk of the investment. The portfolio concept is illustrated in Figure 4. Alternative investments, denoted by the P's, are plotted in terms of expected return and risk. In this case, return is expressed as the Net Option Value, and the risk is expressed as the conditional expected loss.

The characterization of risk for each project enables consideration of the variability of return for each investment. Thus, for example, P4 and P5 are equivalent in terms of return. If return were the only metric, decision-makers would be indifferent between these potential investments. However, once risk is added, it is clear that P4 is the superior investment. Thus, placing the potential investments in the portfolio allows decision-makers to trade-off among them.

In Figure 4, the projects connected by the solid lines constitute the Pareto optimal frontier or nondominated set of projects. A decision-maker should always choose a project off of this frontier. To do otherwise would mean selecting a project that is inferior to another in terms of both risk and return. Considering the Pareto optimal frontier allows a decision-maker to move along

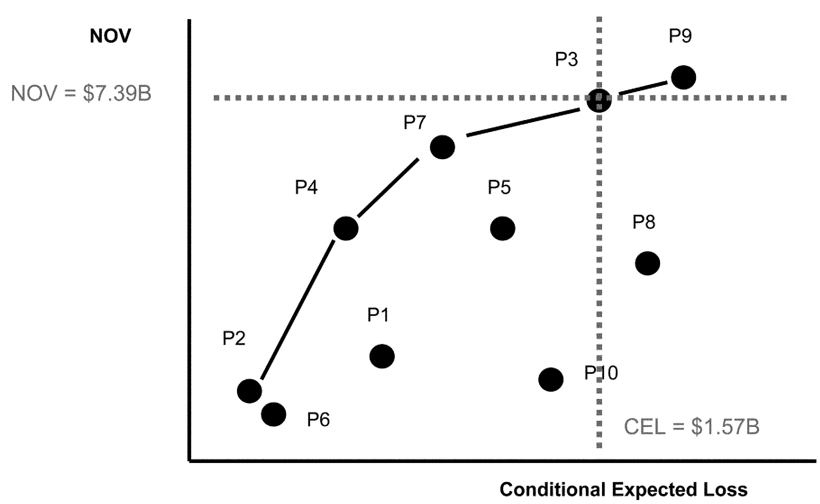

Figure 4. Notional portfolio of acquisition reform projects.

the frontier until he or she finds a project that provides the appropriate balance of risk versus return.

There is one important caveat here. Multiple projects may be selected if their returns are independent. If, however, they interact, the projects must be evaluated as a combined project and can be placed accordingly in the portfolio. This allows us to account for cases where two projects, if both implemented, would either work at cross-purposes to reduce the return or synergistically to increase the return.

Applying the concepts of buying power and production functions allows us to apply investment analysis tools to the assessment of acquisition reform projects and place them in a risk-return portfolio. To more fully illustrate these concepts we will first discuss the nature of the investment valuation tools we employ and then demonstrate them through a notional example.

4.1. Investment Valuation

Under traditional investment analysis, one is concerned with the expected present value of the future cash flows. Of course, other metrics are possible including the increase of shareholder value or the production of growth options. Under our framework, we will consider the future gains in buying power. These are equivalent to monetary savings, and, consequently, we can consider this our cash flow stream. This transforms the value of a public sector initiative into a series of cash flows and opens the door for us to use investment valuation tools developed for private sector investments.

The question posed then is when is it worthwhile to initiate an acquisition process change initiative? We must consider not only the cost savings realized by the process change but also the costs and risks associated with the initiative. Obviously, we assume that there are certain costs to implementation, but how do we account for risk? As indicated in Figure 3, there are multiple sources of risk. We can, at least initially, group these uncertainties into two classes: market risk and technical risk. Market risk is the uncertainty that results from random fluctuations in the marketplace. For a process change project, the savings achieved will be heavily dependent upon the prices of the inputs to the process. As the prices of those inputs fluctuate, so will the value of the project. If, for example, the prices of several major inputs were to fall precipitously, it might make the effort involved to change the processes not seem worth it. Technical risk involves the uncertainty in the execution of the project. Budgets and priorities might shift, the requisite personnel might not be available, or the idea behind the process change simply might not work.

Traditional Approach: Traditionally, investment decisions are made via Net Present Value (NPV). NPV is calculated by discounting the expected benefits and subtracting the discounted expected costs. Usually the discount rate is the cost of capital for the firm or an arbitrary hurdle rate felt to be commensurate with the level of risk. If some of the previously mentioned risks to the initiative are significant, the expected NPV might be negative and, consequently, the opportunity to transform would not appear to be worthwhile. In reality, however, the risks to a successful transformation need not be borne all at once. Any complex project is usually staged to mitigate risk by providing exit points. A project that is failing can be terminated to limit the accumulation of any further costs. This effectively limits the downside of initiating a project, but an NPV calculation does not account for this effect. The NPV calculation implicitly assumes that a project will continue to incur losses no matter how dismal the failure. The issues associated with using the NPV criterion for investment analysis are well documented. In particular, NPV tends to induce underinvestment [Hayes and Abernathy, 1980; Hayes and Garvin, 1982]. Instead of using NPV, we advocate an options-based approach to valuing staged investments.

Real Options: An options-based approach accounts for the opportunity to terminate a project before it is completed. It is in some ways analogous to a stock option. Purchasing a call option gives the option holder the right, but not the obligation, to purchase shares of a stock at predetermined price. When given the opportunity to exercise the option, the holder will only do so if it is profitable. This feature of the option limits exposure to downside risk. In a similar fashion, starting a change initiative provides the government agency the opportunity, but not the obligation to implement process changes.

Black and Scholes [1973] in their seminal paper developed a closed form equation that determines the fair price of a European call option, and subsequent researchers have developed methods to price many other types of options. The basic premise of their pricing scheme is that options draw their value from the behavior of the underlying asset. The similarity of many real investment opportunities to financial options have led to the development of real options analysis or contingent claims analysis. The key difference is that a real option is a contingent claim on an asset that is not traded in financial markets. This could be a natural resource such as an oil reserve, a production asset such as a factory, or intellectual property such as a patent. Like any other economic asset, the value of these real assets will fluctuate with market conditions. If these fluctuations can be replicated with a portfolio of assets traded in financial markets, a real option can be valued in the same manner as a financial option with only minor modifications.

The basis for valuing all types of options is dynamic programming. Dynamic programming finds the optimal policy for a time dependent decision problem. Dynamic programming was first developed by Bellman [1954] and has since become a standard tool in decision analysis. The key issue for an investment decision is the selection of an appropriate discount rate. When using contingent claims analysis, this issue is avoided by making the discount rate endogenous to the model. The market implicitly determines the appropriate discount rate because the value of the option is derived from market-traded assets. This approach is particularly appealing in a commercial setting because it accounts for the risk aversion exhibited by shareholders. As mentioned previously, we cannot realistically apply this concept to a government investment decision, so instead we fix our discount rate at the risk-free rate and consider risk attitudes external to the option valuation. While this effectively devolves the valuation problem to a dynamic programming problem, it is still conceptually analogous to real options. The methods for solving these types of dynamic programs are fairly standard, and the interested reader is directed to Dixit and Pindyck [1994].

5. AN ILLUSTRATIVE EXAMPLE: TRANSFORMING THE ACQUISITION OF SHIPS

In this example, we will assume that the U.S. Navy would like to transform the way it acquires ships and, therefore, propose several changes that will streamline the development and design process and reduce rework. Thus, the Navy has the option to transform its ship acquisition enterprise. In order to determine whether or not the Navy should initiate transformation, we will develop an option model. First, we will develop a method to value a successful transformation, and this will be analogous to the underlying asset we wish to acquire. Next, we will structure a multistage option to acquire this asset. The multiple stages will serve to mitigate both the market and technical risks inherent in transformation. Finally, we will use a modified version of the binomial lattice method [Cox, Ross, and Rubinstein, 1979] to determine the value of the option to transform as well as the optimal exercise policy.

5.1. Impact on Ship Production

First, we need to value a successful transformation. Transformation means that we exchange the current cost stream for a new cost stream. One could simply consider the cost savings (i.e., the difference between the two cost streams) as the value of the transformation, but this would be neglecting some of the benefits. It was noted earlier that the cost of a ship is related to the production rate. More specifically, military shipbuilding exhibits increasing returns to scale. That is the higher the rate of production, the lower the cost per unit. Consequently, if we use the cost savings to produce more ships, the increase in production rate will actually decrease the price per ship further resulting in an even greater gain.

The first feature of this problem that we must consider is the ship production process. Let us define the following:

$B(t) \equiv$ rate of cash flow from shipbuilding budget at time t,
$X(t) \equiv$ rate of consumption of shipbuilding inputs at time t,
$C(t) \equiv$ cost of shipbuilding inputs at time t,
$Y(t) \equiv$ rate of ship production at time t.

To keep the model simple, we will make several assumptions that will facilitate interpretation of the results within the context of this paper. These are summarized in Table I. Of course, if one were to use this method to evaluate any particular proposed transformation project, these assumptions should be adjusted as appropriate. First, we will assume that the model is continuous. While in reality ships are discrete items, and budgets are set annually, we are considering the long-term trends, and, consequently, the discontinuities diminish in importance as we increase our time horizon. Along that line, we will assume that the shipbuilding budget is deterministic and it grows exponentially at rate g,

$$B(t) = B_0 e^{gt},$$

and we assume that the Navy must use the entire shipbuilding budget for ship production. Admittedly, the shipbuilding budget is not so smooth and may be subject to jumps due to major acquisitions such as aircraft carriers. Our emphasis here, however, is to capture the long-term trend in budget levels. Next, we will assume that there is only one type of input required to build ships, and this input wraps up all of the required labor, materials, and capital. In a more detailed analysis, the tradeoffs between these inputs may be important, but to include them here would needlessly complicate our notional example.

As for the cost of this input, we note that ship construction costs have been climbing rapidly. This has

Table I. Summary of Modeling Assumptions

Assumption	Justification
Shipbuilding budget grows exponentially	Allows us to consider the impact of growing or declining budgets.
Ship construction input costs follow geometric Brownian motion	Models the exponential growth in ship cost while accounting for economic noise in prices.
Ship production process is governed by a Cobb-Douglas production function	Allows us to consider the impact of economies of scale on the quantity of ships produced.
Ship production is continuous	Allows us to focus on the long-term trends in ship production sustainability.

likely occurred for a number of reasons not the least of which is the increase in the complexity of modern warships. Since demand for increasing complexity shows no signs of abating, we can safely assume that input cost for warships is growing exponentially. Of course, many input factors fluctuate in price due to economic factors. Consequently, we would like to add a noise term to our input cost. To accomplish this, we will assume that it follows geometric Brownian motion:

$$dC = \alpha_C C dt + \sigma_C C dZ,$$

where α_C is the expected growth rate of input cost, σ_C is the volatility of the input cost, and dZ is an increment of standard Brownian motion (i.e., a Wiener process). Brownian motion is a fairly standard stochastic process used in economics and finance since it captures to a first order the rapid fluctuations in prices due to the normal buying and selling actions of participants in a market place. Geometric Brownian motion is a variation on Brownian motion that exhibits an exponential growth trend in the price.

To capture the increasing returns to scale, we will assume that the production function is Cobb-Douglas (see Varian [1992: Chapter 1]) with parameter a:

$$Y(t) = X(t)^a.$$

The Cobb-Douglas production function is standard in economics, but other functional forms could be used as appropriate for the situation under consideration. The appeal here is that it is fairly easy to consider economies of scale with the Cobb-Douglas production function. When $a > 1$, the production function exhibits increasing returns to scale ($a = 1$ is constant returns to scale, and $0 < a < 1$ is decreasing returns to scale).

Since we expend the entire budget on shipbuilding, we can determine the amount of shipbuilding inputs we can purchase by dividing the budget by the cost of inputs.

$$X(t) = \frac{B(t)}{C(t)}.$$

Thus, we can define the output, $Y(t)$, as a function of input cost, $C(t)$, and the budget, $B(t)$.

$$Y = \left(\frac{B}{C}\right)^a = \frac{B_0^a e^{agt}}{C^a}. \quad (1)$$

Note that the time index has been suppressed to simplify notation. Since C is stochastic, Y must also be stochastic. In order to determine Y's behavior we will make use of stochastic calculus. Applying Ito's Lemma (see Shreve [2004: Chapter 4]), we get

$$dY = \left(ag - a\alpha_C + \frac{1}{2}a(a+1)\sigma_C^2\right)Ydt - a\sigma_C Y dZ$$

(see Appendix A for more detail). Thus, the output rate, $Y(t)$, is also governed by geometric Brownian motion with expected growth rate

$$\alpha_Y = ag - a\alpha_C + \frac{1}{2}a(a+1)\sigma_C^2$$

and volatility $\sigma_Y = -a\sigma_C$.

Since $Y(t)$ is a production rate, we must integrate over time to determine the actual number of ships produced, but that value will be stochastic as well.

Consequently, we would like to know the expected number of ships produced. Let Y_T be the number of ships produced over the interval [0, T]:

$$Y_T = \int_0^T Y(t)dt.$$

To find the expected number of ships produced over the interval, we simply find the expected value of Y_T:

$$E[Y_T] = E\left[\int_0^T Y(t)dt\right] = \frac{Y_0}{\alpha_Y}(e^{\alpha_Y T} - 1).$$

One should note that if $\alpha_Y < 0$, the rate of production is declining over time because costs are increasing faster than the budget. That means that the cost structure is unsustainable, and each year the Navy will be able to buy fewer ships than the previous year. Under this simple model, if nothing changes, costs will eventually rise to the point that Navy will not be able to afford any ships.

With our production model, we can determine the impact of transformation in terms of number of ships produced. To make this more concrete, let us assume some notional parameter values:

Initial Annual Budget Rate (B_0) = \$1 billion,
Budget Growth Rate (g) = 1%,
Initial Input Unit Cost (C_0) = \$1 billion,
Expected Cost Growth Rate (α_C) = 4%,
Cost Volatility (σ_C) = 0.15,
Cobb-Douglas Production Parameter (a) = 1.3.

With this parameter set, the current production rate is one ship per year, but costs are growing faster than the budget. So the production rate is declining 3.5% per year. That means that if current conditions continue, we will only be able to produce 14 ships over the next 20 years. At first glance, this may be surprising since cost growth is only outpacing budget growth by 3%, but with a set to 1.3, this model is exhibiting increasing returns to scale (this is equivalent to an 85% learning curve). The nonlinearity of the production function means that as the production level drops, the per-unit cost of production rises. This is the feedback effect that the Navy is experiencing right now in its shipbuilding program. As ship costs rise, the Navy can afford fewer ships thus lowering the production rate. As the production rate falls, more inefficient means of production are used and the cost per ship rises even more. Thus, the production rate declines even faster than apparent the budget shortfall.

If, on the other hand, a is set to 1 (constant returns to scale), then the current production rate is still one, but it is only declining at 3% per year as we would expect under a linear production function. That means that a greater number of ships, 15, will be produced over the next 20 years. Thus, we can see how the compounding effect from increasing returns to scale hurts production when costs are rising. If we look at cost savings, on the other hand, the opposite is true. Let us assume that our transformation instantaneously drops input costs 20%. With increasing returns to scale the production rate increases 34%, while under constant returns to scale the increase is only 25%. Over the next 20 years, the Navy will produce 19 ships under increasing returns to scale and only 18 ships under constant returns to scale.

5.2. Economic Impact

As the model stands now, we can only compare production levels. While the production levels are certainly of interest, it would be easier to value the investment if we could convert it into monetary terms. Since we indicated earlier that simple cost savings is under-representing the return, we need a means to capture both the initial effect of the savings and the secondary effect of reduced production costs. As stated earlier, we can accomplish this is by measuring the increase in the buying power of the budget. If a cost reduction decreases the cost per ship, this effectively increases the buying power of the budget since it can be used to purchase more ships. One way to look at buying power is through price indices like those used to track inflation. Two common prices indices are the Laspeyres and Paasche indices [Pollak, 1990].

$$P_L = \frac{p_1 \cdot x_0}{p_0 \cdot x_0},$$

$$P_P = \frac{p_1 \cdot x_1}{p_0 \cdot x_1}.$$

The Laspeyres index compares the cost of buying a bundle of goods at a starting time and cost of buying the same bundle of goods at a later time. The Paasche index, on the other hand, starts with the bundle from the later time and costs it in the starting time. The two bundles may differ because of substitution and income effects (i.e., relative price differences or income changes may lead to a reallocation of the bundle over different time periods). This means that the two price indices can differ. The Fisher price index [Pollak, 1990] attempts to split the difference by taking the geometric mean of the two

$$P_F = \sqrt{P_L P_P}.$$

For this analysis we will apply the price indices over two possible scenarios rather than two time periods, but conceptually it is the same. It turns out that for our special case where we are only considering a single good—ships—no substitution is possible, and all three will be equivalent. If we were to broaden our analysis to consider, for example, tradeoffs between ship classes or between ships and aircraft, the choice of price index would matter.

Let us derive the index value for our model. First, we define two different production schedules. Let $Y_C(t)$ be the production rate at time t under the current cost structure, and let $Y_N(t)$ be the production rate at time t under the new cost structure. We can determine the price per ship as follows:

$$p_C(t) = \frac{B(t)}{Y_C(t)},$$

$$p_N(t) = \frac{B(t)}{Y_N(t)}.$$

Using the Laspeyres index, we get

$$P_L(t) = \frac{p_N(t)Y_C(t)}{p_C(t)Y_C(t)} = \frac{Y_C(t)}{Y_N(t)}.$$

Computing the other two indices would reveal that all are equivalent as stated earlier:

$$P_L(t) = P_P(t) = P_F(t) = \frac{Y_C(t)}{Y_N(t)}.$$

Since the production level increases under the new cost structure, the price index will be less than 1. This indicates that ship prices have deflated as one would expect. Thus, we have increased the buying power of our budget. The new buying power can be expressed as

$$\frac{B(t)}{P_F(t)} = B(t)\,\frac{Y_N(t)}{Y_C(t)}.$$

Of course, the return on our investment is the increase in buying power, which can be represented by

$$B(t)\,\frac{Y_N(t)}{Y_C(t)} - B(t).$$

Let $G(t)$ be the new buying power realized from the change in cost structure:

$$G(t) = B(t)\,\frac{Y_N(t)}{Y_C(t)}\,.$$

We can determine the stochastic behavior of $G(t)$ by again applying Ito's Lemma and obtaining

$$dG = (g + \alpha_{Y_N} - \alpha_{Y_C} - \rho\sigma_{Y_N}\sigma_{Y_C} + \sigma^2_{Y_C})Gdt +$$

$$\sigma_{Y_N} GdZ_{Y_N} - \sigma_{Y_C} GdZ_{Y_C},$$

where ρ is the coefficient of correlation between the two increments of Brownian motion (i.e., $E[dZ_{YC}dZ_{YN}] = \rho dt$). Substituting for the parameters we derived earlier, we get

$$dG = \left[g + a(\alpha_{C_C} - \alpha_{C_N}) + \frac{a}{2}(\sigma^2_{C_N} - \sigma^2_{C_C}) + \frac{a^2}{2}(\sigma^2_{C_N} - 2\rho\sigma_{C_N}\sigma_{C_C} + \sigma^2_{C_C})\right]Gdt - a\sigma_{C_N} GdZ_{C_N} + a\sigma_{C_C} GdZ_{C_C}. \quad (2)$$

Though $G(t)$ is a combination of two geometric Brownian processes, it is also governed by geometric Brownian motion (see Appendix B).

As a special case we will assume that the two cost streams have identical volatility, are perfectly correlated, and differ only in magnitude. More specifically, the new cost structure is some fraction of the current [i.e., $C_N(t) = sC_C(t)$, where $0 < s < 1$]. For this special case, $G(t)$ becomes deterministic:

$$dG = gGdt,$$

$$G(t) = G_0 e^{gt} = B_0 \left(\frac{1}{s}\right)^a e^{gt}.$$

If we let r be the discount rate, then the net present value of the increase in buying power when one switches from $C_C(t)$ to $C_N(t)$ is

$$NPV = \int_0^\infty [G(t) - B(t)]e^{-rt}dt = \frac{B_0}{r-g}\left[\left(\frac{1}{s}\right)^a - 1\right]$$

when $r > g$.

Using this simple model, we can again examine the impact of increasing returns to scale. If we assume the following notional parameter values:

Initial Annual Budget Rate (B_0) = \$3 billion,
Discount Rate (r) = 5%,
Budget Growth Rate (g) = 2%,
Input Cost Fraction (s) = 95%,
Cobb-Douglas Production Parameter (a) = 1,

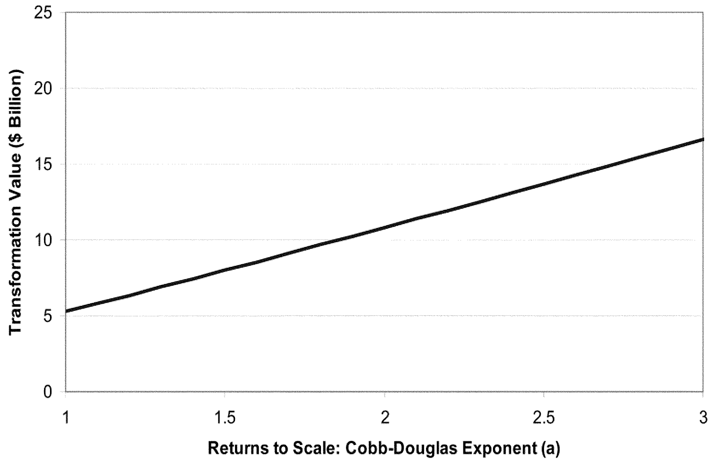

Figure 5. Sensitivity of value of transformation to economy of scale. (Note that when the exponent is set to 1, production exhibits constant returns to scale. When it is greater than 1, production exhibits increasing returns to scale.)

then the net present value of the increase in buying power is $5.26 billion. Since we assumed constant returns to scale, the result is equivalent to calculating the nominal cost savings. If, on the other hand, we have increasing returns to scale (a = 1.3), we find that the NPV is now approximately $6.89 billion. This result demonstrates two things. First, we can value the production gain monetarily, and, second, using only cost savings can significantly undervalue the true gain (in this case by 31%). Figure 5 makes this evident by showing the sensitivity of the transformation's value to the economy of scale.

5.3. Staging Transformation

Now let us extend our simple model by considering the fact that there are technical risks to implementing the transformation. To mitigate these risks, we will assume that there is a three-stage process. The first is for concept development and feasibility analysis. This stage is relatively short and inexpensive. If the transformation idea proves to be infeasible in this stage, the Navy can terminate the project at no additional cost. The second stage pilot tests the changes on the acquisition of a single ship. If the project fails in this stage, rework costs will be required to rectify the situation and complete the acquisition of the ship. Finally, the third stage involves implementing the transformation across the whole shipbuilding enterprise. If the transformation fails in this stage, a substantial cost in rework is incurred. Table II contains the staging parameter values for this example.

The "Stage Cost" column lists the costs required to execute each stage, and the "Rework Cost" column lists the cost incurred if a particular stage fails. The "P(Success)" column lists the probability that each stage will succeed. Finally, the "Duration" column lists the length of each stage. We assume in this example that all costs are deterministic, and are funded from outside the ship construction budget. An interesting but more complicated variation would be to incur costs from the shipbuilding budget. This would alter the production rate and make the costs stochastic.

Since we have no market risk in this example, the option to transform devolves into a simple decision tree. When we solve the decision tree using the previous parameter set and increasing returns to scale (a = 1.3), we find that the net option value (NOV) of the transformation option is approximately $0.61 billion. This drop in value from $6.89 billion is attributable to the significant technical risk inherent in this transformation project. If, on the other hand, we were to calculate the traditional NPV when considering this technical risk, we would find that the value of the transformation project is approximately –$6.43 billion. That means

Table II. Stage Parameter Values

Stage	Stage Cost ($ billions)	P(Success)	Rework Cost ($ billions)	Duration (years)
1	0.001	0.4	0	0.5
2	0.01	0.6	1	3
3	0.1	0.8	10	N/A

that we would expect to incur a substantial loss by initiating this project. Here we can see the discrepancy between the NOV and the NPV. The NPV is too conservative because it fails to account for the risk mitigation inherent in staging. So, in this example, a decision-maker using NPV as the decision criterion would reject a potentially beneficial program.

Let us expand our example by introducing market risk. It is a well-known result in options analysis that market risk actually increases the value of the option. We will demonstrate that here. In our previous model, there was no market risk because the new cost stream was just proportional to the current cost stream. If we alter the way we produce and acquire ships, however, it is unlikely that the new cost stream will be perfectly correlated with our current cost stream. If the cost streams follow different stochastic processes, then there will be market risk inherent in the decision, and we must return to our stochastic equation for dG [Eq. (2)]. While this does increase the complexity of the model, there is a relatively straightforward way to handle it. It turns out that Brownian motion can be approximated via a discrete random walk process. In particular, we will use a random walk process known as the binomial lattice that is particularly useful for valuing options [Cox, Ross, and Rubinstein, 1979]. If the time step used is small enough and the process occurs over a long enough time, a binomial lattice can be a fairly accurate representation of geometric Brownian motion. With the binomial lattice, the probability distributions become discrete, and the option can be valued as a decision tree.

For this example, we will use the previous parameter set, plus these additional parameters to model the market risk:

Current Cost Growth Rate (α_{CC}) = 3%,
New Cost Growth Rate (α_{CN}) = 3%,
Current Cost Volatility (σ_{CC}) = 0.15,
New Cost Volatility (σ_{CN}) = 0.16,
Initial Current Cost Rate (C_{C0}) = \$1 billion,
Initial New Cost Rate (C_{N0}) = \$0.95 billion,
Cost Stream Correlation (ρ) = 0.9.

As before we are achieving a 5% cost savings. The key difference here is that the current and new cost streams have different volatilities and are 90% correlated. The growth rates were kept identical to limit the change to the stochastic behavior, and the same staging parameters were used (Table II). A time step of 0.01 years was used for the binomial lattice. The resulting NOV is \$5.94 billion, a value that is almost 10 times greater than without the market risk. The increase in value occurs for two reasons. The first is that interaction between the two cost streams increases the effective growth rate of the Navy's buying power [see Eq. (2)], and this is also evident in the NPV, which has increased to –\$1.15 billion. The second reason is the downside risk mitigation provided by options. Market risk can work both for and against the decision-maker. Volatility in costs means that they can be above or below expectations, and when the costs are not favorable, the decision-maker will choose not to exercise his option. This effectively limits the downside market risk while preserving the upside. In other words, an option allows one to take advantage of positive market moves while avoiding negative market moves.

With our stochastic model, there is one additional feature to consider, the cost growth rate. While a percentage drop in cost is certainly worth something, when the cost growth rate is exceeding the budget growth rate, it is simply delaying the inevitable. As one reduces the cost growth rate, however, we approach sustainability. Even small drops in the growth rate can mean a major increase in value. For example, if we reduce the cost growth rate of the new cost stream from our previous example just a tenth of a percent (reduce α_{CN} from 3% to 2.9%), we find the option value jumps to \$7.39 billion. If we reduce it even further to a sustainable growth rate of 2%, the net option value explodes to \$36 billion. Considering the outlay for the first stage is only \$1 million, it is quite an attractive investment.

5.4. Risk Aversion

While the methods we have described above allow us to value the option to transform a government acquisition enterprise, it is important to note that the result implies risk neutrality. That means that the decision-maker is indifferent between the expected value of a risky return and the equivalent amount in cash. While we may make the argument that the government as whole may be risk neutral, most decision-makers are not. If we assume that our decision-maker in this case is risk-averse, the theoretically correct way to handle this is to introduce utility functions that capture the decision-maker's level of risk aversion. As discussed previously, it introduces two complications. The first is that one would have to assess utility functions specific to the decision-maker or decision-makers. That reduces the interpretability of the result since it is now specific to the decision-maker; that is certainly a shortcoming when it comes to public policy. Second, when we introduce utility, we lose the monetary valuation of the investment that we just worked to develop.

Consequently, we offer a compromise position. We can describe the distribution of project outcome under the risk-neutral policy. This will allow us to consider the uncertainty in the outcome of the option, and at least allow the risk-averse decision-maker to weigh the uncertainty in his or her decision. The inconsistency that arises here is that we are assuming that after the initial investment decision, the decision-maker will behave in a risk neutral manner for the subsequent stages. With that caveat, it is fairly safe to say that most decision-makers would likely prefer some description of the risk, albeit imperfect, to none at all.

In order to characterize the distribution, we will make use of Monte Carlo simulation. Since the binomial lattice is essentially a decision tree, it is fairly straightforward to generate sample paths over the option lattice. As for the value received at the final exercise decision, we must remember that we are receiving an uncertain cash flow generated by a Brownian motion process. Since Brownian motion sample paths are fairly problematic, we simulate the uncertainty in the received cash flows by extending the lattice for an arbitrary amount of time. There are no decisions on this portion of the lattice, only the up and down movements of the cash flows. The cash flows accumulate as we traverse a sample path of the lattice, and when we reach the end of the lattice we receive a terminal value that is the expected present value of the remaining cash flow. Consequently, the longer the lattice is extended in time, the more accurate the results of the simulation.

For our example, we return to the case described earlier where we had cost growth rates of $\alpha_{CN} = 2.9\%$ and $\alpha_{CC} = 3\%$. The Monte Carlo simulation was run for 5000 iterations with an extended lattice horizon of 200 years. Of course, the NOV calculated previously ($7.39 billion) is the expected value of the distribution, and the simulation reveals that the standard deviation is approximately $34.2 billion. Thus, the distribution has a fairly wide spread. In fact, it is multimodal. Since the technical risks are so high, there is high probability that the project will terminate early with rework costs. Consequently, there is a mode for each stage of the option. If the transformation is successful, the expected reward is quite large, but the realization is fairly spread out. Thus, this distribution has a very long tail. Since this type of distribution can be difficult to interpret, we consider the two risk measures discussed earlier, the probability of a loss and the conditional expected loss. For our example, the probability of a loss is approximately 87% and the conditional expected loss is approximately $1.57 billion. (Note that this risk estimate enables placing this project in the portfolio plot of Fig. 4.) What this tells us is that there is a very high probability that this project will fail, but if it does fail, the expected cost is relatively low compared with the potential returns (without risk or cost, the value of the transformation is on the order of $42 billion). Thus, we end up with a positive NOV, and the investment appears attractive.

5.5. Summary

What we can draw from this example is the importance of properly considering the staged nature of most risky projects. NPV fails as a decision criterion in this respect and can result in overly conservative decision-making because it undervalues high-risk, high-return investments. While we used the risk-free discount rate to calculate the comparative NPV in our example, the problem with NPV is exacerbated when artificially high hurdle rates are used. An options approach accounts for the risk mitigation inherent in staged projects and provides a more realistic assessment of a project's worth.

6. CONCLUSIONS

The acquisition of systems is time-consuming, very expensive, and rife with uncertainties. Consequently, the enterprise associated with acquisition is an excellent candidate for transformation—fundamental changes of organizational processes for policy, authorization, appropriation, acquisition, development and deployment, or of technical processes for design, production, operations, maintenance, and repair. This paper has argued for an enterprise-wide perspective when choosing among alternative transformation initiatives.

We have also argued for economic valuation of the alternative transformation investments and presented an options-based methodology for such economic assessments. A notional example was used to illustrate the impact of this approach versus a more traditional approach. In general, traditional discounted cash flow methods very much under-value multistage initiatives. Options-based approaches, in contrast, enable many more early-stage investments but fewer later-stage investments, thereby not diluting resources to invest in high-payoff transformation initiatives.

APPENDIX A

In stochastic calculus, any transformation on an Ito process requires the application of Ito's Lemma.

$$dY = \frac{\partial Y}{\partial t}\, dt + \frac{\partial Y}{\partial C}\, dC + \frac{1}{2}\frac{\partial^2 Y}{\partial C^2}\, dC^2.$$

One may note that Ito's Lemma is just the chain rule from ordinary calculus with the addition of the second derivative term. This term is required to account for the fact that Brownian motion has nonzero quadratic variation.

For the case of Eq. (1) the derivative terms are

$$\frac{\partial Y}{\partial t} = agY,$$

$$\frac{\partial Y}{\partial C} = \frac{-aY}{C},$$

$$\frac{\partial^2 Y}{\partial C^2} = \frac{a(a+1)Y}{C^2}.$$

This results in

$$dY = agYdt - \frac{aY}{C}dC + \frac{1}{2}\frac{a(a+1)Y}{C^2}dC^2.$$

Substituting for dC, we obtain

$$dY = agYdt - \frac{aY}{C}(\alpha_C Cdt + \sigma_C CdZ)$$

$$+ \frac{1}{2}\frac{a(a+1)Y}{C^2}(\sigma_C^2 C^2 dt).$$

Simplifying, we get

$$dY = agYdt - a\alpha_C Ydt - a\sigma_C YdZ + \frac{1}{2}a(a+1)\sigma_C^2 Ydt,$$

$$dY = \left(ag - a\alpha_C + \frac{1}{2}a(a+1)\sigma_C^2\right)Ydt - a\sigma_C YdZ.$$

APPENDIX B

Here we will show that G is a geometric Brownian motion process. First, we define the following:

$$\alpha_G = g + a(\alpha_{C_C} - \alpha_{C_N}) + \frac{a}{2}(\sigma_{C_N}^2 - \sigma_{C_C}^2)$$

$$+ \frac{a^2}{2}(\sigma_{C_N}^2 - 2\rho\sigma_{C_N}\sigma_{C_C} + \sigma_{C_C}^2),$$

$$\sigma_G = a\sqrt{\sigma_{C_N}^2 - 2\rho\sigma_{C_N}\sigma_{C_C} + \sigma_{C_C}^2},$$

$$dZ_G = \frac{a\sigma_{C_C}dZ_{C_C} - a\sigma_{C_N}dZ_{C_N}}{\sigma_G}.$$

Next, we need to show that dZ_G is an increment of Brownian motion, and we can do this by finding the quadratic variation of Z_G:

$$dZ_G dZ_G = \frac{a^2}{\sigma_G^2}(\sigma_{C_C}^2 dZ_{C_C}^2 - 2\sigma_{C_C}\sigma_{C_N}dZ_{C_C}dZ_{C_N}$$

$$+ \sigma_{C_N}^2 dZ_{C_N}^2),$$

$$dZ_G dZ_G = \frac{a^2}{\sigma_G^2}(\sigma_{C_C}^2 - 2\rho\sigma_{C_C}\sigma_{C_N} + \sigma_{C_N}^2)dt,$$

$$dZ_G dZ_G = \frac{\sigma_G^2}{\sigma_G^2}dt,$$

$$dZ_G dZ_G = dt.$$

This result implies that the quadratic variation is $[Z_G, Z_G](t) = t$. Thus, by the one-dimensional Lévy Theorem (see Shreve [2004: Chapter 4]), Z_G is a Brownian motion process. Substituting terms into Eq. (2), we obtain

$$dG = \alpha_G Gdt + \sigma_G GdZ_G,$$

and we see that $G(t)$ is governed by geometric Brownian motion.

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