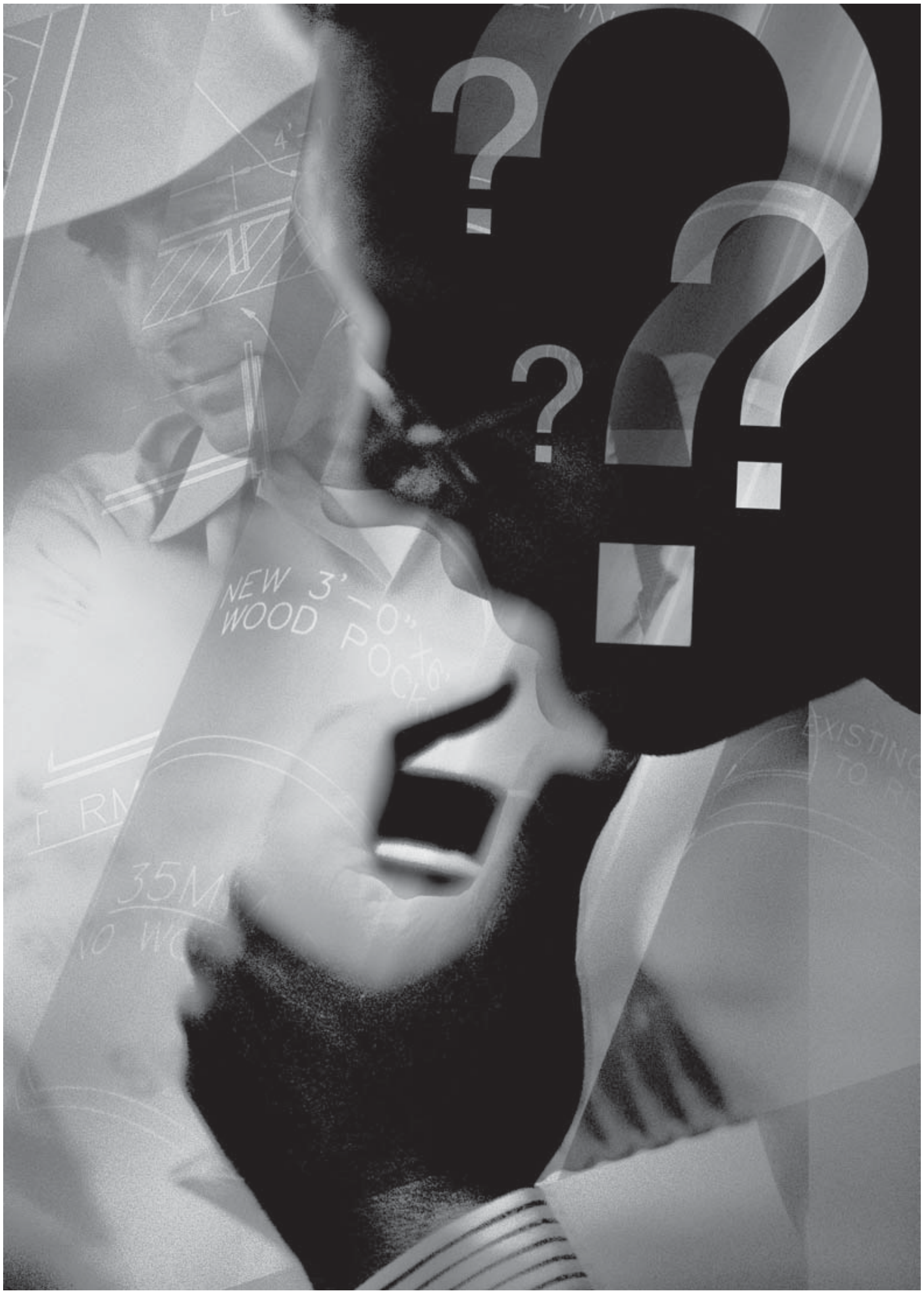
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USING OPTIONS TO MANAGE DYNAMIC UNCERTAINTY IN ACQUISITION PROJECTS

B. Kagan Ceylan, Ph.D. and David N. Ford, Ph.D.

Uncertainty in acquisition projects and environments can degrade performance. Traditional project planning, management tools, and methods can effectively deal with uncertainties in relatively stable environments. But in more uncertain environments conditions can evolve beyond the assumptions used in preproject planning and require major deviations from initial plans. Important uncertainties often cannot be identified and described adequately during preproject planning to design optimal strategies. Therefore, rigid project strategies prepared solely on the most likely outcomes as perceived during preproject planning can result in sub-optimal performance. In these cases, acquisition planners must explicitly incorporate flexibility into project plans to keep effective strategies available until uncertainty resolves adequately to reveal the best choice. Options can provide an effective framework for designing, evaluating, and implementing flexible acquisition project strategies and therefore can improve project performance. A large complex defense project illustrates the potential and challenges of options and research needs to expand and improve their use to manage uncertainty.

Maximizing the value of acquisition projects in dynamic environments is difficult partially because project managers must manage a variety of environmental and internal uncertainties as well as more common project complexities. Miller and Lessard (2000) report that success for 60 large ($985 million average cost) engineering projects, including research and development projects, depended on how uncertainty was managed. Many large complex defense acquisition projects also include technology research and development in dynamic and unpredictable environments. These development efforts can pose significant risks for the entire project because their outcomes are often predecessors of major activities, and failures or delays in these efforts propagate through the project. How can managers of large complex defense projects plan for and manage critical uncertainties?

Development projects risk suboptimal performance if uncertainty is not explicitly addressed in project planning. Many acquisition strategies are based on a project's characteristics and environment during front end planning. If these characteristics and environments are relatively stable, initial plans can absorb changes in the project or its environment, changes in acquisition strategies are not required, and traditional preproject planning is adequate. But some critical conditions evolve over time and the conditions, times, and managerial choices for effective decision making cannot be completely and accurately determined during preproject planning.

Additional data collection can sometimes improve descriptions of apparently large uncertainties and thereby improve preproject planning. But traditional preproject planning can fail to develop adequate strategies for uncertainties that are, or appear to be, too difficult or impossible to accurately predict and, therefore, be the basis for effective strategy development before a project must proceed. These residual uncertainties must be managed both strategically and dynamically because changes that occur during project execution may render the best course of action suboptimal, as determined during front end planning, (Gupta & Rosenhead, 1968). Ford, Lander, and Voyer (2002) refer to these uncertain project components and environmental impacts that only evolve adequately for strategy selection after preproject planning as "dynamic uncertainties" and describe in more detail why they are difficult to manage.

"Designing acquisition strategies that can be used to successfully manage dynamic uncertainties is an important but difficult part of project planning."

Three characteristics of uncertainty in large complex defense projects make it particularly difficult to manage. First, one-of-a-kind research and development efforts provide few opportunities to develop routines that can be evaluated and thereby improved. Therefore, historical experience is not available to inform forecasts of uncertain features. In addition, one-of-a-kind work provides an inadequate understanding of new technologies or their implementation during preproject planning to make forecasts that are accurate enough for strategy selection.

Second, long project durations (e.g., 10.7 years average in the previously cited Miller and Lessard study; 2000) allow environments to evolve far from preproject conditions. These dynamic uncertainties can cause strategies that are optimal during preproject planning to become obsolete in later stages of the projects.

Third, tight coupling among project components create complex dynamic systems. Understanding individual project components is inadequate for understanding the system (Sterman, 1994; Senge, 1990). This increases project uncertainty and the difficulties of forecasting and planning. How can defense acquisition project planners proactively prepare for dynamic uncertainty?

Designing acquisition strategies that can be used to successfully manage dynamic uncertainties is an important but difficult part of project planning. Uncertainties that cannot be identified or forecasted can only be managed reactively with adaptive systems and managers (DeMeyer, Loch, & Pich, 2002). But many dynamic uncertainties can be characterized adequately to be managed proactively by anticipating multiple scenarios to project goals and using flexible strategies to dynamically choose the best strategy based on how uncertainty resolves.

Options can provide a framework for using flexible strategies to describe, design, evaluate, and implement strategies directed at dynamic uncertainties. An option is a right without an obligation to take specific future actions depending on how uncertain conditions evolve (Amram & Kulatilaka, 1999). Mathematical models first developed to value options on financial assets (Bookstaber, 1982; Cox, Ross, & Rubinstein, 1979; Black & Scholes, 1973) have been adapted to real assets and analyzed (Brealey & Meyers, 2000; Trigeorgis, 1993, 1996; Dixit & Pindyck, 1994; Kemna & Vorst, 1990), applied to engineering (Benaroch, 2001; Baldwin & Clark, 2000; Park & Herath, 2000), and promoted as a strategic planning aid by both academics (Miller & Lessard, 2000; Amram & Kulatilaka, 1999; Bierman & Smidt, 1992; Kensinger, 1988) and practitioners (Leslie & Michaels, 1997).

Both options — theory and decision analysis — provide formal mathematical methods for valuing options that have been designed. However, less research exists on option design, assessment, and implementation processes for practicing planners and managers. The recent option design research has primarily focused on modularity in product development (Baldwin & Clark, 2000), where options are created by allowing the mixing and matching of product modules in response to changing conditions in the environment without changing the entire product. Thereby, modularity can provide competitive advantage for modular products, particularly in environments in which product life cycles grow shorter. However, tools and methods to create and measure options in acquisition projects are not yet available. A lack of structured methods and tools that can guide planners in building flexible project plans to manage dynamic complexity remains a barrier to improved acquisition project management.

In the current work, options are described and evaluated as a tool for managing dynamic uncertainty from a managerial perspective. Based on this evaluation, we hypothesize that the lack of a theory of options practice constrains the description, evaluation, and advancement of options to improve acquisition. To specify, clarify, and support our hypothesis, descriptions of approaches to managing uncertainty are followed by a description of options from a managerial process perspective. One use of options in a large complex defense project is described to illustrate the use of options in practice and to identify research needs to improve acquisition planning and management.

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Traditional Planning Tools for Managing Uncertainty

Many domains address aspects of managerial decision making under uncertainty. Among them, strategic management, preproject planning, and risk management provide planning tools and methods that can be applied to managing development project uncertainty. Relevant portions of these theories and their use by defense agencies are briefly described and evaluated to establish the available models of options to manage dynamic project uncertainty in large complex defense projects. The potential contributions of some other theories to the managerial use of options are then described.

Strategic Management

Strategic management explicitly addresses the management of uncertainty with flexible plans and strategic adaptation after initial strategy selection (Mintzberg, 1978; McGrath & MacMillan, 2000). Although strategic management focuses on ongoing enterprises, uncertainty also must be explicitly incorporated into project strategies to maximize performance (Miller & Lessard, 2000). Strategic planning integrates environmental opportunities and threats with internal strengths and weaknesses into potentially flexible strategic plans that are the basis for specific projects (Mintzberg, 1995).

"Rigid strategic planning methods have proven inadequate for the high complexity and dynamics of large public

According to Mintzberg (1978), strategic planning traditionally depicts a highly ordered and neatly integrated process. In response to dynamic environments strategic management uses strategic adaption, which updates strategies continuously, thereby remaining flexible (Porter, 1980). Strategic management, planning, and adaptation processes exist for ongoing enterprises at relatively aggregate levels, but these concepts have not been developed into implemental processes for managing projects.

Rigid strategic planning methods, such as those using the critical path method coupled with risk analysis, have proven inadequate for the high complexity and dynamics of large public acquisition projects (Hughes, 1998). As a result, several federal agencies (e.g., the Department of Defense [DoD] and the National Aeronautics and Space Administration [NASA]) abandoned rigid approaches as early as the 1960s in favor of more strategic and adaptive approaches (Sayles & Chandler, 1971; DoD, 2001; Department of Energy [DOE], 2002; Department of Navy [DON], 2001). For example, Department of Defense Regulation 5000.2-R (DoD, 1996) requires a phased decision-making process with exit criteria reviews at each phase and the parallel development of multiple concepts. These provide options to abandon portions of projects as a means of strategic adaptation if the objectives can no longer be justified in the light of unfolding events.

Preproject Planning

Preproject planning includes a project strategy selection process (Mintzberg, 1978) that is widely used by industry (Construction Industry Institute [CII], 1995; CH2MHill, 1996) and defense agencies (DoD, 1996; DOE, 2002; DON 2001). Preproject planning compares alternative technologies, sites, etc. to identify the best feasible project strategy within project constraints. This method is effective in some contexts, but assumes that planners are fully informed about the project and that the project environment is relatively stable, or at least predictable (Mintzberg, 1978). Therefore, preproject planning does not provide the flexibility required to successfully manage the dynamic complexities inherent in many defense projects.

Risk Management

Risk management tools and methods are also widely used by industry (CII, 1989; Chapman & Ward, 1997; Koller, 1999) and defense agencies (DoD, 2001; DOE, 2002; DON, 2001) to manage project uncertainties by identifying critical risks, marshalling resources to absorb the consequences of uncertainty resolution that threaten project performance, and developing contingency plans. These methods often react to uncertainties after they resolve in undesired ways. For example, contingency funds can be used to respond to uncertain site conditions (e.g., poor soils) by paying for the additional costs of excavation, but only *after* the site conditions have been revealed and the uncertainty has resolved in an undesirable way.

In marshalling resources, risk management aggregates risks to assess their impacts and thereby estimate slack resource requirements. While useful for analysis and modeling, aggregating risks contrasts sharply with the reductionist approach used by managers to isolate specific individual critical uncertainties for customized management. Although sometimes used with options, the identification of critical risks and contingency planning have not been developed operationally in risk management to provide managers guidance concerning how to use flexibility to improve project performance.

Other Domains

Other research domains provide insight into particular aspects of how planners and managers can and do address uncertainty. Research on decision making potentially contributes to understanding the managerial use of options through decision analysis and game theory. By addressing the process of decision making by isolated individuals under uncertainty, decision analysis (Luce & Raiffa, 1957; Raiffa, 1970) provides a potentially effective approach to structuring and managing uncertainties that can be characterized in sufficient detail to select optimal strategies during preproject planning.

However, in highly complex and dynamic acquisition project environments such as those investigated here, project planners may not be able to assess all uncertainties with the well-defined probability distributions required for decision analysis. In these cases, flexibility in the form of options can address this residual uncertainty and improve solutions. For example, Mandelbaum and Buzacott (1990) show that using options in a manufacturing setting with residual uncertainty after preproject planning can improve decisions over those made solely using decision analysis. Game theory (Luce & Raiffa, 1957) adds competition with others to decision analysis and can provide insight if the managed uncertainty conforms to the assumptions used to characterize competing decision makers (e.g., payoff maximization or reconciliation objectives). The contribution

"In marshalling resources, risk management aggregates risks to assess their impacts and thereby estimate slack resource requirements."

of game theory may be limited when the managed uncertainty has a significant natural or random nature (i.e., not human decision making), such as those addressed here.

Senge (1990) describes why dynamic systems are complex and difficult to plan and manage. He recommends systems thinking as an approach to managing dynamically complex systems. Simon (1996) used bounded rationality to explain how the cognitive limitations of decision makers influence their information processing and behavior. In this context, managerial options can be seen as a tool for bridging the gap between the complexities of defense acquisition projects described by Senge and the cognitive capacities of managers described by Simon. Ford (2002) provides a specific example of a traditional tool for bridging this gap in development projects.

"Options add value by allowing managers to capture more benefits or shift risks depending on how one or more uncertain parameters behave."

In summary, strategic management as described by defense agencies and industry provides general guidelines for project flexibility. But the processes, methods, and tools for developing flexible strategic plans for projects and adapting to changes have not been operationalized adequately to be applied in the management of dynamic project uncertainty. Preproject planning, risk management, and other management decision-making theories also do not provide operational processes to proactively use flexibility to manage project uncertainty. A theory of options practices in projects would reflect managerial practice as well as managerial theory.

Options as Tools for Strategically Managing Dynamic Uncertainty

One means of achieving flexibility to address dynamic complexity is to delay committing to a strategy until uncertainty resolves, new information becomes available, and the better strategy is clearer (Gupta & Rosenhead, 1968). For example, Ward, Liker, Cristiano, and Sobek (1995) report how delaying the selection of automobile systems creates competitive advantage for Toyota in time-to-market and quality. Options structure managerial flexibility into delayed opportunities without obligations to change strategies to improve asset performance. Options add value by allowing managers to capture more benefits or shift risks depending on how one or more uncertain parameters behave. For example, a contract clause permitting the termination of the contract if a critical technology is not developed provides the government with an opportunity (but not an obligation) to terminate depending on how the technology feasibility uncertainty resolves.

Option taxonomies have been based on the nature of the managed asset, the objective of the management (risk mitigation or increased benefits), the timing of delayed strategy selection decisions and uncertainty evolution, and actions taken on strategies (e.g., abandon, expand, switch, etc.). Trigeorgis (1996) and others categorize and describe these classifications. Options, as investigated here, are a specific structure for the flexibility through dual sourcing recommended in defense acquisition guidelines (DoD, 2001; Section 5.6.2; DON, 1998, Chapter 1).

A managerial approach to options is adopted here as the basis for investigating their potential, challenges, and research needs as a tool for project planning and management. This approach focuses on the strategy design, assessment, and implementation processes. It differs significantly from existing approaches that focus on option valuation (Trigeorgis, 1996; Amram & Kulatilaka, 1999) or the strategic advantages of options (Courtney, Kirkland, & Viguerie, 1997; Andersen, 1999). This managerial approach also differs from some addressed by defense acquisition researchers and practitioners, including procurement quantity and performance duration issues addressed in codified federal acquisition regulations (FAR; subpart 17.2) and dual-use sourcing methods (DoD, 1996, section 3.3.1.2).

Despite the extensive use of options by acquisition project practitioners (Miller & Lessard, 2000), few options processes are described in the literature, and most of those are normative. Based on fieldwork at the project described later, a typical process begins when a manager recognizes (perhaps through risk assessment) that the value of a managed asset may be significantly impacted by how an unpredictable parameter behaves in the future. For example, a defense project manager may recognize that the costs and planned development of a specialized weapon (the asset) may depend on the design expertise of a critical vendor after the end of an existing contract (the uncertain parameter).

Managers recognize the need for flexibility when a possible resolution of uncertainty (a scenario) using a basic strategy generates a performance scenario to be avoided (e.g., large costs) or captured (e.g., improved product performance). In the example, the depletion of design expertise could increase future costs beyond budgets, constrain weapon development, or both, and the development of design expertise could improve weapon performance.

Alternative strategies that could increase project value under specific uncertainty resolution scenarios are then designed. Examples for the weapon system could include contracting for the right to continue design after the current contract, guaranteeing employment of critical employees, or contracting other work to the vendor that develops design expertise. Option designs include specific decision rules for implementation that describe the conditions that trigger a change in strategy. Options are implemented by monitoring the uncertain parameters, analyzing them as necessary to determine the status of the trigger, and changing strategies if and as indicated by the option design.

"Options are valuable only when their benefits exceed their costs."

Options are valuable only when their benefits exceed their costs. Options can provide a variety of benefits including improvements in economic performance, stronger strategic position, broader managerial perspectives, expanded planning processes, and increased productivity. Options also generate costs, most visibly in financial terms. Both initially purchasing the opportunity to choose strategies in the future and implementing strategy changes can incur costs. In the weapon example, an extension clause might increase the contract price and include computer upgrades at government expense if the clause is invoked. The economic valuation of options as a basis for strategy selection has been a primary focus of options research (Howard, 1976; Trigeorgis, 1996). Valuation methods for real assets compare net asset values with a specific option strategy to asset values using a rigid strategy to estimate option values. Ford, Lander, and Voyer (2002) developed a simple numerical example of how an option can increase the value of a development project.

Many acquisition project managers recognize the value of flexibility in managing dynamic uncertainties and use options. However, the practice is rarely structured into the frameworks developed by options theoreticians. Theories of managing uncertainty and valuing options in particular do not reflect options practice by acquisition planners and managers. This may be due to the complex, multi-dimensional nature of actual option settings, the difficulties of integrating widely varying data types for formal analysis, and the resulting informal and tacit processes used by practitioners. The process gap between options theory and options practice limits the description, evaluation, and improvement of options use practices.

"Theories of managing uncertainty and valuing options in particular do not reflect options practice by acquisition planners and managers."

OPTIONS IN PROCUREMENT FOR THE NATIONAL IGNITION FACILITY

Lawrence Livermore National Laboratory (LLNL) is developing the National Ignition Facility (NIF) under contract with the U.S. Department of Energy (DOE). DOE's goal is to generate the thermonuclear conditions created in nuclear explosions in a laboratory setting. NIF will be the world's largest experimental fusion facility, using 192 lasers to compress and heat a small capsule of material to fusion ignition. The project budget is $2.248 billion to be spent over approximately 11 years (Moses, 2002). Project success depends on several large simultaneous research and development efforts to produce unique subsystems.

Data were collected on the use of options to manage uncertainty at NIF by observing four public presentations on the project by DOE and LLNL management, reviewing project documents, interviewing the DOE project manager and LLNL project and procurement managers, and visiting the site twice, including tours of the facility while under construction. NIF managers were found to use options (although they do not typically use that term) to manage many of the large uncertainties inherent in the project. The LLNL project manager attributed the management team's frequent use of flexibility (including options) to their focus on project objectives instead of specific solutions. This allows managers to identify multiple potential strategies and scenarios to success (Moses, interview, December 13, 2001). As will be illustrated, NIF managers used these strategy: scenario sets to design options.

Several principles for managing uncertainty guided procurement at NIF. Examples include having two or more vendors for all major components to reduce the risk of inflated prices by a sole supplier and LLNL avoiding a manufacturing role to reduce the risks due to uncertain project funding and schedules (Moses, personal communication, December 13, 2001). LLNL preferred to contribute in its areas of strength (scientific expertise and funding) and focus vendor efforts on their strengths (technology development and manufacturing).

LASER GLASS PROCUREMENT: AN EXAMPLE OF APPLYING OPTIONS IN TECHNOLOGY DEVELOPMENT

The NIF laser glass production strategy illustrates the use of options to address a common but important acquisition project question: How many parallel development efforts should be supported? Many factors impacted laser glass production in addition to the options strategy. Some of these factors will be identified to illustrate the complexity of options use in practice. However, here we focus on the options aspects of laser glass procurement, as the details of other aspects or their impacts on laser glass production are beyond the scope of this paper.

NIF will spend more than $350 million to produce over 3,000 pieces of laser glass, each weighing about 150 pounds.[1] Laser glass begins as slabs of very high quality glass called "blanks." The large volume of blanks and project schedule and budget required a production rate 30 times larger and 5 times cheaper than was used in prototype lasers, requiring the development of a new glass production technology and manufacturing facilities. Glass vendors could not justify funding the development. Therefore, NIF invested in glass production technology development (Campbell, interview, December 13, 2001).

The development of a high-volume continuous-melting glass production process included at least two critical uncertainties: whether the technology could make the glass and whether the quality of the glass would be acceptable. The threat posed by these uncertainties was that, if development efforts failed in either way, the project could be delayed too far to meet its deadline and would incur very high-unbudgeted costs. Although LLNL had established relationships with experienced laser glass vendors, none could guarantee successful development within the required time a priori. Therefore, it became clear during laser glass procurement planning in 1994 that alternatives to a one-vendor strategy should be considered.

"It became clear during laser glass procurement planning in 1994 that alternatives to a one-vendor strategy should be considered."

LLNL considered two types of procurement strategy for glass production technology development. A base strategy would invest in a single production development effort — helping as possible and hoping for a successful development. An alternative strategy would simultaneously make initial investments in two independent development efforts by two glass producers, thereby providing two forms of managerial flexibility as well as increasing the likelihood that at least one effort would be successful.[2] First, limiting NIF commitment to initial development provided an additional strategy: scenario set by allowing NIF to delay its decision on the amount of support to provide a vendor until technology feasibility uncertainty resolved. Second, investing in two vendors provided additional flexibility in case either of two scenarios occurred: (1) if only one effort was successful, NIF could abandon the failed development effort, use the successful one, and avoid the consequences of having no successful glass production system at the end of the initial investment period; and (2) if both vendors succeeded NIF, could choose the better one or both.

In the laser glass case, the managed asset is the NIF project and the dynamic uncertainty is the likelihood of a vendor successfully developing a feasible glass production technology with the required quality. In the two-vendor strategy, each individual investment in a vendor can be structured as a staged development with an option to extend support if feasibility is demonstrated or with an option to abandon a vendor if feasibility cannot be demonstrated. The additional flexibility provided by investing in multiple vendors can be structured as an option to choose the successful vendor (if only one succeeds), choose the more successful or attractive vendor (if both succeed), or retain both vendors (if both succeed). The cost of this flexibility is the funds required to invest in a second vendor (approximately $12 million). Given the uncertainties, potential costs, and benefits, does the one-vendor or two-vendor strategy best serve NIF?

"NIF managers considered the two-vendor strategy attractive for both economic and non-economic reasons…."

NIF managers considered the two-vendor strategy attractive for both economic and non-economic reasons (e.g., generating competition between vendors). Despite a plethora of factors that influenced strategy attractiveness, the analysis that valued the option and drove strategy selection centered on the following comparison of strategy: scenario sets. If a single vendor was selected, the development might succeed. But if the single vendor failed, the costs to the project in time, money, and political consequences would prevent the project from meeting its targets. In contrast, if two vendors were selected, none, one, or two could succeed. The likelihood of two failures was considered low. One or two successes would protect NIF from project failure. The avoided costs of project failure if investments were made in two vendors were (informally) estimated to greatly exceed the additional cost of investing in a second vendor (0.5 percent of the project budget), even if the avoided costs were discounted at any reasonable rate to account for the time value of money. Therefore, the option was considered more valuable than its cost. Based on this reasoning, in 1994, DOE and LLNL selected a two-vendor strategy and in 1995 contracted with two vendors to initiate parallel development efforts without further commitments by LLNL or DOE.

The uncertainty about technology viability was resolved in early 1999 when both vendors successfully produced pilot runs of glass using continuous-melting processes. Due largely to the remaining quality uncertainty, NIF chose to not abandon either vendor. Quality uncertainty was resolved near the end of 2000 when both vendors also demonstrated the ability to generate the required glass quality. NIF chose again to continue with both vendors to retain manufacturing and pricing flexibility. By choosing to support both vendors, NIF purchased valuable production and pricing flexibility with which it can manage other project uncertainties (e.g., schedule). The costs avoided remain significant, albeit less than those saved in case of a development failure. The NIF laser glass production option illustrates how options have been used to increase project value and the difficulty of rigorously addressing relatively simple — but important — procurement questions in practice.

DISCUSSION

An acquisition strategist might ask several questions concerning the NIF laser glass procurement strategy. What is the optimal number of vendors for NIF to invest in? Precluding clairvoyant planning that could have perfectly predicted the success of a single vendor, it appears that the NIF management chose the right strategy. But if, in the extreme, the likelihood that a single vendor would succeed was believed to be 99 percent and the added cost of a second vendor was very high, perhaps a single-vendor strategy would have been preferred and the option should not have been purchased. On the other hand, what if both vendors had failed? Perhaps NIF should have invested in more than two vendors. Would strategies in addition to those considered have added even more value to the project? How do acquisition planners know whether all potentially valuable strategies have been identified? How do planners design strategies? More generally, how do project and option structures and development processes impact project value and strategy selection?

Answers to the questions posed above are not obvious or easily obtained. Strategy analysis depends largely on the probabilities of success, costs, and their analysis. Researchers have proposed methods of economically valuing staged parallel development strategies that may be applicable to the multiple-vendor, staged development problem described here (Ding & Eliashberg, 2002). But the simplifying assumptions required for mathematical tractability prevent these models from realistically modeling the complexities inherent in managing uncertainty in large development projects. Better models of the relatively simple processes illustrated by the NIF laser glass case may provide more insight into options use practices. A theory of options practice is needed to relate current options theories and practice.

"Strategy analysis depends largely on the probabilities of success, costs, and their analysis."

One approach to assessing NIF's use of options is to compare and contrast the use of options by NIF managers with existing uncertainty management theories. Laser glass procurement for NIF used some of the methods and tools prescribed by strategic management. NIF managers surveyed the project environment to identify uncertainties that threatened project success (e.g., undeveloped glass production technology). Managers also assessed NIF's internal strengths (e.g., science) and weaknesses (e.g., manufacturing) as a part of strategy development. However, there was no evidence found that the team identified all potentially valuable strategies or was able to test how well the selected strategies addressed the uncertainties compared to alternative strategies.

Laser glass procurement in the NIF project focused on flexibility (ala DoD guidelines) using a reductionist approach to isolate and manage key individual uncertainties. However, the observed use of options on the NIF project differs significantly from existing options theory. This supports our hypothesis that a structured process for the description, design, assessment, and use of options that resembles practice is needed to improve options use. Research is needed to integrate options theories and options practice. One product of such research would be a theory of option practice that can facilitate the improved and expanded use of options by managers to increase project values. The applicability of options to defense acquisition could be further investigated through the comparison of the approach described here and other defense acquisition sourcing methods and the comparison of the NIF experience with dual sourcing in other defense acquisition projects.

This paper has described dynamic uncertainties as a particularly difficult challenge in strategically planning large complex defense projects. Traditional methods and tools for managing uncertainty were reviewed and found unable to adequately address dynamic uncertainties. Options are described as a framework for structuring the management problem, potential strategic responses, and valuation for strategy selection to proactively manage dynamic uncertainty. An example of the use of options for procurement at a large defense project illustrates the potential benefits and challenges of using options in practice and deficiencies in options theories for application. The lack of structured processes and tools for designing, valuing, and implementing options by practitioners, limits their assessment and improvement. These tools and processes would also integrate flexible strategies with existing project planning and management tools and thereby expand the strategic project-planning domain. Applying such tools and processes would increase the value of large complex defense projects.

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ENDNOTES

1. The parallel development of a French facility that also would need laser glass, similar to NIF, increased demand and schedule uncertainty.
2. Other alternatives, such as adding investment or postponing the decision beyond the initial investment period, provided additional options but are not considered here for clarity.

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REFERENCES

Amram, M., & Kulatilaka, N. (1999). *Real options*. Cambridge, MA: Harvard Business School Press.

Andersen, T. J. (1999, August/September). Strategizing in the new competitive energy market. *The Electricity Journal*. 42–48.

Baldwin, C. Y., & Clark, K. B. (2000). *Design rules, the power of modularity*. Cambridge, MA: MIT Press.

Benaroch, M. (2001). Option-based management of technology investment risk. *IEEE Transactions on Engineering Management*, *48*(4): 428–444.

Bierman, H., & Smidt, S. (1992). *The capital budgeting decision — Economic analysis of investment projects* (8th ed.). New York: Macmillan.

Black, F., & Scholes, M. (1973). The pricing of options and corporate liabilities. *Journal of Political Economy*, *81*(3): 637–654.

Bookstaber, R. M. (1982). *Option pricing and strategies in investing*. Reading, MA: Addison-Wesley.

Brealey, R., & Myers, S. (2000). *Principles of corporate finance*. New York: McGraw-Hill.

CH2MHill. (1996). *Project delivery system: A system and process for benchmark performance*. Denver, CO: Author.

Chapman, C., & Ward, S. (1997). *Project risk management*. New York: John Wiley & Sons.

Construction Industry Institute. (1989). Management of project risks and uncertainties. (Publication 6–8). Austin, TX: Author.

Construction Industry Institute. (1995). *Pre-project planning handbook*. Austin, TX: Author.

Courtney, H., Kirkland, J., & Viguerie, P. (1997, November/December). Strategy under uncertainty. *Harvard Business Review,* 67–79.

Cox, J. C., Ross, S. A., & Rubinstein, M. (1979, September). Option pricing: A simplified approach. *Journal of Financial Economics, 7*, 383–402.

DeMeyer, A., Loch, C. H., & Pich, M. T. (2002, Winter). A framework for project management under uncertainty. *Sloan Management Review*, *43*(2), 60–67.

Department of Defense. (1996). *Mandatory procedures for major defense acquisition programs* (Regulation 5000.2-R). Washington, DC: Author.

Department of Defense. (2001). *Risk management guide for DoD acquisition*. Fort Belvoir, VA: Defense Acquisition University. Defense Systems Management College.

Department of Energy. (2002). Program and project management manual (Publication DOE M 413.3). Washington, DC: Author.

Department of the Navy. (1998). *Top eleven ways to manage technical risk* (PAVSO P-3686). Washington, DC: Office of the Assistant Secretary of the Navy (RD&A).

Department of Navy. (2001). *Acquistion strategy decision guide.* Available at http://www.acq-ref.navy.mil/tools/asdg/index.html. Accessed May 15, 2001.

Ding, M., & Eliashberg, J. (2002). Structuring the new product development process. *Management Science, 48*(3), 343–363.

Dixit, A. K., & Pindyck, R. S. (1994). *Investment under uncertainty*. Princeton, NJ: Princeton University Press.

Ford, D. (2002, February). Achieving multiple project objectives through contingency management. *ASCE Journal of Construction Engineering and Management*, *128*(1), 30–39.

Ford, D., Lander, D., & Voyer, J. (2002). The real options approach to valuing strategic flexibility in uncertain construction projects. *Construction Management and Economics*, *20*(4), 43–352.

Gupta, S. K., & Rosenhead, J. (1968). Robustness in sequential investment decisions. *Management Science*, 15(2), B18–B29.

Howard, R. A. (1976). The science of decision making. In Howard, R., Matheson, J., & Miller, K. (Eds), *Readings in Decision Analysis.* Menlo Park, CA: Stanford Research Institute.

Hughes, T. (1998) *Rescuing Prometheus*. Pantheon Books. New York.

Kemna, A. G. Z., & Vorst, A. C. F. (1990, March). A pricing method for options based on average asset values. *Journal of Banking and Finance, 14*(1), 113–129.

Kensinger, J. W. (1988). The capital investment project as a set of exchange options. *Managerial Finance, 14*(2/3), 16–27.

Koller, G. (1999). *Risk assessment and decision making in business and industry: A practical guide*. New York: CRC Press.

Leslie, K. J., & Michaels, M. P. (1997). The real power of real options. *The McKinsey Quarterly, 3,* 5–22.

Luce, R., & Raiffa, H. (1957). *Games and decisions*. New York: John Wiley and Sons.

Mandelbaum, M., & Buzacott, J. (1990). Flexibility and decision making. *European Journal of Operations Research*, *44*, 17–27.

Miller, R., & Lessard, D. (2000). *The strategic management of large engineering projects*. Cambridge, MA: The MIT Press.

Mintzberg, H. (1978). Patterns in strategy formation. *Management Science*, *24*(9), 934–948.

Mintzberg, H. (1995). *The strategy process*. London: Prentice Hall Europe.

Moses, E. (2002, February 6). NIF overview/status presentation to National Research Council Committee on Oversight and Assessment of Department of Energy Project Management.

Park, C. S., & Herath, H. S. B. (2000). Exploiting uncertainty — Investment opportunities as real options: A new way of thinking in engineering economics. *The Engineering Economist, 45*(1), 1–36.

Porter, M. E. (1980). *Competitive strategy*. New York: The Free Press.

Raiffa, H. (1970). *Decision analysis, introductory lectures on choices under uncertainty*. Reading, MA: Addison-Wesley.

Sayles, L. R., & Chandler, M. K. (1971). *Managing large systems*. New York: Harper & Row, Publishers.

Senge, P. M. (1990). *The fifth discipline: The art and practice of the learning organization.* New York: Doubleday.

Simon, H. (1996). *The sciences of the artificial.* Cambridge, MA: MIT Press.

Sterman, J. D. (1994). Learning in and about complex systems. *System Dynamics Review*, *10*(2/3), 291–330.

Trigeorgis, L. (1993, Autumn). Real options and interactions with financial flexibility. *Financial Management*, *22*, 202–224.

Trigeorgis, L. (1996). *Real options, managerial flexibility and strategy in resource allocation.* Cambridge, MA: The MIT Press.

Ward, A., Liker, J. K., Cristiano, J. J., & Sobek II, D.K. (1995, Spring). The second Toyota paradox: How delaying decisions can make better cars faster. *Sloan Management Review*, 43–61.