

**Real Options for Naval Ship Design and Acquisition:  
A Method for Valuing Flexibility under Uncertainty**

by

Jeffrey Allen Gregor

B.S., Chemical Engineering, Carnegie Mellon University, 1994

Submitted to the Department of Ocean Engineering in Partial Fulfillment of  
the Requirements for the Degree of

Master of Science in Naval Architecture and Marine Engineering

at the

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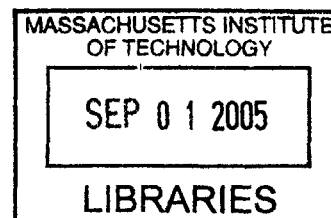
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**ABSTRACT**

The United States Navy is facing a need for a novel surface combatant capability. This new system of ships must be designed to meet the uncertainty associated with constantly changing required mission capabilities, threats, and technological advances. Flexibility in design and management will enable these systems to maximize their performance under changing conditions. Real options involve the 'right but not the obligation' to take a course of action. Real options embody the flexibility that allows projects to be continually reshaped, as uncertainty becomes resolved. This thesis seeks to identify and analyze the real options available for the design and acquisition of naval ships. This thesis also seeks to determine the value of these options and determine the best types and amount of flexibility to design into naval systems in order to maximize the value of the system over time under uncertain conditions.

Thesis Supervisor: Clifford A. Whitcomb  
Title: Senior Lecturer, Engineering Systems Division

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## **BIOGRAPHIC NOTE**

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Lieutenant Jeffrey A. Gregor was born in Latrobe, Pennsylvania and graduated from Greater Latrobe Senior High School in 1990. LT Gregor then attended Carnegie-Mellon University in Pittsburgh, graduating in 1994 with a Bachelor of Science degree in Chemical Engineering with a minor in Biomedical Engineering.

Following graduation, he was commissioned an Ensign through the Navy Reserve Officer Training Corp program and served as Training Officer at Naval Reserve Readiness Center, Pittsburgh from June 1994 to September 1994.

After completing training at Surface Warfare Officer School in Newport, Rhode Island, LT Gregor served his initial sea tour in USS ANTIETAM (CG 54). While onboard, he served as Strike Warfare Officer, Combat Information Center Officer and Assistant Operations Officer from March 1995 to February 1997.

Following his tour in USS ANTIETAM, LT Gregor reported for nuclear power training at Navy Nuclear Power School, Orlando, Florida. After successfully completing reactor prototype training at Nuclear Power Training Unit, Ballston Spa, New York, LT Gregor reported to USS JOHN C. STENNIS (CVN 74). There he served as Reactor Mechanical Division Officer from June 1998 to May 2000. LT Gregor is qualified as a Nuclear Engineer Officer.

LT Gregor reported for duty under instruction at the Massachusetts Institute of Technology in June 2000 as a student in the Course XIII-A program.

LT Gregor has been awarded the Navy Commendation Medal (Gold Star in lieu of second award), and the Navy Achievement Medal.

LT Gregor is married to the former Leisa Maree French of Gympie, Queensland, Australia.

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# CHAPTER 1 Introduction

## 1.1 Motivation

The United States Navy is facing a need for new systems of ships which are designed to meet uncertainty associated with required mission capabilities, threats, technology advances, performance predictions, and design synthesis, among others. Since the end of the Cold War, the types of capabilities required of naval ships, the environments in which they operate, and the threats faced by them continue to evolve and change rapidly.

Previously, with the Soviet Union as the principal opposition force, ships could be designed to carry out specified missions against a known adversary. With the collapse of the Soviet Union, programs such as the Seawolf class submarine have been cancelled. The Seawolf was designed as a blue-water submarine to combat the Soviet submarine fleet. As that mission disappeared, the nearly four billion dollar cost of a Seawolf was no longer justified. Lately the DD-21 destroyer program was cancelled due to a shift in mission requirements.

The US Secretary of Defense has summarized the need for considering uncertainty in the early stages of the ship design process (Rumsfeld 2001):

- During the past 60 years, the US has spent an average of 8% of GDP on defense. Investing in defense during peacetime acts as an insurance policy for the future by decreasing the risk of conflicts for future generations.

- Although the US still fields the world's best fighting force, its legacy systems, designed to win the Cold War, may not be able to meet future requirements.
- The Quadrennial Defense Review must focus on transformation, which will provide a hedge against future uncertainty while continuing to meet current needs.
- Forces must be transformed to rapidly adapt to emerging threats.
- A balance must be struck between forces, resources, and modernization, while accounting for future risk. Transformed forces will be able to defeat more capable adversaries at an affordable cost, while remaining flexible enough to meet uncertain future requirements.
- Combining threat based and capabilities based performance standards will provide a hedge against future uncertainty risk.
- Capabilities based performance standards mitigate risks and hedge against uncertainty in the future. (Though future threats cannot be described with certainty, future capabilities can be determined).
- In an ever-changing environment, a wider range of contingencies and options for employing forces must be considered.

- Dealing with uncertainty must be a focus of US defense planning.
- The DoD must select, develop, sustain a portfolio of capabilities to meet current and future challenges.
- Capabilities and concepts must meet the uncertain challenges of the future.
- A balance must be struck to meet the current challenges while transforming force to meet evolving, uncertain challenges in future.
- Although it cannot be known for certain who the future enemy will be, shifting from a threat to a capabilities based approach, will allow designers to anticipate capabilities that will build up vulnerabilities and enhance capabilities.
- Give greater priority to experimentation and show more tolerance for failure during testing and development of advanced systems.
- Develop more rapidly responsive, scalable, modular units capable of autonomous and integrated operations.
- Reform acquisition, financial, and business practices.
- Uncertainty supports experimentation which creates options and allows learning to make adjustments over time.

- Develop a roadmap for transforming near and far term objectives.
- Identify program options and evaluate based on cost and effect measure of merit.
- Evaluate options against criteria for strategy and preferred characteristics in terms of reference.
- Develop alternative investment profiles across capability areas.
- Identify programs or capabilities for retirement, divestment, and truncation.

In addition, the Navy Strategic Planning Guidance provides further evidence that explicit consideration of uncertainty in future warfare needs would be beneficial (U.S. Chief of Naval Operations 2000):

- The Navy needs to implement a strategy-based approach to the planning, programming, and budgeting process to ensure the Navy that can provide broad access and influence ashore in 21<sup>st</sup> Century Information Age.
- The Navy can guide the transformation by describing organizing principles, operational concepts, and priorities for future naval forces to exploit new opportunities and capabilities to ensure access forward.

- In order to meet future requirements, the Navy must take full advantage of emerging technologies and concepts in order to equip sailors with increasingly capable ships and equipment ready to respond anytime and anywhere.
- Intelligence assessments form the basis for identifying areas where risks can be taken and where we need to hedge against an uncertain future.
- Although the future in a security environment cannot be predicted with certainty, trends point to focus on littorals and in-land.
- Regional and non-state actors and increased globalization of economies points toward a more complex security environment which along with other forces adds uncertainty to the planning process.
- The future Navy requires the capability to dominate over wide spectrum of environments, from dissuading global ambitions of future regional powers to low intensity conflicts and strategic deterrence.
- The spectrum of challenges faced by the Navy will be broad: from information attack to pirates in small fast boats to fully modernized regional combat fleets of surface ships, submarines and aircraft.
- The capabilities required will vary from region to region and in virtually every theatre of operations.

- The capabilities required will be across a spectrum of operations from peacetime presence to combat missions.
- Trends in design towards modular construction will allow for customer specific variations in designs without significant added cost while providing significant additional capability.
- The expanding global market and increasing technology make advanced designs available to many foreign actors.
- Future US Naval forces can be expected to be involved in many missions at the low end of the violence continuum. These forces must be ready to support MIO, humanitarian support, terrorist reaction, and peace-support missions. These missions are more likely than regional or local wars. Supporting these missions requires interest in emerging non-lethal force capabilities.
- The Navy must continue its over 200 year old mission of promoting peace and defeating adversaries when necessary.
- A focus on required capabilities for the near, mid and far terms must be considered, rather than the traditional focus on platforms and systems. Programs must be continuously refined to reflect present and projected capabilities.
- Factors such as operational risk, and effectiveness (benefits) of alternatives, in addition to cost, must be considered when examining desired capabilities, current capabilities, and resources.

Finally, several recent GAO reports cite the need for the Department of Defense to recognize uncertainty and plan for it during the acquisition process (U.S. GAO 1999, 1997a):

- DOD seeks to make its current organization and business practices more agile and responsive. DOD also hopes that this initiative will provide a major source of savings that can be used to help fund DOD's planned \$20 billion annual increase in weapon systems modernization.
- DOD desires to reengineer the Defense business and support operations by adopting and applying revolutionary new business and management practices learned from the private sector.
- DOD managers have had few incentives to improve DOD's financial, acquisition, and infrastructure management approaches. In the DOD culture, the success of a manager's career depends more often on moving programs and operations through the DOD process rather than on improving the process itself.
- DOD strategic goals and objectives have not been linked to those of the military services and Defense agencies, and

DOD's guidance has tended to lack specificity. Without clear, hierarchically-linked goals and performance measures, DOD managers have not been able to show how their work contributes to the attainment of DOD's strategic goals.

- Developing strategic and tactical plans provide a roadmap to guide reform and track progress throughout the organization.
- Establishing objective, outcome-oriented performance measures that link to strategic and tactical plans, establish accountability, and provides information for making mid-course corrections.
- Planning is a dynamic process, and the ongoing and planned activities, along with any additional input from OMB, congressional staff, and other stakeholders, could result in changes to DOD plan.
- The DOD plans should discuss more clearly how external factors link to and could affect achieving its goals. Framing the acquisition problem in this manner would allow the identification of resources needed to implement its

plans, and any external factors that could impede resolution.

- Office of Management and Budget (OMB) Circular A-11 points out that agencies' achievement of their goals and objectives can be influenced by certain external factors that exist, occur, or change over the time period covered by their plans. The circular notes that these factors can be economic, demographic, social, or environmental in nature. It states that the strategic plan should describe each external factor, indicate its link with a particular goal(s) and describe how achieving the goal could be affected by the factor.

## **1.2 Background**

Historically ships rarely fulfill only the missions for which they were initially designed since mission requirements often change due to their long time to be put in service and their expected long service life. For example, some CVNs, with addition of equipment and upgrades, have used their lifetime weight margin and have required extensive hull form changes, which resulted in unsatisfactory ship motions adversely impacting aircraft operation (USS Midway). Flexibility is the key to producing a ship that will be able to evolve with

changing requirements and provide the most utility over the course of many years service.

Upfront systems engineering is used to match mission requirements with resources. Even in this basis case, there is an option to start or not start the program, based on whether the requirements have changed and/or the mission still exists. The key is to maintain flexibility in the requirements, since it should be expected that they will change over the long acquisition and service life of the warship. Unlike engineering thinking, the goal is not to optimize the design, as optimization infers certainty, but rather to design flexibility that can be invoked, if required to hedge against uncertain changes in order to maintain the ship as a viable fleet asset. To optimize for one scenario is to potentially sub-optimize when requirements change. The value of this flexibility cannot be determined from a strictly engineering point of view, but rather the exogenous, or market uncertainties concerning changing mission requirements and threats must be accounted for. Properly valuing flexibility is especially important now with tight budgets and a smaller number of ships, each ship must be flexible enough to continue to be of war fighting value as threats and missions change. Real options may provide a method for properly determining the value of a fleet of small flexible ships that can switch between many missions and a few larger multi-mission ships.

In order to maximize effectiveness for the war fighter and return on investment for the taxpayer, flexibility should be explicitly considered in naval ship design. Ships are designed to meet multiple mission needs that have been identified and validated by future war fighting projections. These ships are

matched to budget and mission projections 10 to 15 years out from the concept design exploration. Ship designers seek to optimize the ship performance to the stated mission requirements while simultaneously minimizing cost of ships through optimizing ship attributes, such as size, installed power, etc., or minimizing life cost attributes, such as fuel use rate or manpower levels, while at the same time maximizing war fighting effectiveness. The challenge is in maintaining the context for the ship system cost and war fighting effectiveness over the long design and acquisition period, when the assumed usage scenario projection usually changes.

Flexibility in the way of providing extra or new capabilities, not specifically identified in the current requirements, is currently accounted for using weight and stability margins. These margins account for some general uncertainty in the design and construction of the ship as well as allowing for some lifetime growth. Adding flexibility to the ship during the design phase to account for mission and other exogenous uncertainty seems to be an obvious solution, but this leads to such possible penalties as carrying weight around as ballast margin to be used for future addition to capability (which wastes weight and impacts fuel cost) or the addition of modular structures which take away from precious payload carrying capability. Defining a way to value how much and what types of flexibility should be added and at what cost is required to allow informed trade off of effectiveness and cost of considering the uncertainty involved.

As with most engineering projects, risk during the project is to be avoided and uncertainty is looked upon as detrimental. Risk management plans are reactive and look to keep the project on a

pre-determined path. A dynamic strategic plan that is flexible to adapt to changes in mission requirements and capabilities, as well as technical uncertainties, should add value to the project; improving return on investment and improving mission effectiveness. Real options are a way of looking at complex projects that involve uncertainty. Real options thinking is proactive towards risk and uncertainty and actually becomes more valuable when uncertainty is high.

### **1.3 Real Options**

Real options provide a dynamic strategic plan that incorporates and values flexibility. Real options match the way decisions are already made, by waiting for uncertainty to be resolved, and showing the value based on possible future outcomes.

The concepts of options thinking, and real options, are based on financial options and methods. A historical view of the application of real options puts these concepts into perspective. The initial application of real options was used to solve the discount rate problem present in traditional Net Present Value (NPV) and decision analysis (DA) methods. The Black-Scholes formula was used once an underlying asset that mimicked the market uncertainty was identified. These examples were applied to private sector projects. Others (Gonzalez-Zugusti, et al 1999, Lamassoure 2001, Ford and Ceylan 2001a, Ford and Ceylan 2001b, Ford and Ceylan 2001c, McVey 2002, Shishko and Ebbeler 1999, Ramirez 2002) extended the application to public sector projects, but the methods still focused on cost savings and primarily dealt with the product uncertainties.

In order to apply Real Options to naval ship design and acquisition, the real options method must be extended to the public sector. Key differences that must be overcome for this application are that the war fighting capability, mission need, and budgetary uncertainty do not deal with a real market, but rather uncertainties exogenous to the project. Additionally, these major uncertainties deal mostly with non-monetary benefits from the project.

In order to constrain the method to be viable in the Navy context, the current practices within the context of current DOD 5000.2 (series) acquisition instructions are referenced. Any extensions to DOD 5000.2 (series) aim to add more flexibility to designs and identify program management options. The thesis seeks to properly value the management of the project and consider flexible physical options that allow faster switching between mission capabilities without the need for extensive ship overhaul. The method will use decision analysis to value these options to determine how much flexibility to add and how to choose among a portfolio of competing designs under uncertainty. The use of real options thinking should enhance current methods used to make ship design trade-off decisions, which do not account for uncertainty.

#### **1.4 Thesis Outline**

This thesis seeks to examine how real options methods can be extended to be useful in a naval ship design and acquisition setting since the most important values derived from the process are non-monetary and very difficult to place a monetary value on.

The thesis divided into 6 chapters including this introduction.

Chapter 2 gives an overview of the defense acquisition system including both historical and recent reform changes. Areas in both acquisition and design that could benefit from the application of real options thinking and methods are identified.

Chapter 3 begins by defining and discussing flexibility. Chapter 3 then provides background for real options from their birth in valuing options on traded securities to current project valuation in public and private settings. Chapter 3 also discusses different methods that can be used to value real options and argues which methods may be appropriate in the case of naval ship design and acquisition.

Chapter 4 draws on the material presented in chapters 2 and 3 to present a practical method for implementing real options techniques into naval ship design and acquisition. The method attempts to identify how flexibility can be incorporated into both design and acquisition and how the types and amounts of flexibility can be valued in order to determine whether the value added by the flexibility is justified.

Chapter 5 applies the method presented in chapter 4 to a representative case study based on current navy design trends and requirements.

Chapter 6 provides an overall summary.

## **CHAPTER 2 Defense Acquisition and Ship Design**

Real options have their roots in the financial realm and as such have thus far been applied to the valuation of private firm projects whose goal is to maximize profits for the firm's shareholders. In order to see how real options might be applied to the valuation of a public sector project, specifically the acquisition of naval warships, the characteristics of the DOD acquisition process are examined. The context for the uncertainty in the projection of war fighting needs, which drives the need for options thinking, is included.

### **2.1 DOD Acquisition Overview**

The government program manager is the agent for the war fighter who ensures requirements are met effectively, efficiently and in the shortest possible time. While the driving force behind private firm projects is to increase profits, the purpose of the DOD acquisition system is characterized as:

The DOD acquisition system exists to secure and sustain the nation's investment in technologies, programs, and product support necessary to achieve the National Security Strategy and support the United States Armed Forces. The Department's investment strategy must be postured to support not only today's force, but also the next force, and future forces beyond that. The primary objective of Defense acquisition is to acquire quality products that satisfy user needs with measurable improvements to mission accomplishment and operational support, in a timely manner,

and at a fair and reasonable price. (U.S. Department of Defense 2000)

A DOD acquisition program is a comprehensive, cradle-to-grave process that includes design, engineering, test and evaluation and operational support of Defense systems. A successful acquisition program is characterized as one that provides a capable and supportable system to the war fighter when and where it is needed and does so affordably. Defense acquisition deals with very long time frames in supporting not only today's force, but also the next force, and the force after next. Its goal is to provide a quality product that creates a measurable improvement in mission accomplishment and operational support, in a timely manner, at a fair price (U.S. Department of Defense 2000).

Defense acquisition projects constitute some of the most costly and complex undertakings and represents one of the largest management challenges within the federal government. Even with reduced budget trends, the Defense operations involve over \$1 trillion in assets and a budgetary authority of about \$250-\$310 billion annually. This annual amount accounts for approximately 15 percent of the Federal budget and is estimated at about 3.2 percent of the U.S. gross domestic product (U.S. Department of Defense 2000).

Most Defense systems are large and extremely complex and none more so than naval warships. The design and production of "a major combatant warship is one of the most complex undertakings of man. It is as complicated as sending a man to the moon." (Maurelli 1997) These large, complex projects are based on a validated mission needs and are also subject to uncertainties in

threats, mission requirements, budgets, and technology, as well as, numerous external factors such as: policies, public opinion, emergencies, and ever present and changing threats to national security.

## **2.2 Defense Acquisition Reform**

With the fall of the Soviet Union and the end of the Cold War, many feel that a "revolution in military affairs" is under way, driven by rapid advanced in technology, evolving threats, and shrinking defense budgets. In order to keep pace with these revolutionary changes in the conduct of warfare, the DOD has embarked on a series of reform measures intended to fundamentally change its business practices and reengineer its infrastructure to better support the evolving needs of the war fighter. This "revolution in business affairs" aims to accomplish three things: (1) expand and fully implement acquisition reform; (2) work to do away with specialized government auditing and accounting procedures in order to attract more private firms to do business with the DOD; and (3) reduce the size and cost of the Defense infrastructure by applying commercial practices (U.S. Department of Defense 2000).

With reduced budgets, programs were forced to prioritize and with fewer new programs being started, the DOD realized that it would not be able to continue with business as usual.

Fundamental changes were required in order to provide the required capabilities faster, better, and cheaper. A new outlook for acquisition was established focusing on mature technology, interoperable systems, and a stronger industrial

base with more civilian and military integration (U.S. Department of Defense 2000).

DOD's vision for Acquisition Reform is:

DOD will be recognized as the world's smartest, most efficient and most responsive buyer of best-value goods and services that meet the war fighters' need from a globally competitive national industrial base (U.S. Department of Defense 2000).

To realize the vision of Acquisition Reform, DOD has taken on the following missions (U.S. Department of Defense 2000):

- Adapting the best practices of world-class customers and suppliers;
- Continually improving the acquisition process to ensure that it remains flexible, agile, and to the maximum extent possible, based on best practices;
- Provide incentives for acquisition personnel to innovate and manage risk, rather than avoid it, and;
- Taking maximum advantage of emerging technologies that enables business process reengineering and enterprise integration.
- Recognizing opportunities for the war fighter to try out new technologies

Acquisition reform also extends to the way that the DOD awards contracts. No longer will the Department buy from the lowest cost supplier who provided the minimum requirements, but rather contracts will be awarded based on overall value. This overall

value is assessed by a trade-off of cost and non-cost factors such as performance, quality, and schedule. Additionally, the war fighter must determine cost objectives that will allow an affordability determination when compared to other needs and their costs (U.S. Department of Defense 2000).

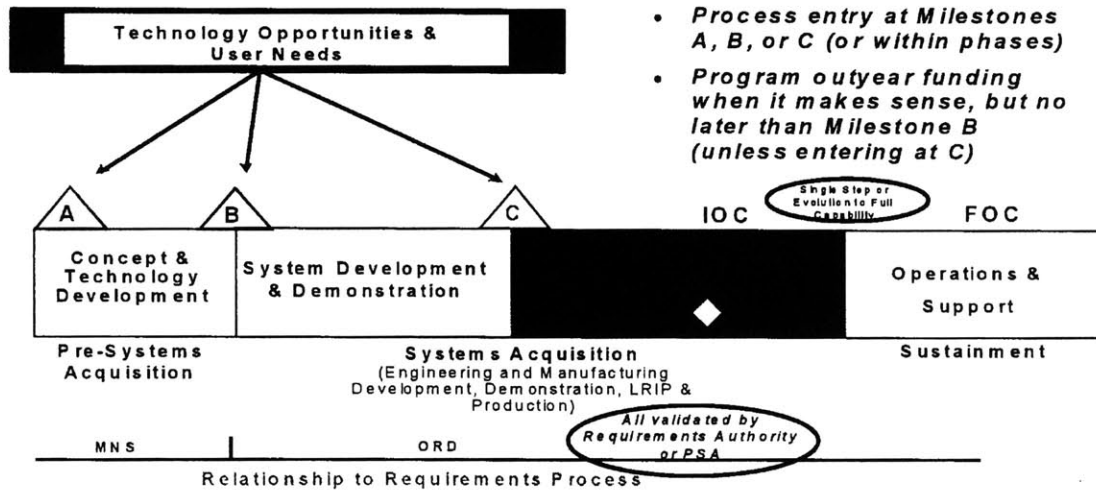
### **2.3 The Reformed DOD Acquisition Program**

Defense acquisition programs begin with a warfare need, an enabling technology, or a combination of both. The acquisition program is comprised on three different systems: the Requirements Generation System, the Defense Acquisition System, and the Planning, Programming, and Budgeting system. The Requirements Generation system identifies the mission needs, deficiencies, or technological opportunities for the program. The Defense Acquisition System combines the need and technologies into reliable, affordable, and sustainable systems. The Planning, Programming, and Budgeting system provided the funding required for carrying out the program.

The acquisition system is comprised of time periods called phases separated by decision points called milestones (Figure 2-1). Under the reformed acquisition process, the milestones are A, B, and C, although each program is unique and may not contain all phases. Milestones allow for program reviews with the opportunity for mid-course corrections.

Figure 2-1

## THE 5000 MODEL



(from Cochrane et al 2001)

Milestone decision authorities use exit criteria to establish goals for an acquisition program during a particular phase. Exit criteria are phase specific tasks selected to track progress in important technical, schedule or risk management areas. They act as "gates," which when successfully passed, demonstrate that the program is on track to meet its final goals.

### 2.3.1 Milestone A

Milestone A is referred to as pre-systems acquisition. This phase defines user needs and develops technology solutions to

validated mission needs. The key concepts in pre-system acquisition are:

- Keep all reasonable options open to allow for cost, schedule, and performance trade-offs
- Avoid early commitment to a specific design solution so as to block insertion of new technology
- Define requirements in broad operational terms
- Plan time-phased requirements for performance parameters

Following these key concepts, an Analysis of Alternatives (AOA) is conducted in order to determine the cost and mission effectiveness of alternative design solutions. The AOA is an independent scientific study meant to aid the decision maker by showing the relative advantages and disadvantages of alternatives considered, as well as their sensitivity to changes in key performance parameters or and assumptions. The AOA should seek to determine whether the military value of a solution is worth the cost, without pre-determining any specific solution.

The results of the AOA allow the Operational Requirements Document (ORD) to be initiated. The ORD lists required operational objectives and goals and threshold values for key performance parameters (KPPs).

Following a successful Milestone A, the program enters the Concept and Technology Development Phase (CTD). There are two work efforts within CTD: Concept Exploration (CE) and Component Advanced Development (CAD). Concept Exploration deals with the evaluation of multiple concepts that consists of competitive,

parallel, short-term concept studies by private industry. Concept Advanced Development is entered when the concept is clear, but subsystem technologies are not mature enough to advance to the next phase.

In addition to developing the ORD, the results of the CTD phase include: the initial acquisition strategy, cost estimates, and the program baseline. The acquisition strategy is an overall plan which indicates program goals and serves as a roads-map for the program. The program baseline contains key cost schedule and performance parameters. Also, near the end of the CTD phase, a risk assessment is conducted.

Successful completion of the CTD phase leads into Milestone B and the System Development and Demonstration Phase (SDD).

### **2.3.2 Milestone B**

Milestone B is normally the program initiation point for acquisition projects. Program initiation requires: (1) a valid requirement in an ORD; (2) mature technology; and (3) funding. The two work efforts in the CDD phase are the System Integration (SI) Phase and the System Demonstration (SD) phase.

### **2.3.3 Milestone C**

Milestone C provides for low-rate initial production (for applicable systems) or production and procurement. Two approaches to Full Operational Capability can be followed:

single step or evolutionary. Evolutionary acquisition is the preferred method.

Evolutionary acquisition develops initial core useful capabilities called "blocks" and is broken into two approaches: (1) full definition of capability for all blocks; or (2) full definition of capability for block one only, with future block requirements to be determined.

Evolutionary acquisition allows a reduced cycle time and speeds delivery of advanced capability to the war fighter by allowing the program to field the advanced capabilities in manageable pieces. The time-phasing of the blocks allows for improved capabilities over time through the insertion of new technologies as they become available. This is especially useful when the full required capability may not be known at the program outset.

Spiral development is an iterative process used to develop the required capabilities within one block.

#### **2.4 Option Thinking Opportunities**

The current ship design and acquisition process includes some option-like features. The process is time sequenced into decision phases. The option to abandon is included at the decision phases, but implementation of this option is not usually considered and more money is added to a project to keep in on the pre-determined track.

The best portion of the cycle to apply options thinking is in the Analysis of Alternatives (AoA), during the study of operational effectiveness and lifecycle costs of various alternatives that may be able to meet mission area needs. The AoA seeks to determine the most cost-effective way to meet the mission needs and prevent the pre-determination of a solution to a need via an independent scientific study. (Azama 2000).

The AoA is intended to aid the decision maker by showing the relative advantages and disadvantages of alternatives being considered and by showing the sensitivity of each alternative to changes in key assumptions (threat) or variables (performance parameters). It attempts to answer the question: "Are any of the proposed alternatives of sufficient military benefit to be worth the cost?" (U.S. Navy, Chief of Naval Operations 2001)

The AoA needs to be framed in such a way that advantages can be compared to costs and evaluated to determine how much to flexibility is worth. A recent AoA performed on the Joint Command and Control ship (JCC(X)) provided the following observations (Doerry and Sims 2002):

- A requirements risk analysis should be performed to anticipate and mitigate the cost of changes in customer or derived requirements.

- Requirements that are likely to change over the service life of the ship should be identified and plans developed for dealing with these changing requirements.
- Rather than develop a system to meet a certain set of requirements, as is typically done, the designer should aim to develop a system that recognizes that requirements are not always firm and change over time.
- To date, approaches for dealing with uncertainty in requirements had been ad hoc such as using margins based on past performance problems and indiscriminately mandating open systems architectures or modularity.

In addition, the ability to enable Navy contracts to have the flexibility in managing under an options framework, a non-standard approach is necessary. One effort to address these concerns was enacted under Section 845 of the National Defense Authorization Act for Fiscal Year 1994. Section 845 provided the Defense Advanced Research Projects Agency with temporary authority to enter into agreements for prototype projects using nonstandard contracting approaches referred to as "other transactions." Other transactions are generally not subject to the federal laws and regulations governing standard procurement

contracts. Consequently, when using Section 845 authority, DOD contracting officials are not required to include standard contract provisions that typically address such issues as financial management or intellectual property rights, but rather may structure the agreements as they consider appropriate (U.S. Government Account Office 2000).

These benefits included attracting firms that typically did not contract with DOD, enabling use of commercial products or processes, providing more flexibility to negotiate agreement terms and conditions, and reducing program costs.

Terms and conditions found in Section 845 agreements provided contractors more flexibility in the business processes and practices they employed than typically provided by standard contract provisions (U.S. Government Account Office 2000).

The Navy determined that because the ship incorporated numerous new technologies, including new hull and propeller designs, it could be considered a prototype for future efforts.

Changes in the agreements' value resulted from (1) decisions to add work to the original agreement, (2) technical or schedule problems that increased the effort's cost, or (3) termination of the planned activity (U.S. Government Account Office 2000).

The top three reasons cited by DOD components were use of commercial products or processes, attracting commercial firms, and increased flexibility in negotiating terms and conditions (U.S. Government Account Office 2000).

For example, flexibility in negotiating terms and conditions—particularly intellectual property and financial management clauses—was viewed as the key determinant in attracting commercial firms on several agreements. Standard contract or provided contractors the flexibility to make performance trade-offs needed to achieve a specific price goal. In other cases, DOD officials also noted that the cost of their specific program was reduced due to the cost-sharing provided by the recipients. For example, they noted that Section 845 agreements allowed recipients to apply independent research and development funds to their specific program. For example, the Navy used a Section 845 agreement on its effort to develop a common cockpit for two helicopters. The Navy wanted to develop the cockpit in a 2-year time frame, but it could not do so because it did not have sufficient funds to pay for tasks that needed to be completed in the first year (U.S. Government Account Office 2000).

Both take advantage of the flexibility afforded by the agreements and protect the government's interests.

DOD a right to terminate a contract, either for its own convenience or for default on the contractor's part; discusses the rights and responsibilities of each party; and prescribes various procedures for audits, property inventories, and disposition, among other contract close-out procedures (U.S. Government Account Office 2000).

Under a termination for convenience, the contractor is compensated for the work done, including a reasonable profit. In a default termination, the government determines that the contractor has, or will, fail to perform its contractual obligations. Consequently, the government is not liable for the contractor's costs on undelivered work and is entitled to repayment of funds provided for that work. However, DOD infrequently terminates research contracts (U.S. Government Account Office 2000).

In summary, the design and acquisition of Navy ships appears to have opportunities for the application of options thinking during the AoA phase, especially if the acquisition process can be done under Section 845.

## CHAPTER 3 Real Options

Just as in the previous chapter where the current state of acquisition and ship design was described in order to evaluate where real options might be applied, this chapter seeks to introduce and discuss real options theory to identify which parts may be applicable for valuing flexibility in a naval ship design and acquisition project.

"The future is uncertain... and in an uncertain environment, having the flexibility to decide what to do after some of that uncertainty is resolved definitely has value. Options-pricing theory provides the means of assessing that value." (Merton 1997).

Engineering systems must deal with risk and risk aversion (de Neufville 1999, 2001). Decision analysis and utility assessment provide a basis for real options analysis that allows flexibility to be designed into systems so that they can evolve and provide the most effective performance even under changing conditions (de Neufville 1999, 2001). The goal is to design systems to provide maximum value over time in presence of uncertainty (de Neufville 1999, 2001). Flexibility provides the way for system to continue to perform at maximum effectiveness as conditions change (de Neufville 1999, 2001). The key is to know what type of flexibility to incorporate into design and when to exercise the flexibility (de Neufville 1999, 2001). Real options allows designers to determine what types and amount

of flexibility is justified in a system design (de Neufville 1999, 2001), by looking to determine system value over time in the context of risk and uncertainty using decision analysis and options analysis

A real options thinking approach builds more flexibility into design by including the capability to change, without requiring change. Given the rapid rate of technological change, it is impossible to accurately forecast future conditions accurately, and therefore, managers need to be able to reshape projects in light of technical or market changes (Shishko and Ebbeler 1999). This approach differs from the traditional view of project valuation where decisions made at beginning of project are followed and unchanged during life of project. Real options recognize that managers make future decisions as uncertainty becomes resolved (Neely and de Neufville 2001) and place greater emphasis on the need to gather information to manage risks by exploiting options at the right time.

Current project valuation techniques fail to capture several important aspects of technical projects, including flexibility and the interface between economics and technology. When analyzing a project, both its technical and economic feasibility must be addressed, as these aspects are generally intertwined. For example, almost any project can be made technologically feasible by spending exorbitant amounts of money on development. Although the project may make technological sense, its financial viability is undercut by the unreasonable development costs (McVey 2002). On the other hand, after a conceptual project is developed, it is important to determine what the potential value to the client is and what they are willing to pay for it. A program can be technically feasible and well managed, but if the

program is producing a product for which there is little or no market, it really has no value. Standard valuation methods tend to underestimate project value by neglecting the options embedded in them which allow managers to adapt and revise decisions based upon new information or developments. Instead, it is assumed that the current market is static with no new competition or other technology developments, which would suggest the need for adapting the project to meet the needs of the market (McVey 2002).

Current valuations in naval ship design tend to focus on valuing a point designed product. Although there have been efforts to more completely explore the design space for the optimal solution, the optimal solution is based on a fixed set of requirements and preferences. In addition, optimization infers certainty. There is no way in the current system to value adding flexibility to the design, since under certainty, flexibility has no value. Flexibility instead, has value, in situations with high uncertainty.

Valuing a project using real options is analogous to climbing a mountain in that getting to the top (i.e. coming up with an "answer") is important, however, the process of climbing, including the lessons learned along the way are equally, if not more, important (McVey 2002).

The goal of any valuation method for real options is to estimate the value of having options to react to resolution of future uncertainty. The underlying principles, which apply to options analysis and decision analysis methods, can be seen as a general framework to embed the value of flexibility into the estimation of project value. It is important to note, that in a world of

certainty, options have no value. Since real options thinking refocuses on opportunities that are created by resolution of future uncertainty (Faulkner 1996), the cornerstone of any option valuation method is the ability to model the uncertainty in the future states of nature (Lamassoure 2001). Real options look to add value to projects by looking for scenarios beyond the most likely one.

Two key organizational aspects in the implementation of real options are:

(1) The decision to abandon a project (or part of a project) must be taken seriously. The project management must be prepared to drop a project that is no longer promising. This is a difficult to implement organizationally, as projects tend to develop own inertia and are hard to stop.

(2) Real options do not automatically justify spreading available investment dollars and organizational effort over a wide range of projects. For each project, the technical options and market potential must be considered (Faulkner 1996).

### **3.1 Options**

Prior to delving into 'real options', it is first necessary to carefully define an 'option' itself. In this context, option has a very exact meaning, different from 'choice' or 'alternative' as used in everyday language. Here an option is defined as used in financial contracts, meaning "a right, but not an obligation, to take some action now, or in the future," "under predefined arrangements." Options are widely used for contracts of all kinds: financial instruments, commodities, and services. All of the key features relating to an option are

described by this definition. The asymmetric returns of options are derived from the right to exercise the option only when beneficial to the option holder. By holding an option, only positive outcomes will be realized and downside losses truncated. The exercise price is different from the cost to acquire the option and since it does not depend on later conditions, can be compared to the instantaneous benefit of exercising the option.

A few more definitions dealing with options are necessary. The option to buy is referred to as a call option. The option to sell is called a put option. If an option can only be exercised on its expiration date, it is a European option. If the option can be exercised at any time prior to or on the expiration date, it is an American option. Most real options are like American options, in that they can be exercised at any time.

A simple example using an American call option will illustrate the important aspects of an option. Suppose you hold an option on a stock whose current price is \$10.00. The strike price, or predetermined price you have agreed to buy the stock for is \$12.00. As the stock price moves due to market forces, the option holder could exercise the option to buy when the stock price exceeds the strike price, for example when the stock is trading at \$14.00. In this case, the option holder can buy the stock for the pre-arranged price of \$12.00 and immediately sell it for \$14.00, profiting the difference of \$2.00 less the cost to acquire the option in the beginning. The asymmetry of returns comes from not being required to exercise the option when the stock price is below the strike price. If the stock price drops to \$6.00, the option would not be exercised, and losses would be limited to the cost of acquiring the option.

The options scenario contrasts that of purchasing the stock outright, where the stock holder's losses are not limited and the entire investment could be lost if the stock price falls.

### **3.2 Real Options**

Real options are a method for valuing projects with future decision opportunities (Oueslati 1999). Real options were derived from financial options and apply to physical things rather than financial instruments. Real options apply the basic principles of financial options, but adapt them to the concept of system design, which generally deals with a unique project that lacks historical data (de Neufville 1999, 2001).

Real options in a project refer to any aspects of the system that provide flexibility and can be designed into projects conceptually, or physically. Conceptual options exist as part of any development project whenever investments involve strategic choices over time that managers can actively direct (Neely and de Neufville 2001). Physical real options are any design characteristic that provides flexibility.

The real options approach is based on financial options valuation techniques to value real projects that have risky or contingent future cash flows or benefits, as well as long-term projects with opportunities for managerial intervention (McVey 2002). In a real options valuation, technology developments are treated as assets whose payoffs are uncertain, but provide the potential for spectacular returns with limited losses (Shishko and Ebbeler 1999). Because options have value, they must be

paid for, either with a monetary cost, or by a design penalty, such as increased size or complexity. The prospect of high gains with losses potentially limited to the nominal cost of acquiring the options is attractive for system design. Real options, like their financial counterparts have more value with increasing uncertainty (de Neufville 1999, 2001). Real options recognizes there are situations where uncertainty represents a potential for future gain, rather than risk of loss and the larger amount of uncertainty, the greater the opportunity for value creation (Faulkner 1996). The real options approach considers both the technical and market aspects of a project in estimating the value of flexibility in the system (de Neufville 1999, 2001). Real options seek to give greater strategic flexibility to projects within limited budgets (Shishko and Ebbeler 1999). The recognition and exploitation of flexibility through real options unlocks fundamental value in risky projects (Neely and de Neufville 2001).

Real options value technology investments by accounting for the flexibility they can offer under considerable uncertainty and thereby can capture value that goes unrecognized by usual valuation methods (Shishko and Ebbeler 1999). Real options also uncover the contribution of active management as a source of value by recognizing that system operators can and do actively manager their systems (Neely and de Neufville 2001).

By calculating the value of added flexibilities, the decision makers have a firm rational for accepting or rejecting them, rather than the current practice which has been mainly conceptual and intuitive (de Neufville 1999, 2001). Options thinking as a conceptual tool helps to explain the strategic

value of intangibles such as active management, flexibility, learning, etc. (Faulkner 1996).

The options thinking approach to uncertainty reframes the approach to design. No longer is the design goal to minimize risk, but rather to seek out and exploit opportunities. A real options approach is proactive towards uncertainties and prepares plans to manage risk, rather than to react to it.

Conventionally good design minimizes risk, but options seek to maximize reward. By looking at sources of uncertainty for situations that can be exploited, designers are led to add more flexibility than is current practice (de Neufville 1999, 2001). Real options also force a longer term focus on design by providing the potential for options chains on future options (Faulkner 1996).

Options thinking recognizes future managerial flexibility by identifying downstream decisions that can be made after future uncertainty is resolved. Recognizing that these decisions are conditional on upstream decisions and that future course changes are probable, active management that can quickly adapt by monitoring the resolution of uncertainties to help understand which scenario is unfolding and anticipating course adjustments will be required (Faulkner 1996).

For managing technology projects, much of the analysis lies in determining when and how to implement options. This analysis is broken into three phases: discovery, selection and monitoring. In these ways, real options seek opportunities to build flexibility into designs, evaluate the possibilities, and implement the best ones, without being required to do so. The essential advantages of real options are that they:

- (1) embody flexibility, and
- (2) permit managers to achieve favorably biased returns.

Real options provide the most value to projects with the following characteristics:

- (1) Contingent investment decisions based on the resolution of some uncertainty
- (2) Uncertainty is large enough to cause the need for flexibility and waiting for resolution adds value and minimizes regret
- (3) Value captures the possibility of future growth options
- (4) Project has opportunities for updates and mid-course corrections
- (5) Decisions enable further project development without committing to it prematurely
- (6) Can adjust systems as needed when more relevant information becomes available
- (7) Greatest for risky projects, especially when later implantation costs are relatively large
- (8) Future investments and commitments are relatively large compared to the investment required to resolve some uncertainty
- (9) Can anticipate availability of future information that will resolve some uncertainty
- (10) Duration of research phase is long and there is uncertainty about future earnings
- (11) Ability to abort poorly performing projects truncates downside risk and increases expected value of project. Also allows for augmentation of upside.

### **3.3 Valuation Methods for Real Options**

When determining the value of real options, some form of decision analysis underlies the evaluation, either alone or combined with a financial options analysis (de Neufville 1999, 2001). Due to the many approximations and assumptions necessary to calculate a real option value, real options necessarily produce approximate rather than precise values. In the case of system design where alternative are compared against one another, these approximations do not greatly detract from the value of the method. The most important focus of real options is on the options thinking aspect of designing flexibility to deal with uncertainty, rather than designing to optimize which assumes certainty. Also, realizing that options value depends largely on market conditions shifts the focus of the system designer from a pure engineering analysis to one that accounts for uncertain market conditions (de Neufville 1999, 2001). Whatever method used, it may still not be possible to set out a theoretical framework when attempting to value several different options types, as the interactions between options is difficult to gauge (Ouselatti 1999).

#### **3.3.1 Decision Analysis**

Decision analysis is a standard approach to system planning and design under uncertainty (de Neufville 1999, 2001); however it is not used in naval ship design and acquisition. Decision analysis is a straightforward method of laying out future decisions that are not set from the start but can depend on the resolution of some uncertain parameter(s). It can account for multiple sources of uncertainty and uses probability estimates of future outcomes to determine the value of a project (McVey

2002). Decision analysis presents the problem as an array of time-phased risks and determines the best reaction to uncertainties as they are resolved to develop the strategy which maximizes performance over time. A great virtue of decision analysis is that it can deal with multiple scenarios and management decisions and truncates specific lines of development in order to limit losses. Although decision analysis is generally reactive, providing best choice under given circumstances, the incorporation of options seeks to identify new paths and change the decision tree by adding flexibility. The real options approach inserts additional decision nodes to reflect options available to the decision maker (Neely 1998).

Decision analysis holds three significant advantages over options analysis in that there is no need to identify an underlying asset that properly mimics the projects risk profile that the scenarios and strategies are laid out in an easy to explain and understand manner, and that the lognormal distribution is not required to describe the uncertainty. In fact, uncertainty can be modeled by any appropriate distribution (Faulkner 1996). By making the analysis more visible to the decision maker, the counter-intuitive outcomes of increased value for increased risk are less surprising (Faulkner 1996). Also, the decision tree serves as a dynamic road-map for the project. In laying out managerial decision points, the method takes into account managerial flexibility. The major drawbacks cited against decision analysis are that the discount rates are theoretically incorrect and constant and also that the estimates for the subjective probability distributions used are potentially hard to justify and form with precision. The approximate value of the option can still be determined by

comparing the value of the flexible decision tree to the baseline non-flexible case (Lammassoure 2001).

Decision tree analysis is easily generalized to situations in which value is not monetary. Decision Tree Analysis is part of the Decision Analysis framework, which is active in developing Utility function approaches. This makes the method particularly suited for system design applications. By considering only the optimal decision after each possible state of nature, decision analysis takes into account the possibility of adapting future decisions based on the resolution of uncertain parameters, which solves the main shortcoming of traditional valuation (Lammassoure 2001).

Valuing real options with decision tree analysis does have limitations. For the decision analysis to remain practical, there must be a finite number of decision nodes, occurring at set decision times. Because of these constraints, decision trees cannot account for flexibility where continuous decision making is required. Additionally, there must be a finite number of possible future states that describe the event nodes. Again, the decision tree cannot account for uncertain parameters that can take on a continuous set of values, such as market demand (Lammassoure 2001). In order to accommodate these limitations, it has been suggested that decision analysis becomes more computationally difficult when more than three or four sources of uncertainty are involved (Oueslati 1999)

Although the results of decision analysis are theoretically incorrect, since the discount rate is not constantly adjusted, the concept of added flexibility is more important than the mechanical flaw in the analysis (de Neufville 1999, 2001).

Decision analysis can still deal well with a range of outcomes and the asymmetry of returns offered by options. In system planning and design, where large system performance uncertainties are the key value drivers, rather than uncertain cash flows, the discount rate adjustments can probably be disregarded (de Neufville 1999, 2001). Additionally, when the calculations based on assumptions for future markets and technology requires sensitivity analysis, adjusting the discount rate for risk can also probably be ignored (de Neufville 1999, 2001). Even when options analysis methods can be applied to the market risks, project risks does not require discount rate adjustments to reflect unavoidable risk, since managers must diversify their project portfolio so that unexpected losses from one project can be compensated for by gains in another (Neely and de Neufville 2001). In any case, a decision analysis framework underlies the valuation of options, whether or not a financial options evaluation can be applied or not.

### **3.3.2 Options Analysis**

In so much as a decision analysis approach fails to properly adjust the discount rate and provide a proper risk-neutral probability distribution, these are the major advantages of a financial options analysis. Although these advantages are of the utmost importance when dealing with financial instruments, or even with projects where the major sources of value and uncertainty can be closely aligned with traded securities, identifying the proper underlying asset is difficult, if not impossible for most real projects. Also, the background of the decision makers must be accounted for when selecting a valuation method. In the case where the key decision makers do not have a

background in finance, the application of options analysis to real projects can seem obscure.

Options theory was initially developed to value traded securities such as stocks, which can take on continuous possible values. Therefore options analysis models account for continuous probability density functions, as well as for continuous decision making (Lamassoure 2001).

Real options theory has not, with few exceptions, been used directly outside of the commercial world (Lamassoure 2001). This is because one of the baseline assumptions in the underlying financial options analysis is that the goal of every firm is to increase the wealth of its shareholders and as such, options analysis has never been interested in capturing non-monetary values. In order to apply options pricing methods to real situations, there must be an underlying asset, whose behavior on the stock market mimics the value and risk of the real project. Therefore, financial options theory cannot be directly applied to all kinds of investment-making situations, in particular not to most system design situations. In these cases, the approximating the options valuation using a decision analysis framework is recommended.

As previously discussed, unique project risks can be diversified by holding a portfolio of projects, however, market risks cannot be diversified away (Neely and de Neufville 2001). Because of this, only options analysis is able to treat market risks properly. In order to use the options analysis method, detailed statistical information on the price and volatility of an underlying asset which closely reflects project is required. Identifying a proper underlying asset is the key to carrying out

an options analysis, and therefore the hurdle to applying options analysis to most real projects.

Options analysis transforms risky outcomes to risk neutral valuations that then can be evaluated with standard decision analysis (Neely and de Neufville 2001). Determining the risk neutral probabilities requires building a portfolio of value-producing assets which replicates future-state values. For the private sector, value-producing assets are typically a portfolio of risk less and risky securities projected to respond in the future period so as to reflect the value of the private sector project. In principle there is no restriction to securities. Portfolio could include private sector projects for which it is possible to asset credible future-state values under conditions assumed when projecting future-state values.

For public sector projects, the endogenous risks can be classified as development risks, i.e. cost, schedule, technical performance, while programmatic (market) risks can be attributed to changes in how end-users might value the project and how it will be used. The programmatic risk can be related to society's willingness to pay for the public good derived from the project. As with private sector project, the overall success depends on both the development success and the market success. The option value must reflect uncertainty and quantitatively account for technology readiness and cost (Shishko and Ebbeler 1999).

In order to evaluate the market risk for products traded in ordinary markets, an options analysis approach requires extensive historical data on an underlying asset. Applying the options analysis is made difficult when the right data is not available (Neely and de Neufville 2001). Even when applied to

private sector cases, the value added by a properly risk adjusted options analysis may not be worth the considerable effort required to collect and analyze this data. Also, the options analysis may give a false sense of precision to the valuation that may not be warranted, based on the uncertainty in the underlying data (de Neufville 1999, 2001).

An options valuation using Black-Scholes, or the binomial method is easily applied, assuming the proper data is available. The problem with liberally applying these methods to many cases is that the underlying assumptions may not hold. For instance, these methods assume that the future value of the project will follow a Brownian motion. Another significant assumption of options analysis is that the future uncertainty can be described by a lognormal distribution, and while this appears to be reasonable for describing the volatility of stock prices, it may not always be appropriate for describing the uncertainty associated with the with real projects (Faulkner 1996).

The addition of real options to a project changes the designers' and managers' thinking in dealing with uncertainty by recognizing that uncertainty adds value to options. Options seek opportunities to add value to the project by exploiting options at right time. By adapting a different perspective on system design for uncertainty, designers and managers will recognize that flexible projects are more valuable than previously considered. Real options provide a way in which to value this flexibility that other project valuation methods lack and shows the desirability of gathering information about uncertainty in order to know when to best exploit the options as the uncertainty becomes resolved (de Neufville 1999, 2001).

## **CHAPTER 4 A Real Options Approach to Navy Ship Acquisition**

This chapter will determine the best way to implement a real options design and evaluation method for naval ship design and acquisition.

The cases for real options in naval ship design and acquisition do not meet the requirements necessary to apply financial options analysis techniques, but rather options thinking. Attempting to apply financial techniques where they are not appropriate will not yield a better result than a decision analysis method that fails to properly adjust the discount rate. In fact, the financial options analysis methods (Black-Scholes, binomial, etc.) have many underlying assumptions and criteria that must be met for their proper use. One must be careful not to use these methods unless the real options valuation problem is very similar to the one encountered in finance (de Neufville and Scholtes 2002).

A significant portion of the theoretical basis for the option-pricing approach for valuing real projects relies on the idea of being able to replicate that project in a portfolio comprised of risk-less and risky securities so that the risk neutral probabilities can be calculated. Proper valuation of the project is essential, as differences between the selling price of the project and the value of the replicating portfolio would create an immediate arbitrage opportunity. A key hurdle that must be overcome in order to apply the option-pricing method in the public sector relies on assembling a replicating portfolio for the projects. This assertion raises two important questions.

First, are these projects so risky that a replicating portfolio cannot be found. A second question is whether a government agency should be risk-neutral altogether without regard to whether uncertainties are hedged or not, or in other words, does the public sector aspect make the case for risk neutral valuation?

The questions raised above deal with the risk-neutral aspects of options-pricing. Risk-neutral investors are investors that do not require a risk premium. There is debate whether governmental agencies fall into this category. If it is assumed that they do, however, all costs for government projects can therefore be discounted at the risk-free interest rate.

Another important aspect of the application to ship design and acquisition is due to the fact that the decision process for a military mission differs greatly from that in the commercial world. To begin, the project (mission) value is not a measure of revenues minus cost, but rather takes the form of a complex utility function which incorporates cost. Thus, value does not have the same linear properties as the cases studied by option-pricing theory. Additionally, there are two possible decision processes when deciding to acquire military systems. When designing a military system during a peace-time, the preferred design is the one which maximizes the mission effectiveness per cost. When making a decision about an operational military mission involved in contingencies, however, the cost factor becomes much less critical than the mission effectiveness. In the second case, the design that maximizes mission effectiveness is generally chosen.

To begin with, it is not possible to find a representative underlying asset that could be applied in these cases. For projects lacking historical data, assumptions can be made and adjusted for with sensitivity analysis. Real options lead to approximate, rather than precise values, so for comparisons, the niceties of greater precision potentially derive from historical data can be ignored (de Neufville 1999, 2001). Also, there is no arbitrage opportunity, which is another requirement for applying options analysis. Even without arbitrage, it has been suggested that governmental projects should be discounted at the risk-free rate (Shisko and Ebbeler 1999, Lamassoure 2001). Additionally, the options methods assume a log-normal distribution for the values, which may be appropriate for stock prices, but not proper for most real projects (Faulkner 1996, de Neufville 1999, 2001). Even when options analysis can be used, the manner in which several real options may interact may be difficult to set out in a theoretically correct way (Oueslatti 1999). For this reason, as well as the amount of time and data required (which may not be available), focusing on the options "thinking" aspect and using a decision analysis framework may be most appropriate (de Neufville 1999, 2001).

Decision analysis allows any appropriate distributions to be used. For strategic decisions, such as are required in the naval ship acquisition process, decision analysis provides a method for altering choices as uncertainty becomes resolved. Decision analysis provides not only the expected path, but shows that decision makers the range of possible outcomes, from the best to worst case results. Constructing the decision tree permits plans to be analyzed that exploit opportunities, but also allow a hedge to avoid losses.

Decision analysis also has many advantages. First, decision analysis is easily generalized to situations in which the important values are non-monetary (Lamassoure 2001). Secondly, decision analysis is better suited for strategic decisions such as those required for naval ship design and acquisition than are financial techniques (de Neufville and Scholtes 2002).

Decision trees are a valid method for valuing real options (de Neufville 1999, 2001, Neely 1998, Oueslati 1999). The major deficiency of a decision analysis framework for evaluating options is that the decision tree assumes a constant discount rate, or an adjusted discount rate must be calculated every time a decision can be made, which is impractical. In the case of naval ship design and acquisition, as in system planning and design, in the context of large uncertainties in system performance and other factors, the deficiencies in the discount rate can be ignored (de Neufville 1999, 2001). Additionally, by validating the results through sensitivity analysis, adjusting the discount rate for varying levels of risk can probably be ignored (de Neufville 1999, 2001).

A second problem cited for using decision analysis for evaluating options is that the decision tree must have a finite number of decision nodes, occurring at set times, and cannot therefore account for outcomes with an infinite possible number of states, such as stock prices or market demand (Lamassoure 2001). Again, this problem is not critical when taken in the context of naval ship design and acquisition. The decisions necessary to describe and value the design and acquisition process do, within a reasonable approximation, occur at discrete and quantifiable time intervals. Additionally, the future

states, although continuous in reality, must be approximated in application to a set of finite likely realities.

Neely's hybrid method and its expansion by Oueslati both allow for pure decision analysis when it is the appropriate method, as determined by the factors above, using decision trees.

Here are the basics for the method:

- (1) Identify options
- (2) Identify major uncertainties
- (3) Determine possible end states (markets)
- (4) Determine major decision points
- (5) Layout decision tree
- (6) Determine decision rule (for example, MAUA for OMOE/COST; pure OMOE/COST; max OMOE with cost constraint; criteria meet minimum requirements)
- (7) Sensitivity analysis (test assumed probabilities and distributions to find when decisions would change)

Method

- (1) Determine requirements (min/max), preferences, and scenarios
- (2) Create designs based on requirements/preferences
- (3) Translate design parameters into cost/OMOE estimates for scenarios
- (4) Transform customer preferences for OMOE/cost using utility
- (5) Calculate Willingness To Pay (WTP) for base case
- (6) Layout scenarios and decisions in tree
- (7) Roll back tree with WTP to determine value of option compared to base case

The method described above will be applied to a case study, described in Chapter 5.

## **CHAPTER 5 Application of the Real Options Method to Naval Ship Design and Acquisition**

### **5.1 Introduction**

Naval ship design and acquisition decision making involves multiple ship types, multiple technologies with simultaneous development paths, multiple missions, requirements uncertainty, mission uncertainty, budget uncertainty, technology readiness uncertainty. It is estimated that 80% of a ships cost is determined during concept design (McCord and Amy 2001). During the design and acquisition phase, decisions must be made with incomplete/uncertain information. The use of new technology (i.e. hull forms) makes concept exploration more difficult and uncertain. Program managers would like a system architecture and development plan with the ability to estimate ramifications of future outcomes prior to execution, flexibility to react to changes in mission, requirements, technology, budget, and minimal need to redo design process for future outcome changes. The key output of the process is not the specification of an optimal ship design, but rather a design process that is used to investigate feasibility and flexibility in design options. The system architecture would identify a range of solution flexibility. It would investigate concept flexibility against requirements such as payload mix, platform performance, and technology insertion. The process would also investigate the impact on concept architecture, such as platform performance; that is, determining whether the flexibility gained is worth the cost.

The hull form of a naval combatant itself cannot be flexible once laid down, but the subsystems, such as payload, can introduce flexibility. The cost of an option is embedded in the design features that add flexibility. Additional size, weight, and complexity in the design model are reflected as additional cost as compared to inflexible base design. Results of an options analysis provide a recommended path of development or choice between competing designs based on cost of flexibility compared with value returned. Value is based on the parameters of future state and likelihood of reaching that state. Additionally, uncertainty in design development, costs, timing, and performance characteristics can be modeled using appropriate distributions. What may seem like a simple intuitive exercise requires a structured, efficient method to deal with the possible situations. People generally do not deal well when evaluating complex, uncertain situations because they tend to focus on extremes and end states, rather than the process (de Neufville et al 2000, 2001). It is difficult to evaluate the interaction of many different probabilities at once without a structured method such as a decision tree. The case study implements the method on a hypothetical case study that is similar to the current Navy acquisition of advanced high-speed surface craft.

## **5.2 Case Study**

According to the Department of the Navy, the primary purpose of forward deployed naval forces is to project power from the sea to influence events ashore. To be successful, our naval forces must be able to gain access to, and operate in the littoral regions of, potential adversaries. Consequently, they must be

able to detect and neutralize enemy sea mines and submarines, and to protect themselves against cruise missiles and other anti-ship weapons. Finally, they must be able to launch and support offensive operations against enemy forces ashore (U.S. GAO 2001).

The key cost driver is the type of capabilities necessary for a ship to effectively perform its intended missions against anticipated threats. Procurement of combat and weapon systems with the necessary capabilities has comprised a large percentage of a surface combatant's basic construction cost. For example, combat and weapon systems account for about 55 percent of the cost of the latest version of the Arleigh Burke-class destroyer. Navy officials indicate that the Aegis combat system is a large cost—at about \$235 million, or about 25 percent of the ship's cost (U.S. GAO 1997b).

By tailoring the capability of a ship concept, a lesser capable ship with high capability in one or two missions areas, but limited or virtually no capability in other areas results. It would provide capability in mission areas requiring large numbers of ships, such as antisubmarine warfare, rather than those capabilities already sufficiently available in the fleet. One version, an antisubmarine ship, would be a smaller, frigate-type ship equipped with state-of-the-art antisubmarine systems, sufficient anti-surface warfare capabilities, and basic self-defense capabilities in other warfare areas (U.S. GAO 1997b). By creating, either modular ships, or an ability to acquire varying levels of tailored ships, a flexible force structure can be achieved.

One shipyard, Blohm and Voss have developed a modular system (MEKO) aimed at production flexibility which is not variable on a mission to mission basis, but allows significant advantages to the shipyard which can configure or outfit a standard ship to meet varying needs of diverse customers (Skvarla et al 2001).

Another method than Blohm and Voss modularity could be to limit the tactical operations of small, faster surface combatants to comprise a fleet mix.

Combining modularity with smaller ship size could also create versatile ships, reconfigurable for different missions over several months using modules. Regional crises require agile, flexible response to meet a wide number of tasks. Design for flexibility to be reconfigured in a number of hours to do a multitude of missions for a lower cost. The Navy seeks to maximize operational flexibility across a wide range of tasks by reconfiguring modules in a single, cost-effective baseline hull (Natter 2002).

Several alternatives of high speed, smaller ships will be explored to determine a best mix through the real options method. Typical hull forms include the Joint Venture, LCS(X) and SEA SLICE.

Some specifications for the Joint Venture are (Natter 2002):

- Speed 38-48 knots
- Draft 12 feet
- Payload 400-1200 tons
- Range 1200-4000 NM

LCS(X) is a small specialized variant of the DD(X) family which will take advantage of newest generation hull form with modularity and scalability. It will focus on mission capabilities, affordability, and life-cycle cost. (Global Security 2002)

As of Mid 2001, the Office of Naval Research has released the following design specifications for LCS(X) (Global Security 2002):

- Displacement 500-60 tons
- Draft 10 feet
- Range 400 NM
- Speed 50-60 knots
- Cost \$90 million (at least)

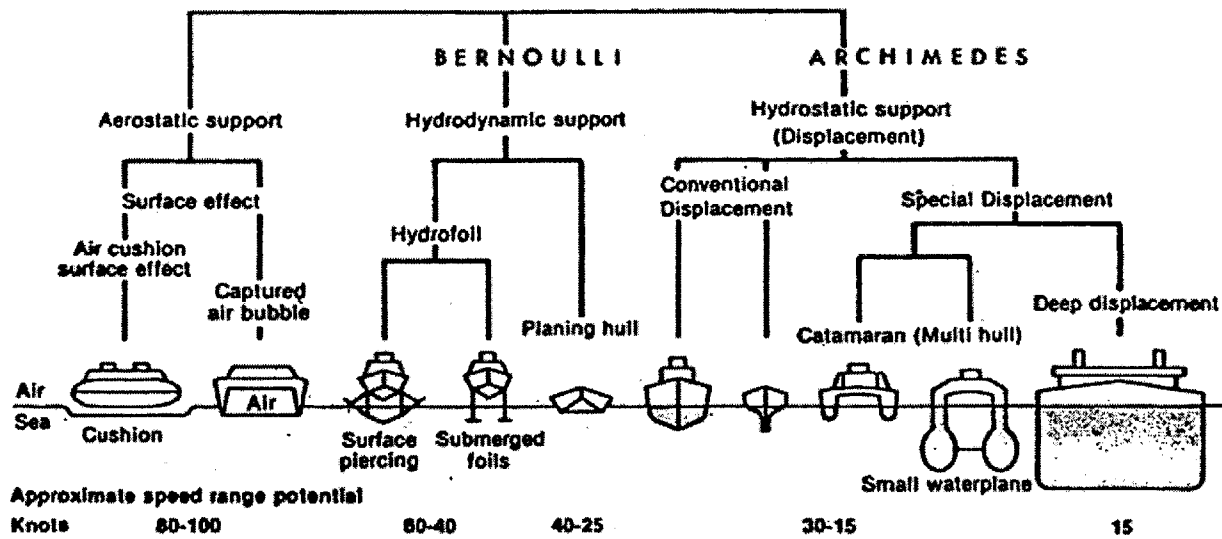
Sea SLICE is one prototype design being considered for the LCS(X). It provides speed, stability, and modularity for shallow-water mine counter-measures, littoral anti-submarine warfare, anti-boat swarm attack. Other characteristics include:

- Stability at speeds up to 30 knots
- Reconfigurable to mission by using modules

The method will be applied to a set of notional high speed ship platforms, with no particular hull form in mind.

### 5.3 Case Study Input Parameters

The study considered six hull types, designated A through F, some with variants indexed by numbers, which yielded a total of 16 variants. The six base hull forms were chosen to span the reasonable set of possible hull types shown in Figure 5-1, from surface effect ship through multi-hull and small water-plane special displacement ships.



Surface Ship Types (from Gilmer and Johnson 1982)

Figure 5-1

The performance parameters and war fighting capabilities analyzed were determined as summarized in Table 5-1. The physical design characteristics are self-explanatory. The mission area attributes are Anti-Surface Warfare (ASUW), Strike Warfare (STK), and Mine Warfare (MIW). Radar Cross-Section (RCS) is also included as a mission characteristic. All mission and sea-keeping characteristics are assigned a value between 0 and 1, based on an estimate of that hull form's suitability to support that mission area.

**Table 5-1**

Design Characteristics Determination

Characteristic	Determination
Calm Water Speed      knots	Calculated
Speed in Waves      knots	Calculated
Payload Weight      long tons	Calculated
Range at Speed in Waves      nautical miles	Calculated
Displacement      long tons	Calculated
Hullborne Draft      feet	Calculated
Foilborne / Cushionborne      feet	Calculated
Rough Order of Magnitude Cost      millions	Calculated
ASUW	Fixed for Hull Form
STK	Fixed for Hull Form
MIW	Fixed for Hull Form
RCS	Fixed for Hull Form
STABILITY	Fixed for Hull Form

Next, a ship synthesis tool was used to obtain a series of balanced designs, the results of which are summarized in Tables 5-2 through 5-4.

**Table 5-2**

## Summary of Design Variant Characteristics (Part 1)

		A1	A2	B1	B2	B3
Calm Water Speed	knots	53.1	53.7	42.7	43.3	42.4
Speed in Waves	knots	50.0	50.0	40.0	40.0	38.1
Payload Weight	long tons	250	250	250	250	250
Range at Speed in Waves	nautical miles	1584	1271	3343	2653	1913
Displacement	long tons	2564	2000	4000	3000	2000
Hullborne Draft	feet	15.4	14.2	25.9	23.5	20.5
Rough Order of Magnitude Cost	millions	\$161.55	\$152.75	\$159.95	\$152.35	\$142.95
ASUW		0.8	0.8	0.7	0.7	0.7
STK		0.7	0.7	0.4	0.4	0.4
MIW		0.8	0.8	0.4	0.4	0.4
RCS		0.6	0.6	0.8	0.8	0.8
STABILITY		0.8	0.8	0.4	0.4	0.4

**Table 5-3**

## Summary of Design Variant Characteristics (Part 2)

		C1	C2	C3	C4	D1
Calm Water Speed	knots	52.3	52.8	53.8	46.0	54.3
Speed in Waves	knots	50.0	50.0	50.0	42.8	50.0
Payload Weight	long tons	250	250	250	250	250
Range at Speed in Waves	nautical miles	3598	2870	1888	2245	663
Displacement	long tons	4000	3000	2000	2000	1000
Hullborne Draft	feet	17.0	15.5	13.5	13.5	26.1
Rough Order of Magnitude Cost	millions	\$169.45	\$158.75	\$147.75	\$144.35	\$134.75
ASUW		0.8	0.8	0.8	0.8	0.8
STK		0.7	0.7	0.7	0.7	0.7
MIW		0.6	0.6	0.6	0.6	0.4
RCS		0.6	0.6	0.6	0.6	0.8
STABILITY		0.7	0.7	0.7	0.7	0.8

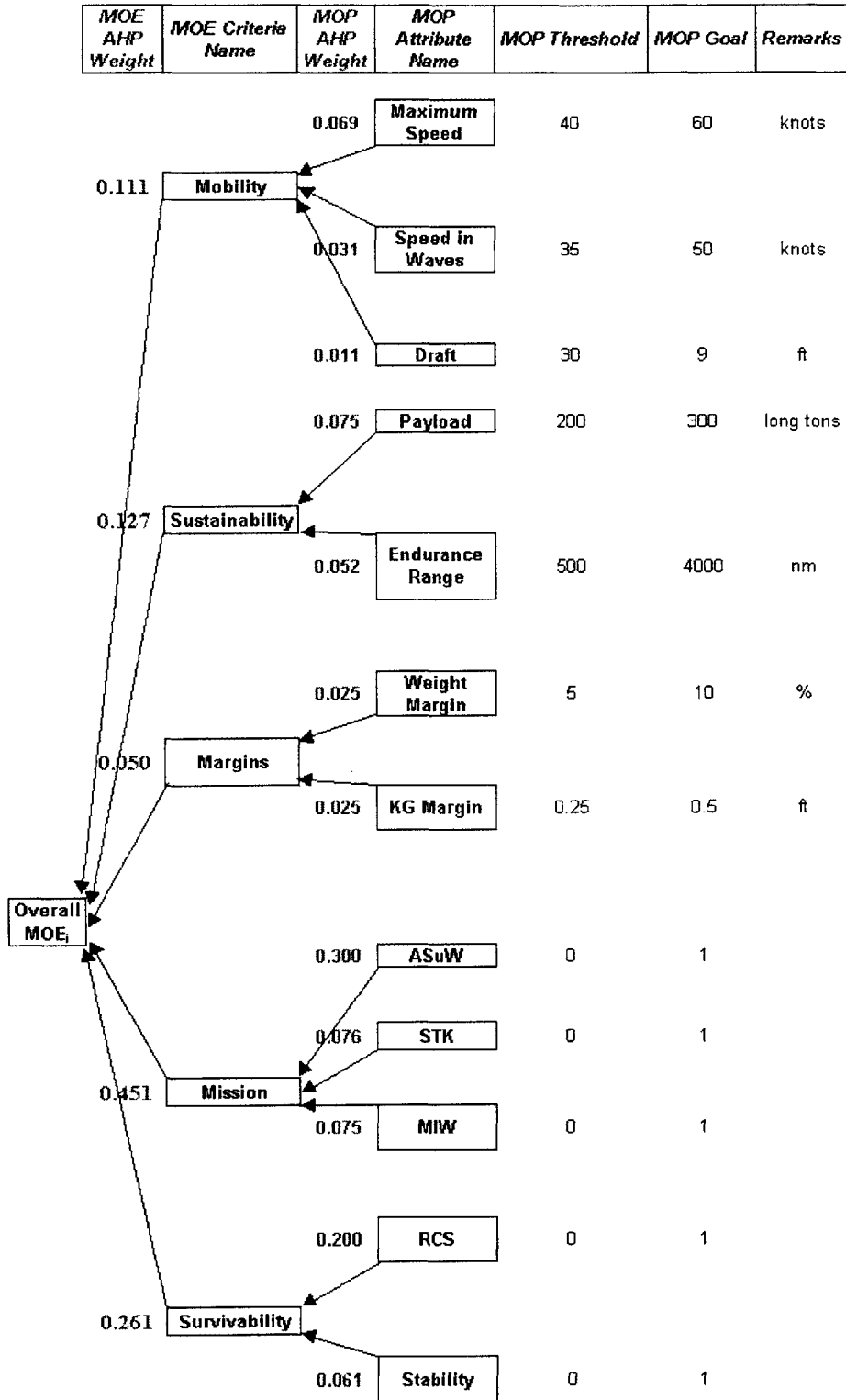
**Table 5-4**

Summary of Design Variant Characteristics (Part 3)

		E1	E2	E3	E4	F1	F2
Calm Water Speed	knots	53.1	51.4	53.8	54.1	50.0	50.0
Speed in Waves	knots	49.5	48.0	50.0	50.0	50.0	50.0
Payload Weight	long tons	250	250	250	250	250	250
Range at Speed in Waves	nautical miles	2429	2949	2024	1185	1441	902
Displacement	long tons	3483	3988	3000	2000	2854	2000
Hullborne Draft	feet	13.8	14.4	13.1	11.4	21.1	18.7
Rough Order of Magnitude Cost	millions	\$168.85	\$172.25	\$164.25	\$152.55	\$165.95	\$154.45
ASUW		0.6	0.6	0.6	0.6	0.7	0.7
STK		0.6	0.6	0.6	0.6	0.6	0.6
MIW		0.6	0.6	0.6	0.6	0.6	0.6
RCS		0.5	0.5	0.5	0.5	0.6	0.6
STABILITY		0.8	0.8	0.8	0.8	0.6	0.6

Next, the Overall Measure of Effectiveness (OMOE) for each design was calculated for each of three scenarios: A, B, C.

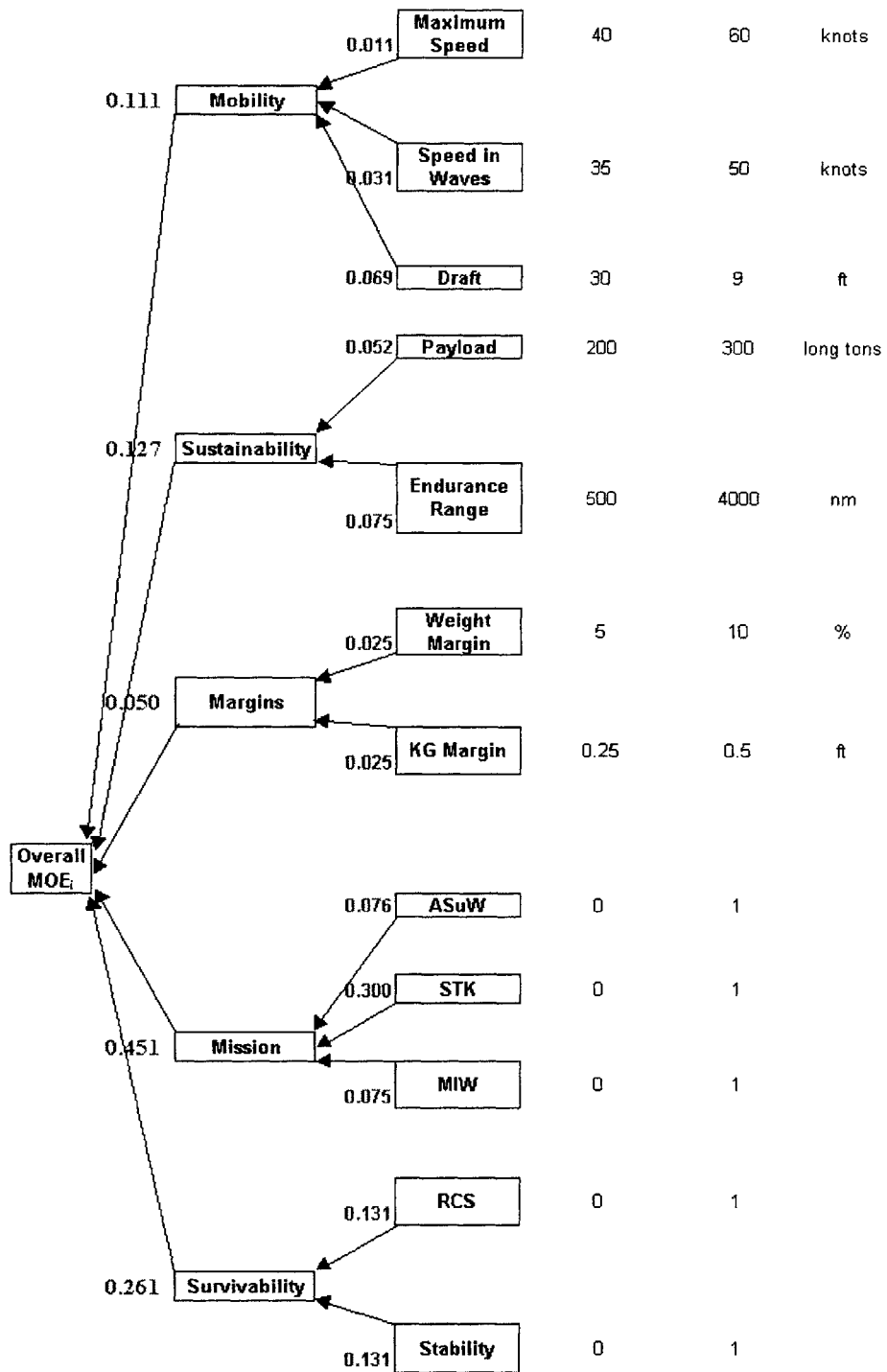
The OMOE was calculated using the Analytic Hierarchical Process (AHP) for each scenario as shown in Figures 5-2 through 5-4.



AHP Process for Determining OMOE (Scenario A)

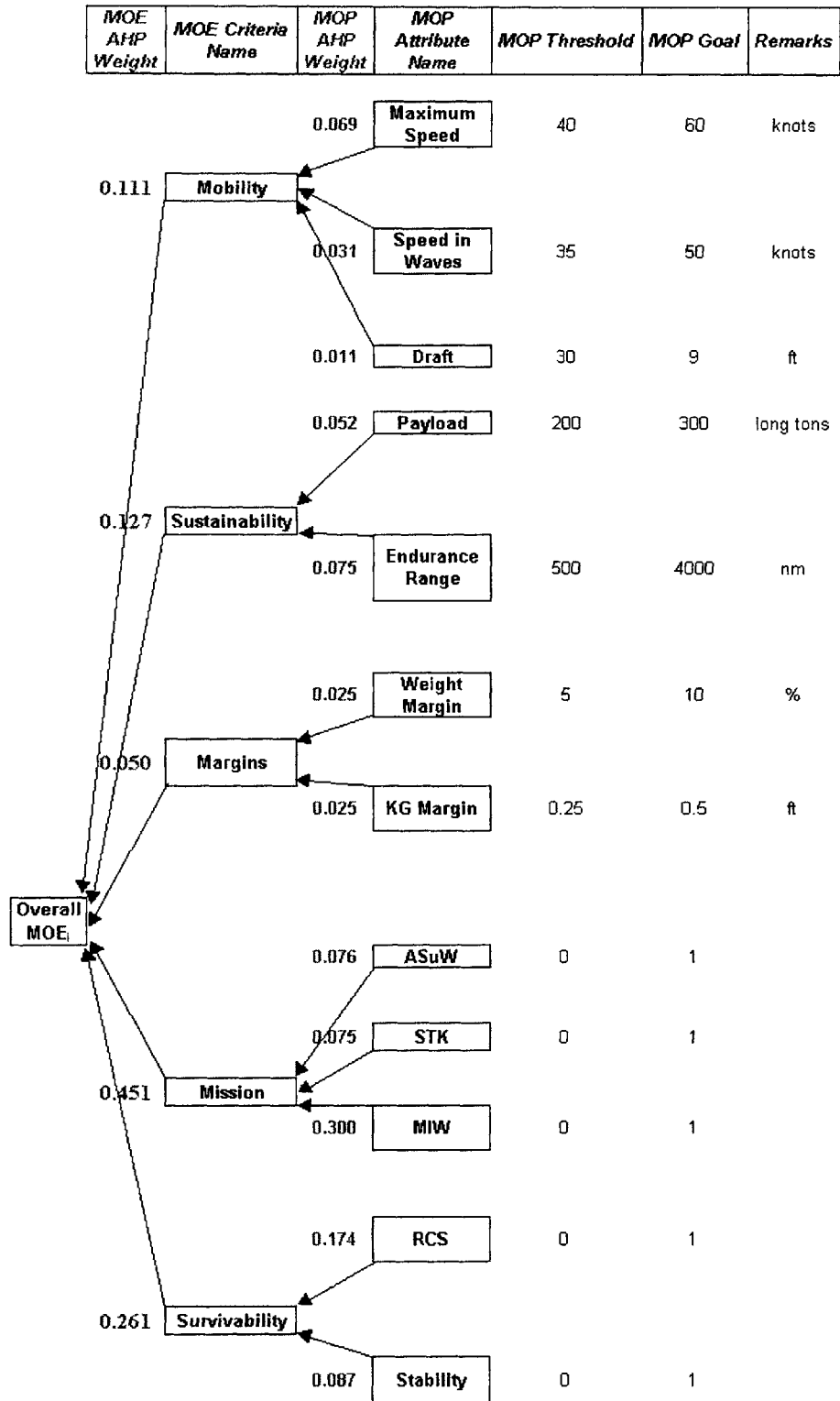
Figure 5-2

<i>MOE AHP Weight</i>	<i>MOE Criteria Name</i>	<i>MOP AHP Weight</i>	<i>MOP Attribute Name</i>	<i>MOP Threshold</i>	<i>MOP Goal</i>	<i>Remarks</i>
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AHP Process for Determining OMOE (Scenario B)

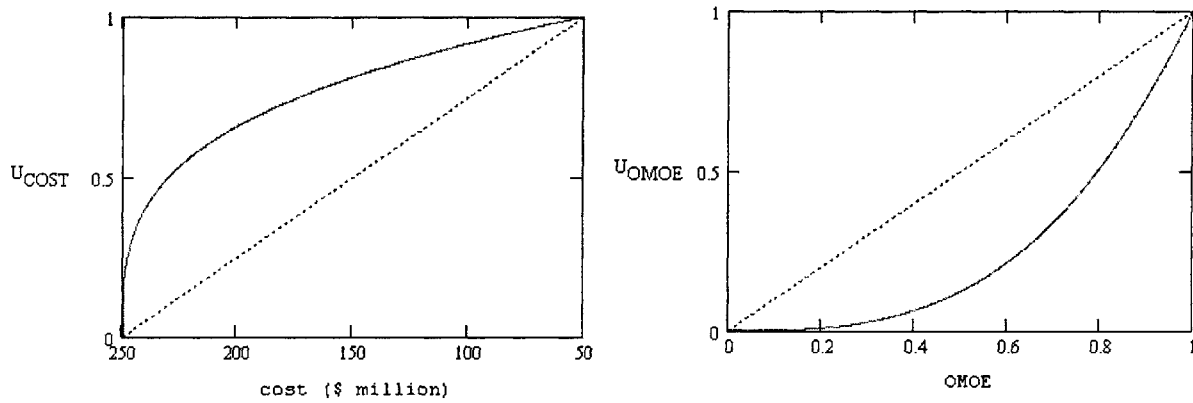
Figure 5-3



AHP Process for Determining OMOE (Scenario C)

Figure 5-4

The OMOE from the AHP method along with the cost calculated by the synthesis model were combined using the single-attribute utility functions shown in Figure 5-5, in order to determine the Multi-Attribute Utility (MAU) for each design.



Utility functions for Cost and OMOE

**Figure 5-5**

The OMOE, cost, and Utility results for each design are summarized in Tables 5-5 through 5-7.

**Table 5-5**

## Summary of Design Variant OMOE and UTILITY (Part 1)

	A1	A2	B1	B2	B3
OMOE Scenario A	0.661	0.659	0.582	0.575	0.559
OMOE Scenario B	0.594	0.592	0.470	0.463	0.453
OMOE Scenario C	0.641	0.637	0.501	0.490	0.468
Rough Order of Magnitude Cost    millions	\$161.55	\$152.75	\$159.95	\$152.35	\$142.95
UTILITY Scenario A	0.430	0.436	0.370	0.371	0.368
UTILITY Scenario B	0.377	0.383	0.307	0.310	0.312
UTILITY Scenario C	0.413	0.417	0.322	0.322	0.319

**Table 5-6**

## Summary of Design Variant OMOE and UTILITY (Part 2)

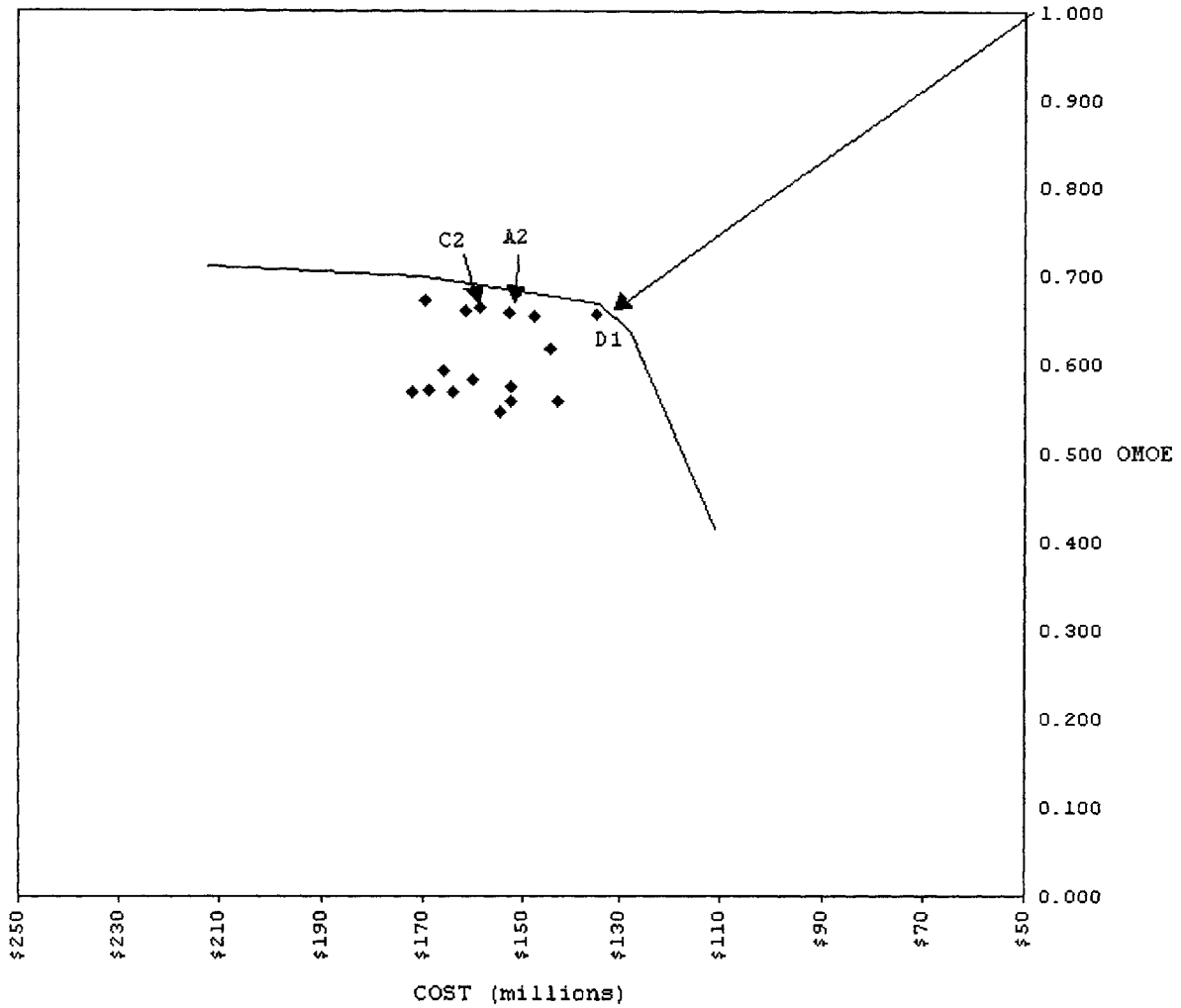
	C1	C2	C3	C4	D1
OMOE Scenario A	0.672	0.664	0.654	0.617	0.656
OMOE Scenario B	0.617	0.607	0.593	0.581	0.536
OMOE Scenario C	0.620	0.607	0.591	0.557	0.534
Rough Order of Magnitude Cost    millions	\$169.45	\$158.75	\$147.75	\$144.35	\$134.75
UTILITY Scenario A	0.434	0.436	0.436	0.408	0.447
UTILITY Scenario B	0.387	0.389	0.387	0.382	0.360
UTILITY Scenario C	0.390	0.389	0.386	0.365	0.359

**Table 5-7**

## Summary of Design Variant OMOE and UTILITY (Part 3)

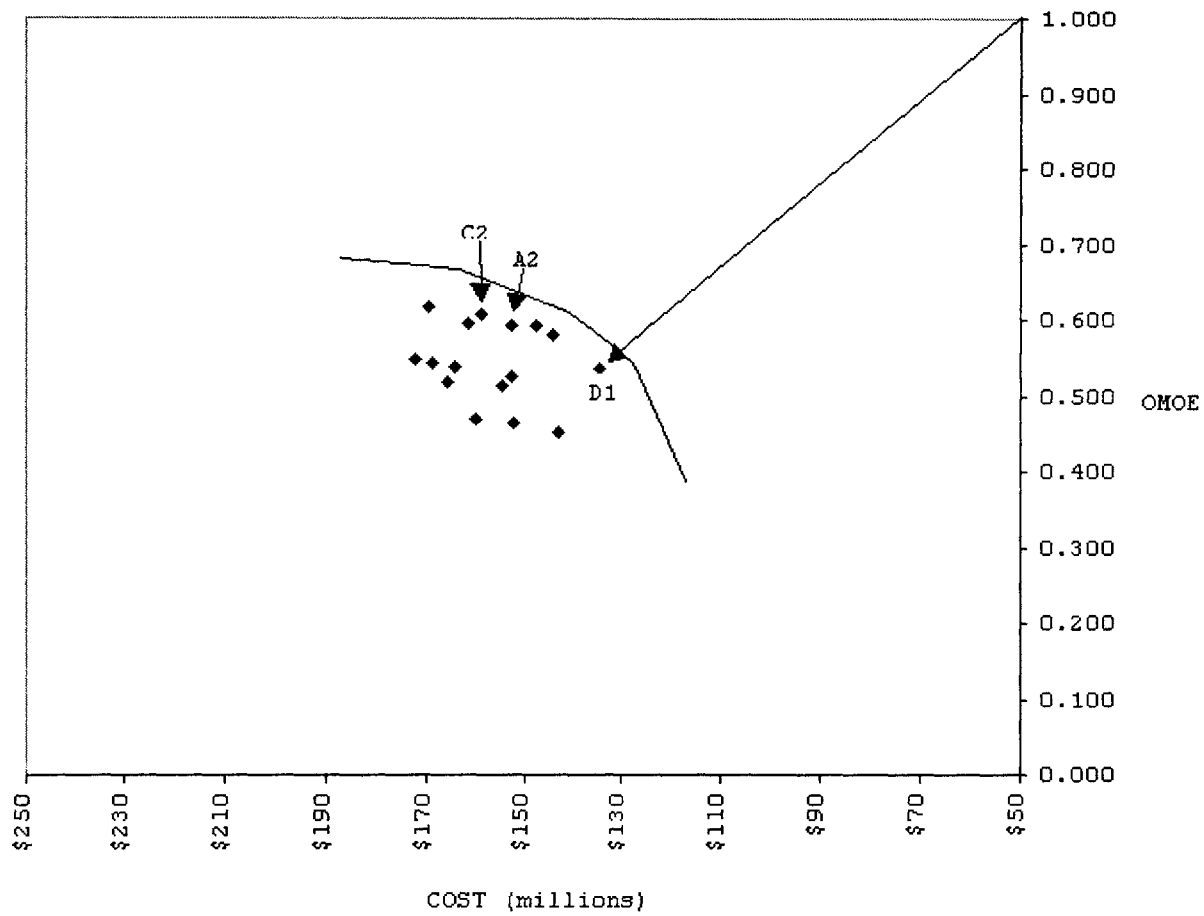
	E1	E2	E3	E4	F1	F2
OMOE Scenario A	0.570	0.569	0.568	0.558	0.592	0.546
OMOE Scenario B	0.544	0.549	0.539	0.526	0.518	0.515
OMOE Scenario C	0.559	0.561	0.554	0.538	0.549	0.539
Rough Order of Magnitude Cost    millions	\$168.85	\$172.25	\$164.25	\$152.55	\$165.95	\$154.45
UTILITY Scenario A	0.354	0.350	0.357	0.360	0.372	0.351
UTILITY Scenario B	0.338	0.338	0.339	0.341	0.326	0.333
UTILITY Scenario C	0.347	0.345	0.348	0.348	0.343	0.347

The results summarized above were then analyzed using two methods to determine which design should be selected as best for each scenario (A, B, and C). The first process is one typically used by the MIT 13A program when selecting preferred design variants. The method plots the OMOE versus cost in order to determine a Pareto frontier. The best design is selected as the one which is on the Pareto frontier and closest to the ideal point. The resulting plots are shown in Figures 5-12 through 5-14.



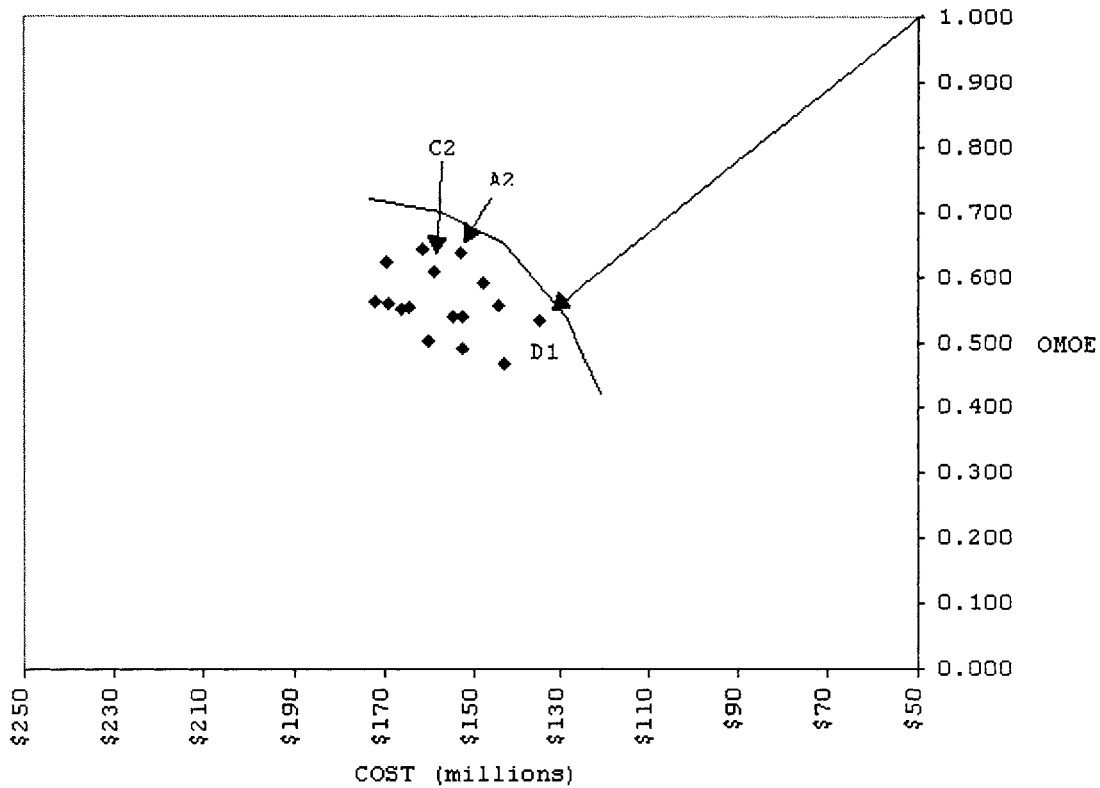
Pareto Plot of Cost and OMOE for Scenario A

Figure 5-6



Pareto Plot of Cost and OMOE for Scenario B

**Figure 5-7**



Pareto Plot of Cost and OMOE for Scenario C

**Figure 5-8**

Using the Pareto method, for all three scenarios, the preferred platform would be design D1.

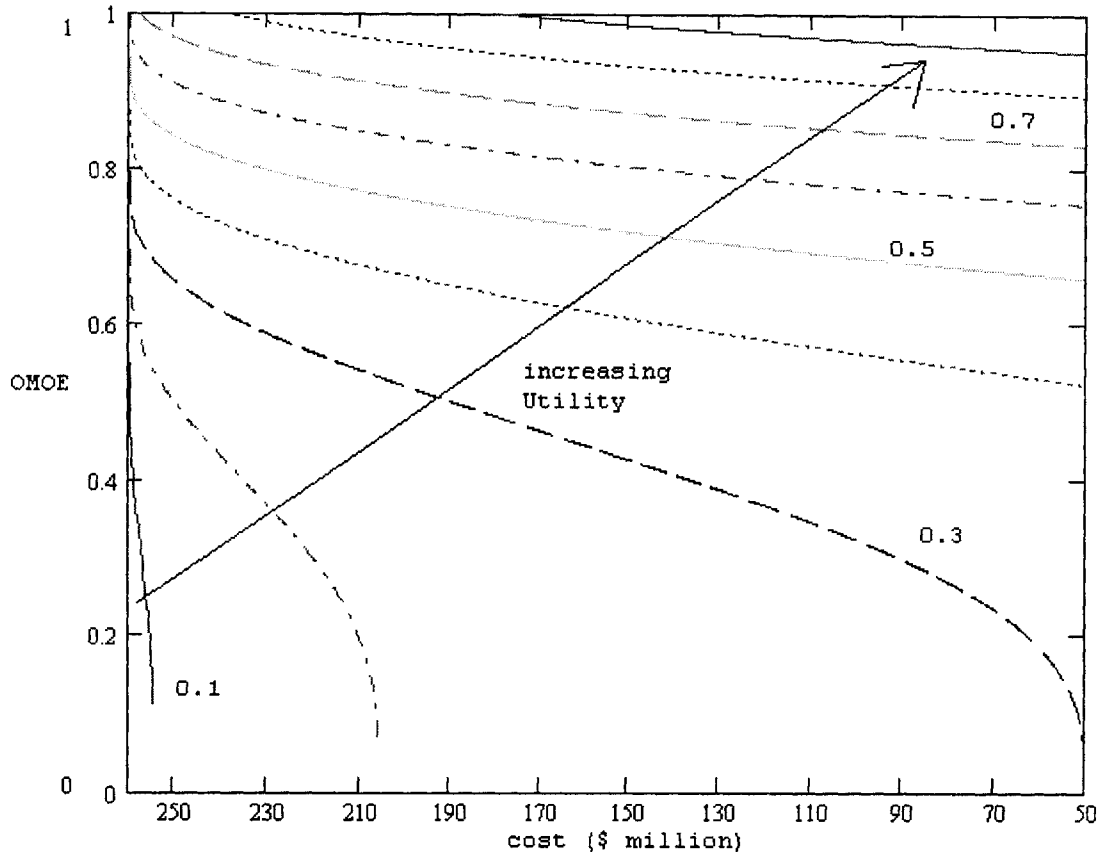
The second method used was to select the preferred platform from each scenario by choosing the design with the highest Utility. This method is straight forward and the preferred design for each scenario is highlighted in the results already presented in Tables 5-5 through 5-7. The preferred designs using the utility method are D1 for scenario A, C2 for scenario B and A2 for scenario C. These three designs will from this point forward be designated as HULL I, HULL II, and HULL III, respectively.

#### 5.4 Options Thinking Applied

As discussed above, when applying the Pareto analysis to determine which design to choose, the same hull was selected for all three scenarios. When factoring in the war fighter's changing preference for both characteristic and risk profile using the MAU method, a different design was preferred for each of the three scenarios. Since the future is uncertain, the remaining analyses in this paper deal with determining the value of having the flexibility to switch between producing one or more of the three preferred designs as the scenario changes (or remains the same) over one time period.

The MAU function that combines the user's preference for the single attribute utilities can be used to determine the user's Willingness to Pay (WTP) for a more preferred design over a less preferred design, e.g. a design with a higher Utility compared to one with a lower Utility. Figure 5-9 shows how the Utility for any combination of OMOE and cost vary, based on the two war fighter single-utility functions for those attributes described above. As shown by the plotted iso-Utility lines, Utility increases as one moves across the plot from left to right and bottom to top.

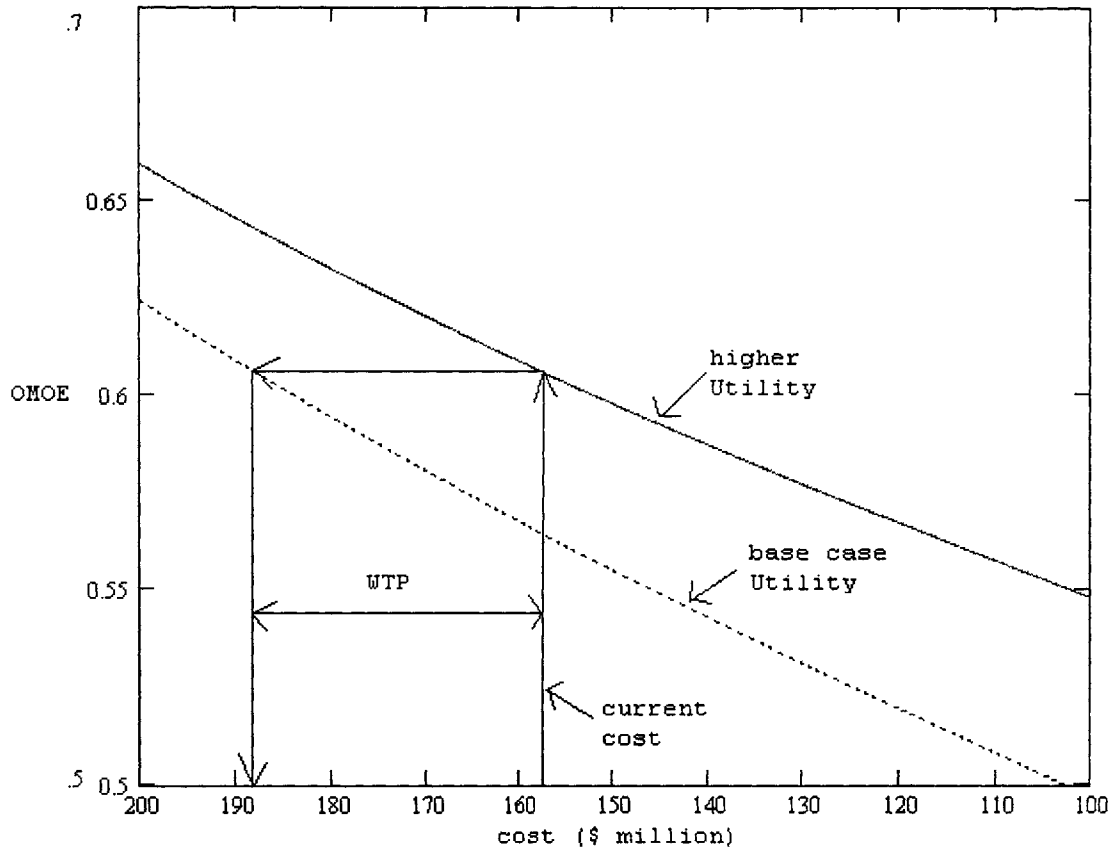
In order to determine the war fighter's willingness to pay for one design over another, the preferred design is compared to a base case design with a known Utility. A graphical representation of the calculation of the WTP is shown in Figure 5-10. The method for determining WTP begins by starting with the cost of the preferred design, i.e. the one with the higher Utility. From the cost axis, a vertical line is drawn which



Iso-Utility Curves for cost and OMOE

**Figure 5-9**

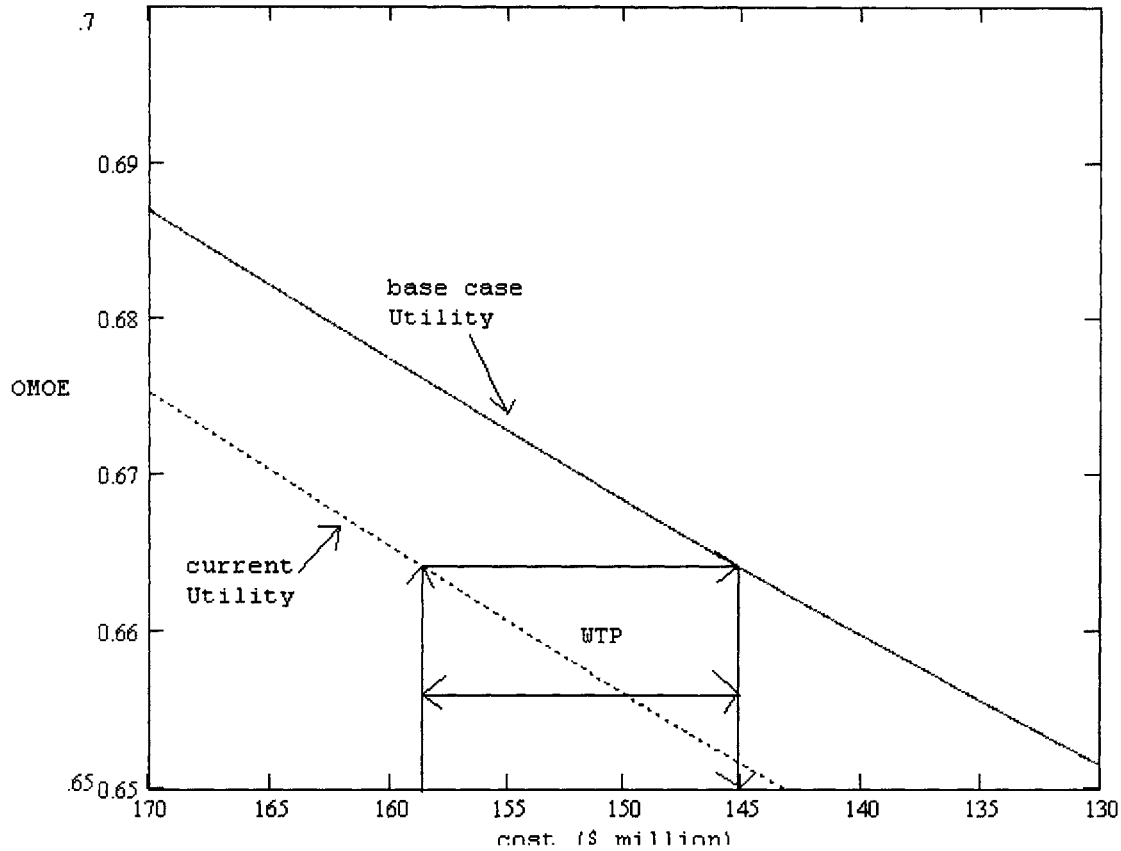
reaches the OMOE which places the end of the line on the preferred design's iso-utility line. At this point, the cost, which when combined with the preferred design's OMOE would yield the base case Utility, must be determined. This is accomplished by connecting a horizontal line across from the preferred design's iso-utility line to the base case iso-utility line. At this point, a line is dropped to the cost axis and the difference between the preferred design's cost and the cost determined by this method represents the WTP.



WTP for Utility Higher than Base Case

Figure 5-10

Figure 5-11 represents the case when the selected design has a lower Utility than the base case. In this instance, the WTP is negative, inferring that the user selecting that design would have over- paid for the selected design by the amount of WTP for the same OMOE.



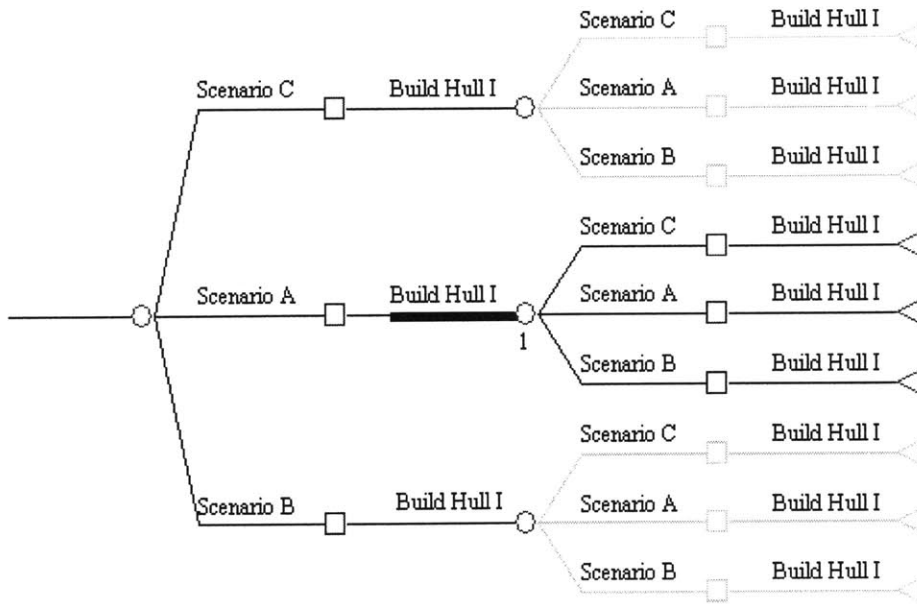
WTP for Utility Lower than Base Case

**Figure 5-11**

Now that a monetary value can be assigned to the difference in Utility for two design alternatives, a decision tree analysis (DTA) will be applied in order to determine the value of holding the option to switch between one or more of the preferred designs as the scenarios may or may not change in a uncertain future.

Since HULL I was the preferred design in the Pareto analysis and also selected as the preferred design for Scenario A, its Utility in each scenario will be taken as the base in that scenario. That is to say that, the WTP for choosing HULL I in any scenario will be zero. Since the decision nodes in the decision tree will be used to maximize WTP, and by choosing HULL I in any scenario will yield a WTP of zero, no negative values will be rolled back through the decision tree. The property represents the option characteristic of truncating down-side losses, while allowing for potentially substantial gains. That is to say, that the worst Utility the war fighter will be provided in any scenario is that provided by HULL I, which would have been chosen by the conventional Pareto method, had flexibility to switch not been incorporated. The value of the flexibility to switch will always be positive, or it will not be exercised.

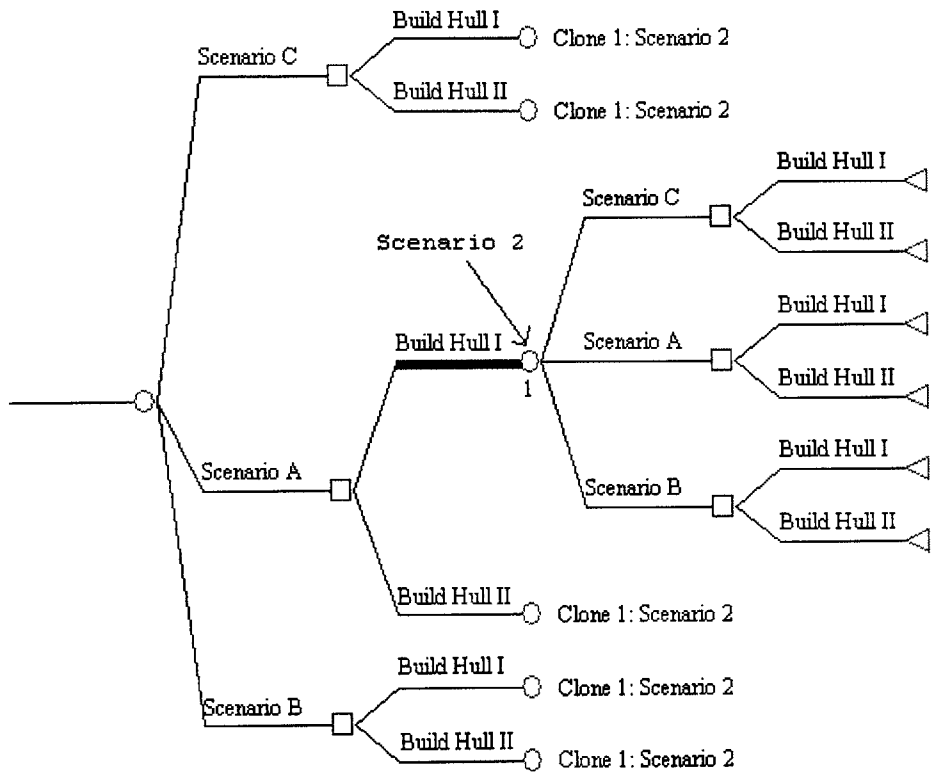
Figure 5-12 represents the decision tree used when only single hull designs are used. A similar tree is used for each of the three cases: HULL I only, HULL II only, HULL III only.



Decision Tree Model for Single Hull Designs

**Figure 5-12**

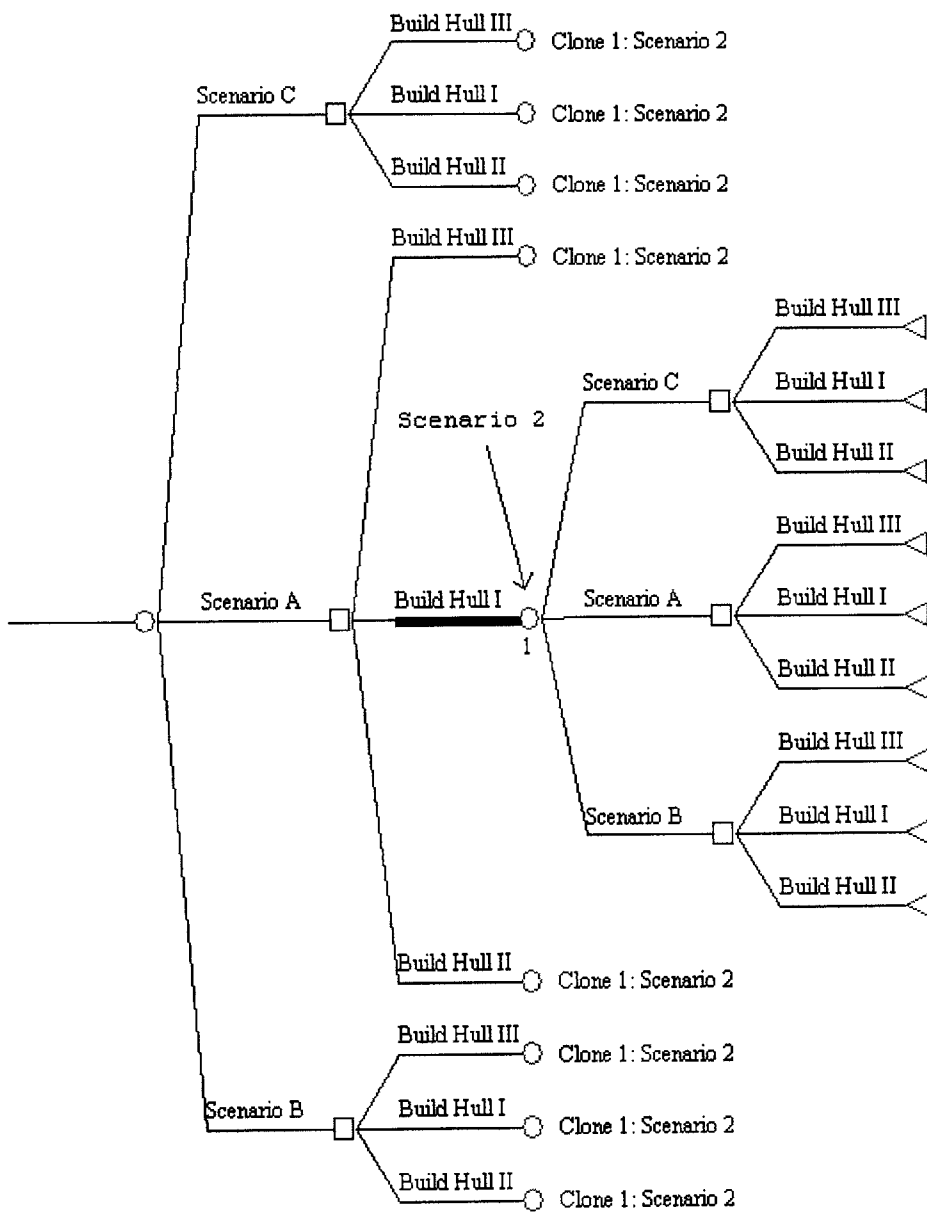
Figure 5-13 represents the decision tree used when two designs are available for switching. Variations of this tree are used to account for all three possible combinations of the pairs of designs.



Decision Tree Model for Option on Two Hull Designs

**Figure 5-13**

Figure 5-14 shows the decision tree used when all three designs are available to be chosen.



Decision Tree Model for Option on Three Hull Designs

**Figure 5-14**

For all of the decision trees and cases used, the probability that any scenario would occur in either time period was fixed at 1/3 for illustrative purposes. Calculating the value for each decision branch used the WTP calculation described above and summed the value for the designs selected over that path in the tree. For example, for a branch which has HULL I, Scenario A in period 1 and HULL II, Scenario B in period 2, the WTP would be calculated by summing the WTP between HULL II/Scenario B with HULL I/Scenario B and HULL I/Scenario A, since the HULL I chosen in period 1 will still be in service in period 2. This value (in this two design example) would be compared to zero (HULL I/Scenario A in period 1 and HULL I/Scenario B in period 2). The greater value will be selected for this branch of the tree. Once all branches are similarly calculated and rolled back, the WTP of the flexibility of being able to choose among the designs as compared to having selected only HULL I is determined. For the DTA with no other uncertainty, the results for each case are summarized in Table 5-8.

**Table 5-8**

Value of Flexibility (WTP) Compared to Hull I Only Base Case

<b>Flexibility Incorporated</b>	<b>WTP Compared to Hull I only</b>
Hull I, Hull II, Hull III	\$85.56
Hull I, Hull III	\$81.73
Hull II, III	\$71.55
Hull III	\$67.46
Hull I, Hull II	\$61.63
Hull II	\$47.41

In order to account for uncertainty in the actual design parameters determined by the synthesis program, a Monte Carlo

simulation was run for each case, using probability distributions to represent the calculated design parameters, rather than single, certain values. The mean and standard deviation of the WTP for each case are summarized on Table 5-9.

**Table 5-9**

Value of Flexibility (WTP) Incorporating Design Uncertainty in Monte Carlo Simulation

<b>Flexibility Incorporated</b>	<b>WTP Compared to Hull I only</b>	<b>WTP Standard Deviation</b>
Hull I, Hull II, Hull III	\$91.3	\$15.9
Hull I, Hull III	\$82.9	\$16.0
Hull II, III	\$79.3	\$22.3
Hull III	\$66.8	\$30.3
Hull I, Hull II	\$64.3	\$18.5
Hull II	\$43.0	\$33.9

### 5.5 Case Results and Discussion

Based on the results presented in Tables 5-8 and 5-9, it has been shown that a monetary metric can be determined for the value of flexibility to switch between one or more ship design options as mission scenarios change. Additionally, by incorporating uncertainty in the resulting design characteristics, the variation of the value of the flexibility can be determined.

Analyzing the results from this particular example, it can be concluded that the value to the war fighter of any design combination other than "HULL I only" would be preferred. It should be noted that this is the opposite conclusion drawn when using the typical Pareto analysis which does not account for the relationship between OMOE and cost, and does not account for flexibility. Additionally, it can be seen that although having the option to choose between all three hull designs has the highest WTP, the choice of only HULL I and HULL III is possibly the best choice, depending on how much it would cost to create a design for HULL II, which only marginally increases the WTP over the HULL I/III case.

The WTP calculated above can be thought of as the amount that the war fighter should be willing to spend to acquire the additional flexibility, in order to be able to exercise the option to switch to the additional design(s) when appropriate. For example, if it would cost \$200M to design HULL III to have it available for a change in scenario, it would not be worth it as the expected WTP is only on the order of \$80M. If, however, it would only cost \$40 to have the additional design ready should the situation dictate, the investment in the flexibility would be justified.

Certainly there are many underlying assumptions that make these results less than exact. One key assumption in the decision tree is that all of the uncertainty is resolved prior to the decision on which design to build is made. This is obviously unrealistic. Additionally, this analysis assumes that the chosen design successfully makes it through the acquisition phase. Again, this is not a certainty, but some of this uncertainty is accounted for in the Monte Carlo simulation which

places a probability distribution on the expected characteristics rather than considering them a certainty. The selection of and transition of the probabilities for each of the decision tree branches is also open to scrutiny. These values will have to be a best estimate, based on intelligence sources, as there is no good way to predict future war fighter needs, based on historical trends.

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## **CHAPTER 6 Conclusions and Further Work**

### **6.1 Conclusions**

Although it requires many underlying assumptions that may be difficult to justify in an absolute sense, the thesis has shown that the use of Real Options thinking can be applied to a public sector project such as Naval ship design and acquisition. A key conclusion from this work is that a monetary value of project flexibility can be determined. Although not with the accuracy of options analysis applied to financial instruments, or even private, tradable projects, the value derived by this method for public sector projects gives an indication of the order of magnitude of incorporating flexibility into a project to deal with future uncertainty. This method deals with both the endogenous (project) uncertainties, as well as exogenous uncertainties, like changing mission needs.

### **6.2 Further Work**

Future applications of this method could include valuing the flexibility for modular payload designs for single ship designs, rather than valuing the flexibility to choose between different designs altogether. Also, the decision tree could model the different stage of the acquisition process and incorporate options to switch to different technologies or systems, or abandon the project in favor of some other project. Finally, a sensitivity analysis could be incorporated to show how decisions would change as the branch probabilities are varied.

A recommendation for further study in a slightly different vein would be to incorporate a Markov method in the decision tree. In this case, the probabilities could be varied in time, if a sufficient transition matrix could be determined. The Markov method would allow the ships built in each time period to be tracked and their value in future scenarios evaluated. A key advantage to this method, since it moves forward in time and does not have to "roll-back" values, would be that many more periods, with more options in each period, could be analyzed.

## REFERENCES

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Azama, Stacy S. (2000), Defense Systems Management College, Funds Management Department, teaching notes.

Cochrane, C. B., and G. J. Hagan (2001), *Introduction to Defense Acquisition Management, Fifth Edition*, Defense Acquisition University Press, Fort Belvoir, VA.

de Neufville, Richard and Stephan Scholtes. Engineering Systems Analysis for Design course notes, 2002.

de Neufville, Richard, Joel Clark, and Frank Field. Dynamic Strategic Planning course notes, 2000.

de Neufville, Richard, Joel Clark, and Frank Field. Engineering Systems Analysis for Design course notes, 2001.

de Neufville, Richard (1999) "Dynamic Strategic Planning for Technology Policy," *International Journal of Technology Management*.

de Neufville, Richard (2001), "Real Options: Dealing with Uncertainty in Systems Planning and Design," 5<sup>th</sup> International Conference on Technology and Policy Innovation, Technical University of Delft, Delft, Netherlands.

Doerry, Norbert, and Phil Sims (2002), "Concept Exploration Lessons Learned," draft.

Faulkner, Terrence W. (1996), "Applying 'Options Thinking' to R&D Valuation", *Research Technology Management*, May-June, 50-56.

Ford, David N. and B. Kagen Ceylan (2001), "Designing Flexible Strategies to Manage Uncertain Acquisition Projects: Draft Technical Report," unpublished.

Ford, David N. and B. Kagen Ceylan (2001), "Designing Flexible Strategies to Manage Uncertain Acquisition Projects: Interim Research Results," unpublished.

Ford, David N. and B. Kagen Ceylan (2001), "Using Options to Manage Dynamic Uncertainty in Acquisition Projects," unpublished.

Gillmer, Thomas C. and Bruce Johnson (1982), *Introduction to Naval Architecture and Marine Engineering*, United States Naval Institute Press, Annapolis, MD.

Global Security.org (2002), "Littoral Combat Ship," webpage <http://198.65.138.161/military/systems/ship/lcs.htm>.

Gonzalez-Zugatsi, Javier P., Kevin N. Otto, and John D. Baker (1999), "Assessing Value for Product Family Design and Selection," *Proceedings of the 25<sup>th</sup> Design Automation Conference, 1999 ASME Design Engineering Technical Conferences, DETC99/DAC-8613*.

Lamassoure, Elizabeth S. (2001), "A Framework to Account for Flexibility in Modeling the Value of On-Orbit Servicing of Space Stations," S.M. Thesis, Department of Aeronautics and

Astronautics Engineering, Massachusetts Institute of Technology, Cambridge, MA.

Maurelli, Joseph (1997), interview by L. R. Sharp, tape recording, Arlington, VA, 26 September.

McCord, Ray S. and John V. Amy, Jr. (2001), System Design and Acquisition of Naval Ships, Massachusetts Institute of Technology Professional Summer course notes.

McVey, Michelle E. (2002), "Valuation Techniques for Complex Space Systems: An Analysis of Potential Satellite Servicing Market," S.M. Thesis, Department of Aeronautics and Astronautics Engineering, Massachusetts Institute of Technology, Cambridge, MA.

Moteff, John D. (1998), "Defense Research: A Primer on the Department of Defense's Research, Development, Test and Evaluation (RDT&E) Program," *Congressional Research Service Report 97-316 SPR*, The Library of Congress.

Natter, Robert J. (2002), "Meeting the Need for Speed," *U.S. Naval Institute Proceedings, Volume 128*, June.

Neely, III, James E. (1998), "Improving the Valuation of Research and Development: A Composite of Real Options, Decision Analysis and Benefit Valuation Frameworks," PhD Thesis, Department of Materials Science and Engineering, Massachusetts Institute of Technology, Cambridge, MA.

Neely, III, J. E., and de Neufville, R. (2001), "Hybrid Real Options Valuation of Risky Product Development Projects," *Intl J. Technology, Policy, and Management*, Vol.1, No. 1, pp. 29-46.

Oueslati, Skander K. (1999), "Evaluation of Nested and Parallel Real Options: Case Study of Ford's Investment in Fuel Cell Technology," S.M. Thesis, Department of Technology and Policy, Massachusetts Institute of Technology, Cambridge, MA.

Ramirez (2002), "Valuing Flexibility in Infrastructure Developments: The Bogota Water Supply Expansion Plan," MS Thesis, Engineering Systems Division, Massachusetts Institute of Technology, Cambridge, MA.

Rumsfeld, Donald H. (2001), *Guidance and Terms of Reference for the 2001 Quadrennial Defense Review*, United States, Department of Defense.

Shishko, Robert and Donald H. Ebbeler (1999), "Strategic Technology Portfolio Selection: An Option Pricing Approach for NASA," Economic Research Series, No. 38, Engineering Economics and Costing Group, Jet Propulsion Laboratory, California Institute of Technology.

Skvarla, Kai A., Chris B. McKesson, and Alan Barlow. "Streetfighter: Sampling Alternatives of Analysis for Future Small Combatants", American Society of Naval Engineers Conference, April 30 - May 1, 2001.

United States Navy, Chief of Naval Operations (2000), *Navy Strategic Planning Guidance with Long Range Planning Objectives*.

United States Navy, Chief of Naval Operations, Assessment Division, N81 (2001), *A Users Guide to Requirements Generation*.

United States, Department of Defense, Systems Management College (2000), *Systems Engineering Fundamentals*. Defense Acquisition University Press, Fort Belvoir, VA.

United States, General Accounting Office (1997), "SURFACE COMBATANTS: Navy Faces Challenges Sustaining Its Current Program," Report to Congressional Committees.

United States, General Accounting Office (1997), "The Results Act: Observations on DOD's Draft Strategic Plan," National Security and Internal Affairs Division, B-277495.

United States, General Accounting Office (1999), "DEFENSE REFORM INITIATIVE: Organization, Status, and Challenges," Report to the Chairman, Subcommittee on Military Readiness, Committee on Armed Services, House of Representatives.

United States, General Accounting Office (2000), "ACQUISITION REFORM: DOD's Guidance on Using Section 845 Agreements Could be Improved," Report to the Chairman and Ranking Minority Member, Committee on Armed Services, Subcommittee on Readiness and Management Support, U.S. Senate.

United States, General Accounting Office (2001), "NAVY ACQUISITIONS: Improved Littoral War-Fighting Capabilities Needed," Report to the Chairman and ranking Minority Member, Subcommittee on Military Research and Development, Committee on Armed Services, House of Representatives.