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# Flexible and Adaptable Ship Options: Assessing the Future Value of Incorporating Flexible Ships Design Features into New Navy Ship Concepts

15 November 2016

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# Abstract

In order to successfully implement the Surface Navy's Flexible Ships concept, PEO-SHIPS requires a new methodology that assesses the total future value of various combinations of Flexible Ships design features and how they will enable affordable warfighting relevance over the ship's full service life. Examples of Flexible Ships design features include decoupling payloads from platforms, standardizing platform-to-payload interfaces, implementing allowance for rapid reconfiguration of onboard electronics and weapons systems, preplanning access routes for mission bays and mission decks, and allowing for sufficient growth margins for various distributed systems. This research analyzes the application of strategic Real Options Valuation methodology within the Integrated Risk Management process to assess the total future value of Flexible Ships design features and for use in the Future Surface Combatant Analysis of Alternatives. The current research has the explicit goal of proposing a reusable, extensible, adaptable, and comprehensive advanced analytical modeling process to help the U.S. Navy in quantifying, modeling, valuing, and optimizing a set of ship design options to create a business case for making strategic decisions under uncertainty.

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| | |
|---|---|
| AAW | Anti-Aircraft Warfare |
| ASUW | Anti-Surface Warfare |
| AWS | Anti-Submarine Warfare |
| CBO | Congressional Budget Office |
| CNO | Chief of Naval Operations |
| CSBA | Center for Strategic and Budgetary Assessments |
| CUO | Common Units of Output |
| DDG | Arleigh Burke Class of Guided Missile Destroyers |
| DOD | U.S. Department of Defense |
| FASO | Flexible and Adaptable Ship Options |
| FSC | Future Surface Combatants |
| IRM | Integrated Risk Management |
| KVA | Knowledge Value Added |
| LCS | Littoral Combat Ship |
| MAS | Modular Adaptable Ships |
| NAVSEA | Naval Sea Systems Command |
| NPV | Net Present Value |
| OFT | Office of Force Transformation |
| OSD | Office of the Secretary of Defense |
| PEO-SHIPS | Program Executive Office, SHIPS |
| ROI | Return on Investment |
| ROKI | Return on Knowledge Investment |
| ROK | Return on Knowledge |
| ROM | Rough Order Magnitude |
| ROV | Real Options Valuation |
| SME | Subject Matter Expert |
| VLS | Vertical Launch Systems |

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# Introduction

The U.S. Navy is tasked with fulfilling its missions globally in environments with rapidly changing threats using an equally rapidly evolving technological base of platform, mission, electronic, and weapon systems. The challenge the U.S. Navy faces is to retain and maintain sufficient military relevance during wartime as well as peacetime, with the added goal of minimizing highly intrusive and costly modernization throughout a ship's service life by incorporating Modular Adaptable Ships (MAS) and Flexible and Adaptable Ship Options (FASO) in the ship design. Pursuing this goal has the added benefit of allowing the Navy to affordably and quickly transform a ship's mission systems over its service life to maintain its required military capabilities (Doerry, 2012).

Historically, naval ship design includes robust features that limit any future capabilities to make requirement changes. For instance, any major requirement changes needed to meet critical operational tasks during wartime would necessitate a major modernization effort or decommissioning the existing ship prior to its end of service life and replacing it with a newly commissioned ship. The concept of MAS and FASO, if applied correctly, with the optimal options implemented, would reduce the need for costly and lengthy major mid-service-life intrusive modernizations, as well as increase the existing platform's flexibility to adapt to new requirements utilizing a faster and cheaper alternative.

The concept of FASO is not new to the Navy. In fact, benefits of MAS/FASO concepts have been detailed by Jolliff (1974), Simmons (1975), Drewry (1975), and others. Even as recently as 2015, the Naval Sea Systems Command's (NAVSEA) PEO-SHIPS put out a presentation on Flexible Ships, detailing its "Affordable Relevance over the Ship's Life Cycle" (Sturtevant, 2015). In it, the Director of Science and Technology, Glen Sturtevant, noted that the main current and future challenges confronting Surface Navy include facing unknown but evolving global threats while managing an accelerated pace of technological changes, coupled with handling rising costs and declining budgets. The analysis found that ships currently cost too much to build and sustain; the ships (Platforms) are too tightly coupled with their capabilities (Payloads); and inflexible and fixed architectures of legacy ships limit growth and capability upgrades or result in lengthy and costly upgrades. The effects of these issues, of course, are compounded by ever-evolving, unknown global threats.

In past speeches, ADM Greenert (Chief of Naval Operations) and VADM Rowden (Commander of Naval Surface Forces) echoed the idea that the ability to quickly change payloads and have modularity on ships would maximize the service life of ships and allow faster and more affordable upgrades to combat systems and equipment.

Some examples of MAS and FASO that had been espoused in Navy research literature, such as in Sturtevant (2015); Doerry (2012); Koenig (2009); Koenig, Czapiewski, and Hootman (2008); and others, include Decoupling of Payloads from Platforms, Standardizing Platform-to-Payload Interfaces, Rapid Reconfiguration, Preplanned Access Routes, and Sufficient Service Life Allowance for Growth. These FASO areas can be applied to a whole host of systems such as weapons, sensors, aircraft, unmanned vehicles, combat systems, C4I, flexible infrastructure, flexible mission bays and mission decks, vertical launch systems (VLS) for various multiple missile types, future high-powered surface weapons (laser weapon systems and electromagnetic railguns), and modular payloads (e.g., anti-submarine warfare, special operations, mine warfare, intelligence gathering, close-in weapon systems, harpoon launchers, rigid hull inflatable boats, gun systems, etc.).

The concepts of Adaptability and Flexibility (plug-and-play concepts of rapidly removing and replacing mission systems and equipment pier-side or at sea), Modularity (common design interface and modular components that will greatly simplify adding, adapting, modifying, or modernizing a ship’s capabilities), and Commonality/Scalability (capabilities that are built independently of a ship by using standardized design specifications that allow similar systems to be placed across multiple ship platforms) are all concepts of strategic Real Options Valuation (ROV) analytical methodologies. ROV has been used in a variety of settings in industry including pharmaceutical drug development, oil and gas exploration and production, manufacturing, start-up valuation, venture capital investment, information technology infrastructure, research and development, mergers and acquisitions, intangible asset valuation, and others. The current project looks at applying the same flexibility modeling empowered by Real Options Valuation methods to identify the optimal ship design alternative.

This current research acknowledges that the U.S. Navy has sought out the ability to incorporate FASO and MAS capabilities in its ship design of Future Surface Combatants (FSC). Further, the Navy acknowledges that there is significant value in terms of being able to rapidly upgrade FASO ships at a lower cost, while extending the ships' service life, all the while being able to quickly adapt to changes in both external threats and internal new technologies. As such, this current research is not meant to identify said FASO/MAS platforms or payloads per se, but to use previously identified platforms such as the DDG 51 Flight III where there are opportunities to insert flexible ship features, and we limit the analysis to said surface combatants in the domain of Anti-Submarine Warfare (ASW). This current research focuses on a series of recommended analytical methodologies to establish a Business Model or Business Case Analysis that supports strategic decision making under uncertainty, specific to identifying, modeling, valuing, and optimizing the various strategic real options in flexible ship designs. Currently, there is only a limited set of real-life applications of FASO/MAS in ship design, and they are classified; therefore, actual empirical data is not used in this research. In addition, because the objective of this research is to illustrate in detail the business case modeling process and analytical methodologies such that the method and process can be replicated and used in all future FASO/MAS design decisions, subject matter expert (SME) opinions, publicly available information, and certain basic assumptions or rough order magnitude (ROM) estimates are used. The use of said ROM or SME inputs in no way detracts from the analytical power, efficacy, or applicability of these methods.

In summary, this current research has the explicit goal of proposing a reusable, extensible, adaptable, and comprehensive advanced analytical modeling process to help the U.S. Navy in quantifying, modeling, valuing, and optimizing a set of ship design options to create a business case for making strategic decisions under uncertainty. The process will accomplish the following:

- Identify which FASO/MAS options have a positive return on investment (i.e., in which options the benefits outweigh the costs).
- Model Uncertainty and Risks (i.e., Monte Carlo Risk Simulations will be applied to simulate hundreds of thousands of possible scenarios and outcomes to model the volatility and ever-changing global threat matrix).
- Frame and Value the Ship Design Options (i.e., each design option will be vetted and modeled; options will be framed in context and valued using cost savings [cost savings due to rapid upgrades at lower costs], costs to obtain these options [costs to design and implement these FASO/MAS options], and potential military benefits [using Knowledge Value Added methods to monetize expected military value]).
- Optimize the Portfolio of Options (i.e., given a set of FASO/MAS design options with different costs, benefits, capabilities, and uncertainties, identify which design options should be chosen given constraints in budget, schedule, and requirements).

## Research Process and Layout of the Paper

The remainder of the current research paper is laid out as follows.

### *Literature Review*

A review of the existing literature in terms of the ship design development process within the U.S. Navy as well as in other shipbuilding programs is presented in this section. First, literature on existing ship design and building processes will be collected, reviewed, and used to develop a comprehensive ship design and building process that is generic and applicable in general for the U.S. Navy. Second, a collection of the most common types of modular and flexible ship design requirements will be identified and reviewed.

### *The Theory of Real Options, Knowledge Value Added, and Integrated Risk Management*

The recommended decision framework is briefly explained. This framework will structure the ROV models and methodology in a way that relates to the various design implementation and facilitates data collection, data analysis, and recommendations, regardless of the design-type alternatives. In addition, the ROV analytical modeling methods will be introduced as part of the Integrated Risk Management (IRM) process, where other advanced decision analytical methodologies such as Monte Carlo Risk Simulation, Knowledge Value Added (KVA), and Portfolio Optimization approaches will also be used.

### *Real Options Valuation Applications in the U.S. Department of Defense*

Some quick examples of how ROV can be applied in the U.S. Department of Defense (DOD) are outlined to illustrate that ROV methods are not restricted to the scope of the current research area, but can be extended into other DOD areas as well.

### *FASO/MAS at PEO-SHIPS: AWS Options for the DDG 51 Flight III*

This section will illustrate the case application of FASO/MAS regarding the anti-submarine warfare domain for the DDG 51 Flight III platform. The case will start with identifying the design options, framing and valuation of said options, and applying ROV methods within the IRM analytical environment.

### *Conclusions and Recommendations*

This final section will detail our conclusions and recommendations going forward, regarding the proposed analytical process, data requirements, analyst/engineer training, and modeling tools.

# Literature Review

In a U.S. Navy research article (Page, 2011), when the analysis was performed under the assumption of risk and uncertainty, the U.S. Navy could realize improved “matching of operational capability and decreased fiscal burden through the conscious design of flexible architectures.” The process explained was straightforward in terms of framing and analysis of the real options but difficult because it requires a change in thinking and mindset for decision makers. First, the U.S. Navy must “identify the sources of uncertainty in each platform design.” This is an important fact as strategic flexibility or real options are always more valuable with uncertainty. In all cases in which the U.S. Navy “designs enough flexibility to realize cost benefits, the value of this flexibility increases with increases in variability of the inputs.” The converse is also true, if the future state is more certain, flexibility has less value. The U.S. Navy could benefit from application of this type of flexibility analysis to “platforms other than medium displacement surface combatants. Amphibious vessels provide an interesting platform for studying service life allowances and design margins.” To conclude, the U.S. Navy would realize “fiscal and operational benefits by incorporating options in its platforms starting in early stage design. The fact is, the Navy already executes options on its platforms and programs, but does so without the recognition and analysis of the uncertainties.”

In the article, “Surviving a Perfect Storm,” Siegel (2005b) found that “the U.S. Navy’s shipbuilding program is charting a course through a perfect storm characterized by strategic change, developing doctrinal concepts, changing managerial approaches, uncertainty over its future force size and mix, and increasing fiscal pressure.” Thus, the Navy has explored “new deployment approaches like Sea Swap” (Siegel, 2005b) and other ways to get more out of its capital investments in ship construction. While these approaches had been identified earlier on as the only viable options to either increase funding levels or slash acquisition and reduce future capabilities, Siegel also states that Sea Swap and other initiatives like it are not adequate. In his article, Siegel (2005b) suggests that there is a third option: “how to get $13 billion worth of shipbuilding effects for $10 billion in funding." Such an option would require changing the navigational rules of the road for what many refer to as a "broken acquisition process." Siegel (2005b) offers the following suggestion to change the shipbuilding rules to help the Navy and the nation get more bang for the shipbuilding buck: "Limit requirements growth and change orders. Requirements growth during development, driven by a dynamic security environment, is a key factor in increased ship cost. Locking in a flexible design with the ability to make scheduled block changes would provide an affordable baseline design that could be upgraded as increased funding becomes available and requirements evolve."

O'Rourke (2010) found that the U.S. Navy's budget pressures are compounded by a "real decline in the DOD budget and policy makers could face difficult choices to fund programs for some kinds of Navy capabilities but not others. If so, the resulting fleet could have gaps in capability as well as capacity." Consequently, the U.S. Navy can utilize strategic real options for addressing this situation such as "finding more U.S. Navy cost-saving efficiencies, reducing the cost of U.S. Navy shipbuilding programs, and shifting to a more highly distributed fleet architecture."

The *Defense Industry Daily* staff (2016) considered Littoral Combat Ships (LCS) and found that they

> exploit simplicity, numbers, the pace of technology development in electronics and robotics, and fast reconfiguration. That was the U.S. Navy's idea for the low-end backbone of its future surface combatant fleet. Inspired by successful experiments like Denmark's Standard Flex ships, the U.S. Navy's $35+ billion 'Littoral Combat Ship' program was intended to create a new generation of affordable surface combatants that could operate in dangerous shallow and near-shore environments, while remaining affordable and capable throughout their lifetimes.

It hasn't always worked that way, though. In practice, the U.S. Navy

> hasn't been able to reconcile what they wanted with the capabilities needed to perform primary naval missions, or with what could be delivered for the sums available. The LCS program has changed its fundamental acquisition plan four times since 2005, and canceled contracts with both competing teams during this period, without escaping any of its fundamental issues. Now, the program looks set to end early. This public-access FOCUS article offers a

> wealth of research material, alongside looks at the LCS program’s designs, industry teams’ procurement plans, military controversies, budgets and contracts. (Defense Industry Daily, 2016)

The *Report to the Congress on the Annual Long-Range Plan for Construction of Naval Vessels for Fiscal Year 2016* states that the shipbuilding plan for the U.S. Navy is to build and maintain a battle force inventory

> above 300 ships, and to ultimately achieve the shipbuilding plan objective of 308 battle force ships between FY2022 and FY2034. The rate of large surface combatant retirements beyond FY2034 exceeds the ability of the Navy to finance a build rate that sustains the 308-ship force structure until after completion of the OR SSBN program. Thus, Navy structure remains about 300 ships until the mid-2040 timeframe. (Office of the Chief of Naval Operations, 2015)

The mix of ships, by quantity and type, contained in this report, possesses the

> requisite capability and capacity to carry out the DSG mission. They enable the COCOMs to meet mission demands to Maintain a Safe, Secure, and Effective Nuclear Deterrent; Deter and Defeat Aggression, Project Power Despite Anti-access/Area Denial Challenges; Counter Terrorism and Irregular Warfare; Provide a Stabilizing Presence; Conduct Stability/Counterinsurgency Operations; and Operate Effectively in Cyberspace/Space. We achieve the desired mix of ships if this shipbuilding plan receives stable and sufficient funding over the long haul. (Office of the Chief of Naval Operations, 2015)

In “Condition Sinking,” Wilson (2014) states that the U.S. Navy faces a

> shipbuilding crisis in the 2020s as several whole classes of ships are ready for replacement all at once. Mismanagement and multibillion dollar cost overruns are becoming bigger enemies for the U.S. Navy than the Chinese military ever could. The U.S. Navy plans for a 306-ship fleet are taking on water, awash in a sea of cost overruns and a huge block of older ships that should be replaced. Hard budgetary choices are needed, and the consequences to U.S. foreign policy could be serious. Also, coming in over budget and in smaller numbers is the Littoral Combat Ship (LCS) program to replace an aging fleet of Oliver Hazard Perry frigates and mine warfare vessels.

The LCS is designed as a high-speed multipurpose vessel for operations in the littorals (coastal waters) with reduced crews compared with the frigates they’re replacing. The LCS has an open architecture capable of handling modules for different missions. Instead of selecting one contractor and one design, the Navy decided in 2009 to build some of each. This approach is a standard strategic real option as flexibility is created in its design (handling of multiple modules is an option to switch and change, fewer crew members is an option to contract, and extension into multiple missions is an option to wait and execute).

Each time a major defense review is undertaken, policymakers must confront a range of complicated issues about the U.S. Navy's

> future force structure, including resource concerns and significant changes in the shipbuilding industrial base. To help answer these concerns, analysts in the Office of the Secretary of Defense (OSD) and the Chief of Naval Operations (CNO) staff turn to the available analytical tools to help provide strategic options to decision makers. Although an array of such tools exists, there is a significant need for improvement to ensure that policy and resource decisions are well analyzed and supported. (Arena, Schank, & Abbott, 2004)

In earlier research, RAND identified the types of issues that arise during these defense reviews and evaluated the capacity of current analytical models to help address these issues. It was found that the most common concerns of defense analysts were

> cost, schedule, industrial base capacity, shipyard performance, and program management strategies. Further, existing tools lacked an integrated approach that would allow analysts to consider not just individual elements (e.g., manpower and procurement funding requirements) but the interaction and interrelationships among the industrial base components—from attrition rates to ship life extensions, from labor learning curves to overhead costs. We then outlined an overarching analytical architecture that could provide this integrated analysis environment—an environment in which the user is able to understand the implications of force structure choices on resource requirements and the private shipyard industrial base. (Arena, Schank, & Abbott, 2004)

In "Institutionalizing Modular Adaptable Ship Technologies," Doerry (2012) found that with an uncertain future,

> the U.S. Navy is tasked with fulfilling its missions in an environment of evolving threats and a corresponding rapidly evolving mission system technology base. Affordability of our fleet is also of paramount concern. An alternative to the traditional approach of optimizing a point ship design to meet a specific set of fixed requirements is needed to maintain a sufficiently sized and relevant naval fleet that can be built and supported within the available budget. Modular Adaptable Ship (MAS) technologies offer an

> opportunity for a ship to affordably transform its mission systems over its service life to maintain military relevance.

While various MAS technologies have been available for years, and in many cases, have been "installed onboard ships in an ad hoc manner, a design methodology does not currently exist to establish a sound technical basis for determining how much of what type of modularity to install on a ship" (Doerry, 2012). Doerry also reviewed the status of several MAS technologies to include modular hull ships, mission bays, container stacks, weapon modules, aperture stations, off-board vehicles, Electronic Modular Enclosures (EME), and Flexible Infrastructures:

> These technologies are evaluated against criteria for their readiness for integration into a ship design, and this paper also described and evaluated the current states of processes needed to successfully integrate MAS technologies on a ship. These processes include: cost estimation; valuing modularity and flexibility; acquisition, maintenance and modernization strategies; and optimizing ship configuration. (Doerry, 2012)

The paper introduced the use of real options theory as part of the solution for measuring value.

In "The Fleet We Need: A Look at Alternative—and Affordable—Futures for the U.S. Navy," the author explores the nature of tomorrow's U.S. Navy by examining and expanding on an "incredibly detailed Congressional Budget Office (CBO) study authored by Eric Labs, who is recognized as one of the nation's premier naval analysts and an objective expert in costing naval programs. This extensive CBO study comes on the heels of a long debate on alternative fleet designs in 2005" (Hoffman, 2006). The main conclusion of the CBO analysis is that

> unless shipbuilding budgets increase significantly or the U.S. Navy designs and builds much cheaper ships, the size of the fleet will fall substantially. The most critical implication to take from this detailed and balanced analysis is the conclusion that the Navy's shipbuilding plan is based upon several optimistic assumptions that cast its validity into severe doubt. (Hoffman, 2006)

In Hoffman's (2006) own words,

> my own option is based on the teachings of Julian S. Corbett, the British strategist/historian who emphasized the use of a navy to serve joint operations ashore. Rather than supporting the Navy's focus on future hypothetical threats, this option exploits our domination of the global

> commons to improve our capacity to execute sea denial in key choke points and penetrate ashore against real threats we face today.

In the article, “Applying Real Options Analysis to Naval Ship Design,” Knight and Singer (2014) found that there is a

> trend in global navies toward highly flexible, modular architectures. This is driven, at least in part, by compressed acquisition cycles, faster technology refresh rates, and contracting budgets. Given the importance of flexibility in naval ship design, the methods used for evaluating naval assets should adequately capture the impact of such flexibility. Static budgetary techniques like net present value (NPV) analysis are known to underestimate the value of the embedded ‘optionality’ of flexible design features. The use of ROV has been proposed to correct this underestimation, however ROV is not universally applicable to the naval domain because of some of its key assumptions, such as the existence of a market and cash flows. Expected utility methods alone are also inadequate as they ignore important considerations such as loss aversion. (Knight & Singer, 2014)

Historically, these constraints have left designers and decision makers to rely on their intuition and engineering experience when evaluating flexible systems and architectures. This paper presents a novel quantitative framework for valuing flexible naval assets, called

> prospect theory-based real options valuation (PB-ROV), which merges concepts from real options theory, utility theory, prospect theory, and game theory. The framework makes it possible to apply the principles of ROA to Navy assets. A simple example is presented demonstrating the valuable insight which the framework may generate. (Knight & Singer, 2014)

In “Real Options for Naval Ship Design and Acquisition: A Method for Valuing Flexibility Under Uncertainty,” Gregor (2003) states that the U.S. 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. (Gregor, 2003)

This thesis was intended to identify and analyze the real options available for the design and acquisition of naval ships, as well as to determine the value of these options and to determine the best types and amount of flexibility to design into naval systems to maximize the value of the system over time under uncertain conditions.

In “A Prospect Theory-Based Real Option Analogy for Evaluating Flexible Systems and Architectures,” Knight (2014) describes the constant trend in the U.S. Navy design and acquisition programs that emphasizes flexible systems and architectures. Modularity and design-for-upgradability are two examples of this trend.

> Given the increasing importance of flexibility in U.S. Navy design, the methods used for valuing naval assets should adequately capture the impact of such flexibility. Current static budgetary techniques and net present value (NPV) analysis underestimate the value of the embedded *optionality* of flexible design features. The use of ROV has been proposed to correct this underestimation, however the theory is not universally applicable to the naval domain because of key assumptions made by a real options approach. For instance, ROV assumes that assets generate cash flows, which have a measurable value based on their volatility and the prevailing market price of risk. Naval assets, however, do not generate cash flows, nor are they traded on a market. Furthermore, traditional ROV does not allow for the possibility of the option’s value being interdependent with the decisions of other agents in one’s environment. These deficiencies leave designers and decision makers to rely on their intuition and engineering experience when evaluating flexible systems and architectures. A quantitative evaluation framework would add valuable analytical rigor to increasingly complex designs and demanding mission requirements. (Knight, 2014)

In the article, “Real Options in Ship and Force Structure Analysis,” Koenig (2009) states that in the

> evaluation of large, risky expenditures on long-lived capital investments, conventional engineering economic analysis methods do not provide adequate insight into the option value of managerial flexibility and strategic interactions. A common practical remedy is to set aside the (incomplete) analysis in favor of intuition and judgment, which in many instances results from tacit knowledge of embedded option-type value. If this value could be explicitly documented, then the decision criteria would be more transparent. A real options analogy with financial options has been proposed; the attraction is that methods for valuing financial options are mature. Naval ship design and acquisition is an option-laden environment. Therefore, if a naval version of the real options analogy were developed, it would add considerable insight. In this paper, the motivation for option-based analysis is introduced, the basic mechanics of financial options are reviewed, and an agenda for developing options-informed naval analyses is suggested. (Koenig, 2009)

In a separate paper, a manifesto on engineering resilient systems (ERS) and conveyed potential of technology-enabled innovations in processes and tools for developing affordably adaptable and effective systems was presented. In addition, this paper sought to clarify the problem by characterizing it as a science and technology problem, rather than a process adherence or reengineering problem. (Neches & Madni, 2013)

> During the long and somewhat turbulent history of the Zumwalt program, the U.S. Navy has continuously supported the ship while expanding its capabilities and reducing its numbers. After years of justifying its requirements, the Navy has reversed direction and is arguing that its future multi-mission destroyer is no longer the answer to the threats the service may face in the future. (Eaglen, 2008)

In "Small Combat Ships and the Future of the Navy," Work (2004) states that

> in November 2001, the U.S. Navy announced a new family of 21st century surface warships that includes a small, focused-mission combatant called the Littoral Combat Ship (LCS). The LCS would be a fast, stealthy warship designed specifically for operations in shallow coastal waters. It would have a modular mission payload, allowing it to take on three naval threats—diesel submarines, mines, and small 'swarming' boats—but only one at a time. There are sound reasons why the LCS should be pursued. On the other hand, much about the ship's concept of operations remains to be proven or explored. The present plan, modified to allow for thorough operational testing of the LCS concept and design, is the proper one. The U.S. Navy is pursuing a new, more distributed fleet architecture to fit its new vision of scalable battle networks. Envisioning the LCS as a component of a larger fleet battle network helps to explain the ship's design goals as well as the missions it will initially perform. The new ship aims to be the Swiss army knife of future naval battle networks. Its design is being shaped by six principles: Get fast, get connected, get modular, get off-board, get unmanned, get reconfigured. (Work, 2004)

In "Navy Ship Acquisition: Options for Lower-Cost Ship Designs—Issues for Congress," O'Rourke (2005) states that

> aside from reducing planned ship procurement rates, one option would be to reduce U.S. Navy ship procurement costs by shifting from currently planned designs to designs with lower unit procurement costs. Lower-cost designs for attack submarines, aircraft carriers, larger surface combatants, and smaller surface combatants have been proposed in recent reports by the Congressional Budget Office (CBO), DOD's Office of Force Transformation (OFT), and the Center for Strategic and Budgetary Assessments (CSBA).

> Options for lower-cost designs can be generated by reducing ship size; shifting from nuclear to conventional propulsion; shifting from a hull built to military survivability standards to a hull built to commercial-ship survivability standards; or using a common hull design for multiple classes of ships. Additionally, lower-cost designs for attack submarines, aircraft carriers, larger surface combatants, and smaller surface combatants have been proposed in three recent reports discussing the future of the U.S. Navy. (O’Rourke, 2005)
>
> Options for lower-cost U.S. Navy ship designs can be generated by
>
> starting with currently planned U.S. Navy ship designs and making one or more of the following changes: reducing ship size, shifting from nuclear to conventional propulsion, shifting from a hull built to military survivability standards to a hull built to commercial-ship survivability standards, and using a common hull design for multiple ship classes. A sixth option for responding to rising ship costs would be to improve the operating efficiency of yards building Navy ships by incorporating more advanced design and production processes and equipment. (O’Rourke, 2005)

In a research report from Northrop Grumman Analysis Center, the author states that “shipbuilding is facing a perfect storm and leadership is dedicated to charting and navigating a course through this storm. Real options exist to improve the nation’s, the U.S. Navy’s, and industry’s ability to navigate the storm” (Siegel, 2005a).

In “Designing Adaptable Ships: Modularity and Flexibility in Future Ship Designs,” the authors “attempt to answer what are the U.S. Navy’s options for extending the service lives of operational ships by adopting the concepts of modularity and flexibility in ship design” (Schank et al., 2016). The researchers examine the concepts of “modularity and flexibility, technological trends, the current geopolitical context, and lessons from past incorporation of new missions and technologies into naval ships” (Schank et al., 2016).

According to a report by Frank Hoffman (2008), “Because of the U.S. Navy’s struggle to present an acceptable rationale for an affordable future fleet to meet the nation’s needs, the U.S. Congress requested several alternative fleet architectures from various agencies.” This report addressed several fleet design options and presented a compromise option designed to be compatible with an Off-Shore Partnering strategy and to be more affordable over the long range.”

In “A More Flexible Fleet,” Commander Jim Griffin (2015) states that

> few people dream of owning a minivan. Rarely associated with performance or handling, they are known for efficiency, adaptability, and practicality. There is nothing sexy about minivans, but they became the vehicle of choice for millions because they provide the best balance of capability, durability, and affordability. The Arleigh Burkes will remain the high-end, top-of-the-line multi-mission platforms, while the LCSs already programmed will be effective at lower-threat missions or operations in shallow littoral waters. A third type of vehicle is needed: one that is capable at a reasonable cost. Today the U.S. Navy is buying luxury sedans and sports cars. If we want to be able to meet the emerging threats of tomorrow within our likely budgets, we will need to replace some of our sports cars with minivans.

In “Flexible Ships: Affordable Relevance Over the Ship’s Life Cycle,” the author found that there are several imperatives for change, including the following challenges:

> Ships cost too much to build and sustain; payloads (capabilities) are strongly coupled to platforms (ships); legacy ship design margins limit growth for capability upgrades; inflexible architectures result in lengthy and costly upgrades to ships; ships need to stay relevant over their entire service life; and the future is uncertain and the pace of changing threats is increasing. (Sturtevant, 2015)

In addition, the author finds that there are a few Flexible Ships Tenets, with the goal of the Flexible Ships Initiative to deliver

> affordable relevance to U.S. Navy ships over their entire life cycle. It consists of the following five attributes: (i) De-coupled Payloads (capabilities) from Platforms (ships). Traditionally, Navy ships have been tightly coupled to weapons and sensors and as such, require lengthy and costly ship overhauls to rip out and modernize their systems. The Flexible Ships concept treats weapons and sensors as modular payloads that can be easily replaced for ship mission adaptability and new capabilities. (ii) Standard Platform-to-Payload Interfaces—well-defined, common interfaces for distributed ship services that are prescribed and managed by the U.S. Navy. (iii) Rapid Reconfiguration—specific C5I compartments that can be easily re-configured with upgraded equipment or new systems. (iv) Pre-planned Access Routes—used for the easy removal and replacement of interior equipment or systems. (v) Sufficient service life allowance growth margins: Space and weight for future capabilities, and provision for projected demand for distributed systems such as electric power, cooling and network bandwidth. (Sturtevant, 2015)

Matthews (2015) believes that new surface ship designs must be flexible and adaptable, stating that

> from 1961 to 2012, the Navy built 16 different types of ships. It seemed like every time they introduced a new sensor or weapon, they built a new ship and if those were shipbuilding’s glory years, they’re over now. Ships cost so much to build now that they must be designed with enough flexibility to accommodate new equipment and new missions as technology and threats change…. And they’ve got to last. A destroyer should last 35 years. The U.S. Navy can no longer afford to retire of ships early, as it did with Spruance-class destroyers.

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# The Theory of Strategic Real Options, Knowledge Value Added, and Integrated Risk Management

In the past, corporate investment decisions were cut and dried. Buy a new machine that is more efficient, make more products costing a certain amount, and if the benefits outweigh the costs, execute the investment. Hire a larger pool of sales associates, expand the current geographical area, and if the marginal increase in forecast sales revenues exceeds the additional salary and implementation costs, start hiring. Need a new manufacturing plant? Show that the construction costs can be recouped quickly and easily by the increase in revenues the plant will generate through new and improved products, and the initiative is approved.

However, real-life business conditions are a lot more complicated. Your firm decides to go with an e-commerce strategy, but multiple strategic paths exist. Which path do you choose? What are the options you have? If you choose the wrong path, how do you get back on the right track? How do you value and prioritize the paths that exist? You are a venture capitalist firm with multiple business plans to consider. How do you value a start-up firm with no proven track record? How do you structure a mutually beneficial investment deal? What is the optimal timing for a second or third round of financing?

Real options are useful not only in valuing a firm through its strategic business options, but also as a strategic business tool in capital investment decisions. For instance, should a firm invest millions in a new facility expansion initiative? How does a firm choose among several seemingly cashless, costly, and unprofitable information-technology infrastructure projects? Should a firm indulge its billions in a risky research and development initiative? The consequences of a wrong decision can be disastrous or even terminal for certain firms. In a traditional discounted cash flow model, these questions cannot be answered with any certainty. In fact, some of the answers generated through the use of the traditional discounted cash flow model are flawed because the model assumes a static, one-time decision-making process, whereas the real options approach takes into consideration the strategic managerial options that certain projects create under uncertainty and management’s flexibility in exercising or abandoning these options at different points in time, when the level of uncertainty has decreased or has become known over time.

The ROV approach incorporates a learning model, such that management makes better and more informed strategic decisions when some levels of uncertainty are resolved through the passage of time, actions, and events. Traditional discounted cash flow analysis assumes a static investment decision and assumes that strategic decisions are made initially with no recourse to choose other pathways or options in the future. To create a good analogy of real options, visualize it as a strategic road map of long and winding roads with multiple perilous turns and branches along the way. Imagine the intrinsic and extrinsic value of having such a road map or global positioning system when navigating through unfamiliar territory, as well as having road signs at every turn to guide you in making the best and most informed driving decisions. Such a strategic map is the essence of real options.

The answer to evaluating such projects lies in real options analysis, which can be used in a variety of settings, including pharmaceutical drug development, oil and gas exploration and production, manufacturing, start-up valuation, venture capital investment, information technology infrastructure, research and development, mergers and acquisitions, e-commerce and e-business, intellectual capital development, technology development, facility expansion, business project prioritization, enterprise risk management, business unit capital budgeting, licenses, contracts, intangible asset valuation, and the like.

## *The Real Options Solution in a Nutshell*

Simply defined, the real options method is a systematic approach and integrated solution using financial theory, economic analysis, management science, decision sciences, statistics, and econometric modeling in applying options theory in valuing real physical assets, as opposed to financial assets, in a dynamic and uncertain business environment where business decisions are flexible in the context of strategic capital investment decision making, valuing investment opportunities, and project capital expenditures. Real options are crucial in

- Identifying different acquisition or investment decision pathways or projects that management can navigate given highly uncertain business conditions
- Valuing each of the strategic decision pathways and what they represent in terms of financial viability and feasibility
- Prioritizing these pathways or projects based on a series of qualitative and quantitative metrics
- Optimizing the value of strategic investment decisions by evaluating different decision paths under certain conditions or using a different sequence of pathways that can lead to the optimal strategy
- Timing the effective execution of investments and finding the optimal trigger values and cost or revenue drivers
- Managing existing or developing new optionalities and strategic decision pathways for future opportunities

ROV is useful for valuing a project, alternative path, implementation option, or ship design through its strategic options especially in capital-intensive investment decisions under uncertainty. In a traditional cost-benefit and cash flow model, the ROI or cost-benefit question cannot be answered with any certainty. In fact, some of the answers generated using traditional cash flow models are flawed because the model assumes a static, one-time decision-making process with no recourse to choose other pathways or options in the future. In contrast, the real options approach takes into consideration the strategic managerial options certain projects create under uncertainty and the decision-makers' flexibility in exercising or abandoning these ship design options at different points in time, when the level of uncertainty has decreased or has become known over time.

### *Industry Leaders Embracing Strategic Real Options*

The first industries to use real options as a tool for strategic decision were oil and gas and mining companies; its use later expanded into utilities, biotechnology, and pharmaceuticals; and now into telecommunications, high-tech, and across all industries. The following examples relate how real options have been or should be used in various kinds of companies.

### Automobile and Manufacturing Industry

In automobile and manufacturing, General Motors (GM) applies real options to create *switching option*s in producing its new series of autos. This option is essentially to use a cheaper resource over a given period. GM holds excess raw materials and has multiple global vendors for similar materials with excess contractual obligations above what it projects as necessary. The excess contractual cost is outweighed by the significant savings of switching vendors when a certain raw material becomes too expensive in a particular region of the world. By spending the additional money in contracting with vendors and meeting their minimum purchase requirements, GM has essentially paid the premium on purchasing an *option to switch,* which is important especially when the price of raw materials fluctuates significantly in different regions around the world. Having an option here provides the holder a hedging vehicle against pricing risks.

### Computer Industry

In the computer industry, HP–Compaq used to forecast sales in foreign countries months in advance. It then configured, assembled, and shipped the highly specific configuration printers to these countries. However, given that demand changes rapidly and forecast figures are seldom correct, the preconfigured printers usually suffer the higher inventory holding cost or the cost of technological obsolescence. HP–Compaq can create an *option to wait* and defer making any decisions too early through building assembly plants in these foreign countries. Parts can then be shipped and assembled in specific configurations when demand is known, possibly weeks in advance rather than months in advance. These parts can be shipped anywhere in the world and assembled in any configuration necessary, while excess parts are interchangeable across different countries. The premium paid on this option is building the assembly plants, and the upside potential is the savings in making wrong demand forecasts.

## Airline Industry

In the airline industry, Boeing spends billions of dollars and takes several years to decide if a certain aircraft model should even be built. If the wrong model is tested in this elaborate strategy, Boeing's competitors may gain a competitive advantage relatively quickly. Because so many technical, engineering, market, and financial uncertainties are involved in the decision-making process, Boeing can conceivably create an *option to choose* through parallel development of multiple plane designs simultaneously, knowing well the increasing cost of developing multiple designs simultaneously with the sole purpose of eliminating all but one in the near future. The added cost is the premium paid on the option. However, Boeing will be able to decide which model to abandon or continue when these uncertainties and risks become known over time. Eventually, all the models will be eliminated save one. This way, the company can hedge itself against making the wrong initial decision and benefit from the knowledge gained through parallel development initiatives.

## Oil and Gas Industry

In the oil and gas industry, companies spend millions of dollars to refurbish their refineries and add new technology to create an *option to switch* their mix of outputs among heating oil, diesel, and other petrochemicals as a final product, using real options as a means of making capital and investment decisions. This option allows the refinery to switch its final output to one that is more profitable based on prevailing market prices, to capture the demand and price cyclicality in the market.

## Telecommunications Industry

In the past, telecommunications companies like Sprint and AT&T installed more fiber-optic cable and other telecommunications infrastructure than any other company to create a *growth option* in the future by providing a secure and extensive network and to create a high barrier to entry, providing a first-to-market advantage. Imagine having to justify to the board of directors the need to spend billions of dollars on infrastructure that will not be used for years to come. Without the use of real options, this decision would have been impossible to justify.

### Real Estate Industry

In the real estate arena, leaving land undeveloped creates an option to develop later at a more lucrative profit level. However, what is the *optimal wait time* or the *optimal trigger price* to maximize returns? In theory, one can wait for an infinite amount of time, and real options provide the solution for the optimal timing and optimal price trigger value.

### Utilities Industry

In the utilities industry, firms have created an *option to execute* and an *option to expand* by installing cheap-to-build inefficient energy generator *peaker* plants to be used only when electricity prices are high and to shut down when prices are low. The price of electricity tends to remain constant until it hits a certain capacity utilization trigger level, when prices shoot up significantly. Although this occurs infrequently, the possibility still exists, and by having a cheap standby plant, the firm has created the option to turn on the expanded capacity generation whenever it becomes necessary, to capture this upside price fluctuation.

### Pharmaceutical Research and Development Industry

In pharmaceutical or research and development initiatives, real options can be used to justify the large investments in what seems to be cashless and unprofitable under the discounted cash flow method but actually creates *sequential compound options* in the future. Under the myopic lenses of a traditional discounted cash flow analysis, the high initial investment of, say, a billion dollars in research and development may return a highly uncertain projected few million dollars over the next few years. Management will conclude under a net present value analysis that the project is not financially feasible. However, a cursory look at the industry indicates that research and development is performed everywhere. Hence, management must see an intrinsic strategic value in research and development. How is this intrinsic strategic value quantified? The real options valuation approach would optimally time and spread the billion-dollar initial investment into a multiple-stage investment structure. At each stage, management has an *option to wait* and see what happens as well as the *option to abandon* or the *option to expand* into the subsequent stages. The ability to defer cost and proceed only if situations are permissible creates value for the investment.

### High-Tech and e-Business Industry

In e-business strategies, real options can be used to prioritize different e-commerce initiatives and to justify those large initial investments that have an uncertain future. Real options can be used in e-commerce to create incremental investment stages compared to a large one-time investment (invest a little now, wait and see before investing more) as well as create *options to abandon* and other future growth options.

### Mergers and Acquisitions

In valuing a firm for acquisition, you should not only consider the revenues and cash flows generated from the firm's operations but also the strategic options that come with the firm. For instance, if the acquired firm does not operate up to expectations, an *abandonment option* can be executed where it can be sold for its intellectual property and other tangible assets. If the firm is highly successful, it can be spun off into other industries and verticals or new products and services can be eventually developed through the execution of an *expansion option*. In fact, in mergers and acquisition, several strategic options exist. For instance, a firm acquires other entities to enlarge its existing portfolio of products or geographic location or to obtain new technology (*expansion option*); or to divide the acquisition into many smaller pieces and sell them off as in the case of a corporate raider (*abandonment option*); or it merges to form a larger organization due to certain synergies and immediately lays off many of its employees (*contraction option*). If the seller does not value its real options, it may be leaving money on the negotiation table. If the buyer does not value these strategic options, it is undervaluing a potentially highly lucrative acquisition target.

## *Knowledge Value Added (KVA)*

In the U.S. military context, the Knowledge Value Added (KVA) methodology is a new way of approaching the problems of estimating the productivity (in terms of ROI) for military capabilities embedded in processes that are impacted by technology. KVA addresses the requirements of the many DOD policies and directives by providing a means to generate comparable value or benefit estimates for various processes and the technologies and people that execute them. It does this by providing a common and relatively objective means for estimating the value of new technologies as required in the

- Clinger-Cohen Act of 1996 that mandates the assessment of the cost benefits for information technology investments.
- Government Accountability Office's *Assessing Risks and Returns: A Guide for Evaluating Federal Agencies' IT Investment Decision-Making, Version 1,* which requires that IT investments apply ROI measures.
- DOD Directive 8115.01, which mandates the use of performance metrics based on outputs, with ROI analysis required for all current and planned IT investments.
- DOD *Risk Management Guidance Defense Acquisition Guide Book* that requires alternatives to the traditional cost estimation be considered because legacy cost models tend not to adequately address costs associated with information systems or the risks associated with them.

KVA is a methodology that describes all organizational outputs in common units, thus providing a means to compare the outputs of all assets (human, machine, information technology) regardless of the aggregated outputs produced. It monetizes the outputs of all assets, including intangible knowledge assets. Thus, the KVA approach can provide insights about the productivity level of processes, people, and systems in terms of a ratio of common units of output (CUO). CUO produced by each asset (a measure of benefits) is divided by the cost to produce the output. By capturing the value of knowledge embedded in an organization's core processes, employees, and technology, KVA identifies the actual cost and value of people, systems, or processes. Because KVA identifies every process required to produce an output and the historical costs of those processes, unit costs and unit values of outputs, processes, functions, or services are calculated. An output is defined as the result of an organization’s operations; it can be a product or service, as shown in Figure 1.

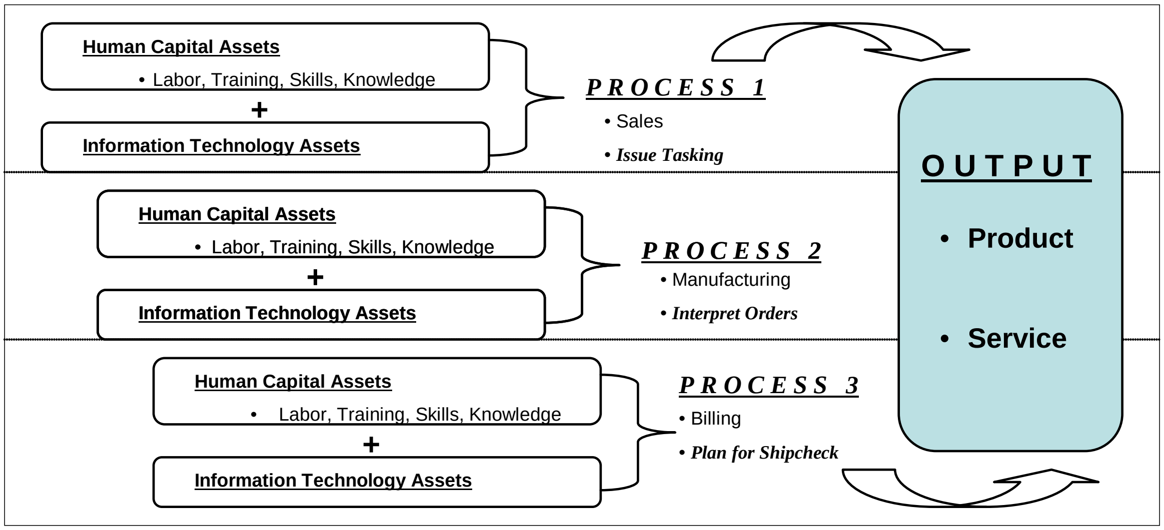


*Figure 1: Measuring Output*

For the purpose of this study KVA was used to measure the value added by the human capital assets (i.e., military personnel executing the processes) and the system assets (e.g., new sensor) by analyzing the performances of the processes. By capturing the value of knowledge embedded in systems and used by operators of the processes, KVA identified the productivity of the system-process alternatives. Because KVA identifies every process output required to produce the final aggregated output, the common unit costs and the common unit values were estimated.

The KVA methodology has been applied in over 80 projects within the DOD, from flight scheduling applications to ship maintenance and modernization. In general, the KVA methodology was used for this study because it could

- Compare alternative approaches in terms of their relative productivity
- Allocate value and costs to common units of output
- Measure value added by the system alternatives based on the outputs each produced
- Relate outputs to cost of producing those outputs in common units

KVA quantifies value in two key productivity metrics: Return on Knowledge (ROK) and Return on Knowledge Investment (ROI). Calculations of these key metrics are shown in Figure 2.

| Metric | Description | Type | Calculation |
|---|---|---|---|
| **Return on Knowledge (ROK)** | Basic productivity, cash-flow ratio | Function or process level performance ratio | Benefits in common units or cost to produce the output |
| **Return on Investment (ROI)** | Same as ROI at the sub-corporate or process level | Traditional investment finance ratio | [Revenue – Investment Cost] / [Investment Cost] |

*Figure 2: KVA Metrics*

Although ROI is the traditional financial ratio, ROK identifies how a specific process converts existing knowledge into producing outputs so decision makers can quantify costs and measure value derived from investments in human capital assets. A higher ROK signifies better utilization of knowledge assets. If IT investments do not improve the ROK value of a given process, steps must be taken to improve that process's function and performance (see Figure 3).

| Traditional Accounting | | KVA Process Costing | |
|---|---|---|---|
| Compensation | 5,000 | Review Task | 1,000 |
| Benefits/OT | 1,000 | Determine OP | 1,000 |
| Supplies/Materials | 2,000 | Input Search Function | 2,500 |
| Rent/Leases | 1,000 | Search/Collection | 1,000 |
| Depreciation | 1,500 | Target Data Acquisition | 1,000 |
| Admin & Others | 900 | Target Data Processing | 2,000 |
| Total | $11,400 | Format Report | 600 |
| | | Quality Control Report | 700 |
| | | Transmit Report | 1,600 |
| | | Total | $11,400 |

**Explains What was Spent**

**Explains How it was Spent**

*Figure 3: Comparison of Traditional Accounting Versus Process-Based Costing*

Based on the tenets of complexity theory, KVA assumes that humans and technology in organizations add value by taking inputs and changing them (measured in common units of complexity) into outputs through core processes. The amount of change an asset within a process produces can be described as a measure of value or benefit. The additional assumptions in KVA include the following:

- Describing all process outputs in common units (e.g., using a knowledge metaphor for the descriptive language in terms of the time it takes an average employee to learn how to produce the outputs) allows historical value and cost data to be assigned to those processes historically.
- All outputs can be described in terms of the time required for a single point of reference learner to learn to produce them.
- Learning Time, a surrogate for procedural knowledge required to produce process outputs, is measured in common units of time. Consequently, units of learning time are proportional to common units of output.
- Common units of output make it possible to compare all outputs in terms of cost per unit as well as value (e.g., price) per unit, because value (e.g., revenue) can now be assigned at the sub-organizational level.
- Once cost and revenue streams have been assigned to suborganizational outputs, normal accounting, financial performance, and profitability metrics can be applied.

Describing processes in common units also permits, but does not require, market comparable data to be generated, particularly important for nonprofits like the U.S. Military. Using a market comparables approach, data from the commercial sector can be used to estimate price per common unit, allowing for revenue estimates of process outputs for nonprofits. This approach also provides a common-unit basis to define benefit streams regardless of the process analyzed.

KVA differs from other nonprofit ROI models because it can allow for revenue estimates, enabling the use of traditional accounting, financial performance, and profitability measures at the suborganizational level. KVA can rank processes or process alternatives by their relative ROIs. This ranking assists decision makers in identifying how much various processes or process alternatives add value.

In KVA, value is quantified in two key metrics: Return on Knowledge (ROK: revenue/cost) and ROI (revenue-investment cost/investment cost). The raw data from a KVA analysis can become the input into the ROI models and various forecasting techniques such as real options analysis, portfolio optimization, and Monte Carlo simulation.

## *Integrated Risk Management (IRM)*

Integrated Risk Management (IRM) is an eight-step, quantitative software-based modeling approach for the objective quantification of risk (cost, schedule, technical), flexibility, strategy, and decision analysis. The method can be applied to program management, resource portfolio allocation, return on investment to the military (maximizing expected military value and objective value quantification of nonrevenue government projects), analysis of alternatives or strategic flexibility options, capability analysis, prediction modeling, and general decision analytics. The method and toolset provide the ability to consider hundreds of alternatives with budget and schedule uncertainty, and provide ways to help the decision maker maximize capability and readiness at the lowest cost. This methodology is particularly amenable to resource reallocation and has been taught and applied by the authors for the past 10 years at over 100 multinational corporations and over 30 projects at the DOD. Appendix 1 provides more detail on the IRM process and methodology while the FASO/MAS case study section shows the IRM in action, adapted specifically to solve the current research problem.

IRM provides a structured approach that will yield a rapid, credible, repeatable, scalable, and defensible analysis of cost savings and total cost of ownership while ensuring that vital capabilities are not lost in the process. The IRM + KVA methods do this by estimating the value of a system or process in a common and objective way across various alternatives and providing the return on investment (ROI) of each in ways that are both comparable and rigorous. These ROI estimates across the portfolio of alternatives provide the inputs necessary to predict the value of various options. IRM incorporates risks, uncertainties, budget constraints, implementation, lifecycle costs, reallocation options, and total ownership costs in providing a defensible analysis describing management options for the path forward. This approach identifies risky projects and programs, while projecting immediate and future cost savings, total lifecycle costs, flexible alternatives, critical success factors, strategic options for optimal implementation paths/decisions, and portfolio optimization. Its employment presents ways for identifying the potential for cost overruns and schedule delays and enables proactive measures to mitigate those risks. IRM provides an optimized portfolio of capability or implementation options while maintaining the value of strategic flexibility.

In the current case, IRM provides a way to differentiate among various alternatives for implementation of FASO/MAS with respect to options in ship design, and to postulate where the greatest benefit could be achieved for the available investment from within the portfolio of alternatives. As a strategy is formed and a plan developed for its implementation, the toolset provides for inclusion of important risk factors, such as schedule and technical uncertainty, and allows for continuous updating and evaluation by the program manager to understand where these risks come into play and to make informed decisions accordingly.

Using Monte Carlo Risk Simulation, the resulting stochastic KVA ROK model yielded a distribution of values rather than a point solution. Thus, simulation models analyze and quantify the various risks and uncertainties of each program. The result is a distribution of the ROKs and a representation of the project's volatility.

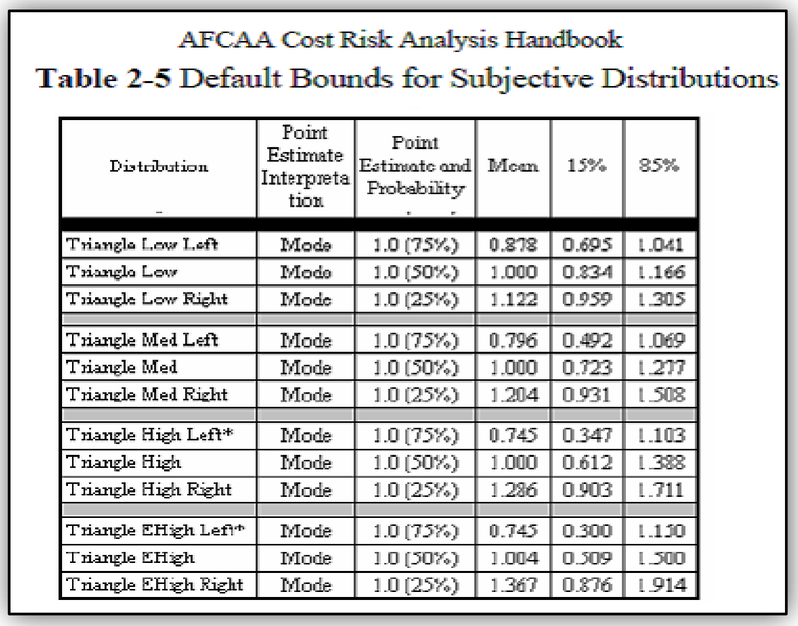
In real options, the analyst assumes that the underlying variable is the future benefit minus the cost of the project. An implied volatility can be calculated through the results of a Monte Carlo Risk Simulation. The results for the IRM analysis will be built on the quantitative estimates provided by the KVA analysis. The IRM will provide defensible quantitative risk analytics and portfolio optimization suggesting the best way to allocate limited resources to ensure the highest possible value over time.

The first step in real options is to generate a strategic map through the process of framing the problem. Based on the overall problem identification occurring during the initial qualitative management screening process, certain strategic options would become apparent for each project. The strategic options could include, among other things, the option to wait, expand, contract, abandon, switch, stage-gate, and choose.

Risk analysis and real options analysis assume that the future is uncertain and that decision makers can make midcourse corrections when these uncertainties become resolved or risk distributions become known. The analysis is usually done ahead of time and, thus, ahead of such uncertainty and risks. Therefore, when these risks become known, the analysis should be revisited to incorporate the information in decision making or to revise any input assumptions. Sometimes, for long-horizon projects, several iterations of the real options analysis should be performed, where future iterations are updated with the latest data and assumptions. Understanding the steps required to undertake an IRM analysis is important because the methodology provides insight not only into the methodology itself but also into how IRM evolves from traditional analyses, showing where the traditional approach ends and where the new analytics start.

The risk simulation step required in the IRM provides us with the probability distributions and confidence intervals of the KVA methodology's resulting ROI and ROK results. Further, one of the outputs from this risk simulation is volatility, a measure of risk and uncertainty, which is a required input into the real options valuation computations. In order to assign input probabilistic parameters and distributions into the simulation models, we relied on the U.S. Air Force's Cost Analysis Agency (AFCAA) handbook, as seen in Figure 4. In the handbook, the three main distributions recommended are the triangular, normal, and uniform distributions. We chose the triangular distribution because the limits (minimum and maximum) are known, and its shape resembles the normal distribution, with the most likely values having the highest probability of occurrence and the extreme ends (minimum and maximum values) having considerably lower probabilities of occurrence. Also, the triangular distribution was chosen instead of the normal distribution because the latter's tail ends extend toward positive and negative infinities, making it less applicable in the model we are developing. Finally, the AFCAA also provides options for left skew, right skew, and symmetrical distributions. In our analysis, we do not have sufficient historical or comparable data to make the proper assessment of skew and, hence, revert to the default of a symmetrical triangular distribution.

Figure 5 shows the steps required in a comprehensive IRM process.



AFCAA Cost Risk Analysis Handbook

Table 2-5 Default Bounds for Subjective Distributions

| Distribution | Point Estimate Interpretation | Point Estimate and Probability | Mean | 15% | 85% |
|---|---|---|---|---|---|
| Triangle Low Left | Mode | 1.0 (75%) | 0.878 | 0.695 | 1.041 |
| Triangle Low | Mode | 1.0 (50%) | 1.000 | 0.834 | 1.166 |
| Triangle Low Right | Mode | 1.0 (25%) | 1.122 | 0.959 | 1.305 |
| | | | | | |
| Triangle Med Left | Mode | 1.0 (75%) | 0.796 | 0.492 | 1.069 |
| Triangle Med | Mode | 1.0 (50%) | 1.000 | 0.723 | 1.277 |
| Triangle Med Right | Mode | 1.0 (25%) | 1.204 | 0.931 | 1.508 |
| | | | | | |
| Triangle High Left* | Mode | 1.0 (75%) | 0.745 | 0.347 | 1.103 |
| Triangle High | Mode | 1.0 (50%) | 1.000 | 0.612 | 1.388 |
| Triangle High Right | Mode | 1.0 (25%) | 1.286 | 0.903 | 1.711 |
| | | | | | |
| Triangle EHigh Left* | Mode | 1.0 (75%) | 0.745 | 0.300 | 1.130 |
| Triangle EHigh | Mode | 1.0 (50%) | 1.004 | 0.509 | 1.500 |
| Triangle EHigh Right | Mode | 1.0 (25%) | 1.367 | 0.876 | 1.914 |

*Figure 4: U.S. Probability Risk Distribution Spreads*

**(U.S. Air Force Cost Analysis Agency Handbook)**

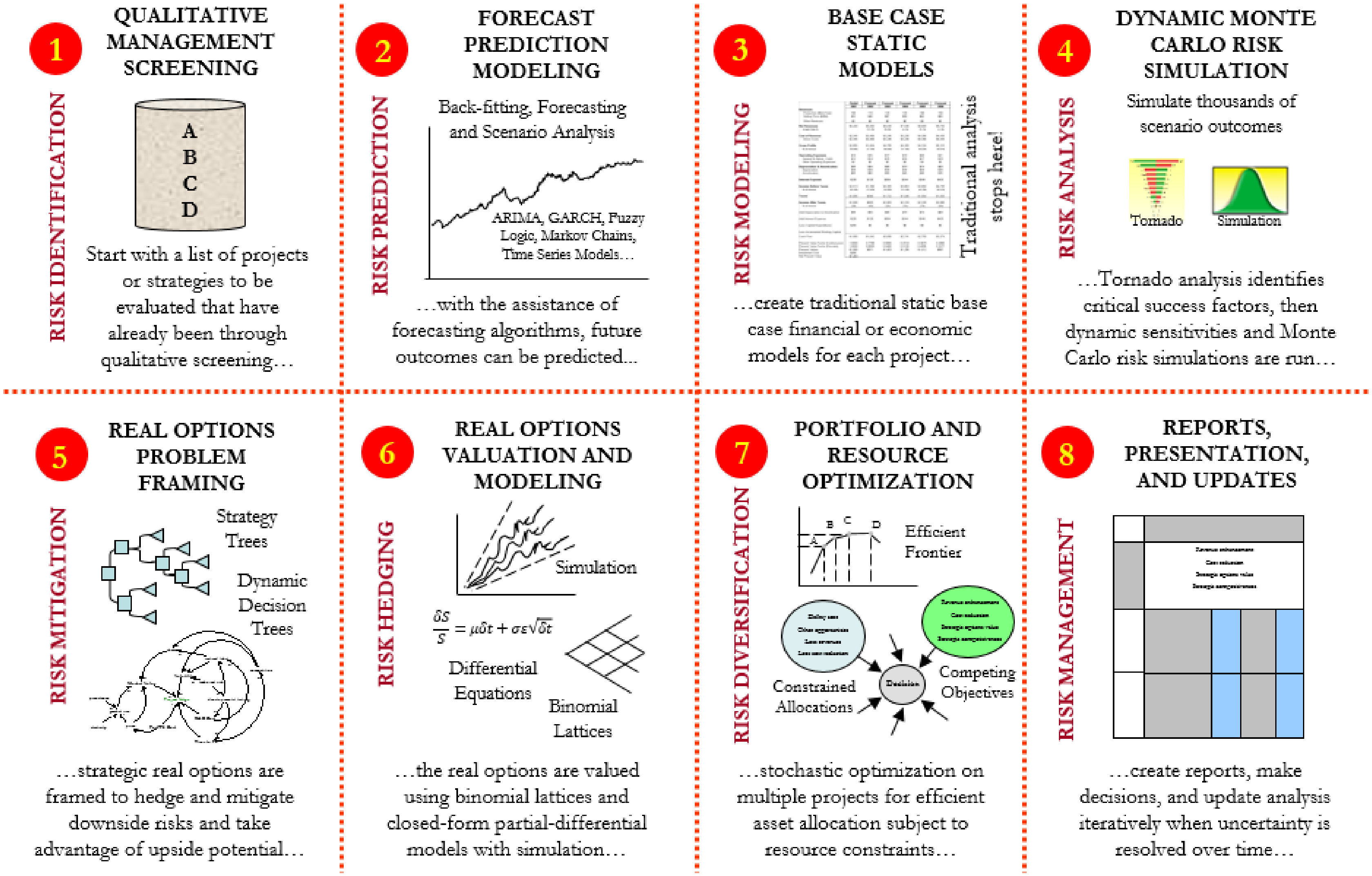


*Figure 5: Integrated Risk Management Process*

## Real Options Valuation Applications in the U.S. Department of Defense

This section provides a quick snapshot of the various ROV option types and their relevance to the DOD in general, as well as applications within the scope of the current research.

### *Option to Wait and Defer (Ability to Wait Before Executing)*

An option to defer allows the holder the option, but not the obligation, to execute a certain strategy when situations make it optimal to do so. An option to wait and defer provides the holder with the following advantages:

- A portfolio of capabilities and readiness for immediate deployment can be created and maintained with the use of options to defer. If the predeveloped payload or platform options exist, they will allow rapid change out of equipment and integration of new weapons or electronics systems, without the excessive schedule and cost penalties.
- Options to defer allow ship designers to incorporate modernization and upgrade options into the ship design early on, and to defer the exact configuration of the ship until a future date when uncertainties on capability requirements are resolved over the passage of time (midlife of the ship’s lifespan), actions (new missions), and events (wartime, peacetime).
- By creating design options and design flexibility specifically for mission and weapon systems that are anticipated to have the maximum change over the lifespan of a ship, and at the same time, using common bow and stern configurations, any changes in future capability requirements can be accommodated quickly and cheaply.
- Other applications within the DOD include, but are not limited to
    - Build or Buy Options (Buy versus Lease Options). That is, should a technology be developed internally or should commercially available off-the-shelf applications be used?
    - Multiple Contracts and Vendors. Having multiple vendors or contracts in place that may or not be executed increases the chances of corporate survivorship and an existing military industrial base to ensure future uncertain demands are met.
    - Capitalizing on other opportunities while reducing large-scale implementation risks, and determining the value of P3I and R&D

    (parallel implementation of alternatives while waiting on technical success of the main project, and no need to delay the project because of one bad component in the project).

    - Low rate initial production (LRIP), advanced weapons R&D, advanced technology demonstrations, and weapons and systems prototyping. Provide the right of first refusal to test and see the results (deferring the final decision) until the outcomes of said trials are evident.
    - There is significant Value of Information in forecasting cost inputs, capability requirements, schedule risks, and other key decision metrics by deferring decisions until a later date, but having the option ready to be triggered at a moment's notice.
    - Military intervention strategies include the naval option, the air option, go-long versus go-deep versus go-home option, first strike option, surge option, force mix option, and deterrent options.

### *Option to Switch (Ability to Switch Applications)*

An option to switch allows the holder the right, but not the requirement or obligation, to maintain the current status quo or to switch among a variety of predetermined options. The decision on which option to execute is deferred until a future date when exact needs and specifications are known, and the optimal option is then executed.

- Standardization and Modularity. By incorporating options to ensure ISO standards for containers, tie-down systems, mission bays, and support structures, ships can take on multi-mission payloads quickly and efficiently.
- Flexible infrastructure options within a ship, such as open power, open HVAC, open data cabling, open outfitting, and open structure, allow ships to be adaptable and reconfigured for different missions quickly without major rework such as stripping and welding.
- Other applications within the DOD include, but are not limited to
    - Switching vendors in Open Architecture (OA) and modular concepts allows the U.S. Navy to use multiple vendors for similar parts, ensuring healthy price and quality competition sustainment in the industry, as well as existing parts suppliers for the future.
    - Readiness and capability risk mitigation can be obtained through ensuring multiple vendors and a strong military industrial base.

## *Simultaneous Compound Option (Parallel Development)*

Simultaneous and parallel development efforts are sometimes used to reduce critical path and schedule risks. The risk of technical failures during development or schedule delays, especially when speed is critical, are mitigated with this simultaneous option where multiple systems are designed in parallel.

- By designing multiple payloads (combat subsystems or electronic subsystems) in parallel with the platform (ship design), newer weapons systems may be ready for integration into the platform years earlier.
- Other applications within the DOD include, but are not limited to
  - Simultaneous test programs (aircraft flight demonstrations and contract competitions)
  - Development of multiple and simultaneous weapons systems

## *Portfolio Option (Basket of Options to Execute)*

A portfolio of options provides the holder a variety or basket of possible option paths to execute. Some of these options may be too expensive, be consistently dominated by other options, take too long to execute, or simply be nonviable options. Determining the optimal portfolio of warfighter capabilities to develop and field within budgetary and time constraints is key to solving and modeling a portfolio optimization problem.

- Determining the optimal portfolios that provide the maximum capability, flexibility, and cost effectiveness with minimal risks given budget, schedule, wartime, and other scenarios. For instance, if Congress authorizes additional funding or cuts existing funding to certain programs, which capabilities or features should be added or cut?
- Helps to model and determine how much flexibility in design options should be incorporated into an MAS/FASO ship. Investing too little in flexibility will result in excessive modernization costs and increased downtime of the ship or its early retirement before the end of the design service life. Investing too much will create excess flexibility that will not be used, and create a higher up-front cost to obtain these flexibility options.
- Allows for different flexible pathways: Mutually Exclusive (C1 or C2 but not both), Platform Technology (C3 requires C2, but C2 can be stand-alone; expensive and worth less if considered by itself without accounting for flexibility downstream options it provides for the next phase), expansion

options, abandonment options, and parallel development or simultaneous compound options.

- Other applications within the DOD include, but are not limited to
    - Determining testing required in modular systems, mean-time-to-failure estimates, and replacement and redundancy requirements to maintain desired readiness and availability levels
    - Maintaining capability and readiness at various levels
    - Force mix options
    - Capability selection and sourcing across a spectrum of vendors

### *Sequential Compound Option (Proof of Concept, Milestones, and Stage-Gate Development)*

The DOD has a requirement for advanced technology to meet warfighter needs, but the technologies needed are in early stages of maturity, and it is highly risky whether the technologies will be available or work when finally incorporated. There are limited vendors/activities capable of undertaking the development, so the program office may mitigate downside risks to the program through a phased approach to the acquisition. For instance, in the first phase, the vendor develops the underlying technology and presents the results to the PEO with a preliminary design. At the end of this phase, the government can either choose to continue through development of a prototype system or harvest the Science and Technology work for later use and abandon the effort. On delivery of a working prototype, the government will conduct tests for performance, evaluate total lifecycle cost, and decide whether to continue to full-scale system development or to abandon the effort, salvaging the knowledge from the prototyping effort for later use.

An acquisition program manager should recognize that multiple approaches to the problem are possible and may decide to pursue a course of parallel development in which a variety of vendors and government labs undertake work to propose a technology solution, which creates a Multiple Activity or Multiple Vendor development of a system or technology. At option points (generally one to two years after contract award), the various solutions will be evaluated for performance, technical merit, and cost, and the universe of participants reduced through a down-select process. After two (or pick a number) rounds, the two most promising approaches are selected for advanced development and prototyping. From those, the best (evaluated in terms of performance, risk, and cost) will be selected for final development and fielding.

The U.S. Navy is currently pursuing the applications of new 3D scanning technology on board a ship to streamline the planning process for depot-level repair work. If the technology works after any technical problems have been ironed out, the scope can be expanded to implement online collaborative tools (requires additional investment) to implement additional process efficiencies for the management of depot-level ship repairs. Expansions across the population of Naval Shipyards will extend the savings/return on investment.

Pursuing Open Architecture (OA) over multiple stages by first performing a proof of concept stage and then executing several small-scale implementations and a final larger-scale implementation is another example of a sequential option. For instance, try OA modular development on a shore-based test system to see if it works before fielding on all units of that class in the fleet once all the bugs are worked out and only if the proof of concept results are encouraging, thereby reducing the risk while at the same time obtaining the additional upside potential of going to OA (lower downtime, reduced cycle time, reduced cost, interchangeable parts, at-sea repairs, multiple vendor parts for one system instead of relying only on a single vendor for the entire system, etc.). Successful implementation of a component or technology in one ship class also provides the opportunity in an OA environment to expand to integrate the capability/technology into other open architected systems for other ship classes.

A PM in charge of a large spiral development may need to determine the value of various items to release in each spiral. For example, the USAF logistics modernization program (called the Enterprise Resource Planning (ERP) System) has a goal to replace 250 separate legacy systems. A single release would likely be a huge failure. Developing various sequential strategies would show how to capture the most savings during each spiral release of the ERP system while minimizing risks as the system matures. The Army is also adopting the spiral development process for its logistics modernization program. Other examples of spiral development include the U.S. Air Force Air Theater Battle Management System and the Army's Future Combat Systems program, a system of systems development. Other applications within the DOD include, but are not limited to

- Stage-gate implementation of high-risk project development, prototyping, low-rate-initial-production (LRIP), technical feasibility tests, and technology demonstration competitions
- Government contracts with multiple stages with the option to abandon at any time and valuing Termination for Convenience (T-for-C), and built-in flexibility to execute different courses of action at specific stages of development
- P3I, Milestones, R&D, and Phased Options
- Platform technology development

### *Expansion Option (Platform Technology with Spinoff Capabilities)*

The C-17 Globemaster III is a long-range cargo/transport aircraft operated by the USAF since 1993. Full-scale development of the C-17 got underway in 1986, but technical problems and funding shortfalls delayed the program. Despite those difficulties, the C-17 retained broad support from Congress. In April 1990, Defense Secretary Cheney reduced the projected buy from 210 to 120 planes, exercising a contraction option. By the mid-1990s, the program's difficulties had been largely resolved. In 1996 the DOD approved plans for more C-17s and planned to end the production at 180 aircraft in FY2007. Congress then approved another $2 billion for 10 additional C-17 aircraft in FY2008. Expansion options put in place allowed the smooth addition of aircraft as needed, including foreign military sales. Other applications within the DOD include, but are not limited to

- Platform Technologies
- Acquisitions
- ACTD follow-on
- Foreign Military Sales (FMS)
- Reusability and Scalability Options

### *Abandonment Option (Salvage and Walk Away)*

A DOD research and development organization in conjunction with a military contractor decides to enter a joint-testing agreement to test a satellite-based voice recognition intelligence gathering hardware-software product combination currently in its infancy stage of development that, if successful, could potentially be very useful in the fight against terrorism. The DOD can hedge its risks (i.e., the risk is the potential that the hardware-software combination will not work as required) and invest a small sum to buy the right of first refusal for a future investment, for some prespecified amount that is agreed upon now. This way, the U.S. Navy gets to participate in the technology if it is successful, but risks only a little if it is unsuccessful. In deciding whether to purchase the intelligence gathering equipment, a military analyst values the potential to abandon and sell off or divest the assets of the company in the future should there be no further use of the technology or if a newer and much more potent technology arrives on the market. The ability to do so will, in fact, reduce the risk on what the military should spend on the technology and allows it to recoup some of its potential losses. Other applications within the DOD include, but are not limited to

- Exit and salvage to cut losses
- Stop before executing the next phase
- Termination for convenience (T-for-C)

### *Contraction Option (Partnerships and Cost/Risk Reduction)*

A contraction option allows two parties to create a joint venture or partnership (e.g., a DOD and military vendor partnership) whereby the DOD agrees to purchase certain quantities of a product while holding partial intellectual property rights to the new development. Risks of failure are shared between the two parties, and no single party will bear all the risks (the DOD hedges its downside risks of the product failing, and the vendor hedges its risks of the DOD not being interested in its product). Other applications within the DOD include, but are not limited to

- Outsourcing, Alliances, Contractors
- Joint Inter-Service Venture and Foreign Partnerships

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# FASO/MAS at PEO-Ships: Flexibility Options for Guided Missile Destroyers

## *DDG 51 FLIGHT III*

The Arleigh Burke class of Guided Missile Destroyers (DDG) is the U.S. Navy's first class of destroyer built around the Aegis Combat System and the SPY-1D multi-function passive electronically scanned array radar. The class is named for Admiral Arleigh Burke, the most famous American destroyer officer of World War II and later Chief of Naval Operations. The class leader, USS *Arleigh Burke*, was commissioned during Admiral Burke's lifetime (Office of the Director, Operational Test and Evaluation [DOT&E], 2013).

The DDG class ships were designed as multi-mission destroyers to fit the Anti-Aircraft Warfare (AAW) role with their powerful Aegis radar and surface-to-air missiles; the Anti-Submarine Warfare (ASW) role with their towed sonar array, anti-submarine rockets, and ASW helicopter; the Anti-Surface Warfare (ASUW) role with their Harpoon missile launcher; and the strategic land strike role with their Tomahawk missiles. With upgrades to AN/SPY-1 phased radar systems and their associated missile payloads, as part of the Aegis Ballistic Missile Defense System, members of this class have demonstrated their value as mobile anti-ballistic missile and anti-satellite weaponry platforms. Some versions of the class no longer have the towed sonar or Harpoon missile launcher (DOT&E, 2013).

The DDG 51 class destroyers have been designed to support carrier strike groups, surface action groups, amphibious groups, and replenishment groups. They perform primarily AAW with secondary land attack, ASW, and ASUW capabilities. The MK 41 vertical launch system has expanded the role of the destroyers in strike warfare, as well as their overall performance.

The U.S. Navy will use the DDG 51 Flight III Destroyer equipped with the Aegis Modernization program and AMDR to provide joint battlespace threat awareness and defense capability to counter current and future threats in support of joint forces ashore and afloat.

## Step 1: Identification of FASO/MAS Options

The following provides two high-level examples of identifying and framing strategic flexibility options in the DDG 51 and DDG1000 environments. These are only notional examples with rough order magnitude values to illustrate the options framing approach.

### Power Plant Options

This real options example illustrates the implications of the standard LM2500 GE Marine Gas Turbines for DDG 51 FLT III ships versus the Rolls-Royce MT30 Marine Gas Turbine Engines for the Zumwalt DDG 1000, where the latter can satisfy large power requirements in warships. The LM2500 provides 105,000 shaft hp for a four-engine plant. In comparison, the MT30 can generate upwards of 35.4MW, and its auxiliary RR4500 Rolls-Royce turbine generators can produce an added 3.8MW, and each DDG1000 carries two MT30s and two RR4500s. This means that the combined energy output from the Zumwalt can fulfil the electricity demands in a small- to medium-sized city. In contrast, two LM2500 gas turbines can only produce a total of 95.2 kW, which is approximately 0.12% or 1/825 of the power the Zumwalt can produce. Manufacturer specifications indicate that the LM2500 has an associated Cost/kW of energy of $0.34 and the MT30 Cost/kW is $0.37. In addition, the MT30 prevents warships from running off balance when an engine cannot be restarted until it has cooled down, as is the case in the LM2500.

Figure 6 illustrates a real options strategy tree with four mutually exclusive paths. Additional strategies and pathways can be similarly created, but these initial strategies are sufficient to illustrate the options framing approach. Path 1 shows the As-Is strategy, where no additional higher capacity power plant is used; that is, only two standard LM2500 units are deployed, maintain zero design margins for growth, and only the requirements for the current ship configuration are designed and built. Medium and large upgrades will require major ship alterations, with high cost and delayed schedule. Path 2 implements the two required LM2500 units with additional and sufficient growth margins for one MT30 power plant but currently only with a smaller power plant incorporated into the design. Sufficient area or modularity is available where parts of the machinery can be removed and replaced with the higher energy production unit if needed. Upfront cost is reduced and future cost and schedule delays are also reduced. Path 3 is to have two prebuilt MT30s and RR4500s initially. While providing the fastest implementation pathway, the cost is higher in the beginning but total cost is lower if indeed higher energy weapons will be implemented. Path 4 is an option to switch whereby one LM2500 is built with one MT30 unit. Depending on conditions, either the LM2500 or MT30 will be used (switched between units). When higher-powered future weapons are required such as electromagnetic railguns (E.M. Rail Guns) or high-intensity lasers (H. I. Lasers) as well as other similarly futuristic weapons and systems, the MT30 can be turned on.

Having a warship flexibility with two LM2500s (As-Is base case), allows the Navy a savings of $31.76 million by deferring the option of the other two additional LM2500s. Therefore, having a flexible ship, the Navy can invest later in one LM2500 and attach another MT30 (preventing any engine off-balance effects when the engines cannot be restarted due to excessive heat), and can save $34.58 million. The usage of options to defer/invest that combine gas turbine specifications allows the Navy to prevent high sunk costs, properly adjusting the true kW requirements, and allows different combinations of propulsion and energy plants. This analysis can be further extended into any direction as needed based on ship designs and Navy requirements.

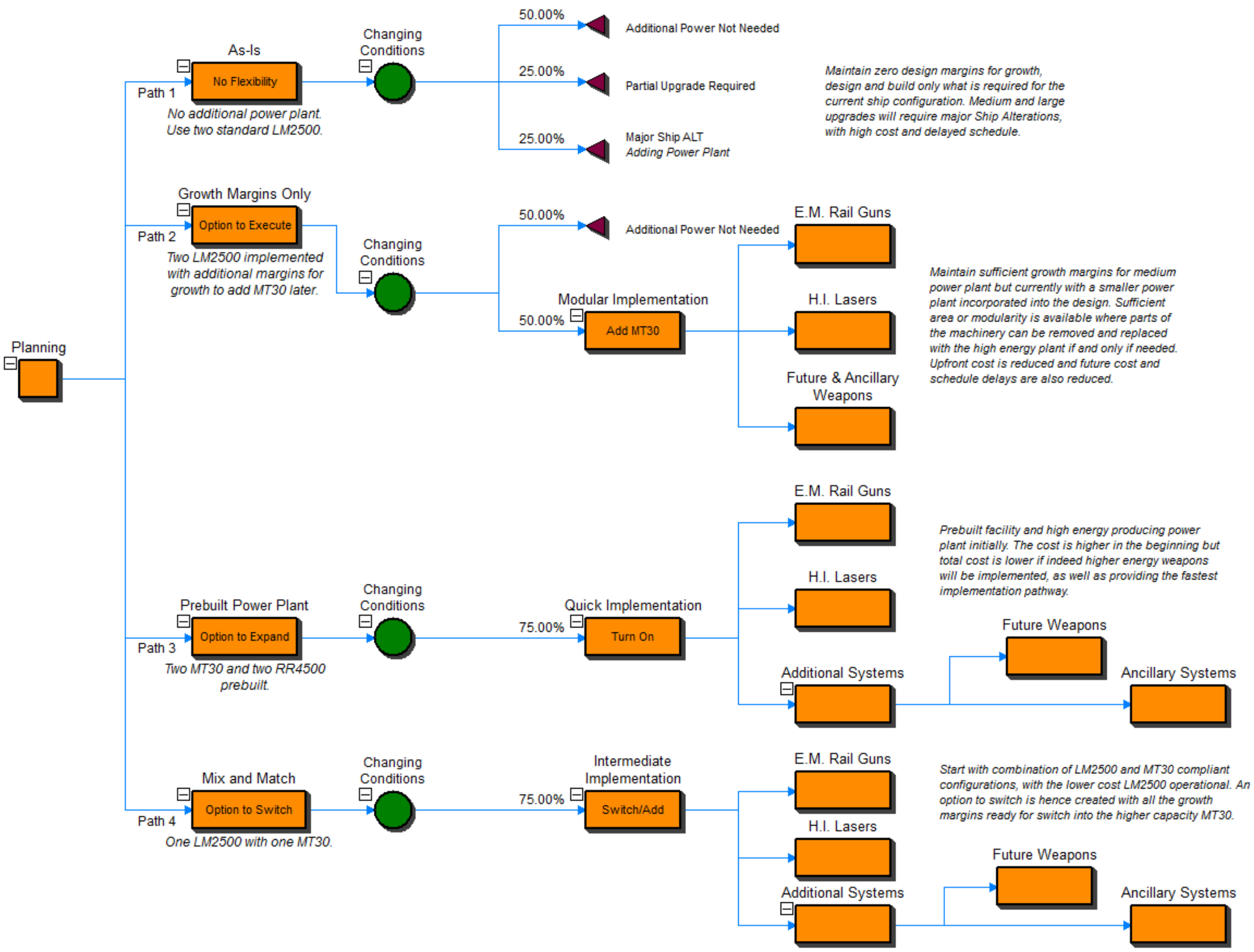


*Figure 6: Options Framing on Power Generation*

### *Vertical Launch System*

Another concern of the DOD is the large capital investments required in Vertical Launch Systems (VLS) in U.S. Navy ships. VLS need to be developed and integrated per Navy requirements, which are constrained by rapid technological change and high uncertainties in costs. The usage of strategic real options aims to assess whether the Navy can *keep the option open* to defer the large investments to help avoid high sunk costs and quick technological obsolescence, or should pre-invest in a new VLS. Consequently, flexibility and uncertainty create the right environment to model VLS using a real options framework. According to DDG 51 (Flight II and Flight III) specifications, the estimated cost of a single VLS is approximately $228 million. The most expensive subarea is the MK41 subsystem

(DDG 51 contains two MK41s). This current example is developed based on the assumptions of a rapid technological obsolescence, high integration costs, time delays, and reduced capability, which can all jeopardize Navy investments in the VLS.

In addition, using a real options framework to possibly defer the implementation of MK41 would allow ship designers and engineers to incorporate modernization and upgrade margins in the VLS within the ship design early on, and to defer the exact configuration of the VLS until a future date when uncertainties on capability requirements (i.e., integration, upgrades, changes, new technology, new requirements, updated military warfighter needs) are resolved over the passage of time, action, and events. Also, we can evaluate the option to invest in the second or third MK41 as the situational needs arise. Figure 7 shows the two simple option paths, in which the first path indicates immediate execution where two MK1s are implemented immediately, not knowing if both are actually needed, as opposed to the second strategic path where the VLS is designed such that either two MK1s can be implemented or only one. Therefore, one MK1 can be first inserted and the second added on later only when required, where the VLS has design growth margins to adapt to slightly different technological configurations. The question, of course, is which strategic pathway makes most sense, as computed using strategic real options value.

Just to reiterate, these are only notional examples with rough order magnitude values to illustrate the options framing approach.

When the flexibility value is added into the mix, the expected total cost is reduced from $110.10 million to $98.51 million. Finally, wartime scenarios can be incorporated into the analysis whereby if there is a higher probability of conflict where the VLS is required, the value to keep open the option to defer is reduced and the Navy is better off executing the option immediately and having the required VLS in place.

The project with flexibility is $118.22 million (flexible VLS warship open to integrate another MK41 in the future as and when needed) against $228.34 million (base case DDG 51 with no flexibility options, where the VLS is already built in). The Navy can save or delay the usage of $110.10 million in cost by holding on to the option of deferring the second MK41. In addition, in the near future, the cost to implement the second MK41 can be reduced due to a flatter learning curve, economies of scale, and the specific technology becoming more readily available, less complex, and easier to implement, or can be more expensive because the technology experiences new updates, higher performance, and greater efficiency. If cost volatility is the main variable for the Navy, we contrast deferring the second MK41 against the base case. It means that we compare the VLS system with no flexibility ($228.32 million) against the cost changes in the second MK41 (assuming Navy engineers develop a plug-and-play structure to integrate the next MK41 quickly). This assumption can be relaxed using cost and schedule modelling and Monte Carlo simulation methods. In terms of the options valuation, the option to defer for the Navy follows cost comparisons. It other words, it reduces the cost exposure for the second MK41 from $110.10 million to an expected value of $69.89 million. In addition, decision makers observe in the options strategy tree and decision tree where they can keep the option to defer *open* and under what conditions the Navy should execute and invest in the second MK41. One likely extension is where the decision maker can introduce probabilities or expectations of Navy actions (new missions and new requirements) or events (wartime, peacetime). This affects the flexibility of the second MK41 by constraining the option's flexibility to defer. For instance, if the Navy has strong expectations of requiring the second MK1 (wartime probability is higher than 30%), it reduces the value of the option to defer and accelerates the availability and execution of the second MK41 option earlier. In peacetime, the Navy has more flexibility in terms of how it implements or assesses its real options to wait and defer.

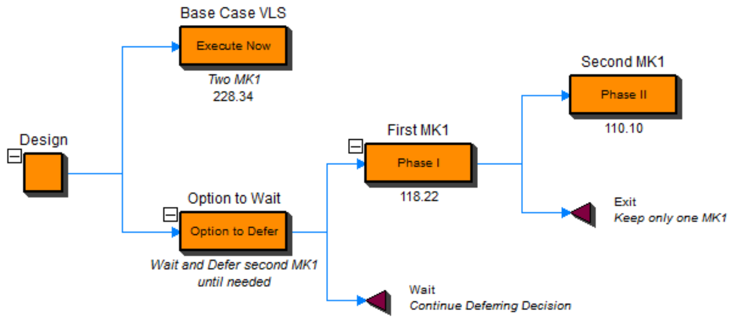


*Figure 7: Options Framing on Vertical Launch Systems*

## Step 2: Cost Analysis and Data Gathering

Once the various FASO/MASO options are framed and modeled, as shown in the previous step, the modeling process continues with additional data gathering activities. The following are some sample parameters of the Surface Warfare program under consideration, and we use the generic terms Option 1, Option 2, and so forth, for generalization purposes:

- For all models, assume a 15% discount rate, 35% tax rate, and a 10-year time horizon for the cost savings (all future savings past Year 10 after discounting will be assumed to be negligible). The discounting base year is 2017 (Year 0, and Capital Investment is required in 2017), whereas immediate savings, short-term benefits, and maintenance savings start in Year 1 (2018). This means Year 10 is 2027.
- Table 1 shows the remaining relevant information you will need to run your models. All monetary values are in thousands of dollars ($000). Remember to save your models and settings.

*Table 1: Cost Analysis and Data Gathering*

| Capability Options | Savings Now | Short-Term Benefits | Maintenance Savings | Capital Cost | Fixed Cost | Operating Cost | OPNAV Value | Command Value | KVA Value |
|---|---|---|---|---|---|---|---|---|---|
| Option 1 | $550 | $30 | $60 | $400 | $3 | $2 | 8.1 | 1.2 | 25.45 |
| Option 2 | $650 | $5 | $10 | $300 | $3 | $2 | 1.27 | 2.5 | 3.99 |
| Option 3 | $700 | $35 | $10 | $350 | $3 | $2 | 5.02 | 7.5 | 15.77 |
| Option 4 | $1,000 | $50 | $20 | $600 | $3 | $2 | 8.83 | 4.5 | 27.74 |
| Option 5 | $2,000 | $100 | $20 | $1,000 | $3 | $2 | 9.88 | 9.7 | 31.04 |
| Option 6 | $1,000 | $10 | $20 | $550 | $3 | $2 | 3.64 | 7.4 | 11.44 |
| Option 7 | $2,000 | $100 | $20 | $750 | $3 | $2 | 5.27 | 4.5 | 16.56 |
| Option 8 | $850 | $75 | $20 | $550 | $3 | $2 | 9.8 | 7.5 | 30.79 |
| Option 9 | $1,500 | $125 | $20 | $750 | $3 | $2 | 5.68 | 7.5 | 17.856 |
| Option 10 | $1,000 | $125 | $20 | $550 | $3 | $2 | 8.29 | 8.5 | 26.05 |

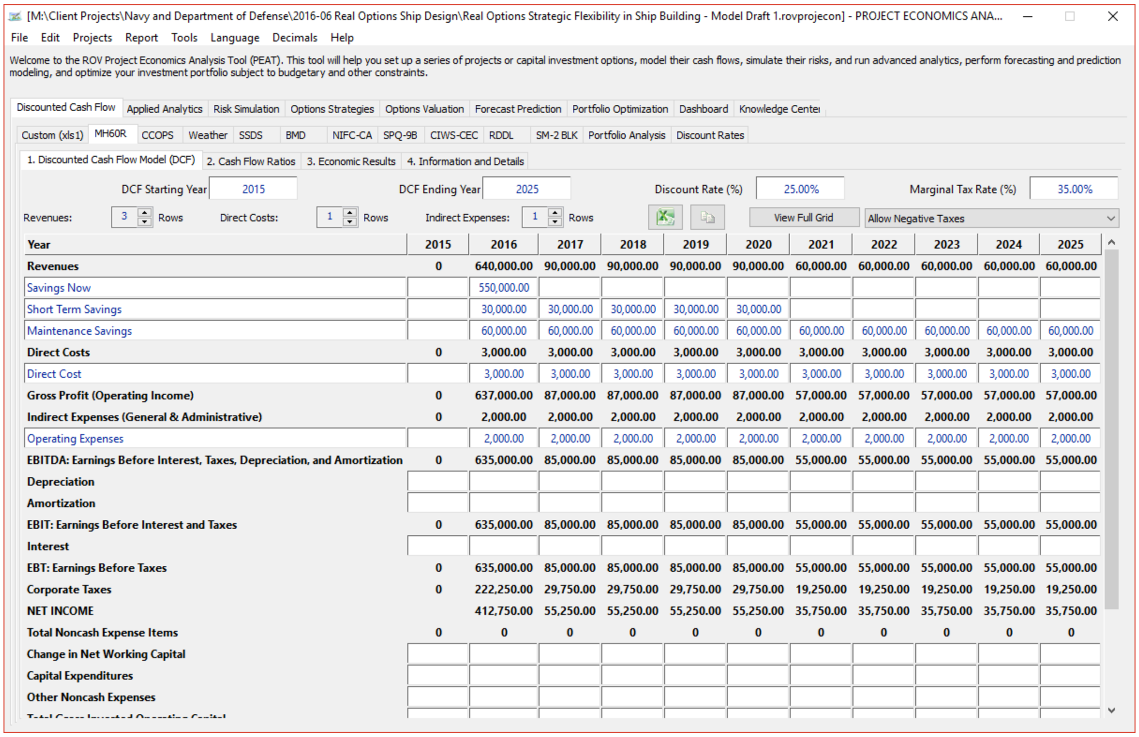
- “Savings Now” is the immediate monetary cost savings benefits obtained by implementing the new upgraded system (e.g., lower overhead requirements, reduced parts and labor requirements). This amount is applied in the first year of the cash flow stream only (Year 1, or 2018), as its effects are deemed immediate.
- “Short-Term Benefits” is the savings per year for the first 5 years, stemming from reduction in staffing requirements, but these savings are deemed to be reabsorbed later. Savings apply from 2018 to 2022.
- “Maintenance Savings” is the savings each year for all 10 years, starting in 2018, where system maintenance cost is reduced and saved.
- “Capital Cost” is applied in Year 0, or 2017, as a one-time capital expenditure.
- Assume a “Fixed Direct Cost” and constant “Indirect Operating Cost” per year for all 10 years starting in 2018. The new equipment upgrades will require some fixed overhead cost and operating expenses to maintain. The idea is these will be less than the total sum of benefits obtained by implementing the capability.
- OPNAV and COMMAND are average values of multiple subject matter experts’ estimates of the criticality (1–10, with 10 being the highest) of each capability. KVA is unit equivalence (this can be multiplied by any market price comparable such as $1 million per unit or used as-is in the optimization model). These will be used later in the optimization section below.

### *Step 3: Financial Modeling*

The *Discounted Cash Flow* section, shown in Figure 8, is at the heart of the input assumptions for the analysis. Analysts would enter their input assumptions—such as starting and ending years of the analysis, the discount rate to use, and the marginal tax rate—and set up the project economics model (adding or deleting rows in each subcategory of the financial model). Additional time-series inputs are entered in the data grid as required, while some elements of this grid are intermediate computed values. The entire grid can be copied and pasted into another software application such as Microsoft Excel, Microsoft Word, or other third-party software applications, or can be viewed in its entirety as a full screen pop-up.

Analysts can also identify and create the various options, and compute the economic and financial results such as net present value (NPV), internal rate of return (IRR), modified internal rate of return (MIRR), profitability index (PI), return on investment (ROI), payback period (PP), and discounted payback (DPP). This section will also auto-generate various charts, cash flow ratios and models, intermediate calculations, and comparisons of the options within a portfolio view, as illustrated in the next few figures. As a side note, the term *Project* is used in PEAT's DCF module to represent a generic analysis option, where each project can be a different asset, project, acquisition, investment, research and development, or simply variations of the same investment (e.g., different financing methods when acquiring the same firm, different market conditions and outcomes, or different scenarios or implementation paths). Therefore, the more flexible terminology of *Project* is adopted instead.

Figure 9 illustrates the *Economic Results* of each project. This Level 3 subtab shows the results from the chosen project and returns the NPV, IRR, MIRR, PI, ROI, PP, and DPP. These computed results are based on the analyst's selection of the discounting convention, if there is a constant terminal growth rate, and the cash flow to use (e.g., net cash flow versus net income or operating cash flow). An *NPV Profile* table and chart are also provided, where different discount rates and their respective NPV results are shown and charted. Analysts can change the range of the discount rates to show/compute by entering the *From/To* percent, copy the results, copy the profile chart, and use any of the chart icons to manipulate the chart's look and feel (e.g., change the chart's line/background color, chart type, chart view, or add/remove gridlines, show/hide labels, and show/hide legend). Analysts can also change the variable to display in the chart. For instance, analysts can change the chart from displaying the NPV profile to the time-series charts of net cash flows, taxable income, operating cash flows, cumulative final cash flows, present value of the final cash flows, and so forth.

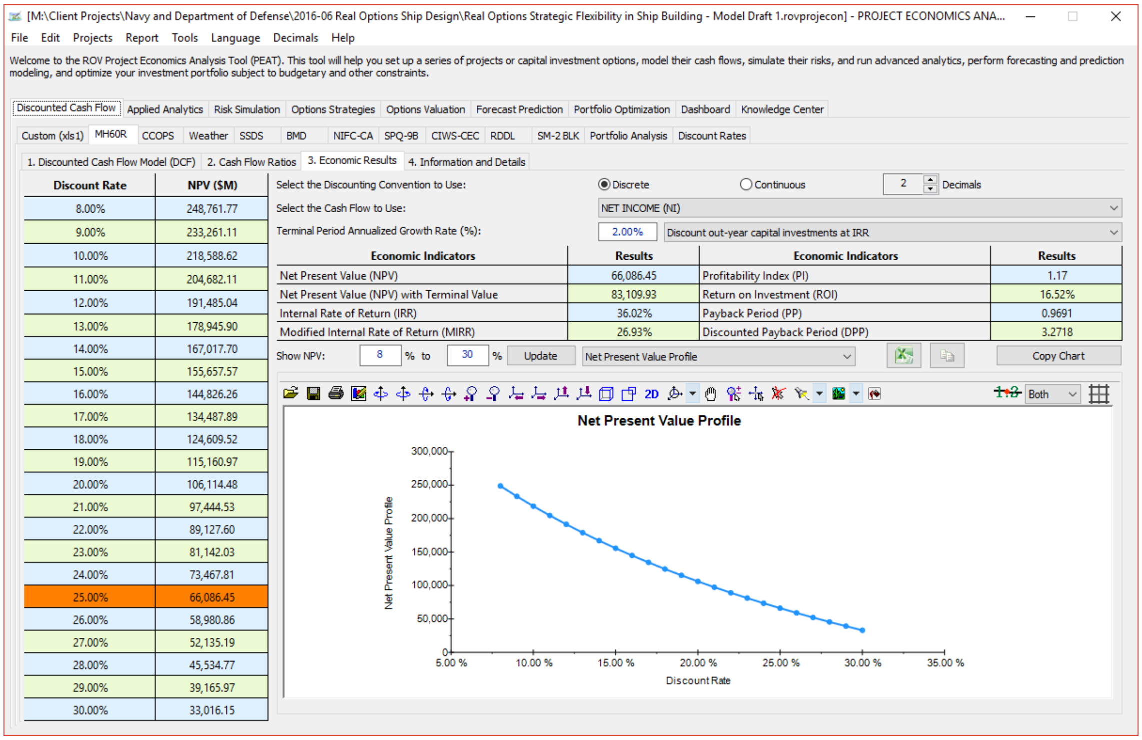


Welcome to the ROV Project Economics Analysis Tool (PEAT). This tool will help you set up a series of projects or capital investment options, model their cash flows, simulate their risks, and run advanced analytics, perform forecasting and prediction modeling, and optimize your investment portfolio subject to budgetary and other constraints.

DCF Starting Year: 2015
DCF Ending Year: 2025
Discount Rate (%): 25.00%
Marginal Tax Rate (%): 35.00%
Revenues: 3 Rows
Direct Costs: 1 Rows
Indirect Expenses: 1 Rows
Allow Negative Taxes

| Year | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Revenues** | **0** | **640,000.00** | **90,000.00** | **90,000.00** | **90,000.00** | **90,000.00** | **60,000.00** | **60,000.00** | **60,000.00** | **60,000.00** | **60,000.00** |
| Savings Now | | 550,000.00 | | | | | | | | | |
| Short Term Savings | | 30,000.00 | 30,000.00 | 30,000.00 | 30,000.00 | 30,000.00 | | | | | |
| Maintenance Savings | | 60,000.00 | 60,000.00 | 60,000.00 | 60,000.00 | 60,000.00 | 60,000.00 | 60,000.00 | 60,000.00 | 60,000.00 | 60,000.00 |
| **Direct Costs** | **0** | **3,000.00** | **3,000.00** | **3,000.00** | **3,000.00** | **3,000.00** | **3,000.00** | **3,000.00** | **3,000.00** | **3,000.00** | **3,000.00** |
| Direct Cost | | 3,000.00 | 3,000.00 | 3,000.00 | 3,000.00 | 3,000.00 | 3,000.00 | 3,000.00 | 3,000.00 | 3,000.00 | 3,000.00 |
| **Gross Profit (Operating Income)** | **0** | **637,000.00** | **87,000.00** | **87,000.00** | **87,000.00** | **87,000.00** | **57,000.00** | **57,000.00** | **57,000.00** | **57,000.00** | **57,000.00** |
| **Indirect Expenses (General & Administrative)** | **0** | **2,000.00** | **2,000.00** | **2,000.00** | **2,000.00** | **2,000.00** | **2,000.00** | **2,000.00** | **2,000.00** | **2,000.00** | **2,000.00** |
| Operating Expenses | | 2,000.00 | 2,000.00 | 2,000.00 | 2,000.00 | 2,000.00 | 2,000.00 | 2,000.00 | 2,000.00 | 2,000.00 | 2,000.00 |
| **EBITDA: Earnings Before Interest, Taxes, Depreciation, and Amortization** | **0** | **635,000.00** | **85,000.00** | **85,000.00** | **85,000.00** | **85,000.00** | **55,000.00** | **55,000.00** | **55,000.00** | **55,000.00** | **55,000.00** |
| **Depreciation** | | | | | | | | | | | |
| **Amortization** | | | | | | | | | | | |
| **EBIT: Earnings Before Interest and Taxes** | **0** | **635,000.00** | **85,000.00** | **85,000.00** | **85,000.00** | **85,000.00** | **55,000.00** | **55,000.00** | **55,000.00** | **55,000.00** | **55,000.00** |
| **Interest** | | | | | | | | | | | |
| **EBT: Earnings Before Taxes** | **0** | **635,000.00** | **85,000.00** | **85,000.00** | **85,000.00** | **85,000.00** | **55,000.00** | **55,000.00** | **55,000.00** | **55,000.00** | **55,000.00** |
| **Corporate Taxes** | **0** | **222,250.00** | **29,750.00** | **29,750.00** | **29,750.00** | **29,750.00** | **19,250.00** | **19,250.00** | **19,250.00** | **19,250.00** | **19,250.00** |
| **NET INCOME** | | **412,750.00** | **55,250.00** | **55,250.00** | **55,250.00** | **55,250.00** | **35,750.00** | **35,750.00** | **35,750.00** | **35,750.00** | **35,750.00** |
| **Total Noncash Expense Items** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** |
| **Change in Net Working Capital** | | | | | | | | | | | |
| **Capital Expenditures** | | | | | | | | | | | |
| **Other Noncash Expenses** | | | | | | | | | | | |

*Figure 8: PEAT Discounted Cash Flow Module*



Welcome to the ROV Project Economics Analysis Tool (PEAT). This tool will help you set up a series of projects or capital investment options, model their cash flows, simulate their risks, and run advanced analytics, perform forecasting and prediction modeling, and optimize your investment portfolio subject to budgetary and other constraints.

| Discount Rate | NPV ($M) |
|---|---|
| 8.00% | 248,761.77 |
| 9.00% | 233,261.11 |
| 10.00% | 218,588.62 |
| 11.00% | 204,682.11 |
| 12.00% | 191,485.04 |
| 13.00% | 178,945.90 |
| 14.00% | 167,017.70 |
| 15.00% | 155,657.57 |
| 16.00% | 144,826.26 |
| 17.00% | 134,487.89 |
| 18.00% | 124,609.52 |
| 19.00% | 115,160.97 |
| 20.00% | 106,114.48 |
| 21.00% | 97,444.53 |
| 22.00% | 89,127.60 |
| 23.00% | 81,142.03 |
| 24.00% | 73,467.81 |
| 25.00% | 66,086.45 |
| 26.00% | 58,980.86 |
| 27.00% | 52,135.19 |
| 28.00% | 45,534.77 |
| 29.00% | 39,165.97 |
| 30.00% | 33,016.15 |

Select the Discounting Convention to Use: ● Discrete ○ Continuous 2 Decimals
Select the Cash Flow to Use: NET INCOME (NI)
Terminal Period Annualized Growth Rate (%): 2.00% Discount out-year capital investments at IRR

| Economic Indicators | Results | Economic Indicators | Results |
|---|---|---|---|
| Net Present Value (NPV) | 66,086.45 | Profitability Index (PI) | 1.17 |
| Net Present Value (NPV) with Terminal Value | 83,109.93 | Return on Investment (ROI) | 16.52% |
| Internal Rate of Return (IRR) | 36.02% | Payback Period (PP) | 0.9691 |
| Modified Internal Rate of Return (MIRR) | 26.93% | Discounted Payback Period (DPP) | 3.2718 |

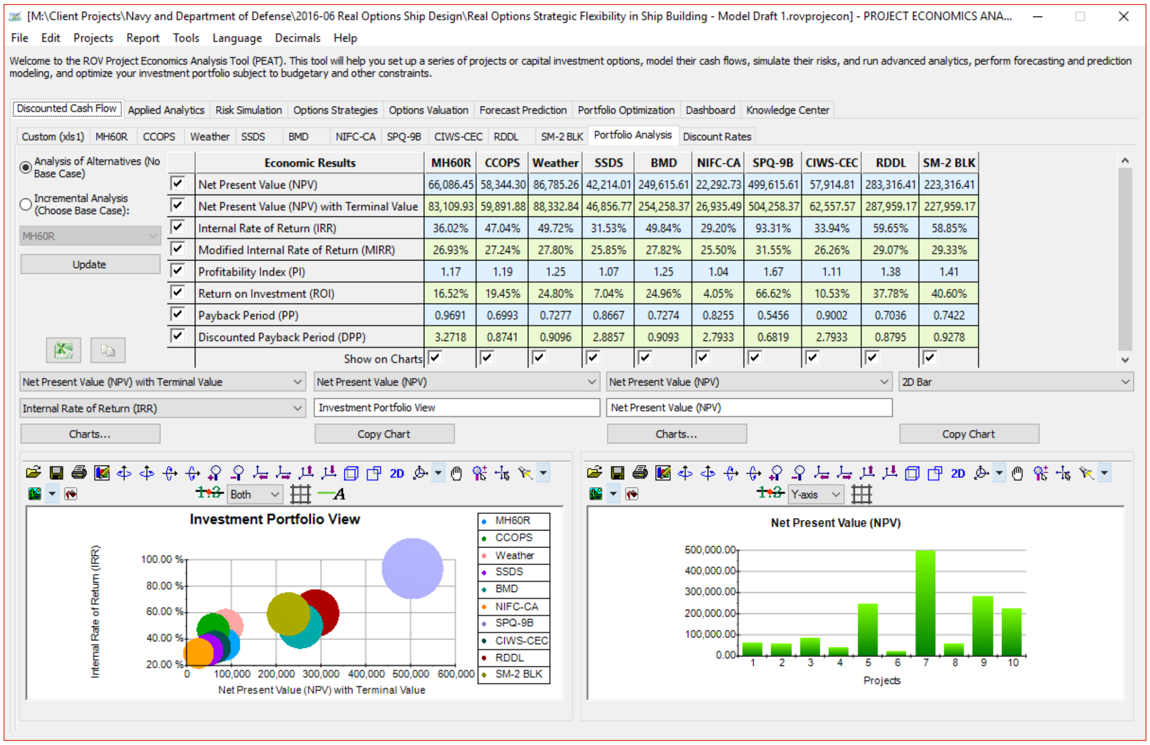
Show NPV: 8 % to 30 % Net Present Value Profile

*Figure 9: Economic Results*

The *Economic Results* subtabs are for each individual project, whereas the *Portfolio Analysis* tab (which is shown later as Figure 10) compares the economic results of all projects at once. The *Terminal Value Annualized Growth Rate* is applied to the last year's cash flow to account for a perpetual constant growth rate cash flow model, and these future cash flows, depending on which cash flow type chosen, are discounted back to the base year and added to the NPV to arrive at the perpetual valuation.

### *Static Portfolio Analysis and Comparisons of Multiple Projects*

Figure 10 illustrates the *Portfolio Analysis* of multiple *Projects*. This Portfolio Analysis tab returns the computed economic and financial indicators such as NPV, IRR, MIRR, PI, ROI, PP, and DPP for all the projects combined into a portfolio view (these results can be stand-alone with no base case or computed as incremental values above and beyond the chosen base case). The *Economic Results* (Level 3) subtabs show the individual project's economic and financial indicators, whereas this Level 2 *Portfolio Analysis* view shows the results of all projects' indicators and compares them side by side. There are also two charts available for comparing these individual projects' results. The *Portfolio Analysis* tab is used to obtain a side-by-side comparison of all the main economic and financial indicators of all the projects at once. For instance, analysts can compare all the NPVs from each project in a single results grid. The bubble chart on the left provides a visual representation of up to three chosen variables at once (e.g., the y-axis shows the IRR, the x-axis represents the NPV, and the size of the bubble may represent the capital investment; in such a situation, one would prefer a smaller bubble that is in the top right quadrant of the chart). These charts have associated icons that can be used to modify their settings (chart type, color, legend, etc.).



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● Analysis of Alternatives (No Base Case)

○ Incremental Analysis (Choose Base Case): MH60R

| | Economic Results | MH60R | CCOPS | Weather | SSDS | BMD | NIFC-CA | SPQ-9B | CIWS-CEC | RDDL | SM-2 BLK |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ☑ | Net Present Value (NPV) | 66,086.45 | 58,344.30 | 86,785.26 | 42,214.01 | 249,615.61 | 22,292.73 | 499,615.61 | 57,914.81 | 283,316.41 | 223,316.41 |
| ☑ | Net Present Value (NPV) with Terminal Value | 83,109.93 | 59,891.88 | 88,332.84 | 46,856.77 | 254,258.37 | 26,935.49 | 504,258.37 | 62,557.57 | 287,959.17 | 227,959.17 |
| ☑ | Internal Rate of Return (IRR) | 36.02% | 47.04% | 49.72% | 31.53% | 49.84% | 29.20% | 93.31% | 33.94% | 59.65% | 58.85% |
| ☑ | Modified Internal Rate of Return (MIRR) | 26.93% | 27.24% | 27.80% | 25.85% | 27.82% | 25.50% | 31.55% | 26.26% | 29.07% | 29.33% |
| ☑ | Profitability Index (PI) | 1.17 | 1.19 | 1.25 | 1.07 | 1.25 | 1.04 | 1.67 | 1.11 | 1.38 | 1.41 |
| ☑ | Return on Investment (ROI) | 16.52% | 19.45% | 24.80% | 7.04% | 24.96% | 4.05% | 66.62% | 10.53% | 37.78% | 40.60% |
| ☑ | Payback Period (PP) | 0.9691 | 0.6993 | 0.7277 | 0.8667 | 0.7274 | 0.8255 | 0.5456 | 0.9002 | 0.7036 | 0.7422 |
| ☑ | Discounted Payback Period (DPP) | 3.2718 | 0.8741 | 0.9096 | 2.8857 | 0.9093 | 2.7933 | 0.6819 | 2.7933 | 0.8795 | 0.9278 |
| | Show on Charts | ☑ | ☑ | ☑ | ☑ | ☑ | ☑ | ☑ | ☑ | ☑ | ☑ |

Net Present Value (NPV) with Terminal Value
Internal Rate of Return (IRR)
Net Present Value (NPV)
Investment Portfolio View
Net Present Value (NPV)
Net Present Value (NPV)
2D Bar

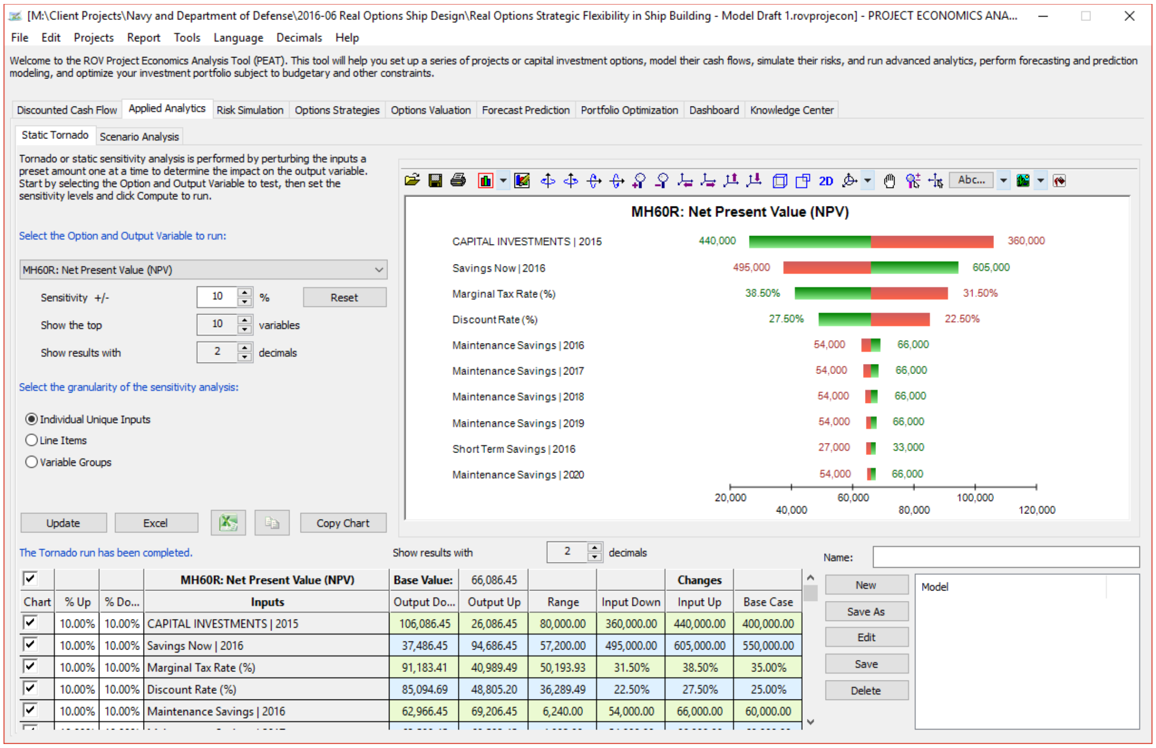
*Figure 10: Static Portfolio Analysis*

## *Step 4: Tornado and Sensitivity Analytics*

Figure 11 illustrates the *Applied Analytics* section, which allows analysts to run *Tornado Analysis* and *Scenario Analysis* on any one of the projects previously modeled—this analytics tab is on Level 1, which means it covers all the various projects on Level 2. Analysts can, therefore, run tornado or scenario analyses on any one of the projects. Tornado analysis is a static sensitivity analysis of the selected model’s output to each input assumption, performed one at a time, and ranked from most impactful to least impactful. Analysts start the analysis by first choosing the output variable to test from the droplist.

Analysts can change the default sensitivity settings of each input assumption to test and decide how many input variables to chart (large models with many inputs may generate unsightly and less useful charts, whereas showing just the top variables reveals more information through a more elegant chart). Analysts can also choose to run the input assumptions as unique inputs, group them as a line item (all individual inputs on a single line item are assumed to be one variable), or run as variable groups (e.g., all line items under *Revenue* will be assumed to be a single variable). Analysts will need to remember to click *Update* to run the analysis if they make any changes to any of the settings. The sensitivity results are also shown as a table grid at the bottom of the screen (e.g., the initial base value of the chosen output variable, the input assumption changes, and the resulting output variable's sensitivity results). The following summarizes the tornado analysis chart's main characteristics:

- Each horizontal bar indicates a unique input assumption that constitutes a precedent to the selected output variable.
- The x-axis represents the values of the selected output variable. The wider the bar chart, the greater the impact/swing the input assumption has on the output.
- A green bar on the right indicates that the input assumption has a positive effect on the selected output (conversely, a red bar on the right indicates a negative effect).
- Each of the precedent or input assumptions that directly affect the NPV with Terminal Value is tested ±10% by default (this setting can be changed); the top 10 variables are shown on the chart by default (this setting can be changed), with a 2-decimal precision setting; and each unique input is tested individually.
- The default sensitivity is globally ±10% of each input variable, but each of these inputs can be individually modified in the data grid. Note that a larger percentage variation will test for nonlinear effects as well.
- The model's granularity can be set (e.g., Variable Groups look at an entire variable group such as all revenues or direct costs and will be modified at once; Line Items change the entire row for multiple years at once; and Individual Unique Inputs look at modifying each input cell).



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Tornado or static sensitivity analysis is performed by perturbing the inputs a preset amount one at a time to determine the impact on the output variable. Start by selecting the Option and Output Variable to test, then set the sensitivity levels and click Compute to run.

Select the Option and Output Variable to run:

MH60R: Net Present Value (NPV)

Sensitivity +/- 10 %

Show the top 10 variables

Show results with 2 decimals

Select the granularity of the sensitivity analysis:

● Individual Unique Inputs
○ Line Items
○ Variable Groups

The Tornado run has been completed.

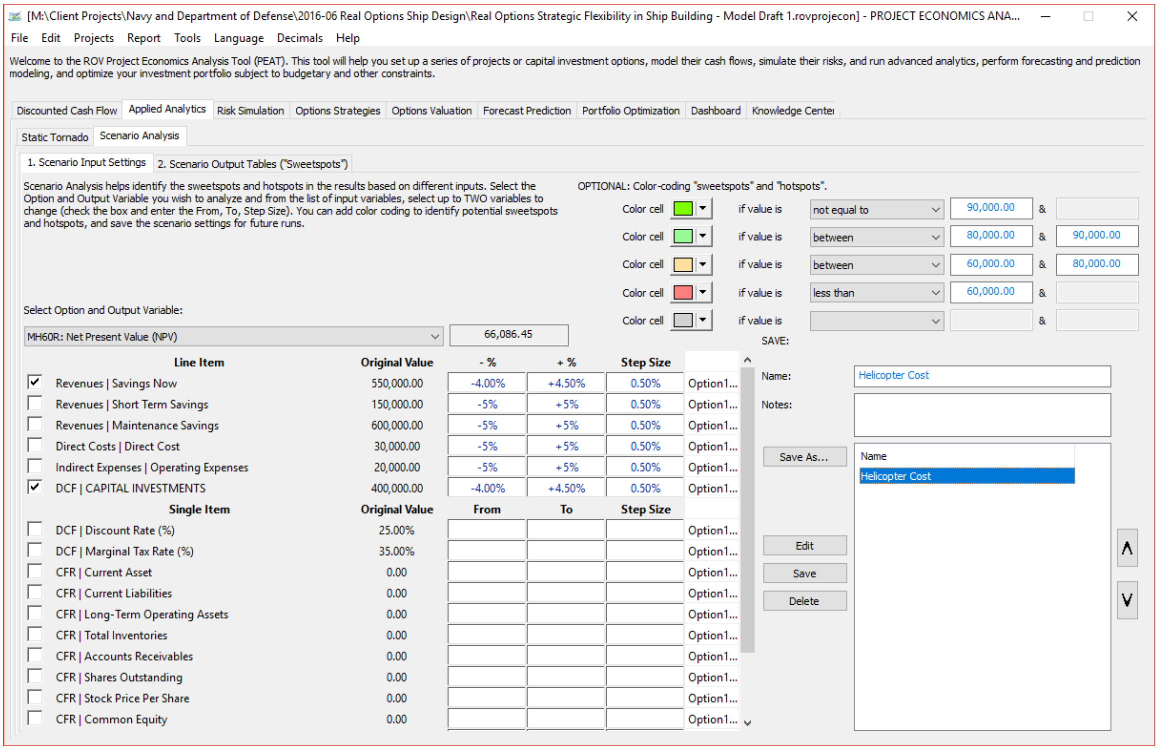
Show results with 2 decimals

| ☑ | | | MH60R: Net Present Value (NPV) | Base Value: | 66,086.45 | | | Changes | |
|---|---|---|---|---|---|---|---|---|---|
| Chart | % Up | % Do... | Inputs | Output Do... | Output Up | Range | Input Down | Input Up | Base Case |
| ☑ | 10.00% | 10.00% | CAPITAL INVESTMENTS \| 2015 | 106,086.45 | 26,086.45 | 80,000.00 | 360,000.00 | 440,000.00 | 400,000.00 |
| ☑ | 10.00% | 10.00% | Savings Now \| 2016 | 37,486.45 | 94,686.45 | 57,200.00 | 495,000.00 | 605,000.00 | 550,000.00 |
| ☑ | 10.00% | 10.00% | Marginal Tax Rate (%) | 91,183.41 | 40,989.49 | 50,193.93 | 31.50% | 38.50% | 35.00% |
| ☑ | 10.00% | 10.00% | Discount Rate (%) | 85,094.69 | 48,805.20 | 36,289.49 | 22.50% | 27.50% | 25.00% |
| ☑ | 10.00% | 10.00% | Maintenance Savings \| 2016 | 62,966.45 | 69,206.45 | 6,240.00 | 54,000.00 | 66,000.00 | 60,000.00 |

*Figure 11: Applied Analytics—Tornado*

Figure 12 illustrates the *Scenario Analysis* tab, where the scenario analysis can be easily performed through a two-step process: identify the model input settings and run the model to obtain scenario output tables. In the *Scenario Input Settings* subtab, analysts start by selecting the output variable they wish to test from the droplist. Then, based on the selection, the precedents of the output will be listed under two categories (*Line Item*, which will change all input assumptions in the entire line item in the model simultaneously, and *Single Item*, which will change individual input assumption items). Analysts select one or two checkboxes at a time and the inputs they wish to run scenarios on, and enter the plus/minus percentage and the number of steps between these two values to test. Analysts can also add color coding of sweetspots or hotspots in the scenario analysis (values falling within different ranges have unique colors). Analysts can create multiple scenarios and *Save As* each one (enter a name and model notes for each saved scenario).

Scenario analysis can sometimes be used as heat maps to identify the combinations of input parameter conditions whereby the calculated outputs will be above or below certain thresholds. A visual heat map can be created by adding color thresholds in the scenario results table.



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Scenario Analysis helps identify the sweetspots and hotspots in the results based on different inputs. Select the Option and Output Variable you wish to analyze and from the list of input variables, select up to TWO variables to change (check the box and enter the From, To, Step Size). You can add color coding to identify potential sweetspots and hotspots, and save the scenario settings for future runs.

OPTIONAL: Color-coding "sweetspots" and "hotspots".

Color cell 🟩 if value is not equal to 90,000.00 &
Color cell 🟩 if value is between 80,000.00 & 90,000.00
Color cell 🟨 if value is between 60,000.00 & 80,000.00
Color cell 🟥 if value is less than 60,000.00 &
Color cell ⬜ if value is &

Select Option and Output Variable:

MH60R: Net Present Value (NPV) 66,086.45

| | Line Item | Original Value | - % | + % | Step Size | |
|---|---|---|---|---|---|---|
| ☑ | Revenues \| Savings Now | 550,000.00 | -4.00% | +4.50% | 0.50% | Option1... |
| ☐ | Revenues \| Short Term Savings | 150,000.00 | -5% | +5% | 0.50% | Option1... |
| ☐ | Revenues \| Maintenance Savings | 600,000.00 | -5% | +5% | 0.50% | Option1... |
| ☐ | Direct Costs \| Direct Cost | 30,000.00 | -5% | +5% | 0.50% | Option1... |
| ☐ | Indirect Expenses \| Operating Expenses | 20,000.00 | -5% | +5% | 0.50% | Option1... |
| ☑ | DCF \| CAPITAL INVESTMENTS | 400,000.00 | -4.00% | +4.50% | 0.50% | Option1... |
| | **Single Item** | **Original Value** | **From** | **To** | **Step Size** | |
| ☐ | DCF \| Discount Rate (%) | 25.00% | | | | Option1... |
| ☐ | DCF \| Marginal Tax Rate (%) | 35.00% | | | | Option1... |
| ☐ | CFR \| Current Asset | 0.00 | | | | Option1... |
| ☐ | CFR \| Current Liabilities | 0.00 | | | | Option1... |
| ☐ | CFR \| Long-Term Operating Assets | 0.00 | | | | Option1... |
| ☐ | CFR \| Total Inventories | 0.00 | | | | Option1... |
| ☐ | CFR \| Accounts Receivables | 0.00 | | | | Option1... |
| ☐ | CFR \| Shares Outstanding | 0.00 | | | | Option1... |
| ☐ | CFR \| Stock Price Per Share | 0.00 | | | | Option1... |
| ☐ | CFR \| Common Equity | 0.00 | | | | Option1... |

SAVE:

Name: Helicopter Cost

Notes:

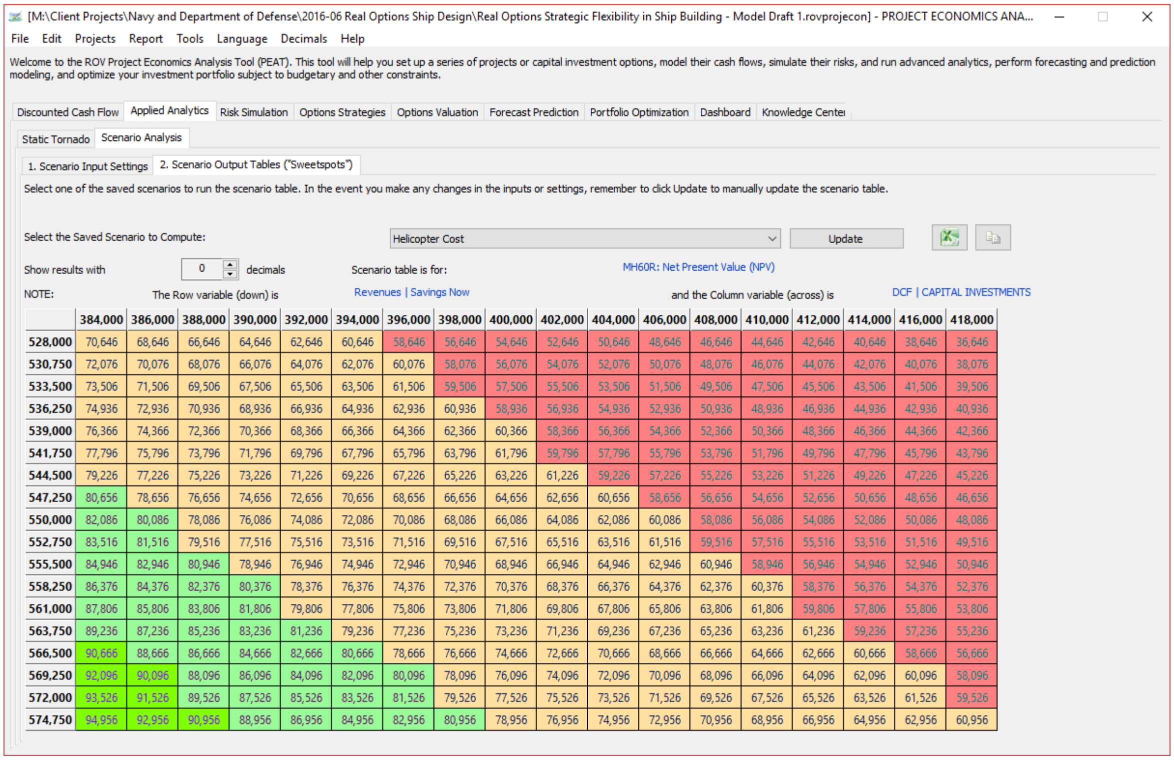
Name
Helicopter Cost

Figure 12: Applied Analytics—Scenario Analysis Input

Figure 13 illustrates the *Scenario Output Tables* to run the saved *Scenario Analysis* models. Analysts click on the droplist to select the previously saved scenarios to *Update* and run. The selected scenario table complete with sweetspot/hotspot color coding will be generated. Decimals can be increased or decreased as required, and analysts can *Copy Grid* or *View Full Grid* as needed. The followings are some notes on using the scenario analysis methodology:

- Create and run scenario analysis on either one or two input variables at once.
- The scenario settings can be saved for retrieval in the future, which means analysts can modify any input assumptions in the options models and come back to rerun the saved scenarios.

- Increase/decrease decimals in the scenario results tables, as well as change colors in the tables for easier visual interpretation (especially when trying to identify scenario combinations, or so-called sweetspots and hotspots).
- Additional input variables are available by scrolling down the form.
- Line Items can be changed using ±X% where all inputs in the line are changed multiple times within this specific range all at once. Individual Items can be changed ±Y units where each input is changed multiple times within this specific range.
- Sweetspots and hotspots refer to specific combinations of two input variables that will drive the output up or down. For instance, suppose investments are below a certain threshold and revenues are above a certain barrier. The NPV will then be in excess of the expected budget (the sweetspots, perhaps highlighted in green). Or if investments are above a certain value, NPV will turn negative if revenues fall below a certain threshold (the hotspots, perhaps highlighted in red).



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Select one of the saved scenarios to run the scenario table. In the event you make any changes in the inputs or settings, remember to click Update to manually update the scenario table.

Select the Saved Scenario to Compute: Helicopter Cost

Show results with 0 decimals

Scenario table is for: MH60R: Net Present Value (NPV)

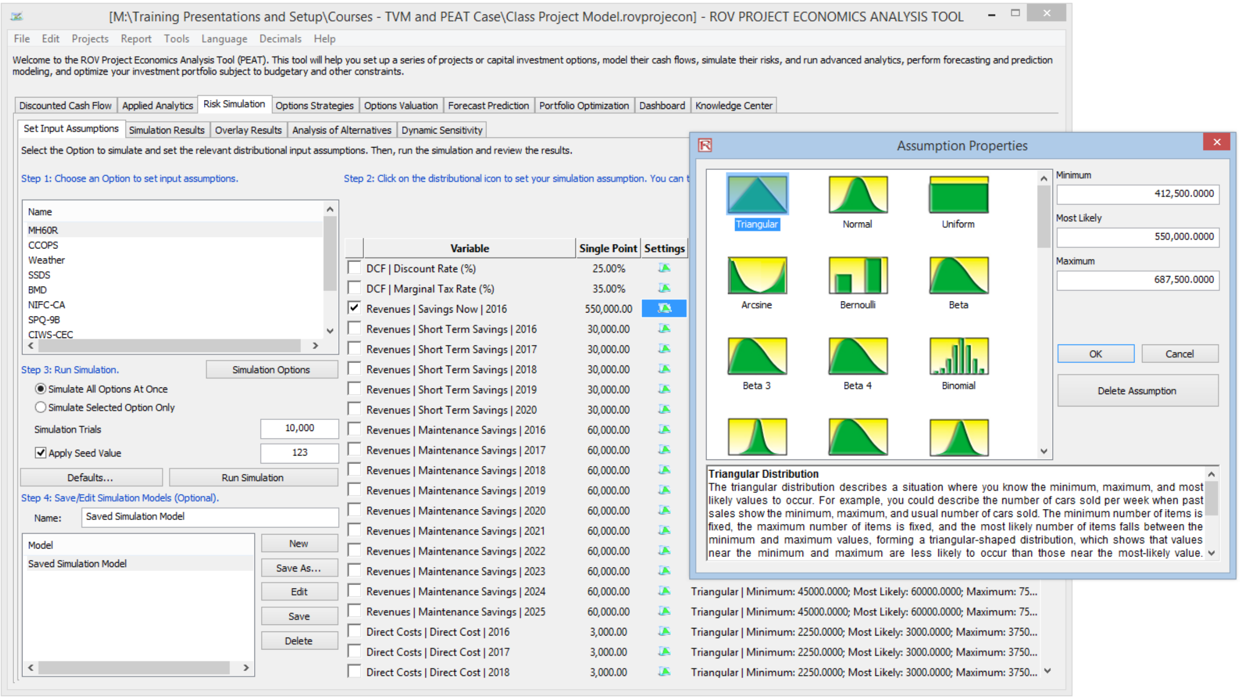
NOTE: The Row variable (down) is Revenues | Savings Now and the Column variable (across) is DCF | CAPITAL INVESTMENTS

| | 384,000 | 386,000 | 388,000 | 390,000 | 392,000 | 394,000 | 396,000 | 398,000 | 400,000 | 402,000 | 404,000 | 406,000 | 408,000 | 410,000 | 412,000 | 414,000 | 416,000 | 418,000 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **528,000** | 70,646 | 68,646 | 66,646 | 64,646 | 62,646 | 60,646 | 58,646 | 56,646 | 54,646 | 52,646 | 50,646 | 48,646 | 46,646 | 44,646 | 42,646 | 40,646 | 38,646 | 36,646 |
| **530,750** | 72,076 | 70,076 | 68,076 | 66,076 | 64,076 | 62,076 | 60,076 | 58,076 | 56,076 | 54,076 | 52,076 | 50,076 | 48,076 | 46,076 | 44,076 | 42,076 | 40,076 | 38,076 |
| **533,500** | 73,506 | 71,506 | 69,506 | 67,506 | 65,506 | 63,506 | 61,506 | 59,506 | 57,506 | 55,506 | 53,506 | 51,506 | 49,506 | 47,506 | 45,506 | 43,506 | 41,506 | 39,506 |
| **536,250** | 74,936 | 72,936 | 70,936 | 68,936 | 66,936 | 64,936 | 62,936 | 60,936 | 58,936 | 56,936 | 54,936 | 52,936 | 50,936 | 48,936 | 46,936 | 44,936 | 42,936 | 40,936 |
| **539,000** | 76,366 | 74,366 | 72,366 | 70,366 | 68,366 | 66,366 | 64,366 | 62,366 | 60,366 | 58,366 | 56,366 | 54,366 | 52,366 | 50,366 | 48,366 | 46,366 | 44,366 | 42,366 |
| **541,750** | 77,796 | 75,796 | 73,796 | 71,796 | 69,796 | 67,796 | 65,796 | 63,796 | 61,796 | 59,796 | 57,796 | 55,796 | 53,796 | 51,796 | 49,796 | 47,796 | 45,796 | 43,796 |
| **544,500** | 79,226 | 77,226 | 75,226 | 73,226 | 71,226 | 69,226 | 67,226 | 65,226 | 63,226 | 61,226 | 59,226 | 57,226 | 55,226 | 53,226 | 51,226 | 49,226 | 47,226 | 45,226 |
| **547,250** | 80,656 | 78,656 | 76,656 | 74,656 | 72,656 | 70,656 | 68,656 | 66,656 | 64,656 | 62,656 | 60,656 | 58,656 | 56,656 | 54,656 | 52,656 | 50,656 | 48,656 | 46,656 |
| **550,000** | 82,086 | 80,086 | 78,086 | 76,086 | 74,086 | 72,086 | 70,086 | 68,086 | 66,086 | 64,086 | 62,086 | 60,086 | 58,086 | 56,086 | 54,086 | 52,086 | 50,086 | 48,086 |
| **552,750** | 83,516 | 81,516 | 79,516 | 77,516 | 75,516 | 73,516 | 71,516 | 69,516 | 67,516 | 65,516 | 63,516 | 61,516 | 59,516 | 57,516 | 55,516 | 53,516 | 51,516 | 49,516 |
| **555,500** | 84,946 | 82,946 | 80,946 | 78,946 | 76,946 | 74,946 | 72,946 | 70,946 | 68,946 | 66,946 | 64,946 | 62,946 | 60,946 | 58,946 | 56,946 | 54,946 | 52,946 | 50,946 |
| **558,250** | 86,376 | 84,376 | 82,376 | 80,376 | 78,376 | 76,376 | 74,376 | 72,376 | 70,376 | 68,376 | 66,376 | 64,376 | 62,376 | 60,376 | 58,376 | 56,376 | 54,376 | 52,376 |
| **561,000** | 87,806 | 85,806 | 83,806 | 81,806 | 79,806 | 77,806 | 75,806 | 73,806 | 71,806 | 69,806 | 67,806 | 65,806 | 63,806 | 61,806 | 59,806 | 57,806 | 55,806 | 53,806 |
| **563,750** | 89,236 | 87,236 | 85,236 | 83,236 | 81,236 | 79,236 | 77,236 | 75,236 | 73,236 | 71,236 | 69,236 | 67,236 | 65,236 | 63,236 | 61,236 | 59,236 | 57,236 | 55,236 |
| **566,500** | 90,666 | 88,666 | 86,666 | 84,666 | 82,666 | 80,666 | 78,666 | 76,666 | 74,666 | 72,666 | 70,666 | 68,666 | 66,666 | 64,666 | 62,666 | 60,666 | 58,666 | 56,666 |
| **569,250** | 92,096 | 90,096 | 88,096 | 86,096 | 84,096 | 82,096 | 80,096 | 78,096 | 76,096 | 74,096 | 72,096 | 70,096 | 68,096 | 66,096 | 64,096 | 62,096 | 60,096 | 58,096 |
| **572,000** | 93,526 | 91,526 | 89,526 | 87,526 | 85,526 | 83,526 | 81,526 | 79,526 | 77,526 | 75,526 | 73,526 | 71,526 | 69,526 | 67,526 | 65,526 | 63,526 | 61,526 | 59,526 |
| **574,750** | 94,956 | 92,956 | 90,956 | 88,956 | 86,956 | 84,956 | 82,956 | 80,956 | 78,956 | 76,956 | 74,956 | 72,956 | 70,956 | 68,956 | 66,956 | 64,956 | 62,956 | 60,956 |

*Figure 13: Applied Analytics—Scenario Tables*

## *Step 5: Monte Carlo Risk Simulation*

Figure 14 illustrates the *Risk Simulation* section, where Monte Carlo risk simulations can be set up and run. Analysts can set up probability distribution assumptions on any combinations of inputs, run a risk simulation tens to hundreds of thousands of trials, and retrieve the simulated forecast outputs as charts, statistics, probabilities, and confidence intervals to develop comprehensive risk profiles of the projects.



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Select the Option to simulate and set the relevant distributional input assumptions. Then, run the simulation and review the results.

Step 1: Choose an Option to set input assumptions.

Name
MH60R
CCOPS
Weather
SSDS
BMD
NIFC-CA
SPQ-9B
CIWS-CEC

Step 2: Click on the distributional icon to set your simulation assumption. You can t

| | Variable | Single Point | Settings | |
|---|---|---|---|---|
| ☐ | DCF \| Discount Rate (%) | 25.00% | | |
| ☐ | DCF \| Marginal Tax Rate (%) | 35.00% | | |
| ☑ | Revenues \| Savings Now \| 2016 | 550,000.00 | | |
| ☐ | Revenues \| Short Term Savings \| 2016 | 30,000.00 | | |
| ☐ | Revenues \| Short Term Savings \| 2017 | 30,000.00 | | |
| ☐ | Revenues \| Short Term Savings \| 2018 | 30,000.00 | | |
| ☐ | Revenues \| Short Term Savings \| 2019 | 30,000.00 | | |
| ☐ | Revenues \| Short Term Savings \| 2020 | 30,000.00 | | |
| ☐ | Revenues \| Maintenance Savings \| 2016 | 60,000.00 | | |
| ☐ | Revenues \| Maintenance Savings \| 2017 | 60,000.00 | | |
| ☐ | Revenues \| Maintenance Savings \| 2018 | 60,000.00 | | |
| ☐ | Revenues \| Maintenance Savings \| 2019 | 60,000.00 | | |
| ☐ | Revenues \| Maintenance Savings \| 2020 | 60,000.00 | | |
| ☐ | Revenues \| Maintenance Savings \| 2021 | 60,000.00 | | |
| ☐ | Revenues \| Maintenance Savings \| 2022 | 60,000.00 | | |
| ☐ | Revenues \| Maintenance Savings \| 2023 | 60,000.00 | | |
| ☐ | Revenues \| Maintenance Savings \| 2024 | 60,000.00 | | Triangular \| Minimum: 45000.0000; Most Likely: 60000.0000; Maximum: 75... |
| ☐ | Revenues \| Maintenance Savings \| 2025 | 60,000.00 | | Triangular \| Minimum: 45000.0000; Most Likely: 60000.0000; Maximum: 75... |
| ☐ | Direct Costs \| Direct Cost \| 2016 | 3,000.00 | | Triangular \| Minimum: 2250.0000; Most Likely: 3000.0000; Maximum: 3750... |
| ☐ | Direct Costs \| Direct Cost \| 2017 | 3,000.00 | | Triangular \| Minimum: 2250.0000; Most Likely: 3000.0000; Maximum: 3750... |
| ☐ | Direct Costs \| Direct Cost \| 2018 | 3,000.00 | | Triangular \| Minimum: 2250.0000; Most Likely: 3000.0000; Maximum: 3750... |

Step 3: Run Simulation.

● Simulate All Options At Once
○ Simulate Selected Option Only
Simulation Trials: 10,000
☑ Apply Seed Value: 123

Step 4: Save/Edit Simulation Models (Optional).

Name: Saved Simulation Model

Model
Saved Simulation Model

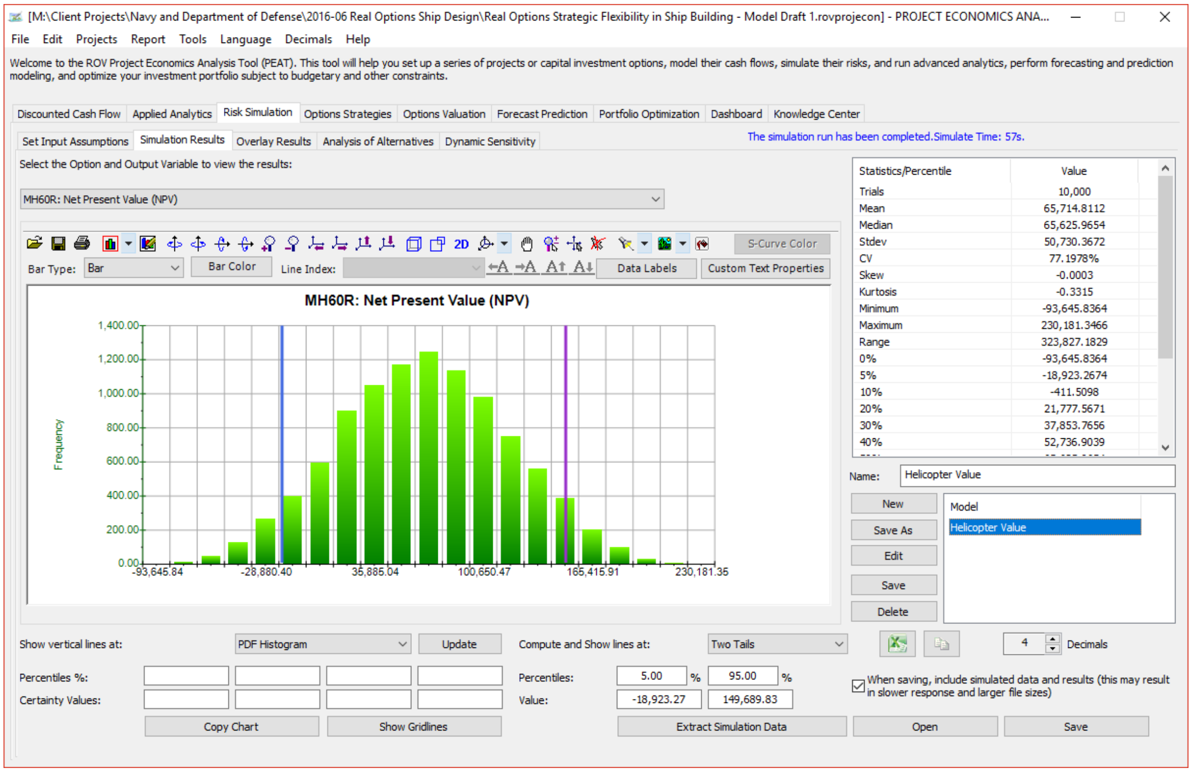
Minimum: 412,500.0000
Most Likely: 550,000.0000
Maximum: 687,500.0000

**Triangular Distribution**
The triangular distribution describes a situation where you know the minimum, maximum, and most likely values to occur. For example, you could describe the number of cars sold per week when past sales show the minimum, maximum, and usual number of cars sold. The minimum number of items is fixed, the maximum number of items is fixed, and the most likely number of items falls between the minimum and maximum values, forming a triangular-shaped distribution, which shows that values near the minimum and maximum are less likely to occur than those near the most-likely value.

*Figure 14: Risk Simulation Input Assumptions*

### *Simulation Results, Confidence Intervals, and Probabilities*

Figure 15 illustrates the Risk Simulation results. After the simulation completes its run, the utility will automatically take the analyst to the *Simulation Results* tab. The analyst selects the output variable to display using the droplist. The simulation forecast chart is shown on the left, while percentiles and simulation statistics are presented on the right.


[M:\Client Projects\Navy and Department of Defense\2016-06 Real Options Ship Design\Real Options Strategic Flexibility in Ship Building - Model Draft 1.rovprojecon] - PROJECT ECONOMICS ANA...

Welcome to the ROV Project Economics Analysis Tool (PEAT). This tool will help you set up a series of projects or capital investment options, model their cash flows, simulate their risks, and run advanced analytics, perform forecasting and prediction modeling, and optimize your investment portfolio subject to budgetary and other constraints.

The simulation run has been completed.Simulate Time: 57s.

Select the Option and Output Variable to view the results: MH60R: Net Present Value (NPV)

Bar Type: Bar

| Statistics/Percentile | Value |
|---|---|
| Trials | 10,000 |
| Mean | 65,714.8112 |
| Median | 65,625.9654 |
| Stdev | 50,730.3672 |
| CV | 77.1978% |
| Skew | -0.0003 |
| Kurtosis | -0.3315 |
| Minimum | -93,645.8364 |
| Maximum | 230,181.3466 |
| Range | 323,827.1829 |
| 0% | -93,645.8364 |
| 5% | -18,923.2674 |
| 10% | -411.5098 |
| 20% | 21,777.5671 |
| 30% | 37,853.7656 |
| 40% | 52,736.9039 |

Name: Helicopter Value

Show vertical lines at: PDF Histogram

Compute and Show lines at: Two Tails

Percentiles %:

Certainty Values:

Percentiles: 5.00 % 95.00 %

Value: -18,923.27 149,689.83

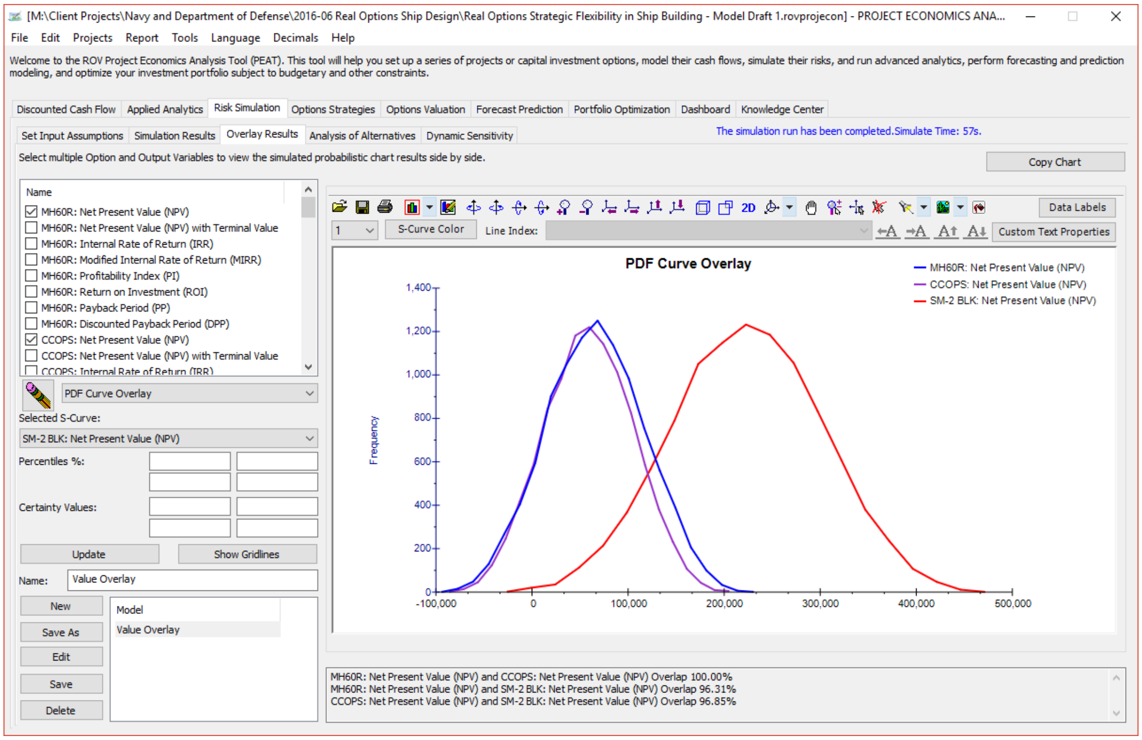
4 Decimals

☑ When saving, include simulated data and results (this may result in slower response and larger file sizes)

*Figure 15: Risk Simulation Results*

## *Probability Distribution Overlay Charts*

Figure 16 illustrates the *Overlay Results*. Multiple simulation output variables can be compared at once using the overlay charts. Analysts simply check/uncheck the simulated outputs they wish to compare and select the chart type to show (e.g., S-Curves, CDF, PDF). Analysts can also add percentile or certainty lines by first selecting the output chart, entering the relevant values, and clicking the *Update* button. The generated charts are highly flexible in that analysts can modify them using the included chart icons (as well as whether to show or hide gridlines), and the chart can be copied into the Microsoft Windows clipboard for pasting into another software application. Typically, S-curves or CDF curves are used in overlay analysis when comparing the risk profile of multiple simulated forecast results.


[M:\Client Projects\Navy and Department of Defense\2016-06 Real Options Ship Design\Real Options Strategic Flexibility in Ship Building - Model Draft 1.rovprojecon] - PROJECT ECONOMICS ANA...

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The simulation run has been completed.Simulate Time: 57s.

Select multiple Option and Output Variables to view the simulated probabilistic chart results side by side.

☑ MH60R: Net Present Value (NPV)
☐ MH60R: Net Present Value (NPV) with Terminal Value
☐ MH60R: Internal Rate of Return (IRR)
☐ MH60R: Modified Internal Rate of Return (MIRR)
☐ MH60R: Profitability Index (PI)
☐ MH60R: Return on Investment (ROI)
☐ MH60R: Payback Period (PP)
☐ MH60R: Discounted Payback Period (DPP)
☑ CCOPS: Net Present Value (NPV)
☐ CCOPS: Net Present Value (NPV) with Terminal Value
☐ CCOPS: Internal Rate of Return (IRR)

PDF Curve Overlay

Selected S-Curve: SM-2 BLK: Net Present Value (NPV)

Name: Value Overlay

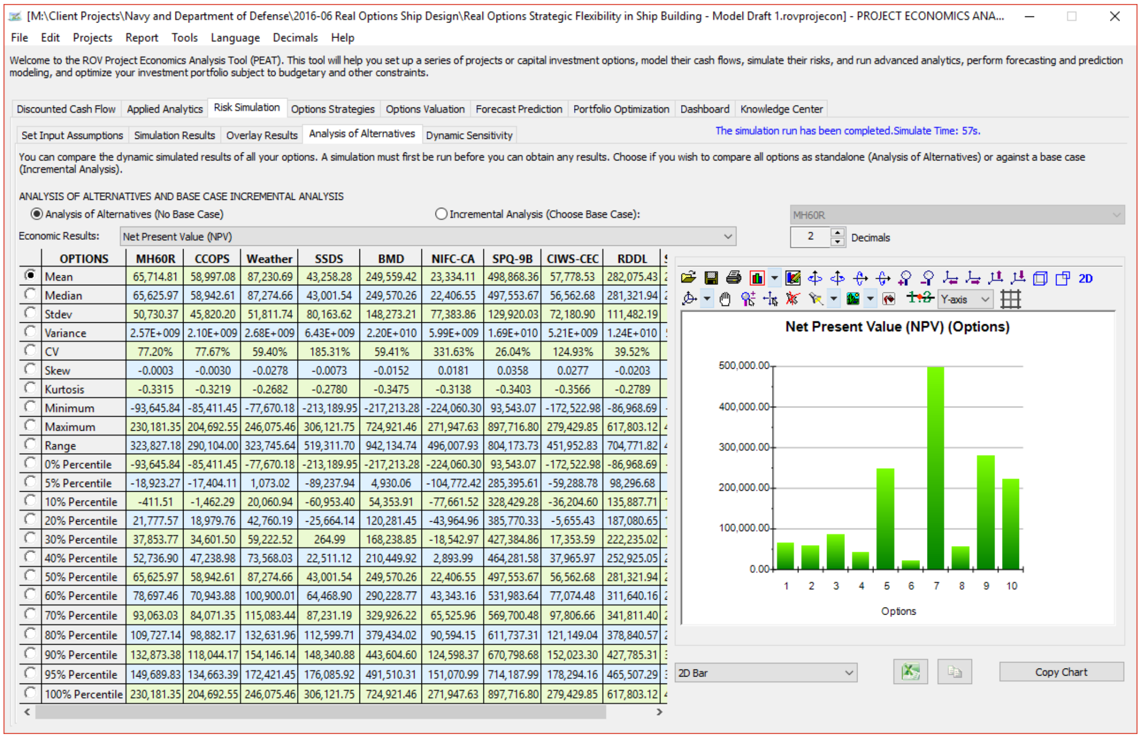
MH60R: Net Present Value (NPV) and CCOPS: Net Present Value (NPV) Overlap 100.00%
MH60R: Net Present Value (NPV) and SM-2 BLK: Net Present Value (NPV) Overlap 96.31%
CCOPS: Net Present Value (NPV) and SM-2 BLK: Net Present Value (NPV) Overlap 96.85%

Figure 16: Simulated Overlay Results

### *Analysis of Alternatives and Dynamic Sensitivity Analysis*

Figure 17 illustrates the *Analysis of Alternatives* subtab. Whereas the *Overlay Results* subtab shows the simulated results as charts (PDF/CDF), the *Analysis of Alternatives* subtab shows the results of the simulation statistics in a table format as well as a chart of the statistics such that one project can be compared against another. The default is to run an analysis of alternatives to compare one project versus another, but analysts can also choose the *Incremental Analysis* project (remembering to choose the desired economic metric to show, its precision in terms of decimals, the *Base Case* project to compare the results to, and the chart display type).

Figure 18 illustrates the *Dynamic Sensitivity Analysis* computations. Tornado analysis and scenario analysis are both static calculations. Dynamic sensitivity, in contrast, is a dynamic analysis, which can only be performed after a simulation is run. Analysts start by selecting the desired project's economic output. Red bars on the *Rank Correlation* chart indicate negative correlations and green bars indicate positive correlations for the left chart. The correlations' absolute values are used to rank the variables with the highest relationship to the lowest, for all simulation input assumptions. The *Contribution to Variance* computations and chart indicate the percentage fluctuation in the output variable that can be statistically explained by the fluctuations in each of the input variables.



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The simulation run has been completed.Simulate Time: 57s.

You can compare the dynamic simulated results of all your options. A simulation must first be run before you can obtain any results. Choose if you wish to compare all options as standalone (Analysis of Alternatives) or against a base case (Incremental Analysis).

ANALYSIS OF ALTERNATIVES AND BASE CASE INCREMENTAL ANALYSIS

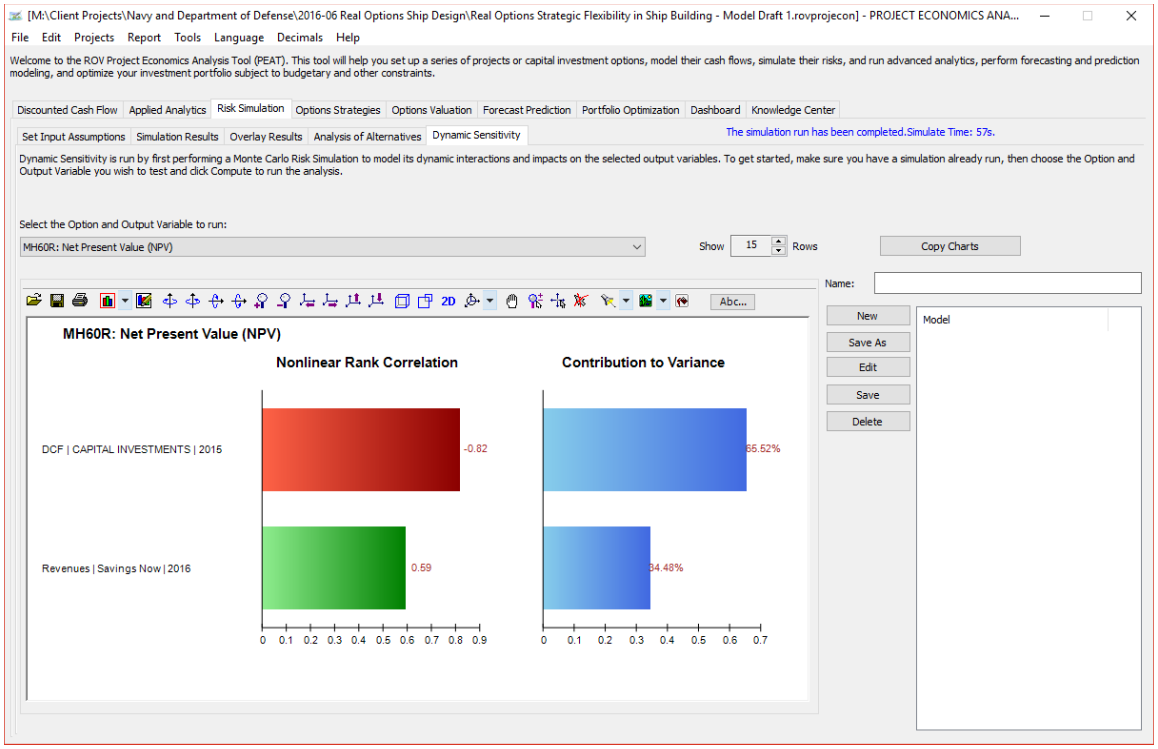
● Analysis of Alternatives (No Base Case)    ○ Incremental Analysis (Choose Base Case): MH60R

Economic Results: Net Present Value (NPV)

Decimals: 2

| | OPTIONS | MH60R | CCOPS | Weather | SSDS | BMD | NIFC-CA | SPQ-9B | CIWS-CEC | RDDL |
|---|---|---|---|---|---|---|---|---|---|---|
| ● | Mean | 65,714.81 | 58,997.08 | 87,230.69 | 43,258.28 | 249,559.42 | 23,334.11 | 498,868.36 | 57,778.53 | 282,075.43 |
| ○ | Median | 65,625.97 | 58,942.61 | 87,274.66 | 43,001.54 | 249,570.26 | 22,406.55 | 497,553.67 | 56,562.68 | 281,321.94 |
| ○ | Stdev | 50,730.37 | 45,820.20 | 51,811.74 | 80,163.62 | 148,273.21 | 77,383.86 | 129,920.03 | 72,180.90 | 111,482.19 |
| ○ | Variance | 2.57E+009 | 2.10E+009 | 2.68E+009 | 6.43E+009 | 2.20E+010 | 5.99E+009 | 1.69E+010 | 5.21E+009 | 1.24E+010 |
| ○ | CV | 77.20% | 77.67% | 59.40% | 185.31% | 59.41% | 331.63% | 26.04% | 124.93% | 39.52% |
| ○ | Skew | -0.0003 | -0.0030 | -0.0278 | -0.0073 | -0.0152 | 0.0181 | 0.0358 | 0.0277 | -0.0203 |
| ○ | Kurtosis | -0.3315 | -0.3219 | -0.2682 | -0.2780 | -0.3475 | -0.3138 | -0.3403 | -0.3566 | -0.2789 |
| ○ | Minimum | -93,645.84 | -85,411.45 | -77,670.18 | -213,189.95 | -217,213.28 | -224,060.30 | 93,543.07 | -172,522.98 | -86,968.69 |
| ○ | Maximum | 230,181.35 | 204,692.55 | 246,075.46 | 306,121.75 | 724,921.46 | 271,947.63 | 897,716.80 | 279,429.85 | 617,803.12 |
| ○ | Range | 323,827.18 | 290,104.00 | 323,745.64 | 519,311.70 | 942,134.74 | 496,007.93 | 804,173.73 | 451,952.83 | 704,771.82 |
| ○ | 0% Percentile | -93,645.84 | -85,411.45 | -77,670.18 | -213,189.95 | -217,213.28 | -224,060.30 | 93,543.07 | -172,522.98 | -86,968.69 |
| ○ | 5% Percentile | -18,923.27 | -17,404.11 | 1,073.02 | -89,237.94 | 4,930.06 | -104,772.42 | 285,395.61 | -59,288.78 | 98,296.68 |
| ○ | 10% Percentile | -411.51 | -1,462.29 | 20,060.94 | -60,953.40 | 54,353.91 | -77,661.52 | 328,429.28 | -36,204.60 | 135,887.71 |
| ○ | 20% Percentile | 21,777.57 | 18,979.76 | 42,760.19 | -25,664.14 | 120,281.45 | -43,964.96 | 385,770.33 | -5,655.43 | 187,080.65 |
| ○ | 30% Percentile | 37,853.77 | 34,601.50 | 59,222.52 | 264.99 | 168,238.85 | -18,542.97 | 427,384.86 | 17,353.59 | 222,235.02 |
| ○ | 40% Percentile | 52,736.90 | 47,238.98 | 73,568.03 | 22,511.12 | 210,449.92 | 2,893.99 | 464,281.58 | 37,965.97 | 252,925.05 |
| ○ | 50% Percentile | 65,625.97 | 58,942.61 | 87,274.66 | 43,001.54 | 249,570.26 | 22,406.55 | 497,553.67 | 56,562.68 | 281,321.94 |
| ○ | 60% Percentile | 78,697.46 | 70,943.88 | 100,900.01 | 64,468.90 | 290,228.77 | 43,343.16 | 531,983.64 | 77,074.48 | 311,640.16 |
| ○ | 70% Percentile | 93,063.03 | 84,071.35 | 115,083.44 | 87,231.19 | 329,926.22 | 65,525.96 | 569,700.48 | 97,806.66 | 341,811.40 |
| ○ | 80% Percentile | 109,727.14 | 98,882.17 | 132,631.96 | 112,599.71 | 379,434.02 | 90,594.15 | 611,737.31 | 121,149.04 | 378,840.57 |
| ○ | 90% Percentile | 132,873.38 | 118,044.17 | 154,146.14 | 148,340.88 | 443,604.60 | 124,598.37 | 670,798.68 | 152,023.30 | 427,785.31 |
| ○ | 95% Percentile | 149,689.83 | 134,663.39 | 172,421.45 | 176,085.92 | 491,510.31 | 151,070.99 | 714,187.99 | 178,294.16 | 465,507.29 |
| ○ | 100% Percentile | 230,181.35 | 204,692.55 | 246,075.46 | 306,121.75 | 724,921.46 | 271,947.63 | 897,716.80 | 279,429.85 | 617,803.12 |

Figure 17: Simulated Analysis of Alternatives



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The simulation run has been completed.Simulate Time: 57s.

Dynamic Sensitivity is run by first performing a Monte Carlo Risk Simulation to model its dynamic interactions and impacts on the selected output variables. To get started, make sure you have a simulation already run, then choose the Option and Output Variable you wish to test and click Compute to run the analysis.

Select the Option and Output Variable to run: MH60R: Net Present Value (NPV)

Show 15 Rows

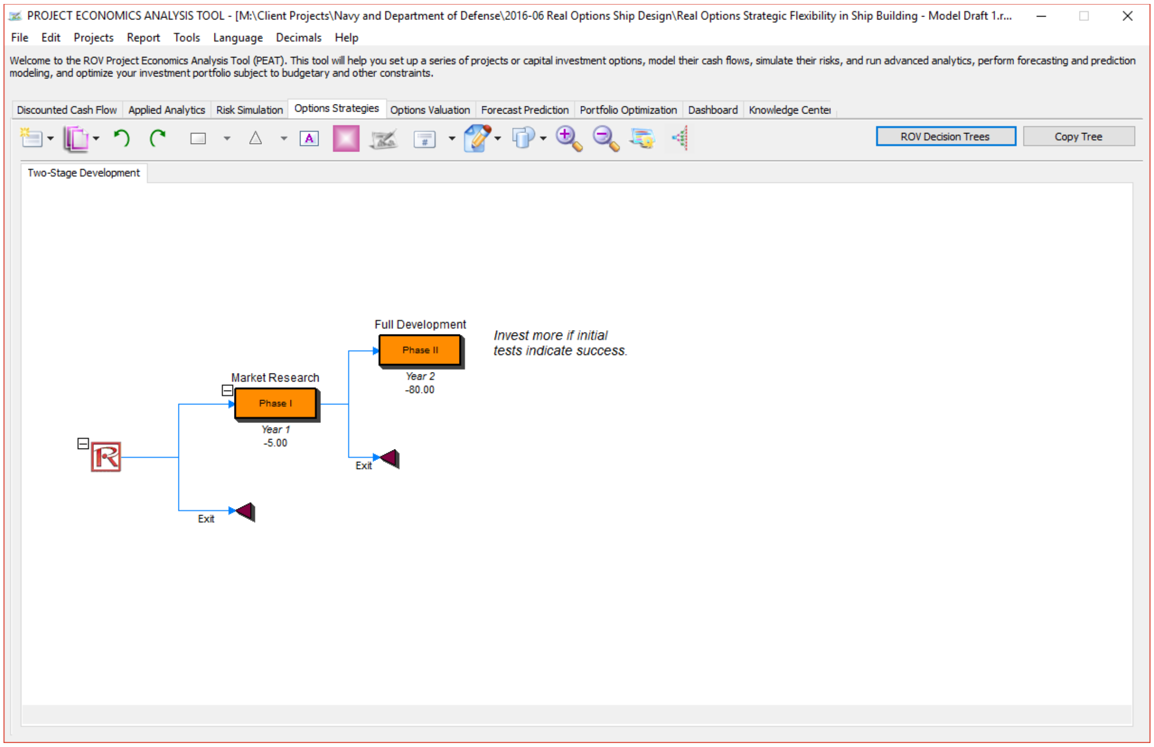
Name:

Model

*Figure 18: Simulated Dynamic Sensitivity Analysis*

## Step 6: Strategic Real Options Valuation Modeling

Figure 19 illustrates the *Options Strategies* tab. Options Strategies is where analysts can draw their own custom strategic maps, and each map can have multiple strategic real options paths. This section allows analysts to draw and visualize these strategic pathways and does not perform any computations. The examples in Figures 6 and 7 can be easily incorporated into the strategy tree seen in Figure 19.



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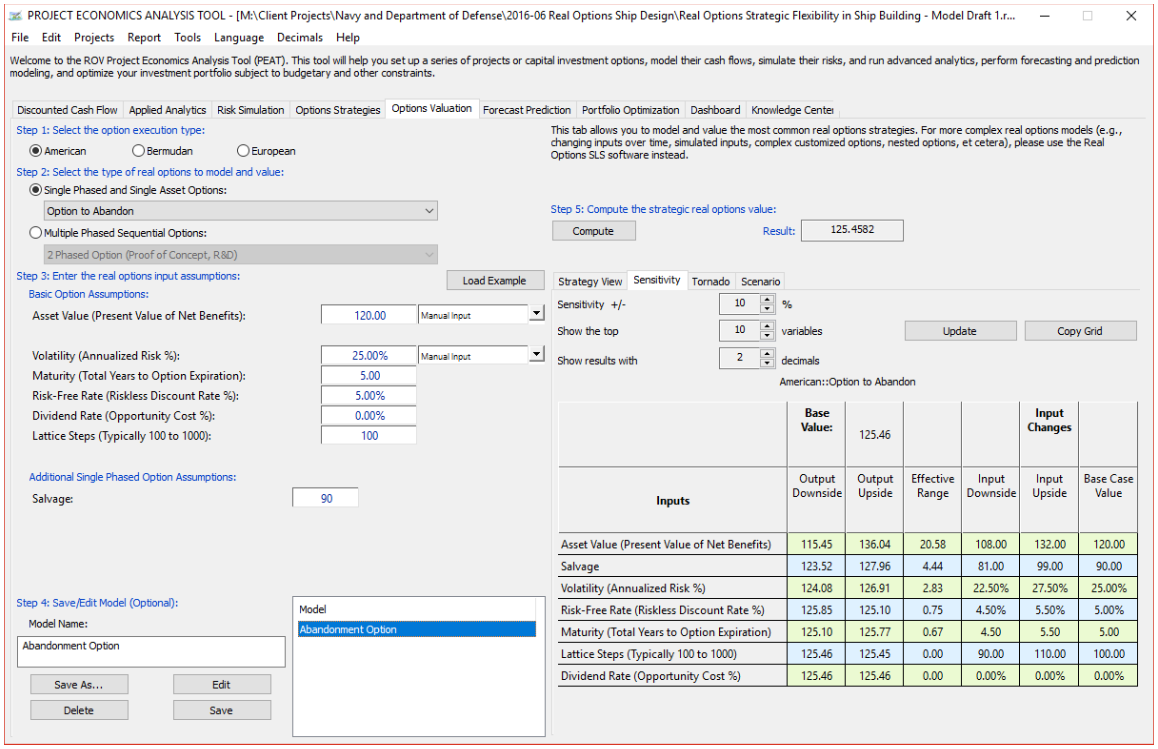
*Invest more if initial tests indicate success.*

*Figure 19: Options Strategies*

## *Real Options Valuation Modeling*

Figure 20 illustrates the *Options Valuation* tab and the *Strategy View*. This section performs the calculations of real options valuation models. Analysts must understand the basic concepts of real options before proceeding. This *Options Valuation* tab internalizes the more sophisticated Real Options SLS software (see Chapter 13 of Mun’s *Modeling Risk* book). Instead of requiring more advanced knowledge of real options analysis and modeling, analysts can simply choose the real option types, and the required inputs will be displayed for entry. Analysts can compute and obtain the real options value quickly and efficiently, as well as run the subsequent tornado, sensitivity, and scenario analyses.



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Step 1: Select the option execution type:

● American ○ Bermudan ○ European

Step 2: Select the type of real options to model and value:

● Single Phased and Single Asset Options: Option to Abandon

○ Multiple Phased Sequential Options: 2 Phased Option (Proof of Concept, R&D)

Step 3: Enter the real options input assumptions:

Basic Option Assumptions:

Asset Value (Present Value of Net Benefits): 120.00 Manual Input

Volatility (Annualized Risk %): 25.00% Manual Input

Maturity (Total Years to Option Expiration): 5.00

Risk-Free Rate (Riskless Discount Rate %): 5.00%

Dividend Rate (Opportunity Cost %): 0.00%

Lattice Steps (Typically 100 to 1000): 100

Additional Single Phased Option Assumptions:

Salvage: 90

Step 4: Save/Edit Model (Optional):

Model Name: Abandonment Option

Model: Abandonment Option

This tab allows you to model and value the most common real options strategies. For more complex real options models (e.g., changing inputs over time, simulated inputs, complex customized options, nested options, et cetera), please use the Real Options SLS software instead.

Step 5: Compute the strategic real options value:

Result: 125.4582

Sensitivity +/- 10 %

Show the top 10 variables

Show results with 2 decimals

American::Option to Abandon

| | **Base Value:** | 125.46 | | | **Input Changes** | |
|---|---|---|---|---|---|---|
| **Inputs** | Output Downside | Output Upside | Effective Range | Input Downside | Input Upside | Base Case Value |
| Asset Value (Present Value of Net Benefits) | 115.45 | 136.04 | 20.58 | 108.00 | 132.00 | 120.00 |
| Salvage | 123.52 | 127.96 | 4.44 | 81.00 | 99.00 | 90.00 |
| Volatility (Annualized Risk %) | 124.08 | 126.91 | 2.83 | 22.50% | 27.50% | 25.00% |
| Risk-Free Rate (Riskless Discount Rate %) | 125.85 | 125.10 | 0.75 | 4.50% | 5.50% | 5.00% |
| Maturity (Total Years to Option Expiration) | 125.10 | 125.77 | 0.67 | 4.50 | 5.50 | 5.00 |
| Lattice Steps (Typically 100 to 1000) | 125.46 | 125.45 | 0.00 | 90.00 | 110.00 | 100.00 |
| Dividend Rate (Opportunity Cost %) | 125.46 | 125.46 | 0.00 | 0.00% | 0.00% | 0.00% |

*Figure 20: Options Valuation*

The strategic real options analysis is solved employing various methodologies, including the use of binomial lattices with a market-replicating portfolios approach, and backed up using a modified closed-form sequential compound option models. The value of a compound option is based on the value of another option. That is, the underlying variable for the compound option is another option, and the compound option can be either sequential in nature or simultaneous. Solving such a model requires programming capabilities. This subsection is meant as a quick peek into the math underlying a very basic closed-form compound option. This section is only a preview of the detailed modeling techniques used in the current analysis and should not be assumed to be the final word. For instance, as suggested in Mun (2016), we first start by solving for the critical value of *I*, an iterative component in the model, using the following equation:

$$X_2 = Ie^{-q(T_2-t_1)}\Phi\left(\frac{\ln(I/X_1)+(r-q+\sigma^2/2)(T_2-t_1)}{\sigma\sqrt{(T_2-t_1)}}\right)$$
$$-X_1e^{-r(T_2-t_1)}\Phi\left(\frac{\ln(I/X_1)+(r-q-\sigma^2/2)(T_2-t_1)}{\sigma\sqrt{(T_2-t_1)}}\right)$$

Then, solve recursively for the value from the previous equation and input it into the model:

$$
\begin{aligned}
\mathit{Compound\ Option} = {} & Se^{-qT_2}\Omega\left[\begin{array}{l}\dfrac{\ln(S/X_1)+(r-q+\sigma^2/2)T_2}{\sigma\sqrt{T_2}};\\ \dfrac{\ln(S/I)+(r-q+\sigma^2/2)t_1}{\sigma\sqrt{t_1}};\sqrt{t_1/T_2}\end{array}\right]\\
& -X_1e^{-rT_2}\Omega\left[\begin{array}{l}\dfrac{\ln(S/X_1)+(r-q+\sigma^2/2)T_2}{\sigma\sqrt{T_2}}-\sigma\sqrt{T_2};\\ \dfrac{\ln(S/I)+(r-q+\sigma^2/2)t_1}{\sigma\sqrt{t_1}}-\sigma\sqrt{t_1};\sqrt{t_1/T_2}\end{array}\right]\\
& -X_2e^{-rt_1}\Phi\left[\dfrac{\ln(S/I)+(r-q+\sigma^2/2)t_1}{\sigma\sqrt{t_1}}-\sigma\sqrt{t_1}\right]
\end{aligned}
$$

The model is then applied to a sequential problem where future phase options depend on previous phase options (e.g., Phase II depends on Phase I's successful implementation).

Definitions of Variables

| | |
|---|---|
| $S$ | present value of future cash flows ($) |
| $r$ | risk-free rate (%) |
| $\sigma$ | volatility (%) |
| $\Phi$ | cumulative standard-normal |
| $q$ | continuous dividend payout (%) |
| $I$ | critical value solved recursively |
| $\Omega$ | cumulative bivariate-normal |
| $X_1$ | strike for the underlying ($) |
| $X_2$ | strike for the option on the option ($) |
| $t_1$ | expiration date for the option on the option |
| $T_2$ | expiration date for the underlying option |

The preceding closed-form differential equation models are then verified using the risk-neutral market-replicating portfolio approach assuming a sequential compound option. In solving the market-replicating approach, we use the following functional forms, noted in Mun (2016):

- Hedge ratio *(h):*

  $$h_{i-1} = \frac{C_{up} - C_{down}}{S_{up} - S_{down}}$$

- Debt load *(D):*

  $$D_{i-1} = S_i(h_{i-1}) - C_i$$

- Call value *(C)* at node *i*:

  $$C_i = S_i(h_i) - D_i e^{-rf(\delta t)}$$

- Risk-adjusted probability *(q):*

  $q_i = \dfrac{S_{i-1} - S_{down}}{S_{up} - S_{down}}$ obtained assuming

  $$S_{i-1} = q_i S_{up} + (1 - q_i) S_{down}$$

- This means that

  $S_{i-1} = q_i S_{up} + S_{down} - q_i S_{down}$ and $q_i[S_{up} - S_{down}] = S_{i-1} - S_{down}$ ,

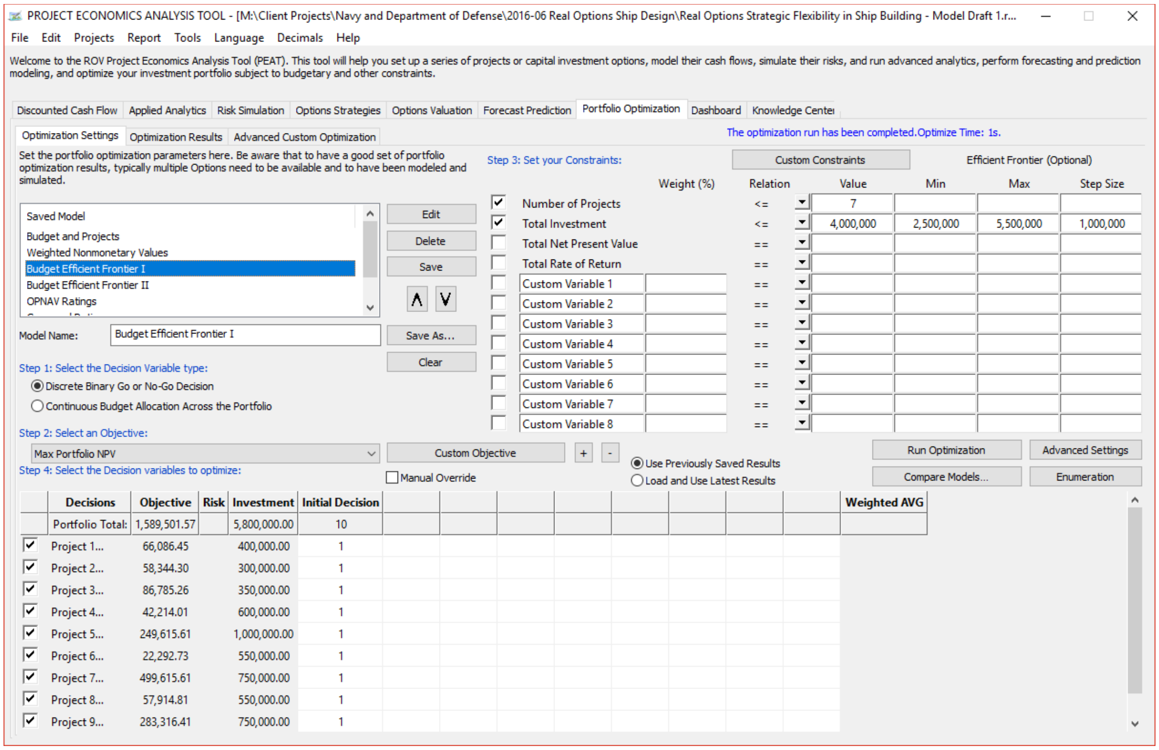
  so we get $q_i = \dfrac{S_{i-1} - S_{down}}{S_{up} - S_{down}}$

Additional methods using closed-form solutions, binomial and trinomial lattices, and simulation approaches, as well as dynamic simulated decision trees that are used in computing the relevant option values of each strategic pathways as previously indicated. Fortunately, Navy analysts do not have to be experts in advanced mathematics to run these models, as they have all been preprogrammed in PEAT, as illustrated in Figure 20.

## *Step 7: Portfolio Optimization*

Figure 21 illustrates the *Portfolio Optimization's Optimization Settings* subtab. In the Portfolio Optimization section, the individual projects can be modeled as a portfolio and optimized to determine the best combination of projects for the portfolio. In today's competitive global economy, companies are faced with many difficult decisions. These decisions include allocating financial resources, building or expanding facilities, managing inventories, and determining product-mix strategies. Such decisions might involve thousands or millions of potential alternatives. Considering and evaluating each of them would be impractical and maybe even impossible. A model can provide valuable assistance in incorporating relevant variables when analyzing decisions and in finding the best solutions for making decisions. Models capture the most important features of a problem and present them in a form that is easy to interpret. Models often provide insights that intuition alone cannot. An optimization model has three major elements: decision variables, constraints, and an objective. In short, the optimization methodology finds the best combination or permutation of decision variables (e.g., which products to sell or which projects to execute) in every conceivable way such that the objective is maximized (e.g., revenues and net income) or minimized (e.g., risk and costs) while still satisfying the constraints (e.g., budget and resources).

The projects can be modeled as a portfolio and optimized to determine the best combination of projects for the portfolio in the *Optimization Settings* subtab. Analysts start by selecting the optimization method (Static or Dynamic Optimization). Then they select the decision variable type of *Discrete Binary* (choose which Project or Options to execute with a Go/No-Go Binary 1/0 decision) or *Continuous Budget Allocation* (returns % of budget to allocate to each *option* or *project* as long as the total portfolio is 100%); select the *Objective* (Max NPV, Min Risk, etc.); set up any *Constraints* (e.g., budget restrictions, number of projects restrictions, or create customized restrictions); select the options or projects to optimize/allocate/choose (default selection is *all options*); and when completed, click *Run Optimization*.



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The optimization run has been completed.Optimize Time: 1s.

Set the portfolio optimization parameters here. Be aware that to have a good set of portfolio optimization results, typically multiple Options need to be available and to have been modeled and simulated.

Saved Model
Budget and Projects
Weighted Nonmonetary Values
Budget Efficient Frontier I
Budget Efficient Frontier II
OPNAV Ratings

Model Name: Budget Efficient Frontier I

Step 1: Select the Decision Variable type:
● Discrete Binary Go or No-Go Decision
○ Continuous Budget Allocation Across the Portfolio

Step 2: Select an Objective:
Max Portfolio NPV

Step 3: Set your Constraints:

Efficient Frontier (Optional)

| | | Weight (%) | Relation | Value | Min | Max | Step Size |
|---|---|---|---|---|---|---|---|
| ☑ | Number of Projects | | <= | 7 | | | |
| ☑ | Total Investment | | <= | 4,000,000 | 2,500,000 | 5,500,000 | 1,000,000 |
| ☐ | Total Net Present Value | | == | | | | |
| ☐ | Total Rate of Return | | == | | | | |
| ☐ | Custom Variable 1 | | == | | | | |
| ☐ | Custom Variable 2 | | == | | | | |
| ☐ | Custom Variable 3 | | == | | | | |
| ☐ | Custom Variable 4 | | == | | | | |
| ☐ | Custom Variable 5 | | == | | | | |
| ☐ | Custom Variable 6 | | == | | | | |
| ☐ | Custom Variable 7 | | == | | | | |
| ☐ | Custom Variable 8 | | == | | | | |

☐ Manual Override

● Use Previously Saved Results
○ Load and Use Latest Results

Step 4: Select the Decision variables to optimize:

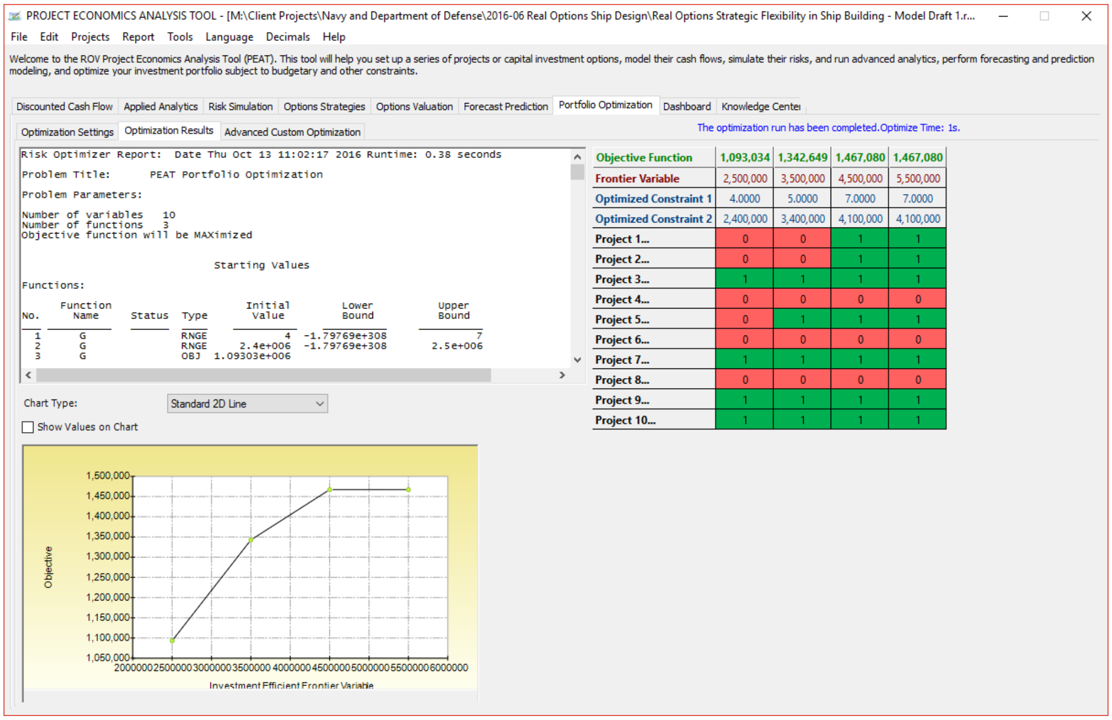
| | Decisions | Objective | Risk | Investment | Initial Decision | Weighted AVG |
|---|---|---|---|---|---|---|
| | Portfolio Total: | 1,589,501.57 | | 5,800,000.00 | 10 | |
| ☑ | Project 1... | 66,086.45 | | 400,000.00 | 1 | |
| ☑ | Project 2... | 58,344.30 | | 300,000.00 | 1 | |
| ☑ | Project 3... | 86,785.26 | | 350,000.00 | 1 | |
| ☑ | Project 4... | 42,214.01 | | 600,000.00 | 1 | |
| ☑ | Project 5... | 249,615.61 | | 1,000,000.00 | 1 | |
| ☑ | Project 6... | 22,292.73 | | 550,000.00 | 1 | |
| ☑ | Project 7... | 499,615.61 | | 750,000.00 | 1 | |
| ☑ | Project 8... | 57,914.81 | | 550,000.00 | 1 | |
| ☑ | Project 9... | 283,316.41 | | 750,000.00 | 1 | |

*Figure 21: Portfolio Optimization Settings*

Figure 22 illustrates the *Optimization Results*, which returns the results from the portfolio optimization analysis. The main results are provided in the data grid, showing the final *Objective Function* results, final *Optimized Constraints*, and the allocation, selection, or optimization across all individual options or projects within this optimized portfolio. The top left portion of the screen shows the textual details and results of the optimization algorithms applied, and the chart illustrates the final objective function. The chart will only show a single point for regular optimizations, whereas it will return an investment efficient frontier curve if the optional *Efficient Frontier* settings are set (min, max, step size).

Figures 22 and 23 are critical results for decision makers as they allow flexibility in designing their own portfolio of options. For instance, Figure 22 shows an efficient frontier of portfolios, where each of the points along the curve are optimized portfolios subject to a certain set of constraints. In this example, the constraints were the number of options that can be selected in a ship and the total cost of obtaining these options are subject to a budget constraint. The colored columns on the right in Figure 22 show the various combinations of budget limits and maximum number of options allowed. For instance, if a program office in the Navy only allocates $2.5 million (see the Frontier Variable located on the second row) and no more than four options per ship, then only options 3, 7, 9, and 10 are feasible, and this portfolio combination would generate the highest bang for the buck while simultaneously satisfying the budgetary and number of options constraints. If the constraints were relaxed to say, five options and $3.5 million budget, then option 5 is added to the mix. Finally, at $4.5 million and no more than seven options per ship, options 1 and 2 should be added to the mix. Interestingly, even with a higher budget of $5.5 million, the same portfolio of options is selected. In fact, the Optimized Constraint 2 shows that only $4.1 million is used. Therefore, as a decision-making tool for the budget-setting officials, the maximum budget that should be set for this portfolio of options should be $4.1 million. Similarly, the decision maker can move backwards, where say, if the original budget of $4.5 million was slashed by the U.S. Congress to $3.5 million, then the options that should be eliminated would be options 1 and 2.

While Figure 22 shows the efficient frontier where the constraints such as number of options allowed and budget were varied to determine the efficient portfolio selection, Figure 23 shows multiple portfolios with different objectives. For instance, the five models shown were to maximize the financial bang for the buck (minimizing cost and maximizing value while simultaneously minimizing risk), maximizing OPNAV value, maximizing KVA value, maximizing Command value, and maximizing a Weighted Average of all objectives. This capability is important because depending on who is doing the analysis, their objectives and decisions will differ based on different perspectives. Using a multiple criteria optimization approach allows us to see the scoring from all perspectives. Options with the highest count (e.g., 5) would receive the highest priority in the final portfolio, as it satisfies all stakeholders' perspectives, would hence be considered first, followed by options with counts of 4, 3, 2, and 1.



Welcome to the ROV Project Economics Analysis Tool (PEAT). This tool will help you set up a series of projects or capital investment options, model their cash flows, simulate their risks, and run advanced analytics, perform forecasting and prediction modeling, and optimize your investment portfolio subject to budgetary and other constraints.

The optimization run has been completed.Optimize Time: 1s.

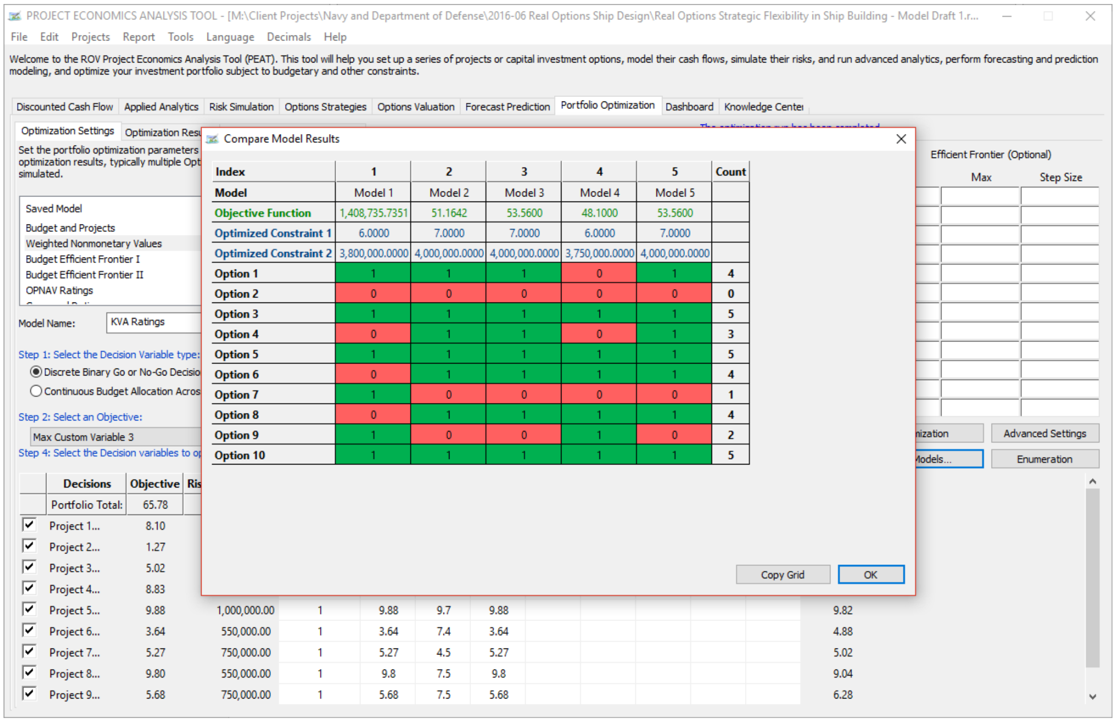
```
Risk Optimizer Report:  Date Thu Oct 13 11:02:17 2016 Runtime: 0.38 seconds

Problem Title:      PEAT Portfolio Optimization

Problem Parameters:

Number of variables   10
Number of functions   3
Objective function will be MAXimized


                          Starting Values

Functions:

      Function                        Initial       Lower          Upper
No.     Name       Status   Type       Value        Bound          Bound
___  _________     ______   ____    __________   __________     __________
 1       G                  RNGE             4  -1.79769e+308            7
 2       G                  RNGE       2.4e+006 -1.79769e+308     2.5e+006
 3       G                  OBJ   1.09303e+006
```

| Objective Function | 1,093,034 | 1,342,649 | 1,467,080 | 1,467,080 |
|---|---|---|---|---|
| Frontier Variable | 2,500,000 | 3,500,000 | 4,500,000 | 5,500,000 |
| Optimized Constraint 1 | 4.0000 | 5.0000 | 7.0000 | 7.0000 |
| Optimized Constraint 2 | 2,400,000 | 3,400,000 | 4,100,000 | 4,100,000 |
| Project 1... | 0 | 0 | 1 | 1 |
| Project 2... | 0 | 0 | 1 | 1 |
| Project 3... | 1 | 1 | 1 | 1 |
| Project 4... | 0 | 0 | 0 | 0 |
| Project 5... | 0 | 1 | 1 | 1 |
| Project 6... | 0 | 0 | 0 | 0 |
| Project 7... | 1 | 1 | 1 | 1 |
| Project 8... | 0 | 0 | 0 | 0 |
| Project 9... | 1 | 1 | 1 | 1 |
| Project 10... | 1 | 1 | 1 | 1 |

Chart Type: Standard 2D Line

☐ Show Values on Chart

Figure 22: Portfolio Optimization Results



Welcome to the ROV Project Economics Analysis Tool (PEAT). This tool will help you set up a series of projects or capital investment options, model their cash flows, simulate their risks, and run advanced analytics, perform forecasting and prediction modeling, and optimize your investment portfolio subject to budgetary and other constraints.

Set the portfolio optimization parameters
optimization results, typically multiple Opt
simulated.

Model Name: KVA Ratings

Step 1: Select the Decision Variable type:

● Discrete Binary Go or No-Go Decisio

○ Continuous Budget Allocation Acros

Step 2: Select an Objective:

Max Custom Variable 3

Step 4: Select the Decision variables to op

Compare Model Results

| Index | 1 | 2 | 3 | 4 | 5 | Count |
|---|---|---|---|---|---|---|
| Model | Model 1 | Model 2 | Model 3 | Model 4 | Model 5 | |
| Objective Function | 1,408,735.7351 | 51.1642 | 53.5600 | 48.1000 | 53.5600 | |
| Optimized Constraint 1 | 6.0000 | 7.0000 | 7.0000 | 6.0000 | 7.0000 | |
| Optimized Constraint 2 | 3,800,000.0000 | 4,000,000.0000 | 4,000,000.0000 | 3,750,000.0000 | 4,000,000.0000 | |
| Option 1 | 1 | 1 | 1 | 0 | 1 | 4 |
| Option 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| Option 3 | 1 | 1 | 1 | 1 | 1 | 5 |
| Option 4 | 0 | 1 | 1 | 0 | 1 | 3 |
| Option 5 | 1 | 1 | 1 | 1 | 1 | 5 |
| Option 6 | 0 | 1 | 1 | 1 | 1 | 4 |
| Option 7 | 1 | 0 | 0 | 0 | 0 | 1 |
| Option 8 | 0 | 1 | 1 | 1 | 1 | 4 |
| Option 9 | 1 | 0 | 0 | 1 | 0 | 2 |
| Option 10 | 1 | 1 | 1 | 1 | 1 | 5 |

| | Decisions | Objective | Ris | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Portfolio Total: | 65.78 | | | | | | | | | | | |
| ☑ | Project 1... | 8.10 | | | | | | | | | | | |
| ☑ | Project 2... | 1.27 | | | | | | | | | | | |
| ☑ | Project 3... | 5.02 | | | | | | | | | | | |
| ☑ | Project 4... | 8.83 | | | | | | | | | | | |
| ☑ | Project 5... | 9.88 | 1,000,000.00 | 1 | 9.88 | 9.7 | 9.88 | | | | | | 9.82 |
| ☑ | Project 6... | 3.64 | 550,000.00 | 1 | 3.64 | 7.4 | 3.64 | | | | | | 4.88 |
| ☑ | Project 7... | 5.27 | 750,000.00 | 1 | 5.27 | 4.5 | 5.27 | | | | | | 5.02 |
| ☑ | Project 8... | 9.80 | 550,000.00 | 1 | 9.8 | 7.5 | 9.8 | | | | | | 9.04 |
| ☑ | Project 9... | 5.68 | 750,000.00 | 1 | 5.68 | 7.5 | 5.68 | | | | | | 6.28 |

Figure 23: Multi-criteria Portfolio Optimization Results

As a side note and for the purposes of being comprehensive and inclusive, we point out that multiple types of algorithms have been developed over the years to find the solutions of an optimization problem, from basic linear optimization using the simplex model and solving first partial differential equations. However, when more and more complex real-life problems are assumed, these basic methods tend to break down and more advanced algorithms are required. In solving our efficient frontier problem, we utilized a combination of genetic algorithm, Lagrange multipliers and taboo-based reduced gradient search methodologies.

Simplistically, the Lagrange multiplier solution assumes some nonlinear problem of:

$$\min \mathit{or} \max f(x)$$

$$s.t. \quad g_i(x) = \ b_i \ \ \forall \ i = 1, \dots, m$$

where the equality is oftentimes replaced by some inequality values indicating a ceiling or floor constraint.

From this functional form, we first derive the Lagrange multiplier *v* for all *i* values:

$$L(x, v) \triangleq f(x) + \sum_{i=1}^{m} v_i[b_i - g_i(x)]$$

$$s.t. constraints\ g_i(x) = b_1, \dots, g_m(x) = b_m$$

The solution (*x**, *v**) is a set of points along the Lagrange function *L(x,v)* if it satisfies the condition:

$$\sum_i \nabla g_i(x^*)v^* = f(x^*)\ which\ requires\ \sum_i \frac{\partial g_i}{\partial x_j} v_i = \frac{\partial f}{\partial x_j} \forall j\ and\ \ g_i(x^*) = b_i$$

This approach is simple and elegant but limited to linear and quasi-linear, as well as some simple nonlinear functional forms of *f(x)*. In order to be able to extend the functional form to generalized nonlinear applications, we need to add additional conditions to the solution set and apply some search algorithms to cover a large (and oftentimes unlimited set of optimal allocations). One limitation is the requirement that the Kuhn-Tucker condition is satisfied where the nonlinear problems have a differentiable general form:

$$\min or \max f(x)$$

$$s.t.\quad g_i(x) \geq\ b_i\ \ \forall\ i \in Feasible\ Set$$

$$g_i(x) \leq\ b_i\ \ \forall\ i \in Feasible\ Set$$

$$g_i(x) =\ b_i\ \ \forall\ i \in Feasible\ Set$$

and the inequality constraints will need to be active at a local optimum or when the Lagrange variable is set to null:

$$v_i[b_i - g_i(x)] = 0$$

In addition, mathematical algorithms will have to be developed to perform both an ad-hoc and systematic search of the optimal solution set. Using an enumeration method will take even a supercomputer close to an infinite number of years to delineate all possible permutations. Therefore, search algorithms are typically used in generating an efficient frontier using optimization. One simple approach is the use of a reduced gradient search method. To summarize the approach, we assume

$$\nabla f(x) \cdot \Delta x$$

where the functional form *f(x)* is the objective function and is divided into two parts, a basic (*B*) and non-basic portion (*N*) is multiplied by the change in vector direction *x*. Using a Taylor expansion, we obtain:

$$\begin{aligned}&\nabla f(x) \cdot \Delta x = \nabla f(x)^B \cdot \Delta x^B + \nabla f(x)^N \cdot \Delta x^N\\&= \nabla f(x)^B \cdot (-B^{-1}N\Delta x^N) + \nabla f(x)^N \cdot \Delta x^N\\&= (\nabla f(x)^N - \nabla f(x)^B B^{-1}N)\Delta x^N\end{aligned}$$

The reduced gradient with respect to the solution matrix *B* is

$$r \triangleq (r^B, r^N)$$

where

$$r^B \triangleq 0$$

$$r^N \triangleq \nabla f(x)^N - \nabla f(x)^B B^{-1} N$$

Solving for this solution set is manually possible when the number of decision variables is small (typically less than four or five), but once the number of decision variables is large, as in all real-life situations, the manual solution is intractable and computer search algorithms have to be employed. The general method employed includes taking the following steps:

1. Starting point estimation and obtain the basis matrix set.
2. Compute sample test points and obtain the reduced gradient vector direction.
3. Test for constraint feasibilities at the limits.
4. Solve for the Lagrange optimal set.
5. Start on a new set of points.
6. Change the basis set if a better set of points is obtained, or stop optimization.
7. Repeat iteration and advance or stop when tolerance level is achieved.

## *Step 8: Results Dashboard and Presentation*

Finally, Figure 24 illustrates the PEAT Dashboard. After all the models are run (simulations, tornado, scenarios, etc.), analysts can access the *Dashboard* to create the settings required to generate the dashboard. Multiple dashboards can be saved and rerun as required for presentation to senior management and decision makers in the Navy.

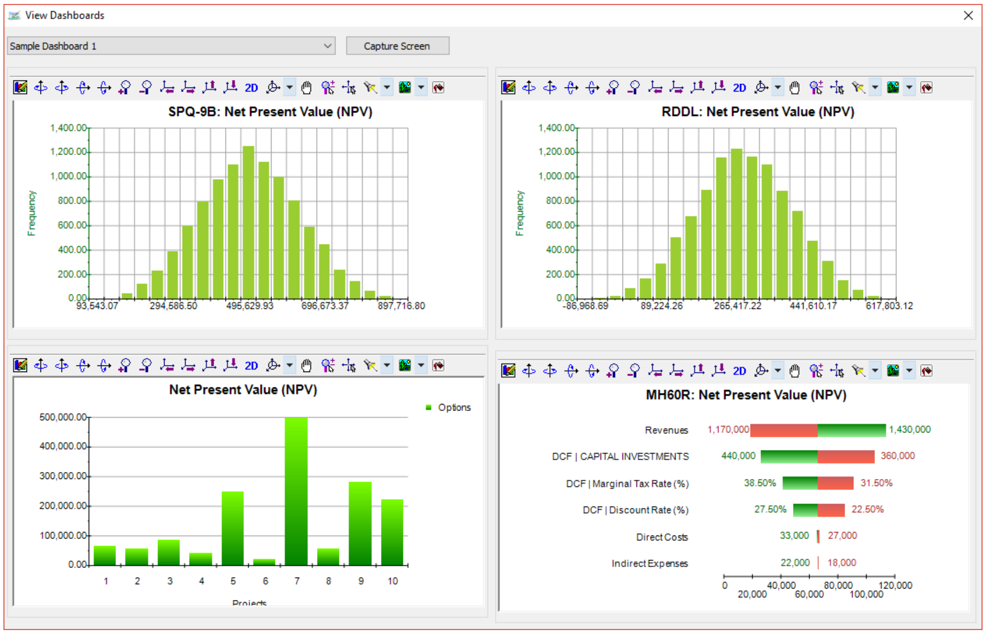


*Figure 24: Dashboard*

# Conclusions and Recommendations

## Key Conclusions and Next Steps

Strategic real options valuation (ROV) provides the option holder the right, but not the obligation, to hold off on executing a certain decision until a later time when uncertainties are resolved and when better information is available. The option implies that flexibility to execute a certain path exists and was predetermined or predesigned in advance. Based on the research performed thus far, we conclude that the methodology has significant merits and is worthy of more detailed follow-on analysis. It is therefore recommended that the ROV methodology be applied on a real case facing the Navy, applied with actual data, and the project's outcomes tracked over time.

## Recommendations on Implementing Real Options Analysis

First, it is vital to understand that real options analysis is *not* a simple set of equations or models. It is an *entire decision-making process* that enhances the traditional decision analysis approaches. It takes what has been tried-and-true financial analytics and evolves it to the next step by pushing the envelope of analytical techniques. In addition, it is vital to understand that 50% of the value in real options analysis is simply thinking about it. Another 25% of the value comes from the number crunching activities, while the final 25% comes from the results interpretation and explanation to management. Several issues should be considered when attempting to implement real options analysis:

- **Tools––**The correct tools are important. These tools must be more comprehensive than initially required because analysts will grow into them over time. Do not be restrictive in choosing the relevant tools. Always provide room for expansion. Advanced tools will relieve the analyst of detailed model building and let him or her focus instead on 75% of the value—thinking about the problem and interpreting the results.
- **Resources––**The best tools in the world are useless without the relevant human resources to back them up. Tools do not eliminate the analyst, but enhance the analyst's ability to effectively and efficiently execute the analysis. The right people with the right tools will go a long way. Because

there are only a few true real options experts in the world, who truly understand the theoretical underpinnings of the models as well as the practical applications, care should be taken in choosing the correct team. A team of real options experts is vital in the success of the initiative. A company should consider building a team of in-house experts to implement real options analysis and to maintain the ability for continuity, training, and knowledge transfer over time. Knowledge and experience in the theories, implementation, training, and consulting are the core requirements of this team of individuals. This is why training is vital. For instance, the CRM/CQRM certification program provides analysts and managers the opportunity to immerse themselves into the theoretical and real-life applications of simulation, forecasting, optimization, and real options (for details please see www.realoptionsvaluation.com).

- **Senior Decision-Maker Buy-in**—The analysis buy-in must be top-down where senior management drives the real options analysis initiative. A bottom-up approach where a few inexperienced junior analysts try to impress the powers that be will fail miserably.

## *Criticisms, Caveats, and Misunderstandings in Real Options*

Before embarking on ROV analytics, analysts should be aware of several caveats. The following five requirements need to be satisfied before an ROV analysis can be run:

- *A financial model must exist.* Real options analysis requires the use of an existing discounted cash flow model, as real options build on the existing tried-and-true approaches of current financial modeling techniques. If a model does not exist, it means that strategic decisions have already been made and no financial justifications are required, and, hence, there is no need for financial modeling or real options analysis.
- *Uncertainties must exist.* Otherwise, the option value is worthless. If everything is known for certain in advance, then a discounted cash flow model is sufficient. In fact, when volatility (a measure of risk and uncertainty) is zero, everything is certain, the real options value is zero, and the total strategic value of the project or asset reverts to the net present value in a discounted cash flow model.
- *Uncertainties must affect decisions* when the firm is actively managing the project, and *these uncertainties must affect the results* of the financial model. These uncertainties will then become risks, and real options can be used to hedge the downside risk and take advantage of the upside uncertainties.
- *Management must have strategic flexibility or options* to make midcourse corrections when actively managing the projects. Otherwise, do not apply

real options analysis when there are no options or management flexibility to value.

- *Management must be smart and credible enough to execute the options when it becomes optimal to do so.* All the options in the world are useless unless they are executed appropriately—at the right time and under the right conditions.

There are also several criticisms against real options analysis. It is vital that the analyst understands what they are and how to respond to them.

- *Real options analysis is merely an academic exercise and is not practical in actual business applications.* Nothing is further from the truth. Although it was true in the past that real options analysis was merely academic, many corporations have begun to embrace and apply real options analysis. Also, its concepts are very pragmatic and with the use of the Real Options Super Lattice Solver software, even very difficult problems can be easily solved. This software has helped bring the theoretical a lot closer to practice. Firms are using it and universities are teaching it. It is only a matter of time before real options analysis becomes part of standard financial analysis.
- *Real options analysis is just another way to bump up and incorrectly increase the value of a project to get it justified.* Again, nothing is further from the truth. If a project has significant strategic options but the analyst does not value them appropriately, he or she is leaving money on the table. In fact, the analyst will be incorrectly undervaluing the project or asset. Also, one of the foregoing requirements states that one should never run real options analysis unless strategic options and flexibility exist. If they do not exist, then the option value is zero, but if they do exist, neglecting their valuation will grossly and significantly underestimate the project or asset's value.
- *Real options analysis ends up choosing the highest risk projects as the higher the volatility, the higher the option value.* This criticism is also incorrect. The option value is zero if no options exist. However, if a project is highly risky and has high volatility, then real options analysis becomes more important. That is, if a project is strategic but is risky, then you need to incorporate, create, integrate, or obtain strategic real options to reduce and hedge the downside risk and take advantage of the upside uncertainties. Therefore, this argument is heading in the wrong direction. It is not that real options will overinflate a project's value, but for risky projects, you should create or obtain real options to reduce the risk and increase the upside, thereby increasing the total strategic value of the project. Also, although an option value is always greater than or equal to zero, sometimes the cost to obtain certain options may exceed their benefits, making the entire strategic value of the option negative, although

> the option value itself is always zero or positive. Thus, it is incorrect to say that real options increase the value of a project or that only risky projects are selected.

People who make these criticisms do not truly understand how real options work. However, having said that, real options analysis is just another financial analysis tool, and the old axiom “garbage in, garbage out” still holds. But if care and due diligence are exercised, the analytical process and results can provide highly valuable insights. In fact, we believe that 50% (rounded, of course) of the challenge and value of real options analysis is simply *thinking about it*. Understanding that you have options, obtaining options to hedge the risks and take advantage of the upside, and to think in terms of strategic options, is half the battle. Another 25% of the value comes from running the analysis and obtaining the results. The final 25% of the value comes from being able to explain it to management, to your clients, and to yourself, such that the results become actionable intelligence that can be capitalized and acted upon, and not merely another set of numbers.

# Appendix 1—A Primer on Integrated Risk Management

Since the beginning of recorded history, games of chance have been a popular pastime. Even in Biblical accounts, Roman soldiers cast lots for Christ's robes. In earlier times, chance was something that occurred in nature, and humans were simply subjected to it as a ship is to the capricious tosses of the waves in an ocean. Even up to the time of the Renaissance, the future was thought to be simply a chance occurrence of completely random events and beyond the control of humans. However, with the advent of games of chance, human greed has propelled the study of risk and chance to ever more closely mirror real-life events. Although these games were initially played with great enthusiasm, no one sat down and figured out the odds. Of course, the individual who understood and mastered the concept of chance was bound to be in a better position to profit from such games of chance. It was not until the mid-1600s that the concept of chance was properly studied, and the first such serious endeavor can be credited to Blaise Pascal, one of the fathers of the study of choice, chance, and probability. Fortunately for us, after many centuries of mathematical and statistical innovations from pioneers such as Pascal, Bernoulli, Bayes, Gauss, LaPlace, and Fermat, and with the advent of blazing fast computing technology, our modern world of uncertainty can be explained with much more elegance through methodological rigorous hands-on applications of risk and uncertainty. Even as recently as two and a half decades ago, computing technology was only in its infancy, and running complex and advanced analytical models would have seemed a fantasy, but today, with the assistance of more powerful and enabling software packages, we can practically apply such techniques with great ease. For this reason, we have chosen to learn from human history that with innovation comes the requisite change in human behavior to apply these new methodologies as the new norm for rigorous risk-benefit analysis.

To the people who lived centuries ago, risk was simply the inevitability of chance occurrence beyond the realm of human control. Nevertheless, many phony soothsayers profited from their ability to convincingly profess their clairvoyance by simply stating the obvious or reading the victims' body language and telling them what they wanted to hear. We modern-day humans, ignoring for the moment the occasional seers among us, with our fancy technological achievements, are still susceptible to risk and uncertainty. We may be able to predict the orbital paths of planets in our solar system with astounding accuracy or the escape velocity required to shoot a man from the Earth to the Moon, or drop a smart bomb within a few feet of its target thousands of miles away, but when it comes to, say, predicting a firm's revenues the following year, we are at a loss. Humans have been struggling with risk our entire existence, but through trial and error, and through the evolution of human knowledge and thought, have devised ways to describe, quantify, hedge, and take advantage of risk.

In the U.S. Military context, risk analysis, real options analysis, and portfolio optimization techniques are enablers of a new way of approaching the problems of estimating return on investment (ROI) and estimating the risk-value of various strategic real options. There are many new Department of Defense (DOD) requirements for using more advanced analytical techniques. For instance, the Clinger-Cohen Act of 1996 mandates the use of portfolio management for all federal agencies. The Government Accountability Office's "Assessing Risks and Returns: A Guide for Evaluating Federal Agencies' IT Investment Decision-Making," Version 1 (February 1997) requires that IT investments apply ROI measures. DOD Directive 8115.01 issued October 2005 mandates the use of performance metrics based on outputs, with ROI analysis required for all current and planned IT investments. DOD Directive 8115.bb (approved in late 2006) implements policy and assigns responsibilities for the management of DOD IT investments as portfolios within the DOD Enterprise where they define a portfolio to include outcome performance measures and an expected return on investment. The DOD Risk Management Guidance Defense Acquisition guide book requires that alternatives to the traditional cost estimation need to be considered because legacy cost models tend not to adequately address costs associated with information systems or the risks associated with them.

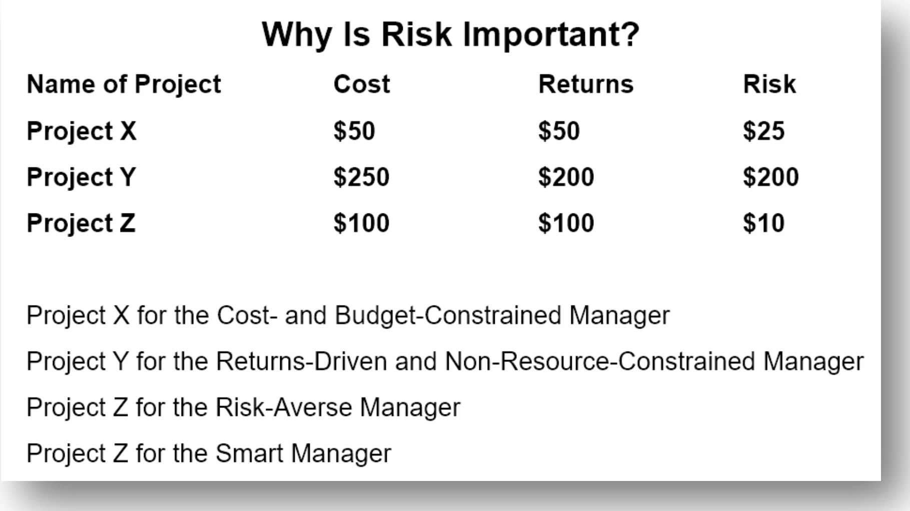
In this quick primer, advanced quantitative risk-based concepts will be introduced, namely, the hands-on applications of Monte Carlo simulation, real options analysis, stochastic forecasting, portfolio optimization, and knowledge value added. These methodologies rely on common metrics and existing techniques (e.g., return on investment, discounted cash flow, cost-based analysis, and so forth), and they complement these traditional techniques by pushing the envelope of analytics, not replacing them outright. We are not asking the reader to embrace a complete change of paradigm and throw out what has been tried and true, but to shift one's paradigm, to move with the times, and to improve upon what has been tried and true. These new methodologies are used in helping make the best possible decisions, allocate budgets, predict outcomes, create portfolios with the highest strategic value and returns on investment, and so forth, where the conditions surrounding these decisions are risky or uncertain. They can be used to identify, analyze, quantify, value, predict, hedge, mitigate, optimize, allocate, diversify, and manage risk for military options.

### *Why Is Risk Important in Making Decisions?*

Before we embark on the journey to review these advanced techniques, let us first consider why risk is critical when making decisions, and how traditional analyses are inadequate in considering risk in an objective way. Risk is an important part of the decision-making process. For instance, suppose projects are chosen based simply on an evaluation of returns alone or cost alone; clearly the higher-return or lower-cost project will be chosen over lower-return or higher-cost projects.

As mentioned, projects with higher returns will in most cases bear higher risks. And those projects with immediately lower returns would be abandoned. In those cases, where return estimates are wholly derived from cost data (with some form of cost in the numerator and denominator of ROI), the best thing to do is reduce all the costs, that is, never invest in new projects. The result of this primary focus on cost reduction is a stifling of innovation and new ways of doing things. The goal is not simply cost reduction. In this case, the simplest approach is to fire everyone and sell off all the assets. The real question that must be answered is how cost compares to desired outputs, that is, “cost compared to what?”

To encourage a focus on improving processes and innovative technologies, a new way of calculating return on investment that includes a unique numerator is required. ROI is a basic productivity ratio that requires unique estimates of the numerator (i.e., value, revenue in common units of measurement) and the denominator (i.e., costs, investments in dollars). ROI estimates must be placed within the context of a longer-term view that includes estimates of risk and the ability of management to adapt as they observe the performance of their investments over time. Therefore, instead of relying purely on immediate ROIs or costs, a project, strategy, process innovation, or new technology should be evaluated based on its total strategic value, including returns, costs, and strategic options, as well as its risks. Figures A.1 and A.2 illustrate the errors in judgment when risks are ignored. Figure A.1 lists three mutually exclusive projects with their respective costs to implement, expected net returns (net of the costs to implement), and risk levels (all in present values). Clearly, for the budget-constrained decision maker, the cheaper the project the better, resulting in the selection of Project X. The returns-driven decision maker will choose Project Y with the highest returns, if budget is not an issue. Project Z will be chosen by the risk-averse decision maker as it provides the least amount of risk while providing a positive net return. The upshot is that, with three different projects and three different decision makers, three different decisions will be made. Who is correct and why?



**Why Is Risk Important?**

| Name of Project | Cost | Returns | Risk |
|---|---|---|---|
| Project X | $50 | $50 | $25 |
| Project Y | $250 | $200 | $200 |
| Project Z | $100 | $100 | $10 |

Project X for the Cost- and Budget-Constrained Manager

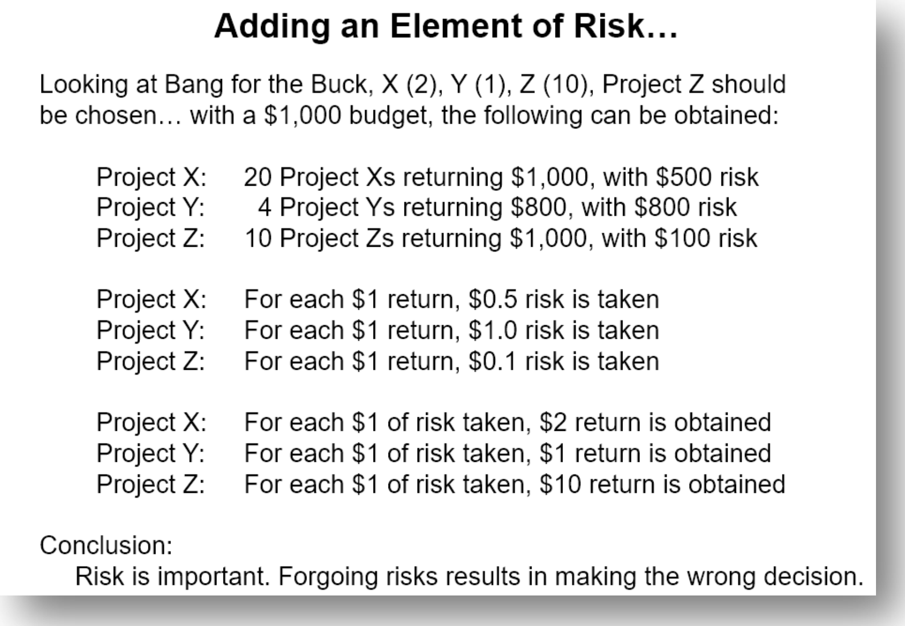
Project Y for the Returns-Driven and Non-Resource-Constrained Manager

Project Z for the Risk-Averse Manager

Project Z for the Smart Manager

*Figure A.1. Why Is Risk Important?*

Figure A.2 shows that Project Z should be chosen. For illustration purposes, suppose all three projects are independent and mutually exclusive, and that an unlimited number of projects from each category can be chosen but the budget is constrained at $1,000. Therefore, with this $1,000 budget, 20 project Xs can be chosen, yielding $1,000 in net returns and $500 risks, and so forth. It is clear from Figure A.2 that project Z is the best project as for the same level of net returns ($1,000), the least amount of risk is undertaken ($100). Another way of viewing this selection is that for each $1 of returns obtained, only $0.1 amount of risk is involved on average, or that for each $1 of risk, $10 in returns are obtained on average. This example illustrates the concept of bang for the buck or getting the best value (benefits and costs both considered) with the least amount of risk. An even more obvious example is if there are several different projects with identical single-point average net benefit or cost of $10 million each. Without risk analysis, a decision maker should in theory be indifferent in choosing any of the projects. However, with risk analysis, a better decision can be made. For instance, suppose the first project has a 10% chance of exceeding $10 million; the second, a 15% chance; and the third, a 55% chance. Additional critical information is obtained on the riskiness of the project or strategy and a better decision can be made.



**Adding an Element of Risk…**

Looking at Bang for the Buck, X (2), Y (1), Z (10), Project Z should be chosen… with a $1,000 budget, the following can be obtained:

Project X: 20 Project Xs returning $1,000, with $500 risk
Project Y: 4 Project Ys returning $800, with $800 risk
Project Z: 10 Project Zs returning $1,000, with $100 risk

Project X: For each $1 return, $0.5 risk is taken
Project Y: For each $1 return, $1.0 risk is taken
Project Z: For each $1 return, $0.1 risk is taken

Project X: For each $1 of risk taken, $2 return is obtained
Project Y: For each $1 of risk taken, $1 return is obtained
Project Z: For each $1 of risk taken, $10 return is obtained

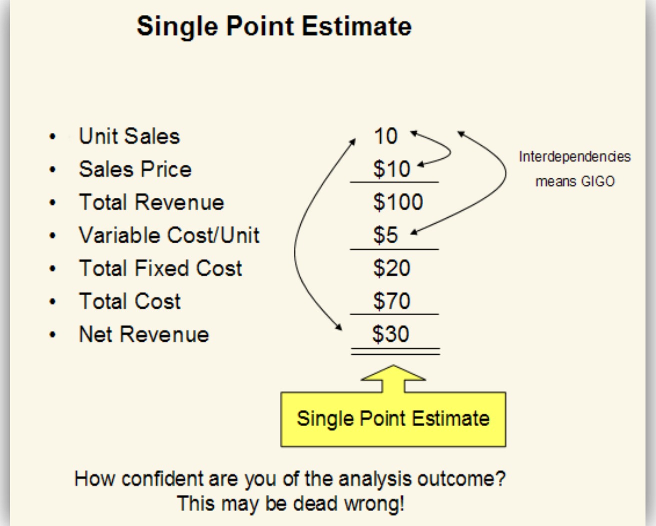
Conclusion:
Risk is important. Forgoing risks results in making the wrong decision.

*Figure A.2. Adding an Element of Risk*

### *From Dealing with Risk the Traditional Way to Monte Carlo Simulation*

Military and business leaders have been dealing with risk since the beginning of the history of war and commerce. In most cases, decision makers have looked at the risks of a particular project, acknowledged their existence, and moved on. Little quantification was performed in the past. In fact, most decision makers look only to single-point estimates of a project’s benefit or profitability. Figure A.3 shows an example of a single-point estimate. The estimated net revenue of $30 is simply that: a single point whose probability of occurrence is close to zero. Even in the simple model shown in Figure A.3, the effects of interdependencies are ignored, and in traditional modeling jargon, we have the problem of garbage-in, garbage-out (GIGO). As an example of interdependencies, the units sold are probably negatively correlated to the price of the product, and positively correlated to the average variable cost; ignoring these effects in a single-point estimate will yield grossly incorrect results. There are numerous interdependencies in military options as well, for example, the many issues in logistics and troop movements beginning with the manufacturer all the way to the warrior in the field.

In the commercial example shown in Figure A.3, if the unit sales variable becomes 11 instead of 10, the resulting revenue may not simply be $35. The net revenue may decrease due to an increase in variable cost per unit while the sale price may be slightly lower to accommodate this increase in unit sales. Ignoring these interdependencies will reduce the accuracy of the model.



**Single Point Estimate**

| | |
|---|---|
| Unit Sales | 10 |
| Sales Price | $10 |
| Total Revenue | $100 |
| Variable Cost/Unit | $5 |
| Total Fixed Cost | $20 |
| Total Cost | $70 |
| Net Revenue | $30 |

Interdependencies means GIGO

Single Point Estimate

How confident are you of the analysis outcome?
This may be dead wrong!

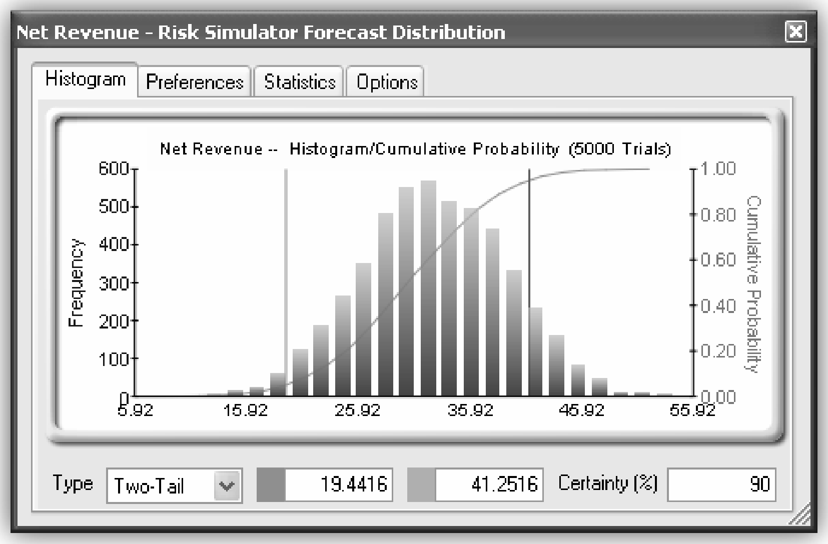
*Figure A.3. Single-Point Estimates*

One traditional approach used to deal with risk and uncertainty is the application of scenario analysis. For example, scenario analysis is a central part of the capabilities-based planning approach in widespread use for developing DOD strategies. In the commercial example illustrated in Figure A.3, suppose three scenarios were generated: the worst-case, nominal-case, and best-case scenarios. When different values are applied to the unit sales, the resulting three scenarios' net revenues are obtained. As earlier, the problems of interdependencies are not addressed with these common approaches. The net revenues obtained are simply too variable. Not much can be determined from such an analysis.

In the military planning case, the problems are exacerbated by the lack of objective ways to estimate benefits in common units. Without the common-unit benefits analysis, it becomes difficult, if not impossible, to compare the net benefits of various scenarios. In addition, interdependencies must be interpreted in a largely subjective manner, making it impossible to apply powerful mathematical and statistical tools that enable more objective portfolio analysis. The problem arises for the top leaders in the DOD to make judgment calls, selecting among alternatives (often referred to as “trades”) about the potential benefits and risks of numerous projects and technologies investments.

A related approach is to perform what-if or sensitivity analysis. Each variable is perturbed a prespecified amount (e.g., unit sales is changed ±10%, sales price is changed ±5%, and so forth) and the resulting change in net benefits is captured. This approach is useful for understanding which variables drive or impact the result the most. Performing such analyses by hand or with simple Excel spreadsheets is tedious and provides marginal benefits at best. A related approach that has the same goals but employs a more powerful analytic framework is the use of computer-modeled Monte Carlo simulation and tornado sensitivity analysis, where all perturbations, scenarios, and sensitivities are run hundreds of thousands of times automatically.

Therefore, computer-based Monte Carlo simulation, one of the advanced concepts introduced in this paper, can be viewed as simply an extension of the traditional approaches of sensitivity and scenario testing. The critical success drivers or the variables that affect the bottom-line variables the most, which at the same time are uncertain, are simulated. In simulation, the interdependencies are accounted for by using correlation analysis. The uncertain variables are then simulated tens of thousands of times automatically to emulate all potential permutations and combinations of outcomes. The resulting net revenues-benefits from these simulated potential outcomes are tabulated and analyzed. In its most basic form, simulation is simply an enhanced version of traditional approaches such as sensitivity and scenario analysis but automatically performed for thousands of times while accounting for all the dynamic interactions between the simulated variables. The resulting net revenues from simulation, as seen in Figure A.4, show that there is a 90% probability that the net revenues will fall between $19.44 and $41.25, with a 5% worst-case scenario of net revenues falling below $19.44. Rather than having only three scenarios, simulation created 5,000 scenarios, or trials, where multiple variables are simulated and changing simultaneously (unit sales, sale price, and variable cost per unit), while their respective relationships or correlations are maintained.



Type Two-Tail 19.4416 41.2516 Certainty (%) 90

*Figure A.4. Simulation Results*

Monte Carlo simulation, named for the famous gambling capital of Monaco, is a very potent methodology. For the practitioner, simulation opens the door for solving difficult and complex but practical problems with great ease. Perhaps the most famous early use of Monte Carlo simulation was by the Nobel physicist Enrico Fermi (sometimes referred to as the father of the atomic bomb) in 1930, when he used a random method to calculate the properties of the newly discovered neutron. Monte Carlo methods were central to the simulations required for the Manhattan Project, where in the 1950s Monte Carlo simulation was used at Los Alamos for early work relating to the development of the hydrogen bomb and became popularized in the fields of physics and operations research. The Rand Corporation and the U.S. Air Force were two of the major organizations responsible for funding and disseminating information on Monte Carlo methods during this time, and today there is a wide application of Monte Carlo simulation in many different fields including engineering, physics, research and development, business, and finance.

Simplistically, Monte Carlo simulation creates artificial futures by generating thousands and even hundreds of thousands of sample paths of outcomes and analyzes their prevalent characteristics. In practice, Monte Carlo simulation methods are used for risk analysis, risk quantification, sensitivity analysis, and prediction. An alternative to simulation is the use of highly complex stochastic closed-form mathematical models. For a high-level decision maker, taking graduate level advanced math and statistics courses is just not logical or practical. A well-informed analyst would use all available tools at his or her disposal to obtain the same answer the easiest and most practical way possible. And in all cases, when modeled correctly, Monte Carlo simulation provides similar answers to the more mathematically elegant methods. In addition, there are many real-life applications where closed-form models do not exist and the only recourse is to apply simulation methods. So, what exactly is Monte Carlo simulation and how does it work?

Monte Carlo simulation in its simplest form is a random number generator that is useful for forecasting, estimation, and risk analysis. A simulation calculates numerous scenarios of a model by repeatedly picking values from a user-predefined probability distribution for the uncertain variables and using those values for the model. As all those scenarios produce associated results in a model, each scenario can have a forecast. Forecasts are events (usually with formulas or functions) that you define as important outputs of the model.

Think of the Monte Carlo simulation approach as picking golf balls out of a large basket repeatedly with replacement. The size and shape of the basket depend on the distributional input assumption (e.g., a normal distribution with a mean of 100 and a standard deviation of 10, versus a uniform distribution or a triangular distribution) where some baskets are deeper or more symmetrical than others, allowing certain balls to be pulled out more frequently than others. The number of balls pulled repeatedly depends on the number of trials simulated. Each ball is indicative of an event, scenario, or condition that can occur. For a large model with multiple related assumptions, imagine the large model as a very large basket, wherein many baby baskets reside. Each baby basket has its own set of colored golf balls that are bouncing around. Sometimes these baby baskets are linked with each other (if there is a correlation between the variables), forcing the golf balls to bounce in tandem whereas in other uncorrelated cases, the balls are bouncing independently of one another. The balls that are picked each time from these interactions within the model (the large basket) are tabulated and recorded, providing a forecast output result of the simulation.

### *Knowledge Value Added Analysis*

As the U.S. Military is not in the business of making money, referring to revenues throughout this paper may appear to be a misnomer. For nonprofit organizations, especially in the military, we require Knowledge Value Added (KVA), which will provide the required “benefits” or “revenue” proxy estimates to run ROI analysis. ROI is a basic productivity ratio with revenue in the numerator and cost to generate the revenue in the denominator (ROI is revenue-cost/cost). KVA generates ROI estimates by developing a market comparable price per common unit of output multiplied by the number of outputs to achieve a total revenue estimate.

KVA is a methodology whose primary purpose is to describe all organizational outputs in common units. It provides a means to compare the outputs of all assets (human, machine, information technology) regardless of the aggregated outputs produced. For example, the purpose of a military process may be to gather signal intelligence or plan for a ship alteration. KVA would describe the outputs of both processes in common units thus making their performance comparable.

KVA measures the value provided by human capital assets and IT assets by analyzing an organization, process, or function at the process level. It provides insights into each dollar of IT investment by monetizing the outputs of all assets, including intangible assets (e.g., such as that produced by IT and humans). By capturing the value of knowledge embedded in an organization’s core processes (i.e., employees and IT), KVA identifies the actual cost and revenue of a process, product, or service. Because KVA identifies every process required to produce an aggregated output in terms of the historical prices and costs per common unit of output of those processes, unit costs and unit prices can be calculated. The methodology has been applied in 45 areas within the DOD, from flight scheduling applications to ship maintenance and modernization processes.

As a performance tool, the KVA methodology

- compares all processes in terms of relative productivity,
- allocates revenues and costs to common units of output,
- measures value added by IT by the outputs it produces, and
- relates outputs to cost of producing those outputs in common units.

Based on the tenets of complexity theory, KVA assumes that humans and technology in organizations add value by taking inputs and changing them (measured in units of complexity) into outputs through core processes. The amount of change an asset within a process produces can be a measure of value or benefit. The additional assumptions in KVA include

- Describing all process outputs in common units (e.g., using a knowledge metaphor for the descriptive language in terms of the time it takes an average employee to learn how to produce the outputs) allows historical revenue and cost data to be assigned to those processes historically.
- All outputs can be described in terms of the time required to learn how to produce them.
- Learning Time, a surrogate for procedural knowledge required to produce process outputs, is measured in common units of time. Consequently, Units of Learning Time = Common Units of Output (K).
- Common unit of output makes it possible to compare all outputs in terms of cost per unit as well as price per unit, because revenue can now be assigned at the suborganizational level.
- Once cost and revenue streams have been assigned to suborganizational outputs, normal accounting and financial performance and profitability metrics can be applied.

Describing processes in common units also permits market comparable data to be generated, particularly important for nonprofits like the U.S. Military. Using a market comparables approach, data from the commercial sector can be used to estimate price per common unit, allowing for revenue estimates of process outputs for nonprofits. This approach also provides a common-unit basis to define benefit streams regardless of the process analyzed.

KVA differs from other nonprofit ROI models because it allows for revenue estimates, enabling the use of traditional accounting, financial performance, and profitability measures at the suborganizational level. KVA can rank processes by the degree to which they add value to the organization or its outputs. This ranking assists decision makers in identifying how much processes add value. Value is quantified in two key metrics: Return on Knowledge (ROK: revenue/cost) and ROI (revenue-investment cost/investment cost). The outputs from a KVA analysis become the input into the ROI models and real options analysis. By tracking the historical volatility of price and cost per unit as well as ROI, it is possible to establish risk (as compared to uncertainty) distributions, which is important for accurately estimating the value of real options.

The KVA method has been applied to numerous military core processes across the services. The KVA research has more recently provided a means for simplifying real options analysis for DOD processes. Current KVA research will provide a library of market comparable price and cost per unit of output estimates. This research will enable a more stable basis for comparisons of performance across core processes. This data also provides a means to establish risk distribution profiles for Integrated Risk Management approaches such as real options, and KVA currently is being linked directly to the Real Options Super Lattice Solver and Risk Simulator software for rapid adjustments to real options valuation projections.

### *Strategic Real Options Analysis*

Suppose you are driving from point A to point B, and you only have or know one way to get there, a straight route. Further suppose that there is a lot of uncertainty as to what traffic conditions are like further down the road, and you risk being stuck in traffic, and there’s a 50% chance that will occur. Simulation will provide you the 50% figure. But so what? Knowing that half the time you will get stuck in traffic is valuable information, but the question now is, so what? Especially if you must get to point B no matter what. However, if you had several alternate routes to get to point B, you can still drive the straight route but if you hit traffic, you can make a left, right, or U-turn, to get around congestion, mitigating the risk, and getting you to point B faster and safer; that is, you have options. So, how much is such a strategic road map or global positioning satellite map worth to you? In military situations with high risk, real options can help you create strategies to mitigate these risks. In fact, businesses and the military have been utilizing real options for hundreds of years without realizing it. For instance, in the military, we call it courses of action or analysis of alternatives—do we take Hill A so that it provides us the option and ability to take Hill B and Valley C, or how should we take Valley C or do we avoid taking Valley C altogether, and so forth. A piece that is missing is the more formal structure and subsequent analytics that real options analysis provides. Using real options analysis, we can quantify and value each strategic pathway, and frame strategies that will hedge or mitigate, and sometimes take advantage of, risk.

Real options analysis can be used to frame strategies to mitigate risk, value and find the optimal strategic pathway to pursue, and generate options to enhance the value of the project while managing risks. Sample options include the option to expand, contract, or abandon, or sequential compound options (phased stage-gate options, options to wait and defer investments, proof of concept stages, milestone development, and research and development initiatives). Some sample applications in the military include applications of real options to acquisitions, Spiral Development, and various organizational configurations, as well as the importance of how Integrated and Open Architectures become real options multipliers. Under OMB Circular A-76, comparisons using real options analysis could be applied to enhance outsourcing comparisons between the Government’s Most Efficient Organization (MEO) and private sector alternatives. Real options can be used throughout JCIDS requirements generation and the Defense Acquisition System, for example, DOTMLPF versus New Program/Service solution, Joint Integration, Analysis of Material Alternatives (AMA), Analysis of Alternatives (AoA), and Spiral Development. Many other applications exist in military decision analysis and portfolios.

## *Real Options: A Quick Peek Behind the Scenes*

Real options analysis will be performed to determine the prospective value of the basic options over a multi-year period using KVA data as a platform. The strategic real options analysis is solved employing various methodologies, including the use of binomial lattices with a market-replicating portfolios approach, and backed up using a modified closed-form sequential compound option model. The value of a compound option is based on the value of another option. That is, the underlying variable for the compound option is another option, and the compound option can be either sequential in nature or simultaneous. Solving such a model requires programming capabilities. This subsection is meant as a quick peek into the math underlying a very basic closed-form compound option. This section is only a preview of the detailed modeling techniques used in the current analysis and should not be assumed to be the final word.

For instance, we first start by solving for the critical value of *I*, an iterative component in the model using:

$$\begin{aligned} X_2 &= Ie^{-q(T_2-t_1)}\Phi\left(\frac{\ln(I/X_1)+(r-q+\sigma^2/2)(T_2-t_1)}{\sigma\sqrt{(T_2-t_1)}}\right) \\ &\quad - X_1e^{-r(T_2-t_1)}\Phi\left(\frac{\ln(I/X_1)+(r-q-\sigma^2/2)(T_2-t_1)}{\sigma\sqrt{(T_2-t_1)}}\right) \end{aligned}$$

Then, solve recursively for the value *I* above and input it into the model:

$$\begin{aligned} Compound\ Option &= Se^{-qT_2}\Omega\left[\begin{array}{l} \dfrac{\ln(S/X_1)+(r-q+\sigma^2/2)T_2}{\sigma\sqrt{T_2}}; \\ \dfrac{\ln(S/I)+(r-q+\sigma^2/2)t_1}{\sigma\sqrt{t_1}}; \sqrt{t_1/T_2} \end{array}\right] \\ &\quad - X_1e^{-rT_2}\Omega\left[\begin{array}{l} \dfrac{\ln(S/X_1)+(r-q+\sigma^2/2)T_2}{\sigma\sqrt{T_2}} - \sigma\sqrt{T_2}; \\ \dfrac{\ln(S/I)+(r-q+\sigma^2/2)t_1}{\sigma\sqrt{t_1}} - \sigma\sqrt{t_1}; \sqrt{t_1/T_2} \end{array}\right] \\ &\quad - X_2e^{-rt_1}\Phi\left[\frac{\ln(S/I)+(r-q+\sigma^2/2)t_1}{\sigma\sqrt{t_1}} - \sigma\sqrt{t_1}\right] \end{aligned}$$

The model is then applied to a sequential problem where future phase options depend on previous phase options (e.g., Phase II depends on Phase I's successful implementation).

Definitions of Variables

| | |
|---|---|
| $S$ | present value of future cash flows (\$) |
| $r$ | risk-free rate (%) |
| $\sigma$ | volatility (%) |
| $\Phi$ | cumulative standard-normal |
| $q$ | continuous dividend payout (%) |
| $I$ | critical value solved recursively |
| $\Omega$ | cumulative bivariate-normal |
| $X_1$ | strike for the underlying (\$) |
| $X_2$ | strike for the option on the option (\$) |
| $t_1$ | expiration date for the option on the option |
| $T_2$ | expiration date for the underlying option |

The preceding closed-form differential equation models are then verified using the risk-neutral market-replicating portfolio approach assuming a sequential compound option. In solving the market-replicating approach, we use the following functional forms (Mun, 2016):

- Hedge ratio ($h$):

$$h_{i-1} = \frac{C_{up} - C_{down}}{S_{up} - S_{down}}$$

- Debt load ($D$):

$$D_{i-1} = S_i(h_{i-1}) - C_i$$

- Call value ($C$) at node $i$:

$$C_i = S_i(h_i) - D_i e^{-rf(\delta t)}$$

- Risk-adjusted probability (*q*):

$$q_i = \frac{S_{i-1} - S_{down}}{S_{up} - S_{down}}$$ obtained assuming

$$S_{i-1} = q_i S_{up} + (1 - q_i) S_{down}$$

This means that

$$S_{i-1} = q_i S_{up} + S_{down} - q_i S_{down}$$

and

$$q_i [S_{up} - S_{down}] = S_{i-1} - S_{down},$$

so, we get

$$q_i = \frac{S_{i-1} - S_{down}}{S_{up} - S_{down}}$$

### ***Portfolio Optimization***

In most decisions, there are variables over which leadership has control, such as how much to establish supply lines, modernize a ship, use network centricity to gather intelligence, and so on. Similarly, business leaders have options in what they charge for a product or how much to invest in a project or which projects they should choose in a portfolio when they are constrained by budgets or resources. These decisions could also include allocating financial resources, building or expanding facilities, managing inventories, and determining product-mix strategies. Such decisions might involve thousands or millions of potential alternatives. Considering and evaluating each of them would be impractical or even impossible. These controlled variables are called *decision variables*. Finding the optimal values for decision variables can make the difference between reaching an important goal and missing that goal. An optimization model can provide valuable assistance in incorporating relevant variables when analyzing decisions, and finding the best solutions for making decisions. Optimization models often provide insights that intuition alone cannot. An optimization model has three major elements: decision variables, constraints, and an objective. In short, the optimization methodology finds the best combination or permutation of decision variables (e.g., best way to deploy troops, build ships, which projects to execute) in every conceivable way such that the objective is maximized (e.g., strategic value, enemy assets destroyed, return on investment) or minimized (e.g., risk and costs) while still satisfying the constraints (e.g., time, budget, and resources).

Obtaining optimal values generally requires that you search in an iterative or ad hoc fashion. This search involves running one iteration for an initial set of values, analyzing the results, changing one or more values, rerunning the model, and repeating the process until you find a satisfactory solution. This process can be very tedious and time consuming even for small models, and often it is not clear how to adjust the values from one iteration to the next. A more rigorous method systematically enumerates all possible alternatives. This approach guarantees optimal solutions if the model is correctly specified. Suppose that an optimization model depends on only two decision variables. If each variable has 10 possible values, trying each combination requires 100 iterations ($10^2$ alternatives). If each iteration is very short (e.g., two seconds), then the entire process could be done in approximately three minutes of computer time. However, instead of two decision variables, consider six, then consider that trying all combinations requires 1,000,000 iterations ($10^6$ alternatives). It is easily possible for complete enumeration to take many years to carry out. Therefore, optimization has always been a fantasy until now; with the advent of sophisticated software and computing power, coupled with smart heuristics and algorithms, such analyses can be done within minutes.

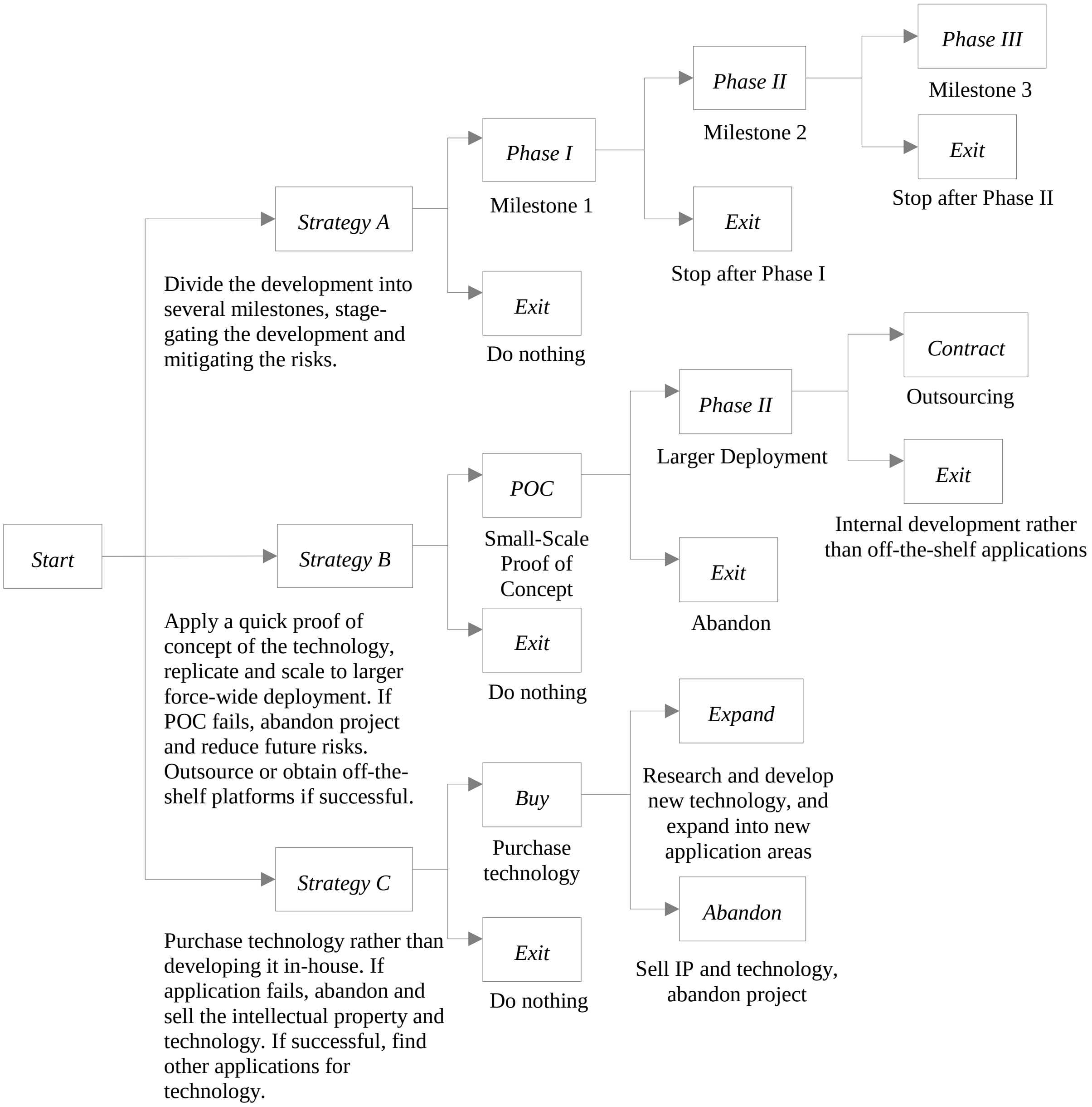
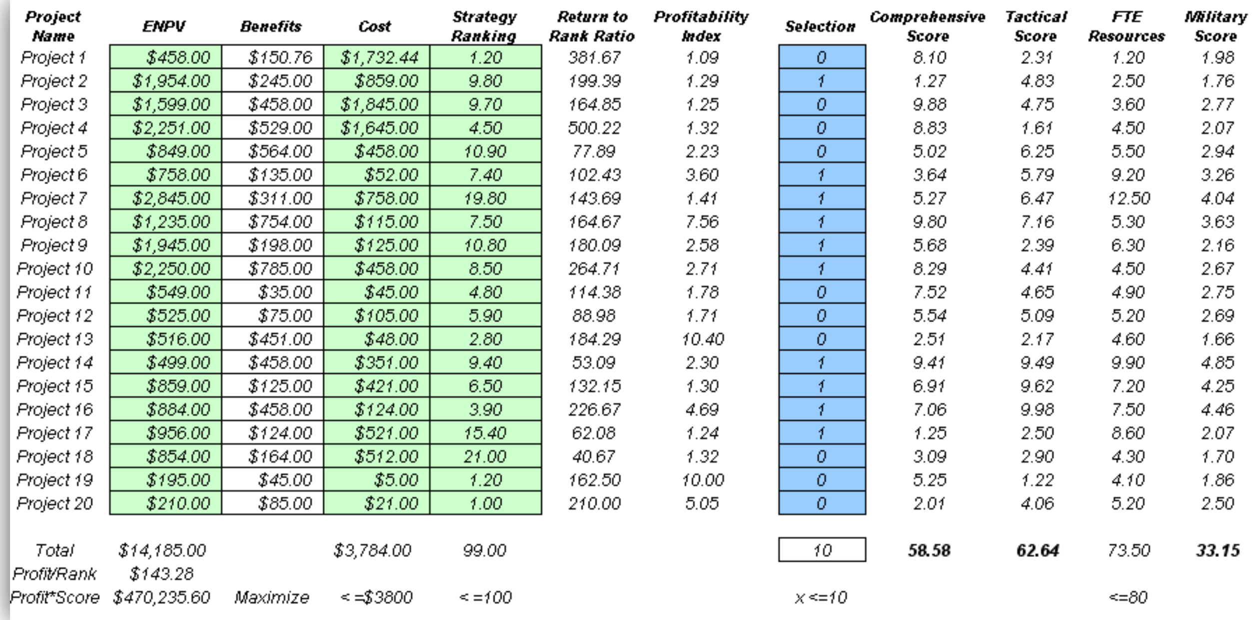


*Figure A.5. Example Real Options Framing*

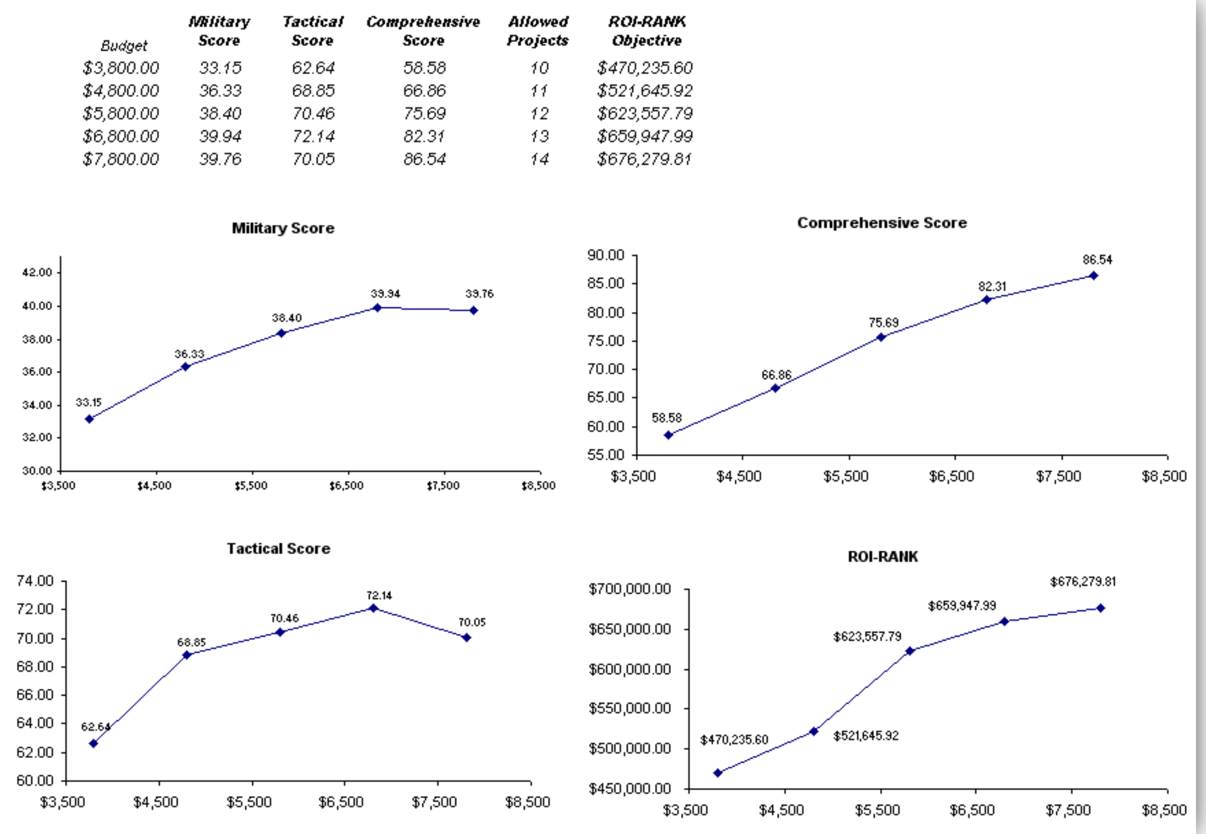
Figures A.6, A.7, and A.8 illustrate a sample portfolio analysis where in the first case, there are 20 total projects to choose from (if all projects were executed, it would cost $10.2 billion) and where each project has its own returns on investment or benefits measure, cost, strategic ranking, comprehensive, and tactical and total military scores (these were obtained from field commanders through the Delphi method to elicit their thoughts about how strategic a particular project or initiative will be, and so forth). The constraints are full-time equivalence resources, budget, and strategic score. In other words, there are 20 projects or initiatives to choose from, where we want to select the top 10, subject to having enough money to pay for them and the people to do the work, and yet have the most strategic portfolio possible. All the while, Monte Carlo simulation, real options, and forecasting methodologies are applied in the optimization model (e.g., each project's values shown in Figure A.6 are linked from its own large model with simulation and forecasting methodologies applied, and the best strategy for each project is chosen using real options analysis, or perhaps the projects shown are nested within one another; for instance, you cannot exercise Project 2 unless you execute Project 1, but you can only exercise Project 1 without having to do Project 2, and so forth). The results are shown in Figure A.6.

Figure A.7 shows the optimization process done in series, while relaxing some of the constraints. For instance, what would be the best portfolio and the strategic outcome if a budget of $3.8 billion was imposed? What if it was increased to $4.8 billion, $5.8 billion, and so forth? The efficient frontiers depicted in Figure A.7 illustrate the best combination and permutation of projects in the optimal portfolio. Each point on the frontier is a portfolio of various combinations of projects that provides the best allocation possible given the requirements and constraints. Finally, Figure A.8 shows the top 10 projects that were chosen and how the total budget is best and most optimally allocated to provide the best and most well-balanced portfolio.



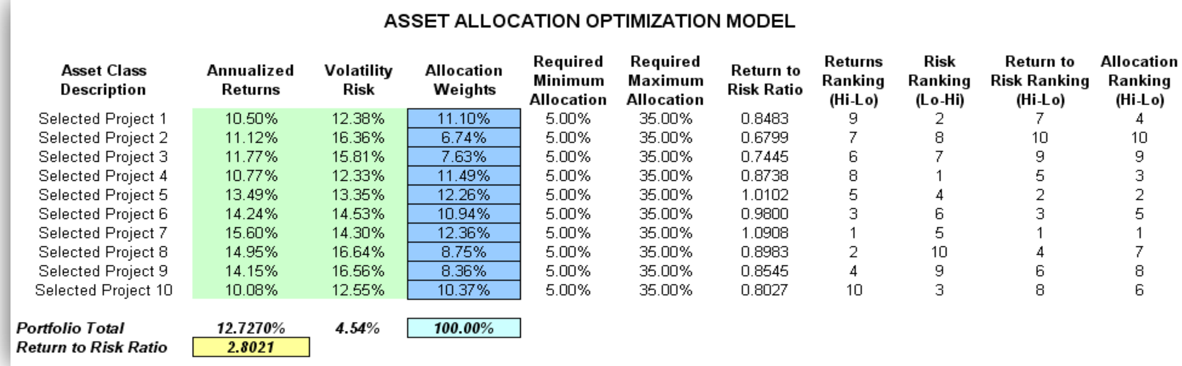
| Project Name | ENPV | Benefits | Cost | Strategy Ranking | Return to Rank Ratio | Profitability Index | Selection | Comprehensive Score | Tactical Score | FTE Resources | Military Score |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Project 1 | $458.00 | $150.76 | $1,732.44 | 1.20 | 381.67 | 1.09 | 0 | 8.10 | 2.31 | 1.20 | 1.98 |
| Project 2 | $1,954.00 | $245.00 | $859.00 | 9.80 | 199.39 | 1.29 | 1 | 1.27 | 4.83 | 2.50 | 1.76 |
| Project 3 | $1,599.00 | $458.00 | $1,845.00 | 9.70 | 164.85 | 1.25 | 0 | 9.88 | 4.75 | 3.60 | 2.77 |
| Project 4 | $2,251.00 | $529.00 | $1,645.00 | 4.50 | 500.22 | 1.32 | 0 | 8.83 | 1.61 | 4.50 | 2.07 |
| Project 5 | $849.00 | $564.00 | $458.00 | 10.90 | 77.89 | 2.23 | 0 | 5.02 | 6.25 | 5.50 | 2.94 |
| Project 6 | $758.00 | $135.00 | $52.00 | 7.40 | 102.43 | 3.60 | 1 | 3.64 | 5.79 | 9.20 | 3.26 |
| Project 7 | $2,845.00 | $311.00 | $758.00 | 19.80 | 143.69 | 1.41 | 1 | 5.27 | 6.47 | 12.50 | 4.04 |
| Project 8 | $1,235.00 | $754.00 | $115.00 | 7.50 | 164.67 | 7.56 | 1 | 9.80 | 7.16 | 5.30 | 3.63 |
| Project 9 | $1,945.00 | $198.00 | $125.00 | 10.80 | 180.09 | 2.58 | 1 | 5.68 | 2.39 | 6.30 | 2.16 |
| Project 10 | $2,250.00 | $785.00 | $458.00 | 8.50 | 264.71 | 2.71 | 1 | 8.29 | 4.41 | 4.50 | 2.67 |
| Project 11 | $549.00 | $35.00 | $45.00 | 4.80 | 114.38 | 1.78 | 0 | 7.52 | 4.65 | 4.90 | 2.75 |
| Project 12 | $525.00 | $75.00 | $105.00 | 5.90 | 88.98 | 1.71 | 0 | 5.54 | 5.09 | 5.20 | 2.69 |
| Project 13 | $516.00 | $451.00 | $48.00 | 2.80 | 184.29 | 10.40 | 0 | 2.51 | 2.17 | 4.60 | 1.66 |
| Project 14 | $499.00 | $458.00 | $351.00 | 9.40 | 53.09 | 2.30 | 1 | 9.41 | 9.49 | 9.90 | 4.85 |
| Project 15 | $859.00 | $125.00 | $421.00 | 6.50 | 132.15 | 1.30 | 1 | 6.91 | 9.62 | 7.20 | 4.25 |
| Project 16 | $884.00 | $458.00 | $124.00 | 3.90 | 226.67 | 4.69 | 1 | 7.06 | 9.98 | 7.50 | 4.46 |
| Project 17 | $956.00 | $124.00 | $521.00 | 15.40 | 62.08 | 1.24 | 1 | 1.25 | 2.50 | 8.60 | 2.07 |
| Project 18 | $854.00 | $164.00 | $512.00 | 21.00 | 40.67 | 1.32 | 0 | 3.09 | 2.90 | 4.30 | 1.70 |
| Project 19 | $195.00 | $45.00 | $5.00 | 1.20 | 162.50 | 10.00 | 0 | 5.25 | 1.22 | 4.10 | 1.86 |
| Project 20 | $210.00 | $85.00 | $21.00 | 1.00 | 210.00 | 5.05 | 0 | 2.01 | 4.06 | 5.20 | 2.50 |
|  |  |  |  |  |  |  |  |  |  |  |  |
| Total | $14,185.00 |  | $3,784.00 | 99.00 |  |  | 10 | **58.58** | **62.64** | 73.50 | **33.15** |
| Profit/Rank | $143.28 |  |  |  |  |  |  |  |  |  |  |
| Profit*Score | $470,235.60 | Maximize | < =$3800 | < =100 |  |  | x <=10 |  |  | <=80 |  |

Figure A.6. Portfolio Optimization and Allocation



| Budget | Military Score | Tactical Score | Comprehensive Score | Allowed Projects | ROI-RANK Objective |
|---|---|---|---|---|---|
| $3,800.00 | 33.15 | 62.64 | 58.58 | 10 | $470,235.60 |
| $4,800.00 | 36.33 | 68.85 | 66.86 | 11 | $521,645.92 |
| $5,800.00 | 38.40 | 70.46 | 75.69 | 12 | $623,557.79 |
| $6,800.00 | 39.94 | 72.14 | 82.31 | 13 | $659,947.99 |
| $7,800.00 | 39.76 | 70.05 | 86.54 | 14 | $676,279.81 |

Figure A.7. Efficient Frontiers of Portfolios



ASSET ALLOCATION OPTIMIZATION MODEL

| Asset Class Description | Annualized Returns | Volatility Risk | Allocation Weights | Required Minimum Allocation | Required Maximum Allocation | Return to Risk Ratio | Returns Ranking (Hi-Lo) | Risk Ranking (Lo-Hi) | Return to Risk Ranking (Hi-Lo) | Allocation Ranking (Hi-Lo) |
|---|---|---|---|---|---|---|---|---|---|---|
| Selected Project 1 | 10.50% | 12.38% | 11.10% | 5.00% | 35.00% | 0.8483 | 9 | 2 | 7 | 4 |
| Selected Project 2 | 11.12% | 16.36% | 6.74% | 5.00% | 35.00% | 0.6799 | 7 | 8 | 10 | 10 |
| Selected Project 3 | 11.77% | 15.81% | 7.63% | 5.00% | 35.00% | 0.7445 | 6 | 7 | 9 | 9 |
| Selected Project 4 | 10.77% | 12.33% | 11.49% | 5.00% | 35.00% | 0.8738 | 8 | 1 | 5 | 3 |
| Selected Project 5 | 13.49% | 13.35% | 12.26% | 5.00% | 35.00% | 1.0102 | 5 | 4 | 2 | 2 |
| Selected Project 6 | 14.24% | 14.53% | 10.94% | 5.00% | 35.00% | 0.9800 | 3 | 6 | 3 | 5 |
| Selected Project 7 | 15.60% | 14.30% | 12.36% | 5.00% | 35.00% | 1.0908 | 1 | 5 | 1 | 1 |
| Selected Project 8 | 14.95% | 16.64% | 8.75% | 5.00% | 35.00% | 0.8983 | 2 | 10 | 4 | 7 |
| Selected Project 9 | 14.15% | 16.56% | 8.36% | 5.00% | 35.00% | 0.8545 | 4 | 9 | 6 | 8 |
| Selected Project 10 | 10.08% | 12.55% | 10.37% | 5.00% | 35.00% | 0.8027 | 10 | 3 | 8 | 6 |
|  |  |  |  |  |  |  |  |  |  |  |
| ***Portfolio Total*** | ***12.7270%*** | ***4.54%*** | ***100.00%*** |  |  |  |  |  |  |  |
| ***Return to Risk Ratio*** | ***2.8021*** |  |  |  |  |  |  |  |  |  |

*Figure A.8. Portfolio Optimization (Continuous Allocation of Funds)*

## *Integrated Risk Management Framework*

We are now able to put all the pieces together into an integrated risk management framework and see how these different techniques are related in a risk analysis and risk management context. This framework comprises eight distinct phases of a successful and comprehensive risk analysis implementation, going from a qualitative management screening process to creating clear and concise reports for management. The process was developed by the author (Mun) based on previous successful implementations of risk analysis, forecasting, real options, KVA cash flow estimates, valuation, and optimization projects both in the consulting arena and as applied to industry-specific problems. These phases can be performed either in isolation or together in sequence for a more robust integrated analysis.

Figure A.9 shows the integrated risk management process up close. We can segregate the process into the following eight simple steps:

1. Qualitative management screening
2. Time-series and regression forecasting
3. Base case KVA and net present value analysis
4. Monte Carlo simulation
5. Real options problem framing
6. Real options modeling and analysis
7. Portfolio and resource optimization
8. Reporting and update analysis

### 1. Qualitative Management Screening

Qualitative management screening is the first step in any integrated risk management process. Decision makers must decide which projects, assets, initiatives, or strategies are viable for further analysis, in accordance with the organization’s mission, vision, goal, or overall business strategy. The organization’s mission, vision, goal, or overall business strategy may include strategies and tactics, and competitive advantage, technical, acquisition, growth, synergistic, or global threat issues. That is, the initial list of projects should be qualified in terms of meeting the leadership’s agenda. Often the most valuable insight is created as leaders frame the complete problem to be resolved. This is where the various risks to the organization are identified and fleshed out.

### 2. Time-Series and Regression Forecasting

The future is then forecasted using time-series analysis, stochastic forecasting, or multivariate regression analysis if historical or comparable data exist. Otherwise, other qualitative forecasting methods may be used (subjective guesses, growth rate assumptions, expert opinions, Delphi method, and so forth).

### 3. Base Case KVA and Net Present Value Analysis

For each project that passes the initial qualitative screens, a KVA-based discounted cash flow model is created. This model serves as the base case analysis where a net present value and ROI are calculated for each project, using the forecasted values in the previous step. This step also applies if only a single project is under evaluation. This net present value is calculated with the traditional approach of using the forecast revenues and costs, and discounting the net of these revenues and costs at an appropriate risk-adjusted rate. The ROI and other financial metrics are generated here.

### 4. Monte Carlo Simulation

Because the static discounted cash flow produces only a single-point estimate result, there is oftentimes little confidence in its accuracy given that future events that affect forecast cash flows are highly uncertain. To better estimate the actual value of a particular project, Monte Carlo simulation should be employed next.

Usually, a sensitivity analysis is first performed on the discounted cash flow model; that is, setting the net present value or ROI as the resulting variable, we can change each of its precedent variables and note the change in the resulting variable. Precedent variables include revenues, costs, tax rates, discount rates, capital expenditures, depreciation, and so forth, which ultimately flow through the model to affect the net present value or ROI figure. By tracing back all these precedent variables, we can change each one by a preset amount and see the effect on the resulting net present value. A graphical representation can then be created in Risk Simulator, which is often called a tornado chart because of its shape, where the most sensitive precedent variables are listed first, in descending order of magnitude. Armed with this information, the analyst can then decide which key variables are highly uncertain in the future and which are deterministic. The uncertain key variables that drive the net present value and, hence, the decision are called *critical success drivers*. These critical success drivers are prime candidates for Monte Carlo simulation. Because some of these critical success drivers may be correlated, a correlated and multidimensional Monte Carlo simulation may be required. Typically, these correlations can be obtained through historical data. Running correlated simulations provides a much closer approximation to the variables' real-life behaviors.

### 5. Real Options Problem Framing

The question now is that after quantifying risks in the previous step, what next? The risk information obtained somehow needs to be converted into actionable intelligence. Just because risk has been quantified to be such and such using Monte Carlo simulation, so what and what do we do about it? The answer is to use real options analysis to hedge these risks, to value these risks, and to position yourself to take advantage of the risks. The first step in real options is to generate a strategic map through the process of framing the problem. Based on the overall problem identification occurring during the initial qualitative management screening process, certain strategic optionalities would have become apparent for each particular project. The strategic optionalities may include, among other things, the option to expand, contract, abandon, switch, choose, and so forth. Based on the identification of strategic optionalities that exist for each project or at each stage of the project, the analyst can then choose from a list of options to analyze in more detail. Real options are added to the projects to hedge downside risks and to take advantage of upside swings.

### 6. Real Options Modeling and Analysis

Using Monte Carlo simulation, the resulting stochastic discounted cash flow model will have a distribution of values. Thus, simulation models, analyzes, and quantifies the various risks and uncertainties of each project. The result is a distribution of the NPVs and the project's volatility. In real options, we assume that the underlying variable is the future profitability of the project, which is the future cash flow series. An implied volatility of the future free cash flow or underlying variable can be calculated through the results of a Monte Carlo simulation previously performed. Usually, the volatility is measured as the standard deviation of the logarithmic returns on the free cash flow stream. In addition, the present value of future cash flows for the base case discounted cash flow model is used as the initial underlying asset value in real options modeling. Using these inputs, real options analysis is performed to obtain the projects' strategic option values.

### 7. Portfolio and Resource Optimization

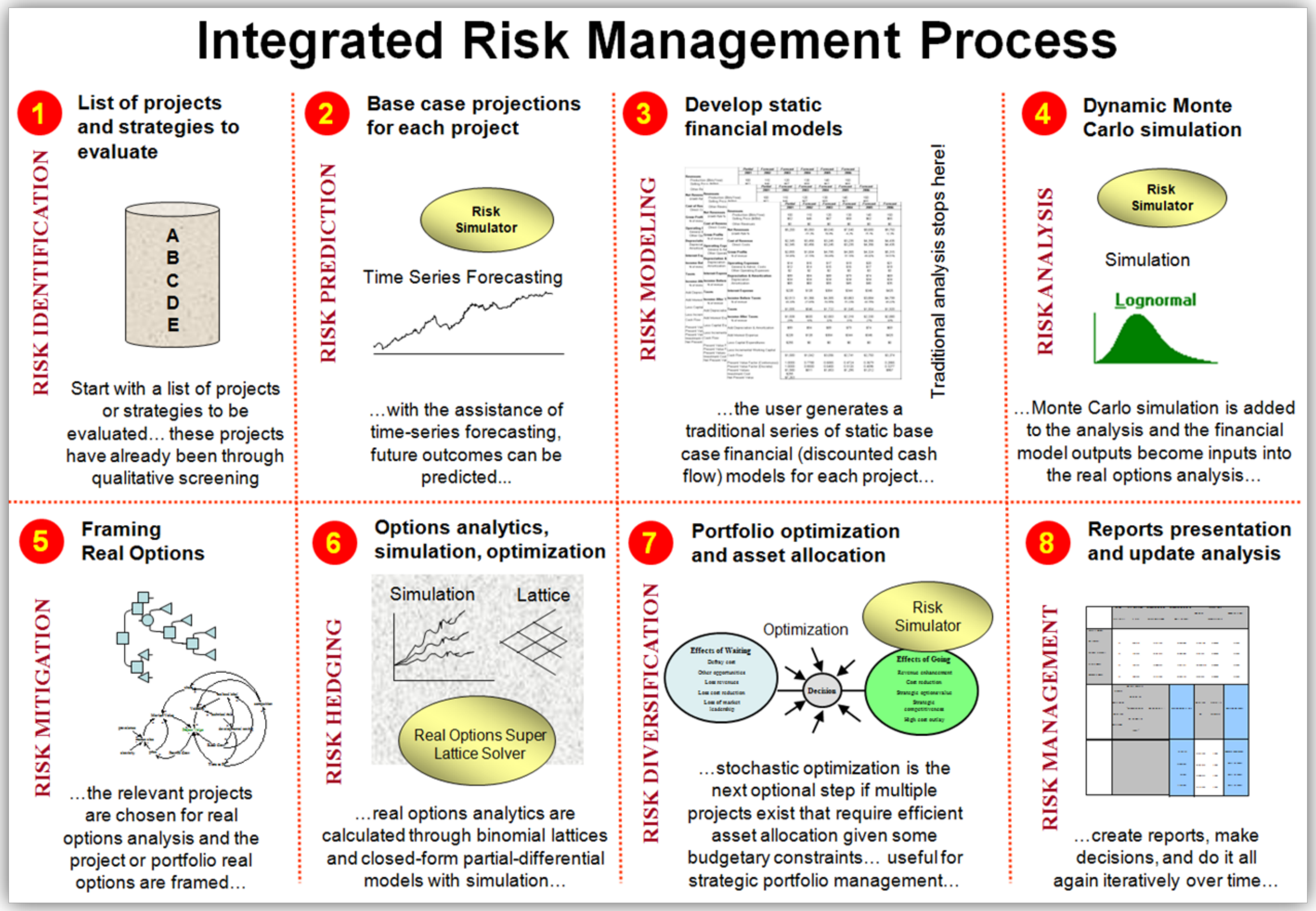
Portfolio optimization is an optional step in the analysis. If the analysis is done on multiple projects, decision makers should view the results as a portfolio of rolled-up projects because the projects are in most cases correlated with one another, and viewing them individually will not present the true picture. As organizations do not only have single projects, portfolio optimization is crucial. Given that certain projects are related to others, there are opportunities for hedging and diversifying risks through a portfolio. Because firms have limited budgets and time and resource constraints, while at the same time having requirements for certain overall levels of returns, risk tolerances, and so forth, portfolio optimization considers all these to create an optimal portfolio mix. The analysis will provide the optimal allocation of investments across multiple projects.

### 8. Reporting and Update Analysis

The analysis is not complete until reports can be generated. Not only are results presented, but the process should also be shown. Clear, concise, and precise explanations transform a difficult black-box set of analytics into transparent steps. Decision makers will never accept results coming from black boxes if they do not understand where the assumptions or data originate and what types of mathematical or analytical massaging takes place. Risk analysis assumes that the future is uncertain and that decision makers have the right to make midcourse corrections when these uncertainties become resolved or risks become known; the analysis is usually done ahead of time and thus ahead of such uncertainty and risks. Therefore, when these risks become known over the passage of time, actions, and events, the analysis should be revisited to incorporate the decisions made or to revise any input assumptions. Sometimes, for long-horizon projects, several iterations of the real options analysis should be performed, where future iterations are updated with the latest data and assumptions. Understanding the steps required to undertake an integrated risk management analysis is important because it provides insight not only into the methodology itself but also into how it evolves from traditional analyses, showing where the traditional approach ends and where the new analytics start.

## *Conclusion*

Hopefully it has now become evident that the DOD leadership can take advantage of more advanced analytical procedures for making strategic investment decisions and when managing portfolios of projects. In the past, due to the lack of technological maturity, this would have been extremely difficult, and, hence, businesses and the government had to resort to experience and managing by gut feel. Nowadays with the assistance of technology and more mature methodologies, there is every reason to take the analysis a step further. Corporations such as 3M, Airbus, AT&T, Boeing, BP, Chevron, Johnson & Johnson, Motorola, and many others have already been successfully using these techniques for years, and the military can follow suit. The relevant software applications, books, case studies, and public seminars have been created, and case studies have already been developed for the U.S. Navy. The only barrier to implementation, simply put, is the lack of exposure to the potential benefits of the methods. Many in the military have not seen or even heard of these new concepts. This appendix primer, if it is successful, serves to reveal the potential benefits of these analytical techniques and tools that can complement what leadership is currently doing. To be ready for the challenges of the 21st century, and to create a highly effective and flexible military force, strategic real options, KVA, and risk analysis are available to aid leadership with critical decision making. Real options and KVA are tools that will help ensure maximum strategic flexibility and analysis of alternatives where risks must be considered.



## Integrated Risk Management Process

**1** **List of projects and strategies to evaluate**

RISK IDENTIFICATION

Start with a list of projects or strategies to be evaluated… these projects have already been through qualitative screening

**2** **Base case projections for each project**

RISK PREDICTION

…with the assistance of time-series forecasting, future outcomes can be predicted…

**3** **Develop static financial models**

RISK MODELING

Traditional analysis stops here!

…the user generates a traditional series of static base case financial (discounted cash flow) models for each project…

**4** **Dynamic Monte Carlo simulation**

RISK ANALYSIS

…Monte Carlo simulation is added to the analysis and the financial model outputs become inputs into the real options analysis…

**5** **Framing Real Options**

RISK MITIGATION

…the relevant projects are chosen for real options analysis and the project or portfolio real options are framed…

**6** **Options analytics, simulation, optimization**

RISK HEDGING

…real options analytics are calculated through binomial lattices and closed-form partial-differential models with simulation…

**7** **Portfolio optimization and asset allocation**

RISK DIVERSIFICATION

…stochastic optimization is the next optional step if multiple projects exist that require efficient asset allocation given some budgetary constraints… useful for strategic portfolio management…

**8** **Reports presentation and update analysis**

RISK MANAGEMENT

…create reports, make decisions, and do it all again iteratively over time…

Figure A.9. Integrated Risk Management

# Appendix 2—Case Example: United States Naval Special Warfare Group Mission Support Center (MSC)

We developed the following case study for the DOD's Office of Force Transformation to demonstrate the power of applying real options analysis, populated with new raw data gathered using Knowledge Value Added (KVA), to battlespace strategic planning initiatives. The quantitative analyses provided by pairing KVA and real options analysis enabled the DOD to better understand its return on investment in people and information technology for a technology-heavy mission support center. It also enabled the DOD to gain clarity regarding the many benefits of real options analysis for future planning purposes.

The Naval Special Warfare Group One (NSWG-1) of the United States Navy established and utilized a Mission Support Center (MSC) to assist in conducting mission planning and execution during Operation Enduring Freedom (OEF) and Operation Iraqi Freedom (OIF). The MSC was a reach-back component, located in San Diego, California, that used information technologies to enhance the collaboration between forward and rear units and provided shared situational awareness for war planners and war fighters.

The MSC was designated NSWTG-REAR and could generate high-priority requests for information (RFI) that the intelligence community answered. Three new IT tools were also used as an integral part of MSC operations:

- *A3*—A relational database developed to provide tailored intelligence products.
- *WEBBE*—A multi-point instant messaging tool with voice-over capabilities.
- Access to *GBS*—A satellite downlink that provided for fast transfers of large data files.

Figure A.10 summarizes the people, processes, and technologies that made up the MSC for OIF.

| **Force Elements** | **MSC for Operation Iraqi Freedom (OIF)** |
|---|---|
| **Information Sources** | Collaborated intelligence/info sources sensors, HUMINT |
| **Value Added Services** | Federated network, Blue Force Tracking, A3, Global Broadcast System, WEBBE, JWICS, SIPRNET for strategic and tactical missions |
| **Command and Control** | MSC was permanent and co-located; staffed 24 hours a day, 7 days per week |
| **Effectors** | Force composition was 110 staff forward in theater; 75 staff rear at MSC; supported 600 SOF forces and 7805 METOC requests |
| **Operating Environment** | Desert |

*Figure A.10. People, Processes, and Technology for OIF MSC*

The *Mission Planning Cycle* supported by the MSC included several core processes such as *Mission Feasibility Assessment, Warning Order, Fragmentary Order, Concept of Operations,* and *Execution Order.*

We selected the *Mission Feasibility Assessment* (MFA) cycle for our analysis and made the following assumptions: The Mission Feasibility Assessment Cycle was the only segment of the Mission Planning Process in which the MSC-Rear participated, and the remainder of the Mission Planning Process occurred forward in the field. These assumptions allowed us to equate the total costs and proxy revenues for the MFA cycle with the costs and proxy revenues for the MSC for use in developing net cash flows for discounted cash flow and real options analyses.

The MFA cycle consisted of 10 subprocesses: Receipt of Mission, Mission Feasibility Analysis, Assess SOF Operational Criteria, Develop Courses of Action, Analyze Courses of Action, Compare Courses of Action, Recommend Course of Action, Commander's and Forward Staff's Planning Guidance, Issue Warning Order, and Issue Feasibility Assessment to JTF/ Requested Element. In addition, we included IT infrastructure support in the analysis.

## *Statement of the Real Options Case Problem*

According to a detailed study (June 2004) by Booz Allen Hamilton that assessed the effectiveness of the MSC, the MSC enhanced command and control, increased mission unit effectiveness, altered initial conditions, significantly increased combat power by increasing the number of combat missions that could be simultaneously conducted worldwide, and decisively impacted events in the global war on terror.

For this reason, the United States DOD has decided that it needs several more MSCs to assist *Joint Forces Special Operations* in their warfighting missions. However, the DOD does not know the most effective force mix to use to staff the MSCs and whether the supporting IT should be built, bought, or outsourced. The uncertainties related to acquiring the right MSC analysts and IT, and budgetary constraints were significant.

Instead of simply making a decision on whether implementing the MSCs is prudent and executing it without regard for an ongoing implementation strategy, the DOD has chosen to create a sequential compound option for quantification and review. This stage-gating approach will allow the DOD to halt strategy execution at any given decision node, should that strategy no longer be desirable to pursue.

## *Three Strategies for Analysis*

Three strategies have been selected for analysis. All three have the same initial assumptions:

- The requirements of projected combat potential indicate that Joint Forces will need to enlarge the current MSC to full capacity during Year 1, using current IT.
- Within the next three years, the DOD will also need an additional five MSCs, containing 25 analysts each, to support five Combatant Command teams of five (i.e., five analysts will be assigned to one Combatant Command team).
- The MSCs will begin to serve all Joint Force special operations groups, rather than just NSWG-1.

The other critical assumption is that the Mission Feasibility Assessment Cycle is the only segment of the Mission Planning Process in which the MSC will participate. The remainder of the Mission Planning Process will occur strictly in the field. This assumption allows us to equate the total costs and proxy revenues for the MFA cycle with the costs and proxy revenues for the entire MSC. Simplified descriptions of the three strategies are presented next.

### ***Strategy A***

The increasingly complex technologies and training required to develop, staff, and operate an MSC in support of widely dispersed, ever-changing, asymmetric warfighting scenarios are probably best obtained from the already intensive, mission-specific R&D and long-term training and expertise offered by in-house DOD initiatives. Although Command does not want to utilize warriors from the tip of the spear as MSC analysts, the Reserves have an excellent pool of talent that could be retrained and used in this capacity. In addition, these Reserves would have actual military training and experience and would not need the extensive preparation required for civilian analysts.

The DOD wants to rehab existing military facilities to house the MSCs and will use the current MSC as a prototype for the initial rehab of a physical plant. In addition, the DOD will lease the IT infrastructure and hardware necessary to operate the MSCs and develop customized software over a six-month period, using contract labor under the direction of DOD experts.

### ***Strategy B***

The increasingly complex technologies and training required to develop, staff, and operate an MSC in support of widely dispersed, ever-changing, asymmetric warfighting scenarios represents a challenge. Command feels that, given the unique nature of Special Forces Operations, the best pool of talent to use in MSC staffing is regular military, preferably with exposure to Special Forces Operations. Neither Reservists nor civilians fit this profile. Command also feels that there is not enough time to develop software in-house or by outsourcing to meet the urgent needs in the field today. So, Command has made the decision to purchase off-the-shelf software, utilize intensive training on the software for seasoned military analysts, and adjust as needed at the end of Year 1.

The DOD wants to rehab existing military facilities to house the MSCs and will use the current MSC as a prototype for the initial rehab of a physical plant. In addition, the DOD will lease the IT infrastructure and hardware necessary to operate the MSCs and will enter a joint venture with the vendor supplying the software in which the vendor will supply the initial software and upgrades at a healthy discount from private sector prices.

### *Strategy C*

The increasingly complex technologies and training required to develop, staff, and operate an MSC in support of widely dispersed, ever-changing, asymmetric warfighting scenarios is probably best obtained from the private sector. Here the profit motive, extensive R&D, and technology entrepreneurship will provide a much fuller menu of choices at a lower cost than those offered by DOD research and development initiatives.

The DOD wants to rehab existing military facilities to house the MSCs and will use the current MSC as a prototype for the initial rehab of a physical plant. In addition, the DOD wants to purchase and own the IT infrastructure and hardware necessary to operate the MSCs, but does not want to buy or build the software in-house. A software developer will provide customized software and upgrades for all MSC functions, hire and manage all analysts, and hire the original five military analysts at equivalent private sector rates to use them as trainers and analysts. The vendor will retrain and redeploy the analysts assigned to the MSCs for other DOD functions, should the DOD seek to cancel the contract after Year 1. The strategic tree for this analysis is found in Figure A.11.

## Unique Data Needs

As the future MSC concept will be developed and owned by the DOD, a not-for-profit organization, the analysis requires the use of unique datasets for revenue. Traditionally, for government forecasting, budgeted revenues are equivalent to budgeted cost. This makes it impossible to develop a genuine return on investment (ROI) or to change strategic focus from cost savings to value creation. In addition, in this setting, the for-profit capital markets provide no reasonable proxies or comparable data by which to develop the discount rate to be used in Discounted Cash Flow (DCF) analysis or other inputs to the real options analysis model.

To solve these problems, we took two steps: (1) We developed proxy revenues, and (2) we used KVA to assign these proxy revenues to the MFA cycle subprocesses to develop a discount rate and real options analysis model inputs.

### Developing Proxy Revenues

In the MFA cycle, processes are executed by humans, assisted by information technology. In a very real sense, humans drive the “revenues” (i.e., cash inflows) of the MSC because, without their agency, the MSC would cease to function, and it would receive no budget dollars. For this reason, we have chosen to use the private sector “market values” of these human agents as proxy revenues for the MSC. These proxy revenues are a conservative reflection of market expectations for the leverage of human capital in producing revenue (value) for the organization.

Such market values are equivalent to private sector salaries for human agents with similar experience, skill sets, and responsibilities. We developed our proxy revenues by increasing budgeted annual military salaries by a market premium. This market premium is the percent by which private sector salaries would exceed military salaries for the same levels of experience and responsibility.

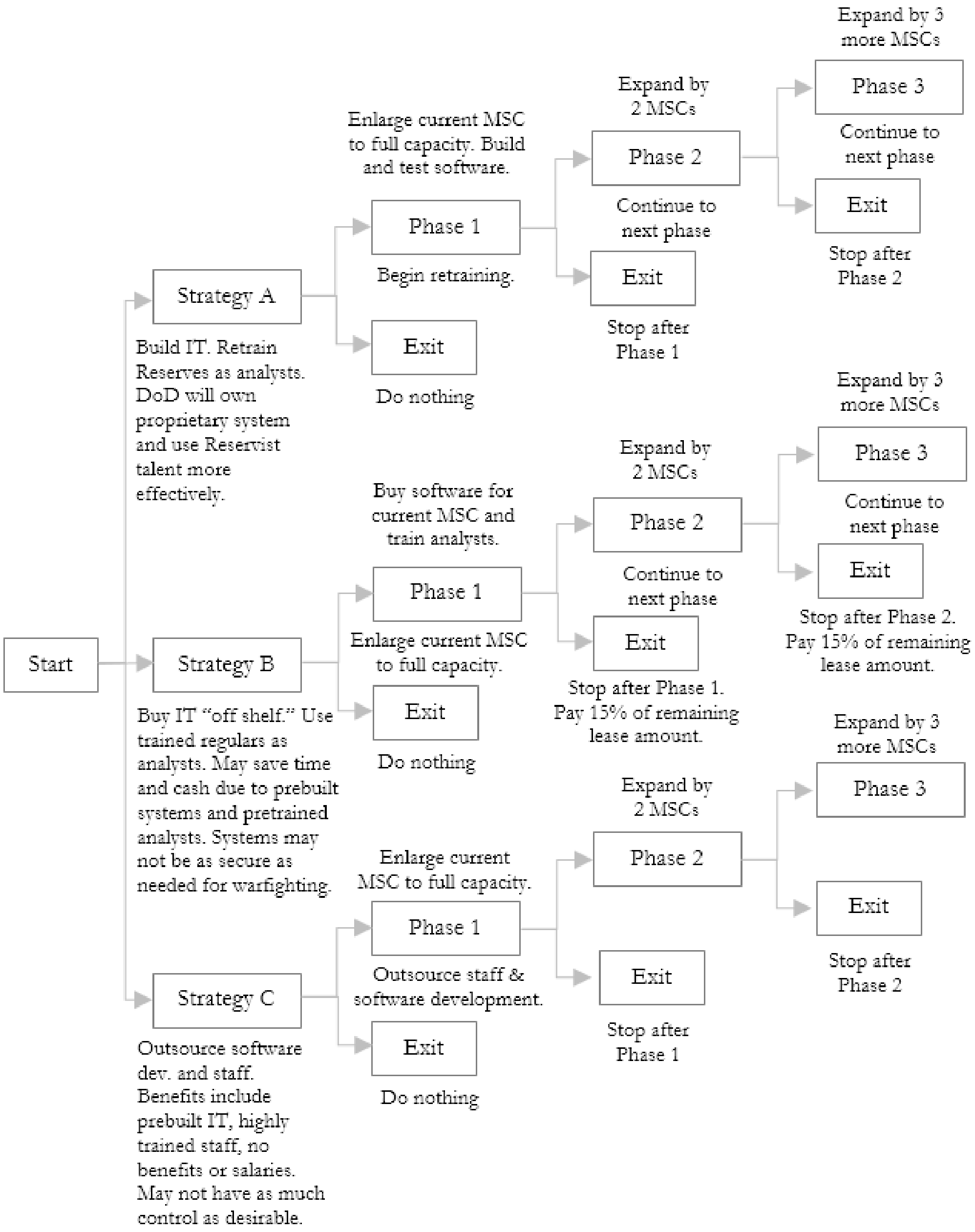


*Figure A.11. MSC Strategy Tree*

### *KVA and Its Uses*

KVA is the seminal work of Dr. Tom Housel (Naval Postgraduate School), the coauthor of this report, and Dr. Valery Kanevsky (Agilent Labs). Developed from the complexity theoretic concept of the fundamental unit of change (i.e., a unit of complexity), KVA provides a means to count the amount of organizational knowledge, in equivalent units, that is required to produce the outputs of the organization.

The following four assumptions allow KVA to equate units of change (complexity) with units of organizational knowledge and then count them:

- Humans and technology in organizations take inputs and change them into outputs through core processes.
- All outputs can be described in terms of the amount of change (i.e., complexity) required to produce them.
- All outputs can also be described in terms of the time required by an “average” learner to learn how to produce them. Learning time can be considered a surrogate for organizational knowledge required to produce the outputs. KVA describes these common units of learning time (i.e., units of output) by using the term knowledge units ($K_\mu$).
- A $K_\mu$ is proportionate to a unit of complexity, which is proportionate to a unit of change.

By describing all process outputs in common units (i.e., the $K_\mu$ required to produce them), it is possible to assign revenue, as well as cost, to those units inside the organizational boundary at any given point in time. This makes it possible to compare all outputs in terms of revenue per unit as well as cost per unit. In addition, once we have assigned both revenue and cost streams to suborganizational outputs, we can apply standard accounting and financial performance and profitability metrics to them. This methodology applies to not-for-profit as well as for-profit organizations. However, in the current research, KVA may or may not be exactly applicable and warrants additional analysis to make this determination.

### *KVA and Real Options Analysis for the MSC Sequential Compound Option*

The question that remains after building and analyzing the strategic tree is "Which strategy is optimal?" The KVA methodology provides the raw inputs (return on knowledge investments as well as assignment of both costs and proxies for revenue). Real options analysis uses these inputs to determine the optimal strategy to execute.

### *Run Base Case NPV Analysis and Applying Results in Monte Carlo Simulation*

First, we modeled the results from the KVA approach into a set of discounted cash flows for the three strategies, resulting in expected net present values (NPVs, i.e., benefits less cost, on a present-dollar value basis), *without flexibility,* for each. For base case NPV analysis, DCFs were run for each year and then summed to arrive at a total NPV for the three years for each strategy. This base case approach assumes that all future net cash flows are known with certainty and therefore there is zero volatility around input values.

However, the future net cash flows related to the MSC project strategies do involve uncertainty. For example, salary levels may fluctuate over the course of the project. Since we pegged proxy revenues to budgeted salaries, proxy revenue fluctuation will be correlated to the volatility of salaries. In addition, the rate of inflation, modeled in the base case as 4.5%, may fluctuate (i.e., exhibit volatility), as may the risk-free rate used to discount future net cash flows. These kinds of input volatilities suggest that we should develop a probabilistic range of NPVs for our analysis, rather than use a single-point estimate of value.

These probabilistic value distributions are generated by using Monte Carlo simulation. All the volatile (i.e., fluctuating) inputs into the model are simultaneously run through 1,000 trials, allowing them to all change at the same time. The results are 1,000 NPVs, collated into probabilistic distributions.

For example, Strategy A's NPV is distributed such that its expected NPV is $24.37 million. However, due to the probabilities related to input volatility, the 90% statistical confidence range places this NPV at between $23.60 and $25.13 million.

Figure A.12 shows the expected NPVs and statistical confidence ranges of the three strategies.

| | Expected NPV | 90% Statistical Confidence Range |
|---|---|---|
| **Strategy A** | $24.37M | $23.60M – $25.13M |
| **Strategy B** | $26.63M | $26.24M – $27.02M |
| **Strategy C** | $24.75M | $24.02M – $25.51M |

*Figure A.12. Expected NPVs and Statistical Confidence Ranges*

As we review these results, they indicate that, using the base case NPV approach, Strategy B is the optimal decision to pursue.

However, NPV analysis only provides a static description of a single decision pathway for each strategy, utilizing a single probability distribution to represent each strategy's input fluctuations. It does not consider the discrete volatilities and uncertainties related to staged MSC implementations or the option to exit and abandon the program if a future stage proves to be unsuccessful. NPV analysis looks at the strategy as a straight path that must be traversed regardless of the learning and changes that occur at a later date. It ignores the inherent flexibility to abandon or expand to the next phase.

So, we used real options analysis to look at the complete strategic value of each pathway, accounting for not only the underlying base case input volatilities and uncertainties but also the strategic flexibility embedded in each stage of the pathway.

### *Develop Volatility Parameter and Calculate Option Results with Simulation*

One of the more difficult input parameters to estimate in ROV is volatility. The base case NPV probability distributions do not tell us what volatility parameters we should apply to inputs in a staged MSC implementation. Ordinarily, to get these we could go out to the markets and make estimates based on our informed professional judgment, or use historical data to help us build our estimates. However, the DOD has no market-comparable data that could reasonably be used for this purpose.

KVA produces an internally generated historical ratio, return on knowledge investment (ROKI), which can be used in a Monte Carlo simulation to generate a volatility parameter. This volatility parameter is a statistical value representing the distilled, integrated effects of all the volatilities and uncertainties inherent in the forecasted values for each MSC strategy stage. Several methods are available to calculate volatility. We used the Logarithmic Present Value Approach with Monte Carlo simulation, as it was the most robust method and provided a higher degree of results precision. When implied ROKI volatilities were simulated using the Logarithmic Present Value Approach, they produced the volatility parameters shown in Figure A.13. These parameters implied that there were high levels of fluctuation by staged ROKIs around base case returns, suggesting high degrees of risk inherent in all strategies.

| | **Volatility Parameter for ROKI** |
|---|---|
| **Strategy A** | 92% |
| **Strategy B** | 86% |
| **Strategy C** | 92% |

*Figure A.13. Volatility Parameters Related to Strategy ROKIs*

Using these volatility parameters as well as the other inputs associated with each stage of each strategy, we ran real options analysis using binomial lattices and simulation.

Each real options analysis provided us with two new valuations to consider along with the base case NPVs: the total strategic value and the value of the options built into the staged models. Figure A.14 summarizes these values for our three strategies. [Columns (A) + (B) = (C)]

Once the real options analysis was completed for all strategies, we were able to compare total strategic values with base case NPVs under varying levels of volatility, to identify the optimal strategy to execute. Figure A.15 presents the results of this statistical comparison.

| | (A)<br>Base Case NPVs | (B)<br>Option Values | (C)<br>Total Strategic Values |
|---|---|---|---|
| **Strategy A** | $24.37M | $9.42M | $33.79M |
| **Strategy B** | $26.63M | $8.37M | $35.00M |
| **Strategy C** | $24.75M | $14.17M | $38.92M |

*Figure A.14. Base Case, Option, and Total Strategic Values*

| Volatility | 10% | 20% | 30% | 40% | 50% | 60% | 70% | 80% | 90% | 100% | 110% | 120% |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Total Strategic Value | B | B | B | B | C | C | C | C | C | C | C | C |
| Base Case NPV | B | B | B | B | B | B | B | B | B | B | B | B |

*Figure A.15. Reversion of Optimal Strategy under Different Volatilities*

An interesting result emerges. When volatilities are low, Strategy B is optimal. However, when the volatility is high, the total strategic value (NPV plus real options value) indicates that Strategy C is optimal. Because the analysis of each strategy involved a relatively high volatility for ROKIs (92%, 86%, and 92%), the optimal strategy is C.

Hence, when accounting for the strategic flexibility of the MSC implementations, Strategy C should be undertaken. In fact, Figure A.16 indicates that 99.90% of the time, Strategy C has a higher strategic value than Strategy B.

Type Right-Tail ≥ 33,790.00 Infinity Certainty % 99.90

*Figure A.16. Strategy C's Statistical Probably of Exceeding Strategy B's Value*

### *Problem-Solving Contributions of KVA to Real Options Analysis*

At the most aggregated level, real options analysis occurs in four phases over time:

- Phase One—Establish the structure for the problem.
- Phase Two—Plan and frame the options (i.e., lay out the options).
- Phase Three—Implement (exercise) the options over time.
- Phase Four—Track options results and adjust decision paths.

KVA can make significant contributions in Phase One by providing a higher quality of fundamental data inputs to the problem structure. Currently real options analysts use project-level, or even company-level, data for real options analysis. There are currently no specific suborganizational data that can be used. KVA can analyze the effects of core processes on a project and provide fresh raw data based on estimated suborganizational revenues and costs. This suborganizational-level data also allows analysts to identify and understand the inter-dependencies among processes within the project and between the project and the company.

In addition, KVA can make significant contributions in Phase Four. As KVA data is gathered, it can be used to build near real-time option performance assessments. Currently, there has been no direct way for management to measure option performance on an ongoing basis once an option decision path has been selected.

# Appendix 3—Case Example: Ship Maintenance Processes With Collaborative Product Lifecycle Management and 3D Terrestrial Laser Scanning Tools: Reducing Costs and Increasing Productivity

The current cost-constrained environment within the federal government and Department of Defense (DOD) requires a cogent approach to cost reductions that will not result in compromising the productivity of core defense support processes such as ship maintenance. At the same time, defense leaders must also navigate a complex information technology (IT) acquisition process. The DOD spends over $63 billion annually, or 14% of its total budget, on defense maintenance programs throughout the world (Office of the Deputy Under Secretary of Defense [Logistics and Material Readiness], 2006).

One such core process central to naval operations is the ship maintenance process. This process alone accounts for billions of dollars of the Navy's overall annual budget. There have been a series of initiatives designed to reduce the cost of this core process, including ship maintenance (SHIPMAIN), which was designed to standardize ship maintenance alterations to take advantage of the cost savings from standardizing core processes. One purpose of SHIPMAIN was to take advantage of the well-documented cost-savings learning curve found in the manufacturing arena. A problem in using the SHIPMAIN approach has been that the normal cost-reduction learning curve for common ship alterations, across a series of common ship platforms, has not materialized.

SHIPMAIN was created, in part, to address the glaring disparity in ship maintenance performance within the Navy. However, the initial instantiation of SHIPMAIN did not include two recommended technologies, 3D TLS + collab-PLM, which were deemed necessary by Bob Stout, the creator of SHIPMAIN, for ensuring the success of the new standardized approach (i.e., normal learning curve cost savings).

These technologies are currently employed in shipbuilding. When they are also incorporated into the maintenance cycle, the results should lead to the benefits projected. The use of the tools in shipbuilding will allow for the reuse of their outputs (i.e., 3D images of the entire ship inside and out can be created, updated, and distributed remotely, cross-platform sharing of these images, and the capability for cross-platform searches). Using the tools across the entire shipbuilding and maintenance lifecycle should result in substantial cost savings and increased shipyard capacity to accommodate Secretary of the Navy, the Honorable Ray Mabus' goal of a large increase in the fleet.

To evaluate and select ship maintenance options (e.g., strategies for the use of the collab-PLM + 3D TLS technologies) that promise the best cost savings and highest returns, measurement methods are essential to define, capture, and measure the cost savings and returns on these technologies. In addition to estimating potential cost savings, these measurement methods also must incorporate and analytically quantify elements of uncertainty and risks inherent in predicting the future value of these technologies for ship maintenance processes. This will allow acquisition professionals to develop ways to mitigate these risks by taking advantage of the most promising strategic ship maintenance options, while analytically developing and allocating budgets to optimize project portfolios.

In this example case study, the IRM framework is used to quantify and project potential process cost savings and the potential benefits of selecting collab-PLM + 3D TLS technology in the ship maintenance program. SHIPMAIN is a large program with many interrelated concepts, instructions, policies, and areas of study. Although the quantitative scope of the research was constrained to Phases IV and V of the SHIPMAIN process, the technologies evaluated in this research are likely to provide additional benefits (e.g., more accurate cost-estimation, higher quality, less rework, and more efficient system dynamics) across all phases of ship maintenance.

In this appendix, a description of the SHIPMAIN program is followed by a description of the collab-PLM + 3D TLS technologies. Following this, the IRM framework is applied to Phase IV of SHIPMAIN to perform a real options analysis and future research will incorporate portfolio optimization using modern portfolio theory (MPT).

The Knowledge Value Added + Systems Dynamics + Integrated Risk Management (KVA+SD+IRM) framework measures operating performance, cost-effectiveness, return on investment, risk quantification, strategic real options (capturing strategic flexibility), and analytical portfolio optimization. The use of SD scenario modeling provides a means to estimate the impact of ship maintenance process improvements with collaborative product lifecycle management + 3D terrestrial laser scanning (collab-PLM + 3D TLS) technologies over time. The analysis can be compared with historical static data to assess the fidelity of the SD models. Background on the system dynamics methodology and its application to the current work are provided in Ford, Housel, and Mun (2011).

## *SHIPMAIN*

In August 2006, the *Surface Ship and Carrier Entitled Process for Modernization (SSCEPM) Management and Operations Manual* became the Navy's official document for the modernization of all surface ships and aircraft carriers (Commander, Naval Sea Systems Command [NAVSEA], 2006). SSCEPM provides the policy and processes associated with ship maintenance (SHIPMAIN) for planning, budgeting, engineering, and installing timely, effective, and affordable shipboard improvements while maintaining configuration management and supportability. The SHIPMAIN process represents a sweeping change in the modernization of surface ships and carriers. The SHIPMAIN process streamlines and consolidates several existing modernization practices, processes, meetings, and supporting documents to provide a single, hierarchical decision-making process for modernizing surface ships and carriers.

The SHIPMAIN process comprises five distinct phases[1] and three decision points (DP)[2] that take a proposed change from concept to completion in a single

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[1] The five phases are as follows: I—Conceptual, II—Preliminary Design, III—Detailed Design, IV—Implementation, and V—Installation (NAVSEA, 2006).

Ship Change Document (SCD). The SCD is a single lifecycle-management document depicting a modernization change from concept to completion for ships (NAVSEA, 2006, pp. 1–3). Although SHIPMAIN has a functional governance structure and supporting business rules, it has yet to reach a fully implemented state, especially in Phases IV and V. Business rules for Phases IV and V are in a maturing phase, and the process owners are regularly gathering input from stakeholders to resolve issues and refine the business rules to move forward with this initiative.

SHIPMAIN is designed to take advantage of best business practices from industry that lead to cost reductions based on the production learning curve. The Navy implemented the SHIPMAIN process in FY2004 to increase the efficiency of the maintenance and modernization process without compromising its effectiveness, to define a common planning process for surface ship maintenance and alterations, to install a disciplined management process with objective measurements, and to institutionalize that process and provide continuous improvement methodology (NAVSEA, 2006).

SHIPMAIN seeks to identify and eliminate redundancies in maintenance processes. It provides a single entitled process, assisting the Navy in realizing the maximum cost savings in maintenance by eliminating time lags, prioritizing ship jobs, and empowering Sailors in their maintenance decisions (NAVSEA, 2006). The five-phase process was originally designed to employ collab-PLM + 3D TLS. However, these technologies were not incorporated in the implementation of the SHIPMAIN program.

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[2] DPs occur at the conclusion of Phases I–III. Each DP is an approval for funding of successive phases and has an associated Cost Benefit Analysis (CBA), Alteration Figure of Merit (AFOM), and Recommended Change Package (RCP; NAVSEA, 2006).

### *3D Terrestrial Laser Scanning, Collaborative Product Lifecycle Management Technology*

Terrestrial laser scanning technology is currently used in a variety of industries. According to industry analysts, laser scanner manufacturers and related software and service providers report strong activity across many markets, including shipbuilding, offshore construction and repair, onshore oil and gas, fossil and nuclear power, civil and transportation infrastructure, building, automotive and construction equipment, manufacturing, and forensics (Greaves & Jenkins, 2007). Sales of terrestrial 3D laser scanning hardware, software, and services reached $253 million in 2006—a growth of 43% over 2005 (Greaves & Jenkins, 2007). Most manufacturers' scanners work by scanning a target space with a laser light mounted on a highly articulating mount, enabling data capture in virtually any orientation with minimal operator input. Some also incorporate a digital camera that simultaneously captures a 360° field-of-view color photo image of the target. Once the capture phase is complete, the system automatically executes proprietary point-processing algorithms to process the captured image. The system can generate an accurate[3] digital 3D model of the target space, automatically fuse image texture onto 3D model geometry, export file formats ready for commercial, high-end design, and import them into 2D/3D computer-aided design (CAD) packages.

Collab-PLM technology provides a common platform to electronically integrate 3D TLS images in three-dimensional surface representations to enable collaboration among all parties involved in each project, regardless of their geographic location. It also provides a means to store the images and all related maintenance work within a common database accessible by all participants in a ship alteration or modernization project. PLM is defined by CIMdata as a strategic business approach applying a consistent set of business solutions in support of the collaborative creation, management, dissemination, and use of product definition information across the extended enterprise, from concept to end-of-life (CIMdata,

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[3] NSRP's study (2006, 2007b) requirement was within 3/16 of an inch to actual measurements.

2007).[4] It integrates people, processes, and information. The collab-PLM tools include technologies that support data exchange, portfolio management, digital manufacturing, enterprise application integration, and workflow automation. Various industries have invested in collab-PLM solutions, including those involved in aerospace and defense, automotive and transportation, utilities, process manufacturing, and high-tech development and manufacturing. The collab-PLM market is poised for further growth with vendors expanding product offerings as the industry evolves.

## *SHIPMAIN: Collab-PLM+3D TLS Technologies*

The KVA+SD+IRM valuation framework was used to demonstrate how the integration of these two technologies within Phase IV of SHIPMAIN can result in substantial cost savings and decreased fleet cycle time via significant productivity improvements. The results also demonstrate the possible increases in shipyard capacity when these tools are used in ship maintenance. This may become a critical benefit for the Navy per the Secretary of Navy’s recently articulated goal for a substantial long-term increase in the fleet’s size. A prior study of the ship maintenance process (Komoroski, 2005) was used as a basis for the current work. That study identified seven sequential core processes, as well as the subprocesses within each core process, that are utilized to plan for ship maintenance alterations on U.S. Navy surface ships. See Ford, Housel, and Mun (2011) for details. The study collected data from the Puget Sound Planning Yard through extensive interviews with subject matter experts. This data was used to quantitatively describe ship maintenance in an “As-Is” environment, that is, without collab-PLM + 3D TLS technologies. The KVA method was applied to model the “As-Is” environment, which is used as baseline cost and productivity data for the current work.

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[4] CIMdata is a consulting firm with over 20 years of experience in strategic IT applications and is an acknowledged leader in the application of PLM and related technologies (CIMdata, 2007).

The Komoroski study estimated baseline costs for these SHIPMAIN Phase IV seven core processes to be $45 million per year. This estimate was based on executing the seven core planning processes 40 times across the four public shipyards. The model was then used to model costs in a “To-Be” environment in which 3D TLS had been adopted by the four shipyards. Adding 3D TLS to the planning process cycle lowered expenses a projected 84% (to less than $8 million), as seen in Table A.1. Introduction of 3D TLS in the “To-Be” environment could result in projected cost savings of nearly $37 million because Subprocesses 3, 4, and 7 were dramatically re-engineered (Komoroski et al., 2006).

The second notional “To-Be” KVA model evaluated the effects of adding both 3D TLS and the collab-PLM suite of software to the “As-Is” baseline. Projections for this scenario (based on increased savings in Core Processes 3, 4, and 7, as well as additional savings realized in Core Processes 2 and 5, included a cost savings of 90%, or approximately $40 million.

*Table A.1. KVA Results—Analysis of Costs of Seven Core Planning Processes*

| Seven Core Processes | Cost |
|---|---|
| **1** ISSUE TASKING | $173,500 |
| **2** INTERPRET ORDERS | $520,000 |
| **3** PLAN FOR SHIP CHECK | $1,655,000 |
| **4** CONDUCT SHIP CHECK | $2,604,500 |
| **5** REPORT ASSEMBLY | $235,000 |
| **6** REVISE SCHEDULE | $131,000 |
| **7** GENERATE DRAWINGS | $39,386,000 |
| TOTALS | **$44,705,000** |

## *KVA Results*

The cost analysis results were based on the “As-Is” KVA baseline analysis. The return on investment (ROI) for each of the seven core processes was calculated (Table A.2). The numerator of the ROI calculation was the difference between the surrogate revenue (based on common units of output for each process) per time period for each process and the cost of the process, divided by the cost for the process:

ROI = (Revenue per process – Cost for the process)/Cost for the process

These estimates provided baseline relative productivities for each of the core processes. For example, Process 3 – Plan for Ship Check, provided the lowest ROI (-99%) even though it was not the costliest. And Process 7, clearly the costliest ($39,386,000 from Table A.1), was not the least productive process in terms of its ROI performance (-37%, 5th of the seven core processes). These baseline estimates provide a reference point for comparing relative productivity increases when the technologies are included in the process modeling, which results in substantial increases in the two "To-Be" ROI estimates.

***Table A.2. KVA Results—Analysis on ROI***

| Core Process | Process Title | "AS IS" ROI |
|---|---|---|
| **1** | Issue Tasking | -69% |
| **2** | Interpret Orders | 518% |
| **3** | Plan for Ship Check | -99% |
| **4** | Conduct Ship Check | 552% |
| **5** | Report Assembly | 783% |
| **6** | Revise Schedule | 1375% |
| **7** | Generate Drawings | -37% |

This baseline model provided the inputs for the current study's SD model. A comparison with the SD model and the static KVA analysis revealed that the SD model was of high fidelity with the previous results and could be used for further analysis and projections for the "To-Be" scenarios. These analyses can describe a variety of environmental conditions, such as different product lifespans, thereby capturing the potential effects of the two technologies on resulting costs and ROIs. While these results might be considered relatively positive, the current work reveals that the addition of collab-PLM + 3D TLS technologies promises to return even more significant savings and higher ROIs.

### *Collab-PLM and 3D TLS Adoption Conditions and Simulation Results and Discussion*

SHIPMAIN was simulated with the SD model (see Ford, Housel, & Mun, 2011, for model details) by varying four conditions: (1) the number of shipyards that adopt the technology, (2) the cycle-time reduction due to the adoption of the technologies, (3) the lifespan of the technologies before they were replaced, and (4) the finance plan for adoption. The three simulated numbers of shipyards adopting were zero, which represents the As-Is conditions; four, which represents adoption by the Navy yards but not the commercial yards; and seven, which represents adoption by the four Navy yards and the three commercial yards. The three simulated levels of cycle-time reduction were 20%, 40%, and 60%, based on estimates of experience by other industries provided by the product vendor. Three product lifespans were simulated: 5, 10, and 15 years (researcher estimates). Two financing plans were simulated, based on either adoption of the technologies by the four Navy yards over several years or the simultaneous adoption of those technologies by all four Navy yards. The first plan (adoption over several years) assumed that the Navy paid a total of $6,400,000 based on an estimated $1,600,000 per Navy yard (vendor estimate) for each of the four Navy yards. The second financing plan (simultaneous adoption) assumed that the Navy paid a total cost of $3,200,000 for all four Navy yards. The 36 scenarios generated by the possible combinations of these adoption alternatives (two-yard adoption alternatives, three cycle-time reductions, three lifespans, two finance plans) were used to estimate ship maintenance cost.

The simulated costs with no yards adopting the technologies (As-Is conditions) over the product lifespans assuming four or seven yards of production were used as base cases for estimating savings. As an example, the As-Is costs for four yards if the product lifespan is five years is estimated to be $228.15 million, or $45.63 million/year x 5 years. The difference between each simulated cost of an adoption scenario and the base case cost for the same number of yards and product lifespan is the estimated cost savings for the scenario. The resulting cost savings for each adoption scenario are shown in Table A.3. For example, the estimated cost of four yards adopting the technologies for a 5-year lifespan and capturing 20% cycle-time reduction with a cost of $1.6 million for the two technologies per yard is $39.05 million. Therefore, estimated savings is $189.1 million ( = $228.2 – $39.05), the value shown in the upper left estimated savings cell in Table A.3.

By adopting collab-PLM and 3D TLS, net estimated cost savings potential ranges from $161 million to $1.03 billion (in bold and underlined print in Table A.3). As expected, cost savings increase with the number of yards adopting collab-PLM and 3D TLS and product lifespan. Savings reduction was seen with increased cycle-time reduction, a counterintuitive result. The impact of cycle-time reduction on the throughput of ships explains this behavior because the increased throughputs increase costs, thus decreasing savings.

*Table A.3. Simulated SHIPMAIN Cost Savings Due to Adoption of Collaborative PLM and 3D TLS*

| **Reduced Total Ownership Costs ($millions)** | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Finance Plan: $1.6m for each of 4 yards = $6.4m total** | | | | | | | | | | | |
| *20% CT reduction* | **Product Lifespan** | | | *40% CT reduction* | **Product Lifespan** | | | *60% CT reduction* | **Product Lifespan** | | |
| **No. Yards Adopting** | **5 years** | **10 years** | **15 years** | **No. Yards Adopting** | **5 years** | **10 years** | **15 years** | **No. Yards Adopting** | **5 years** | **10 years** | **15 years** |
| **4** | 189.10 | 384.59 | 580.08 | **4** | 179.73 | 365.87 | 552.01 | **4** | **161.04** | 328.48 | 495.92 |
| **7** | 337.96 | 682.34 | 1026.68 | **7** | 321.58 | 649.57 | 977.55 | **7** | 288.86 | 584.13 | 879.40 |
| **Finance Plan: $3.2m for 4 yards = $3.2m total** | | | | | | | | | | | |
| *20% CT reduction* | **Product Lifespan** | | | *40% CT reduction* | **Product Lifespan** | | | *60% CT reduction* | **Product Lifespan** | | |
| **No. Yards Adopting** | **5 years** | **10 years** | **15 years** | **No. Yards Adopting** | **5 years** | **10 years** | **15 years** | **No. Yards Adopting** | **5 years** | **10 years** | **15 years** |
| **4** | 192.29 | 387.79 | 583.28 | **4** | 182.93 | 369.07 | 555.21 | **4** | 164.24 | 331.69 | 499.10 |
| **7** | 341.16 | 685.53 | **1029.88** | **7** | 341.16 | 652.77 | 980.75 | **7** | 324.78 | 588.94 | 884.23 |

For example, for four yards acquiring the two technologies for $1.6 million each (see the top row of Table A.3) with a product lifespan of 10 years, savings dropped from $385 million to $366 million to $328 million as cycle-time reduction increases from 20% to 40% to 60%. The increased throughput capacity of the maintenance yards made available by the adoption of collab-PLM and 3D TLS may prove critical for Navy development. Navy Secretary Mabus recently announced plans to build a 324 warship Navy by 2020 (Howe, 2011). This will require increased ship maintenance capacity. The increased capacity may prove a critical part of growing the fleet without increasing the number of maintenance yards. The modeling described above assumes that the Navy has the demand and other required resources needed to utilize the increased capacity created by reduced cycle times. This may not be accurate, but describes an extreme condition on a continuum of potential combinations of increased throughput and decreased capacity. The other end of that continuum assumes that the throughput rate remains unchanged. Similar calculations to those above show that the required capacities with reduced cycle times are proportionate to the cycle-time reduction. Therefore, a 20% cycle-time reduction for the current throughput requires 20% less capacity, and so forth. This scenario could allow the Navy to maximize capacity use at certain yards and idle or close one or more yards that were not needed, depending on the cycle-time reduction captured.

### *Integrated Risk Management*

The results for the IRM analysis are built on the quantitative estimates provided by the KVA+SD analysis. The IRM analysis provides defensible quantitative risk analytics and portfolio optimization that suggest the best way to allocate limited resources to ensure the highest possible cost savings over time in ship maintenance processes. The first step in IRM using real options is to generate a strategic map through the process of framing the problem. Generally, problem identification during the initial qualitative management screening process leads to the identification of strategic options for each project. Those strategic options can include flexibility to, among other things, expand, contract, abandon, switch, and choose. The current work focuses on the use of real options to expand the adoption of collab-PLM and 3D TLS, including some options to abandon the adoption effort. Using Monte Carlo simulation, the stochastic KVA ROK model that is based on the identified options has a distribution of values for the drivers of project value. Thus, simulation models analyze and quantify the various risks of each project. The product of the simulations is a distribution of the ROKs and the project's volatility. In real options, we assume that the underlying variable is the future benefit minus the cost of the project. An implied volatility can be calculated through the results of a Monte Carlo simulation performed. Usually, the volatility is measured as the annualized standard deviation of the logarithmic relative returns on the free net benefit stream.

Portfolio optimization will be performed in a future phase of the project because, as of now, there is insufficient data to perform an adequate portfolio optimization applying modern portfolio theory. A description of the proposed optimization approach is presented here. When the analysis is done on multiple projects or processes, decision makers can view the results as a portfolio of rolled-up projects because the projects are in most cases correlated with one another, and viewing them individually will not present the true picture. As organizations do not have only single projects, portfolio optimization becomes crucial. Given that certain projects are related to others, there are opportunities for hedging and diversifying risks through a portfolio. Because organizations have limited budgets, along with time, people, and resource constraints, and at the same time have requirements for certain overall levels of returns, risk tolerances, and so forth, portfolio optimization would consider all these conditions to create an optimal portfolio mix. The analysis would provide guidance for identifying the optimal allocation of investments across multiple projects.

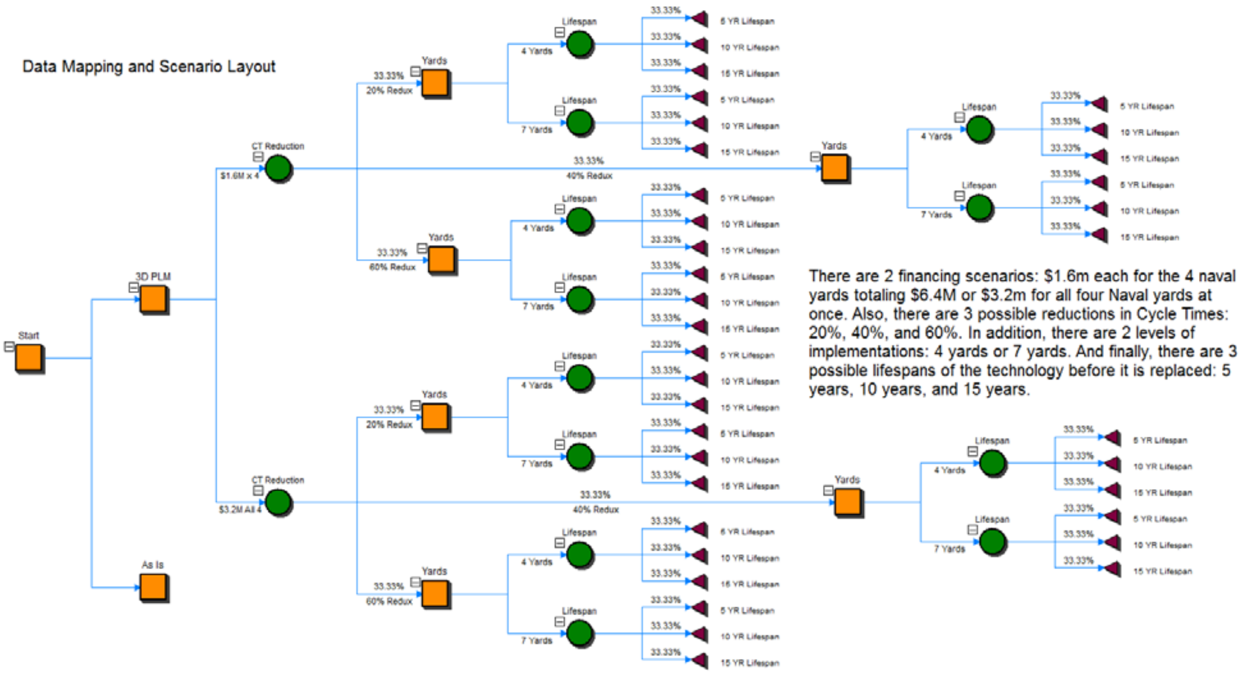
The current work addresses how the Navy can use real options to manage risk. Risk management using real options assumes that the future is uncertain and that decision makers have the right to make midcourse corrections when these uncertainties become resolved or risks distributions become known. Risk analysis for the design and use of real options is usually done ahead of time and, thus, ahead of experiencing such uncertainty and risks. Therefore, when these risks become known and better understood, the analysis should be revisited to incorporate new information into decision-making or to revise any input assumptions. Sometimes, for long-horizon projects, several iterations of the real options analysis should be performed, where future iterations are updated with the latest data and assumptions. Understanding the steps required to undertake an integrated risk analysis is important because it provides insight not only into the methodology itself, but also into how it evolves from traditional analyses, showing where the traditional approach ends and where the new analytics start.

Real options analysis was performed to determine the prospective value of the basic options over a multi-year period using KVA data as a platform. The strategic real options analysis is solved employing various methodologies, including the use of binomial lattices with a market-replicating portfolios approach, and backed up using a modified closed-form sequential compound option model. Risk analysis of the current work requires the modeling of compound options. Compound options occur when managers have an option to use a second option, or when an option is “nested” within a different option. The value of a compound option is based on the value of another option. That is, the underlying variable for the compound option is another option, and the compound option can be either sequential in nature or simultaneous. Solving such a model requires programming capabilities. Figure A.17 shows the graphical depiction of the scenarios available for this initial 3D TLS and collab-PLM analysis. This figure uses a decision tree to depict the two alternate financing scenarios (Scenario 1 comprises a total of $6.4 million, where $1.6 million per shipyard is implemented over time for a total of four shipyards, and in Scenario 2, all four shipyards are implemented simultaneously, for a total of $3.2 million); the three possible reductions in cycle time (20%, 40%, and 60%), the two levels of implementation (four yards or seven yards), and the technology’s lifespan (5 years, 10 years, and 15 years). We chose the decision tree for its simplicity in graphically depicting the various scenarios and conditions. In decision trees, square nodes depict investment decisions such as how many yards to implement; circles depict uncertainty events such as cycle-time reduction and lifespan; and triangles indicate end points of all possible combinations of outcomes. In this case, there are 36 possible combinatorial outcomes. The decision tree is only used for showing these various combinatorial outcomes and not used as a computational method due to its many limitations. Instead, we revert to using the Monte Carlo risk simulation and strategic real options methodologies, as discussed in subsequent paragraphs.

Figure A.18 shows the three investment option paths. The first strategy (Strategy A) is a phased implementation, where the first four yards are implemented sequentially, one at a time, and at the end of the fourth yard (Phase IV), an additional three yards can be implemented at once. The benefit of this first option is that a lower initial investment is at risk, and at any time, the entire project can be abandoned. That is, at the end of Phase I or during any of the phases, if significant problems arise during the implementation process, the Navy can decide to abandon the project altogether and not risk the entire investment amount (e.g., only $1.6 million will be expended in Phase I instead of risking a total of $3.2 million in implementing all four yards at once, or $7.2 million for all seven yards). The disadvantage of this scenario is that the total ownership cost savings will not be realized as quickly as in Strategy B, where multiple yards are simultaneously implemented.

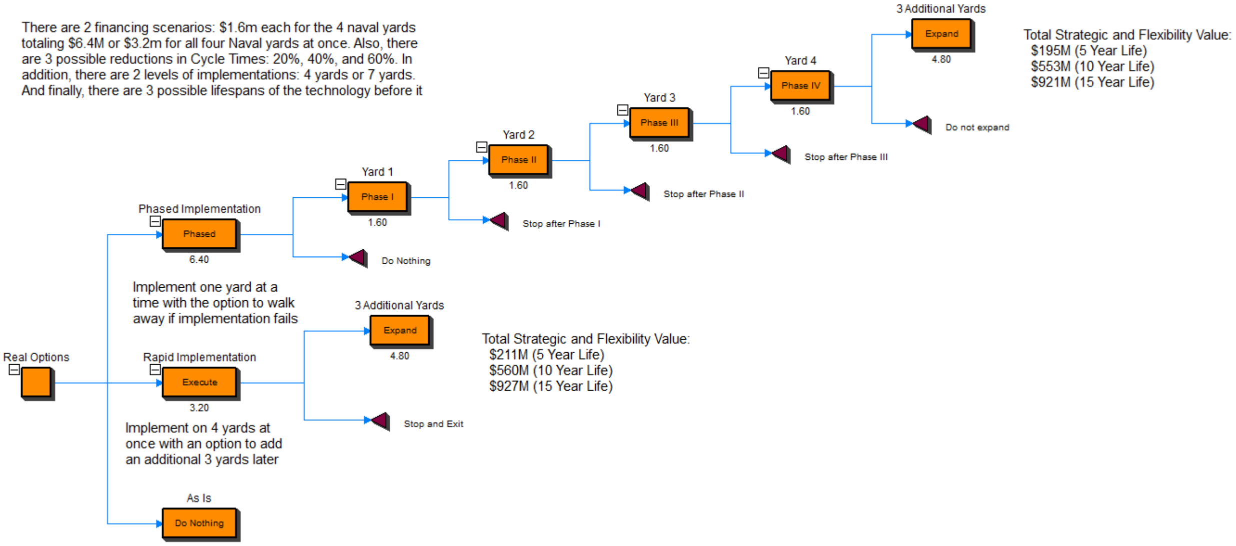
This second option path, or Strategy B, involves rapid implementation by investing in four yards simultaneously, thereby reducing the total investment cost ($3.2 million instead of $6.4 million as in Strategy A), but clearly the investment amount risked is higher. The benefit is that implementation is rapid and the savings can be obtained faster, and if all goes well with the implementation, the additional three yards can be added to the portfolio quickly.

Both Strategies A and B are compared to Strategy C, the As-Is, or Do-Nothing-New, situation. Therefore, the analysis results from the strategic real options analysis is a relative analysis, where the results indicate reduction in total ownership costs and strategic values relative to Strategy C. Figure A.19 shows the various scenarios and the reduction in total ownership cost (TOC) savings. It also shows the risk-adjusted, inflation-adjusted, and diminishing marginal returns adjusted savings, as well as their relative volatilities. These adjustments are required because the different implementation paths take on different timelines and, hence, have different inflation effects as well as risk-time effects. Further, we assumed some levels of diminishing marginal returns on the reduction in TOC over time, as will be discussed later.



There are 2 financing scenarios: $1.6m each for the 4 naval yards totaling $6.4M or $3.2m for all four Naval yards at once. Also, there are 3 possible reductions in Cycle Times: 20%, 40%, and 60%. In addition, there are 2 levels of implementations: 4 yards or 7 yards. And finally, there are 3 possible lifespans of the technology before it is replaced: 5 years, 10 years, and 15 years.

*Figure A.17. Representation of Implementation Scenarios and Data Requirements*



There are 2 financing scenarios: $1.6m each for the 4 naval yards totaling $6.4M or $3.2m for all four Naval yards at once. Also, there are 3 possible reductions in Cycle Times: 20%, 40%, and 60%. In addition, there are 2 levels of implementations: 4 yards or 7 yards. And finally, there are 3 possible lifespans of the technology before it

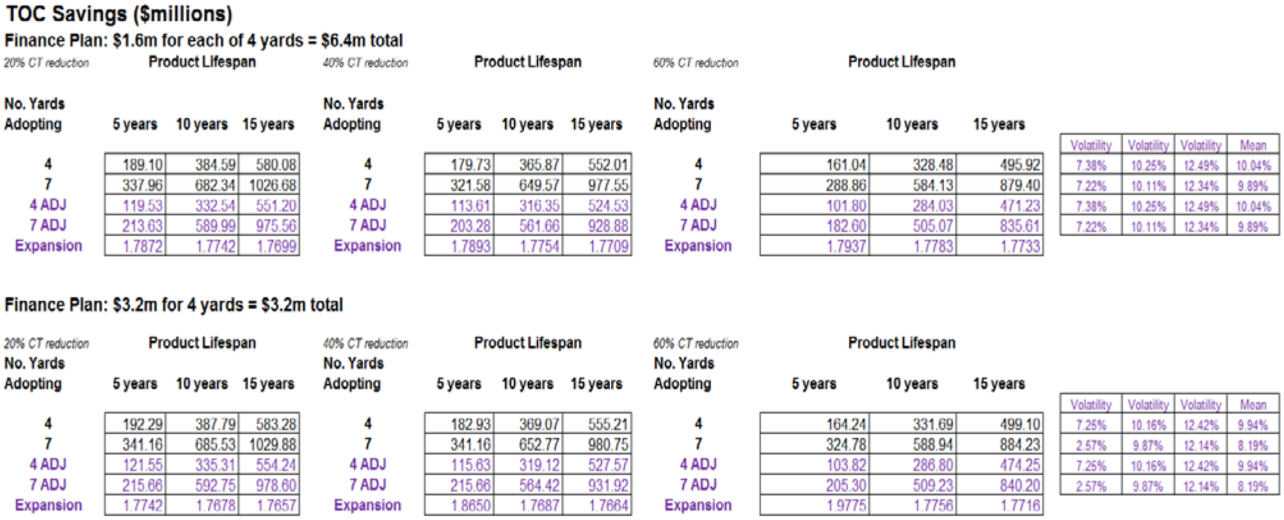
Total Strategic and Flexibility Value:
$195M (5 Year Life)
$553M (10 Year Life)
$921M (15 Year Life)

Implement one yard at a time with the option to walk away if implementation fails

Total Strategic and Flexibility Value:
$211M (5 Year Life)
$560M (10 Year Life)
$927M (15 Year Life)

Implement on 4 yards at once with an option to add an additional 3 yards later

*Figure A.18. Strategic Real Options of Investment Paths*



**TOC Savings ($millions)**

**Finance Plan: $1.6m for each of 4 yards = $6.4m total**

*20% CT reduction*

| No. Yards Adopting | 5 years | 10 years | 15 years |
|---|---|---|---|
| 4 | 189.10 | 384.59 | 580.08 |
| 7 | 337.96 | 682.34 | 1026.68 |
| 4 ADJ | 119.53 | 332.54 | 551.20 |
| 7 ADJ | 213.63 | 589.99 | 975.56 |
| Expansion | 1.7872 | 1.7742 | 1.7699 |

*40% CT reduction*

| No. Yards Adopting | 5 years | 10 years | 15 years |
|---|---|---|---|
| 4 | 179.73 | 365.87 | 552.01 |
| 7 | 321.58 | 649.57 | 977.55 |
| 4 ADJ | 113.61 | 316.35 | 524.53 |
| 7 ADJ | 203.28 | 561.66 | 928.88 |
| Expansion | 1.7893 | 1.7754 | 1.7709 |

*60% CT reduction*

| No. Yards Adopting | 5 years | 10 years | 15 years |
|---|---|---|---|
| 4 | 161.04 | 328.48 | 495.92 |
| 7 | 288.86 | 584.13 | 879.40 |
| 4 ADJ | 101.80 | 284.03 | 471.23 |
| 7 ADJ | 182.60 | 505.07 | 835.61 |
| Expansion | 1.7937 | 1.7783 | 1.7733 |

| Volatility | Volatility | Volatility | Mean |
|---|---|---|---|
| 7.38% | 10.25% | 12.49% | 10.04% |
| 7.22% | 10.11% | 12.34% | 9.89% |
| 7.38% | 10.25% | 12.49% | 10.04% |
| 7.22% | 10.11% | 12.34% | 9.89% |

**Finance Plan: $3.2m for 4 yards = $3.2m total**

*20% CT reduction*

| No. Yards Adopting | 5 years | 10 years | 15 years |
|---|---|---|---|
| 4 | 192.29 | 387.79 | 583.28 |
| 7 | 341.16 | 685.53 | 1029.88 |
| 4 ADJ | 121.55 | 335.31 | 554.24 |
| 7 ADJ | 215.66 | 592.75 | 978.60 |
| Expansion | 1.7742 | 1.7678 | 1.7657 |

*40% CT reduction*

| No. Yards Adopting | 5 years | 10 years | 15 years |
|---|---|---|---|
| 4 | 182.93 | 369.07 | 555.21 |
| 7 | 341.16 | 652.77 | 980.75 |
| 4 ADJ | 115.63 | 319.12 | 527.57 |
| 7 ADJ | 215.66 | 564.42 | 931.92 |
| Expansion | 1.8650 | 1.7687 | 1.7664 |

*60% CT reduction*

| No. Yards Adopting | 5 years | 10 years | 15 years |
|---|---|---|---|
| 4 | 164.24 | 331.69 | 499.10 |
| 7 | 324.78 | 588.94 | 884.23 |
| 4 ADJ | 103.82 | 286.80 | 474.25 |
| 7 ADJ | 205.30 | 509.23 | 840.20 |
| Expansion | 1.9775 | 1.7756 | 1.7716 |

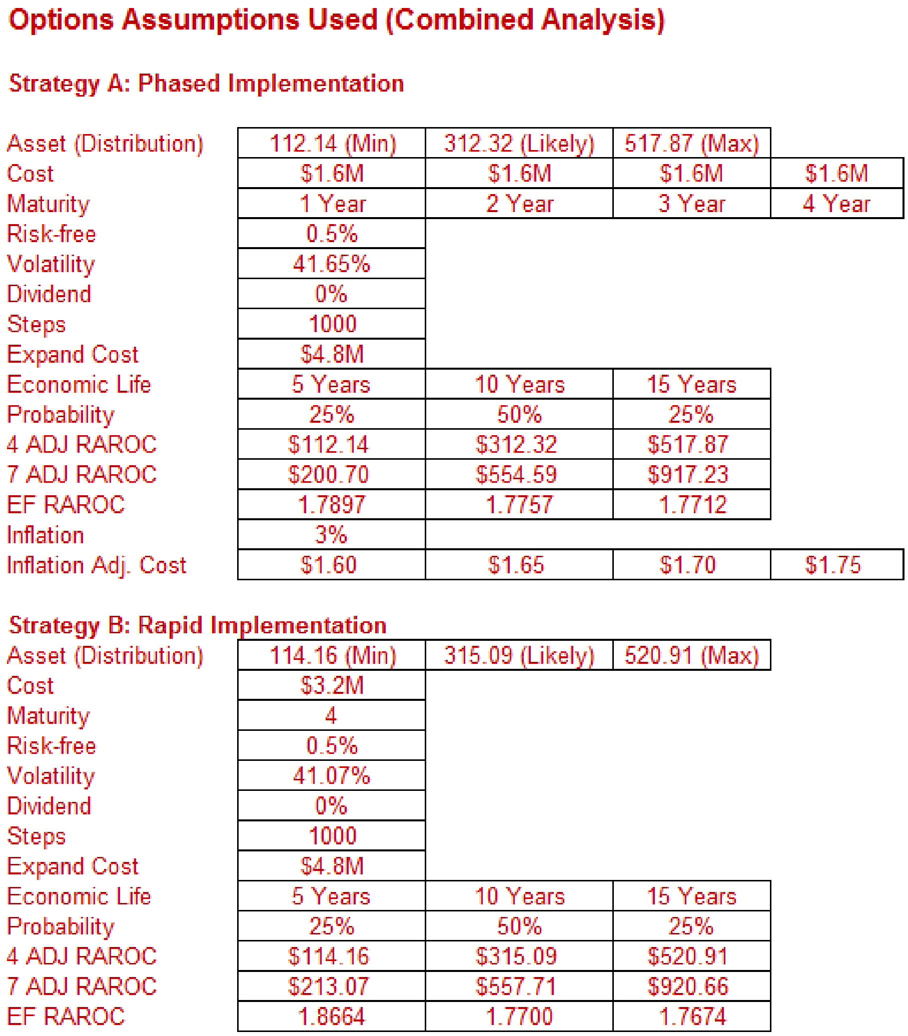
| Volatility | Volatility | Volatility | Mean |
|---|---|---|---|
| 7.25% | 10.16% | 12.42% | 9.94% |
| 2.57% | 9.87% | 12.14% | 8.19% |
| 7.25% | 10.16% | 12.42% | 9.94% |
| 2.57% | 9.87% | 12.14% | 8.19% |

*Figure A.19. Reduction in Total Ownership Costs*

Figure A.20 shows the input assumptions used in the strategic real options analysis, as well as Monte Caro risk simulation analysis for the two implementation strategies. Simulations of 10,000 to 100,000 trials were applied using these values, and the various combinatorial effects were collapsed into probability distributions and then simulated. The results were then used as inputs into the real options analysis. Figure A.18 illustrates the two strategies' (Strategy A, phased implementation and Strategy B, rapid implementation) input into the real options model (e.g., the net reduction in total ownership costs minimum, most likely, and maximum values, implementation costs over time, simulated risk volatility and other assumptions).

Figures A.21 and A.22 show the results from both strategies. Specifically, Strategy A's phased implementation (sequential compound option) shows a value of $546 million, whereas Strategy B has a value of $557 million. This shows that the rapid implementation has a higher strategic value in that, although the risk is slightly higher with the higher up-front investment amount, the savings received will be faster and the total invested cost is lower (as compared to the higher total investment cost for Strategy A). However, the values of the two strategies are quite close (within 2%). In addition, Figure A.22 shows that when simulation was applied to compare the relative values of Strategies A and B, Strategy B, the rapid implementation path, has a 53.20% probability of exceeding Strategy A. In fact, the relative risk measures show that both scenarios have very close relative risks (41.65% versus 41.07%). This further explains why the values of the two strategic real options are so close.

The results of the simulations indicate that both Strategies A and B are valuable and that their values are very similar. This suggests that the choice of one strategy over the other should be up to the decision maker based on which path makes more sense in an operational environment. Both strategies show a significant reduction in TOC overall, even after considering risk effects and diminishing marginal returns.



**Options Assumptions Used (Combined Analysis)**

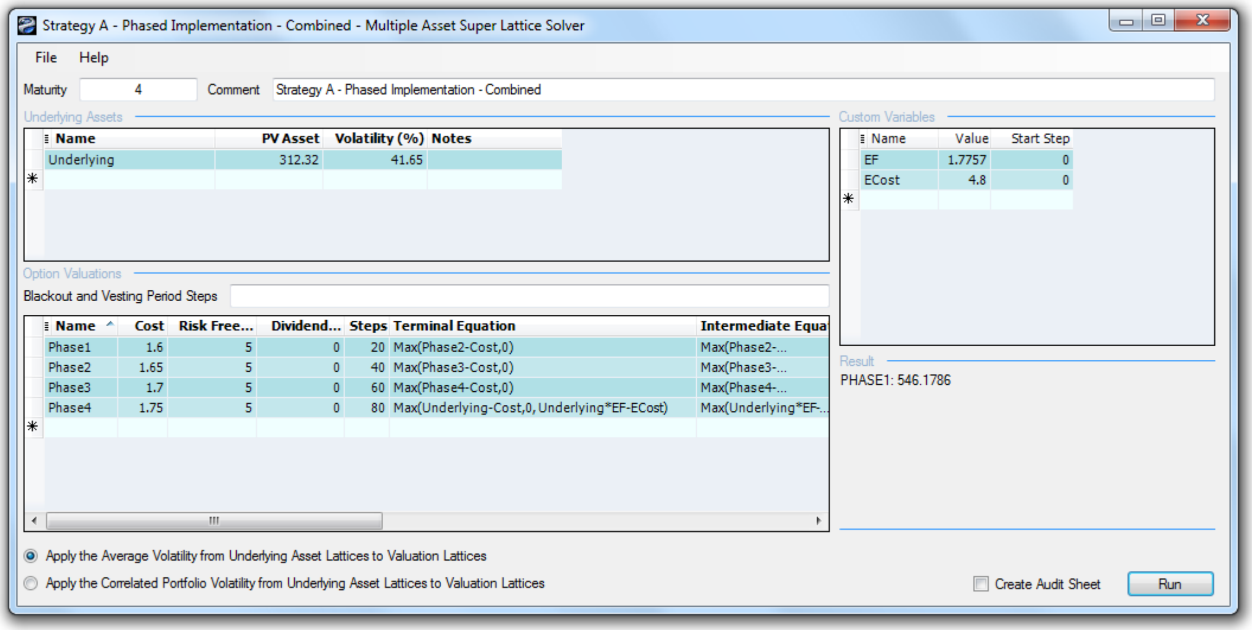
**Strategy A: Phased Implementation**

| | | | | |
|---|---|---|---|---|
| Asset (Distribution) | 112.14 (Min) | 312.32 (Likely) | 517.87 (Max) | |
| Cost | $1.6M | $1.6M | $1.6M | $1.6M |
| Maturity | 1 Year | 2 Year | 3 Year | 4 Year |
| Risk-free | 0.5% | | | |
| Volatility | 41.65% | | | |
| Dividend | 0% | | | |
| Steps | 1000 | | | |
| Expand Cost | $4.8M | | | |
| Economic Life | 5 Years | 10 Years | 15 Years | |
| Probability | 25% | 50% | 25% | |
| 4 ADJ RAROC | $112.14 | $312.32 | $517.87 | |
| 7 ADJ RAROC | $200.70 | $554.59 | $917.23 | |
| EF RAROC | 1.7897 | 1.7757 | 1.7712 | |
| Inflation | 3% | | | |
| Inflation Adj. Cost | $1.60 | $1.65 | $1.70 | $1.75 |

**Strategy B: Rapid Implementation**

| | | | |
|---|---|---|---|
| Asset (Distribution) | 114.16 (Min) | 315.09 (Likely) | 520.91 (Max) |
| Cost | $3.2M | | |
| Maturity | 4 | | |
| Risk-free | 0.5% | | |
| Volatility | 41.07% | | |
| Dividend | 0% | | |
| Steps | 1000 | | |
| Expand Cost | $4.8M | | |
| Economic Life | 5 Years | 10 Years | 15 Years |
| Probability | 25% | 50% | 25% |
| 4 ADJ RAROC | $114.16 | $315.09 | $520.91 |
| 7 ADJ RAROC | $213.07 | $557.71 | $920.66 |
| EF RAROC | 1.8664 | 1.7700 | 1.7674 |

*Figure A.20. Real Options Valuation Input Assumptions*



Maturity 4

Comment Strategy A - Phased Implementation - Combined

| Name | PV Asset | Volatility (%) | Notes |
|---|---|---|---|
| Underlying | 312.32 | 41.65 | |

| Name | Value | Start Step |
|---|---|---|
| EF | 1.7757 | 0 |
| ECost | 4.8 | 0 |

Blackout and Vesting Period Steps

| Name | Cost | Risk Free... | Dividend... | Steps | Terminal Equation | Intermediate Equa |
|---|---|---|---|---|---|---|
| Phase1 | 1.6 | 5 | 0 | 20 | Max(Phase2-Cost,0) | Max(Phase2-... |
| Phase2 | 1.65 | 5 | 0 | 40 | Max(Phase3-Cost,0) | Max(Phase3-... |
| Phase3 | 1.7 | 5 | 0 | 60 | Max(Phase4-Cost,0) | Max(Phase4-... |
| Phase4 | 1.75 | 5 | 0 | 80 | Max(Underlying-Cost,0, Underlying*EF-ECost) | Max(Underlying*EF-... |

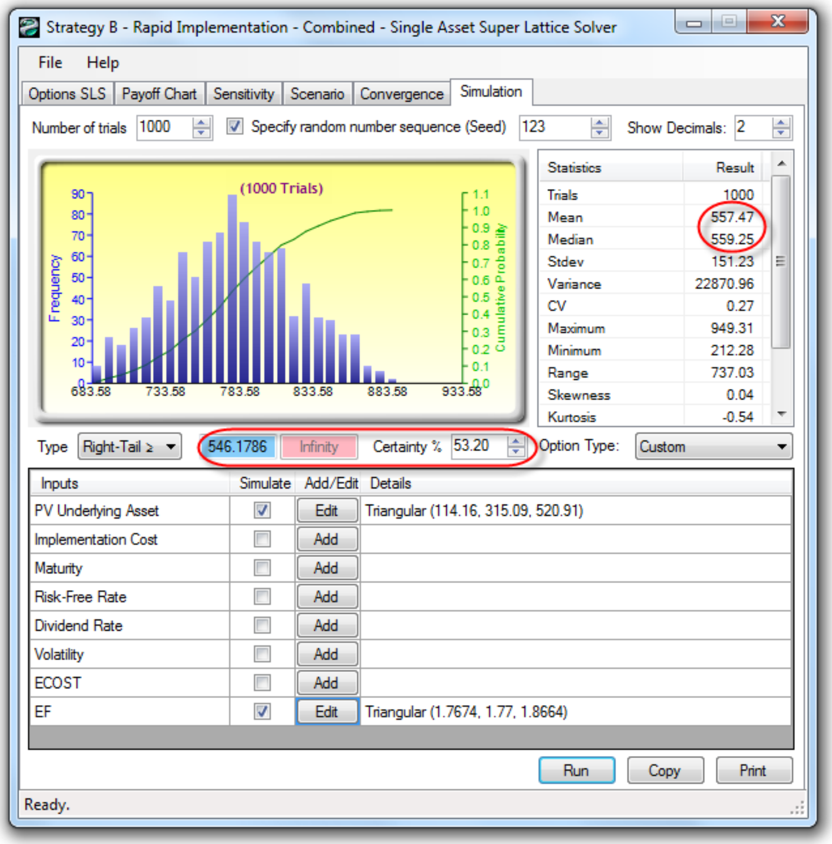
PHASE1: 546.1786

● Apply the Average Volatility from Underlying Asset Lattices to Valuation Lattices

○ Apply the Correlated Portfolio Volatility from Underlying Asset Lattices to Valuation Lattices

☐ Create Audit Sheet

*Figure A.21. Strategy A's Real Options Valuation Results*



Number of trials 1000 ☑ Specify random number sequence (Seed) 123 Show Decimals: 2

| Statistics | Result |
|---|---|
| Trials | 1000 |
| Mean | 557.47 |
| Median | 559.25 |
| Stdev | 151.23 |
| Variance | 22870.96 |
| CV | 0.27 |
| Maximum | 949.31 |
| Minimum | 212.28 |
| Range | 737.03 |
| Skewness | 0.04 |
| Kurtosis | -0.54 |

Type Right-Tail ≥ 546.1786 Infinity Certainty % 53.20 Option Type: Custom

| Inputs | Simulate | Add/Edit | Details |
|---|---|---|---|
| PV Underlying Asset | ☑ | Edit | Triangular (114.16, 315.09, 520.91) |
| Implementation Cost | ☐ | Add | |
| Maturity | ☐ | Add | |
| Risk-Free Rate | ☐ | Add | |
| Dividend Rate | ☐ | Add | |
| Volatility | ☐ | Add | |
| ECOST | ☐ | Add | |
| EF | ☑ | Edit | Triangular (1.7674, 1.77, 1.8664) |

Ready.

*Figure A.22. Strategy B's Real Options Valuation Results*

# Appendix 4—Understanding Probability Distributions

To begin to understand probability, consider this example: You want to look at the distribution of nonexempt wages within one department of a large company. First, you gather raw data—in this case, the wages of each nonexempt employee in the department. Second, you organize the data into a meaningful format and plot the data as a frequency distribution on a chart. To create a frequency distribution, you divide the wages into group intervals and list these intervals on the chart's horizontal axis. Then you list the number or frequency of employees in each interval on the chart's vertical axis. Now you can easily see the distribution of nonexempt wages within the department.

A glance at Figure A.23 reveals that the employees earn from $7.00 to $9.00 per hour. You can chart this data as a probability distribution. A probability distribution shows the number of employees in each interval as a fraction of the total number of employees. To create a probability distribution, you divide the number of employees in each interval by the total number of employees and list the results on the chart's vertical axis.

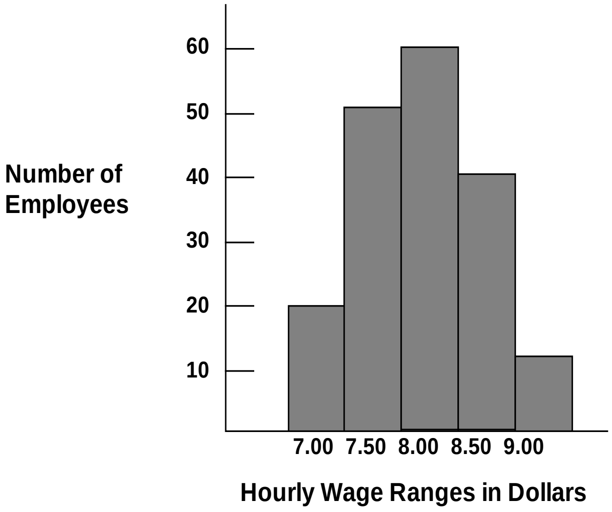


*Figure A.23. Frequency Histogram*

Figure A.24 shows the number of employees in each wage group as a fraction of all employees; you can estimate the likelihood or probability that an employee drawn at random from the whole group earns a wage within a given interval. For example, assuming the same conditions exist at the time the sample was taken, the probability is 0.20 (a one in five chance) that an employee drawn at random from the whole group earns $8.50 an hour.

Probability distributions are either discrete or continuous. *Discrete probability distributions* describe distinct values, usually integers, with no intermediate values and are shown as a series of vertical bars. A discrete distribution, for example, might describe the number of heads in four flips of a coin as 0, 1, 2, 3, or 4. *Continuous probability distributions* are actually mathematical abstractions because they assume the existence of every possible intermediate value between two numbers; that is, a continuous distribution assumes there is an infinite number of values between any two points in the distribution. However, in many situations, you can effectively use a continuous distribution to approximate a discrete distribution even though the continuous model does not necessarily describe the situation exactly.

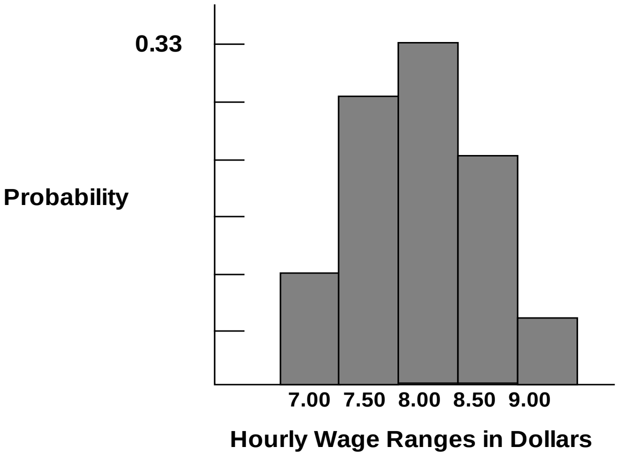


*Figure A.24. Frequency Histogram*

## *Selecting a Probability Distribution*

Plotting data is one method for selecting a probability distribution. The following steps provide another process for selecting probability distributions that best describe the uncertain variables in your spreadsheets.

To select the correct probability distribution, use the following steps:

- Look at the variable in question. List everything you know about the conditions surrounding this variable. You might be able to gather valuable information about the uncertain variable from historical data. If historical data are not available, use your own judgment, based on experience, listing everything you know about the uncertain variable.
- Review the descriptions of the probability distributions.
- Select the distribution that characterizes this variable. A distribution characterizes a variable when the conditions of the distribution match those of the variable.

Alternatively, if you have historical, comparable, contemporaneous, or forecast data, you can use Risk Simulator’s distributional fitting modules to find the best statistical fit for your existing data. This fitting process will apply some advanced statistical techniques to find the best distribution and its relevant parameters that describe the data.

## *Probability Density Functions, Cumulative Distribution Functions, and Probability Mass Functions*

In mathematics and Monte Carlo simulation, a probability density function (PDF) represents a *continuous* probability distribution in terms of integrals. If a probability distribution has a density of *f(x)*, then intuitively the infinitesimal interval of [*x, x* + *dx*] has a probability of *f(x) dx*. The PDF therefore is a smoothed version of a probability histogram; that is, by providing an empirically large sample of a continuous random variable repeatedly, the histogram using very narrow ranges will resemble the random variable’s PDF. The probability of the interval between [*a, b*] is given by $\int_a^b f(x)dx$ which means that the total integral of the function *f* must be 1.0**.** *It is a common mistake to think of f(a) as the probability of a.* In fact, *f(a)* can sometimes be larger than 1—consider a uniform distribution between 0.0 and 0.5. The random variable *x* within this distribution will have *f(x)* greater than 1. The probability is the function *f(x)dx* mentioned previously, where *dx* is an infinitesimal amount.

The cumulative distribution function (CDF) is denoted as $F(x) = P(X \leq x)$ indicating the probability of *X* taking on a less than or equal value to *x*. Every CDF is monotonically increasing, is continuous from the right, and, at the limits, has the following properties: $\lim_{x \to -\infty} F(x) = 0$ and $\lim_{x \to +\infty} F(x) = 1$. Further, the CDF is related to the PDF by $F(b) - F(a) = P(a \leq X \leq b) = \int_a^b f(x)dx$, where the PDF function *f* is the derivative of the CDF function *F*.

In probability theory, a probability mass function, or PMF, gives the probability that a *discrete* random variable is exactly equal to some value. The PMF differs from the PDF in that the values of the latter, defined only for continuous random variables, are not probabilities; rather, its integral over a set of possible values of the random variable is a probability. A random variable is discrete if its probability distribution is discrete and can be characterized by a PMF. Therefore, *X* is a discrete random variable if $\sum_u P(X = u) = 1$ as *u* runs through all possible values of the random variable *X*.

## *Normal Distribution*

The normal distribution is the most important distribution in probability theory because it describes many natural phenomena, such as people's IQs or heights. Decision makers can use the normal distribution to describe uncertain variables such as the inflation rate or the future price of gasoline.

The following are the three conditions underlying the normal distribution:

- Some value of the uncertain variable is the most likely (the mean of the distribution).
- The uncertain variable could as likely be above the mean as it could be below the mean (symmetrical about the mean).
- The uncertain variable is more likely near the mean than further away.

The mathematical constructs for the normal distribution are as follows:

$$f(x) = \frac{1}{\sqrt{2\pi}\sigma} e^{\frac{-(x-\mu)^2}{2\sigma^2}} \quad \text{for all values of } x \text{ and } \mu; \text{ while } \sigma > 0$$

*Mean* = $\mu$

*Standard Deviation* = $\sigma$

*Skewness = 0* (this applies to all inputs of mean and standard deviation)

*Excess Kurtosis = 0* (this applies to all inputs of mean and standard deviation)

Mean ($\mu$) and standard deviation ($\sigma$) are the distributional parameters.

Input requirements: Standard deviation > 0 and can be any positive value whereas mean can be any value

## *PERT Distribution*

The PERT distribution is widely used in project and program management to define the worst-case, nominal-case, and best-case scenarios of project completion time. It is related to the beta and triangular distributions. PERT distribution can be used to identify risks in project and cost models based on the likelihood of meeting targets and goals across any number of project components using minimum, most likely, and maximum values, but it is designed to generate a distribution that more closely resembles realistic probability distributions. The PERT distribution can provide a close fit to the normal or lognormal distributions. Like the triangular distribution, the PERT distribution emphasizes the *most likely* value over the minimum and maximum estimates. However, unlike the triangular distribution, the PERT distribution constructs a smooth curve that places progressively more emphasis on values around (near) the most likely value, in favor of values around the edges. In practice, this means that we *trust* the estimate for the most likely value, and we believe that even if it is not exactly accurate (as estimates seldom are), we have an expectation that the resulting value will be close to that estimate. Assuming that many real-world phenomena are normally distributed, the appeal of the PERT distribution is that it produces a curve similar to the normal curve in shape, without knowing the precise parameters of the related normal curve. Minimum, most likely, and maximum are the distributional parameters.

The mathematical constructs for the PERT distribution are shown below:

$$f(x) = \frac{(x - Min)^{A1-1}(Max - x)^{A2-1}}{B(A1, A2)(Max - Min)^{A1+A2-1}}$$

$$where\ A1 = 6\left[\frac{\frac{Min + 4(Likely) + Max}{6} - Min}{Max - Min}\right]\ and\ A2 = 6\left[\frac{Max - \frac{Min + 4(Likely) + Max}{6}}{Max - Min}\right]$$

$$and\ B\ is\ the\ Beta\ function$$

$$\textit{Mean} = \frac{Min + 4Mode + Max}{6}$$

$$\textit{Standard Deviation} = \sqrt{\frac{(\mu - Min)(Max - \mu)}{7}}$$

$$\textit{Skew} = \sqrt{\frac{7}{(\mu - Min)(Max - \mu)}}\left(\frac{Min + Max - 2\mu}{4}\right)$$

*Excess Kurtosis* is a complex function and cannot be readily computed

Input requirements: Min ≤ Most Likely ≤ Max and can be positive, negative, or zero

## *Triangular Distribution*

The triangular distribution describes a situation where you know the minimum, maximum, and most likely values to occur. For example, you could describe the number of cars sold per week when past sales show the minimum, maximum, and usual number of cars sold.

The three conditions underlying the triangular distribution are:

- The minimum number of items is fixed.
- The maximum number of items is fixed.
- The most likely number of items falls between the minimum and maximum values, forming a triangular-shaped distribution, which shows that values near the minimum and maximum are less likely to occur than those near the most-likely value.

The mathematical constructs for the triangular distribution are as follows:

$$f(x) = \begin{cases} \dfrac{2(x - Min)}{(Max - Min)(Likely - \min)} & for\ Min\ <\ x\ <\ Likely \\ \dfrac{2(Max - x)}{(Max - Min)(Max - Likely)} & for\ Likely\ <\ x\ <\ Max \end{cases}$$

*Mean* = $\frac{1}{3}(Min + Likely + Max)$

*Standard Deviation* = $\sqrt{\frac{1}{18}(Min^2 + Likely^2 + Max^2 - Min\,Max - Min\,Likely - Max\,Likely)}$

*Skewness* = $\dfrac{\sqrt{2}(Min + Max - 2Likely)(2Min - Max - Likely)(Min - 2Max + Likely)}{5(Min^2 + Max^2 + Likely^2 - MinMax - MinLikely - MaxLikely)^{3/2}}$

*Excess Kurtosis* = –0.6 (this applies to all inputs of Min, Max, and Likely)

Minimum (Min), most likely (Likely) and maximum (Max) are the parameters.

Input requirements:

Min ≤ Most Likely ≤ Max and can take any value

However, Min < Max and can take any value

## *Uniform Distribution*

With the uniform distribution, all values fall between the minimum and maximum and occur with equal likelihood.

The following are the three conditions underlying the uniform distribution:

- The minimum value is fixed.
- The maximum value is fixed.
- All values between the minimum and maximum occur with equal likelihood.

The mathematical constructs for the uniform distribution are as follows:

$$f(x) = \frac{1}{Max - Min} \quad for\ all\ values\ such\ that\ Min < Max$$

*Mean* = $\frac{Min + Max}{2}$

*Standard Deviation* = $\sqrt{\frac{(Max - Min)^2}{12}}$

*Skewness* = 0 (this applies to all inputs of Min and Max)

*Excess Kurtosis* = –1.2 (this applies to all inputs of Min and Max)

Maximum value (*Max*) and minimum value (*Min*) are the distributional parameters.

Input requirements: Min < Max and can take any value

# References

Arena, M. V., Schank, J. F., & Abbott, M. (2004). *The shipbuilding and force structure analysis tool: A user's guide.* Santa Monica, CA: RAND. Retrieved from http://www.rand.org/pubs/monograph_reports/MR1743.html

Chairman of the Joint Chiefs of Staff (CJCS). (2007). *Warfighting mission area information technology portfolio management and net-centric data sharing* (CJCS Instruction 8410.01). Washington, DC: Author.

Chief of Naval Operations. (1995). *Fleet Modernization Program (FMP) policy* (OPNAV Instruction 4720.2G). Retrieved from http://www.usa-federal-forms.com/usa-fedforms-dod-opnavinst/dod-opnavinst-4720-2g-nonfillable.pdf

Chief of Naval Operations. (2003, July 11). *Maintenance policy for U.S. Navy ships* (OPNAV Instruction 4700.7K). Retrieved from http://doni.daps.dla.mil/Directives/04000%20Logistical%20Support%20and%20Services/04700%20General%20Maintenance%20and%20Construction%20Support/4700.7K.pdf

Chizek, J. G. (2003, January 17). *Military transformation: Intelligence, surveillance and reconnaissance* (CRS Report RL31425, p. 2). Washington, DC: Congressional Research Service.

CIMdata. (2007). All about PLM. Retrieved from http://www.cimdata.com/en/resources/about-plm

Clinger–Cohen Act of 1996, 40 U.S.C. § 1401 (1996).

Department of the Navy (DON). (2007b, February 26). *Joint fleet maintenance manual* (COMFLTFORCOMINST 4790 REV A CH-7). Retrieved from http://www.submepp.navy.mil/jfmm/documents/00_JFMM.pdf

Commander, Naval Sea Systems Command (NAVSEA). (2002). *Fleet Modernization Program (FMP) management and operations manual* (NAVSEA SL720-AA-MAN-010, 2nd ed.). Retrieved from http://www.fmp.navy.mil/FMPACTIVE/BusinessPolicy/FMPDocuments/FMP_Manual/FMPManpageinit.htm

Commander, Naval Sea Systems Command (NAVSEA). (2006). *Surface ship and carrier entitled process for modernization management and operations manual* (SL720-AA-MAN-030). Retrieved from http://www.fmp.navy.mil/FMPACTIVE/BusinessPolicy/FMPDocuments/draft_onebook_1a.htm

Commander, Naval Sea Systems Command (NAVSEA). (2007). SHIPMAIN training. Retrieved from http://www.fmp.navy.mil/FMPACTIVE/BusinessPolicy/FMPDocuments/Documents/SHIPMAINentitledocs/Training/SHIPMAINTraining1.htm

Department of the Navy (DON). (2007a). Highlights of the Department of the Navy's FY 2008 budget. Retrieved from http://www.finance.hq.navy.mil/fmb/08pres/highbook/Highlights_book.pdf

Defense Industry Daily. (2016, September 14). LCS: The USA's littoral combat ships. Retrieved from http://www.defenseindustrydaily.com/the-usas-new-littoral-combat-ships-updated-01343/

Doerry, N. H. (2012, August). Institutionalizing modular adaptable ship technologies. *Journal of Ship Production and Design, 30*(3), 126–141. Retrieved from http://www.sname.org/pubs/viewtechnicalpaper?DocumentKey=f20b0085-7010-4f09-873b-546862111d08; also available at http://doerry.org/norbert/papers/20120628MAS-doerry.pdf

Drewry, J. T., & Jons, O. P. (1975, April). Modularity: Maximizing the return on the Navy's investment. *Naval Engineer's Journal, 87*(2), 198–214.

Eaglen, M. (2008). *Changing course on Navy shipbuilding: Questions Congress should ask before funding*. Retrieved from http://www.heritage.org/research/reports/2008/10/changing-course-on-navy-shipbuilding-questions-congress-should-ask-before-funding

Ford, D., Housel, T., & Mun, J. (2011). *Ship maintenance processes with collaborative product lifecycle management and 3D terrestrial laser scanning tools: Reducing costs and increasing productivity* (NPS-AM-11-180). Monterey, CA: Naval Postgraduate School, Acquisition Research Program.

General Accounting Office (GAO). (1997, February). *Assessing risk and returns: A guide for evaluating federal agencies' IT investment decision-making, Version 1* (GAO/AIMD-10.1.13). Washington, DC: Author.

General Accounting Office (GAO). (2004, June). *Defense logistics: GAO's observations on maintenance aspects of the Navy's Fleet Response Plan* (GAO-04-724R). Retrieved from http://www.gao.gov/new.items/d04724r.pdf

Government Accountability Office (GAO). (2005a). *Navy's Fleet Readiness Plan would benefit from a comprehensive management approach and rigorous testing* (GAO-06-84). Retrieved from http://www.gao.gov/cgi-bin/getrpt?GAO-06-84

Government Accountability Office (GAO). (2005b, November). *Better support of weapon system program managers needed to improve outcomes* (GAO-06-110). Retrieved from http://www.gao.gov/new.items/d06110.pdf

Greaves, T., & Jenkins, B. (2007). 3D laser scanning market red hot: 2006 industry revenues $253 million, 43% growth. *SparView, 5*(7). Retrieved from http://www.sparllc.com/archiveviewer.php?vol=05&num=07&file=vol05no07-01

Gregor, J. A. (2003). *Real options for naval ship design and acquisition: A method for valuing flexibility under uncertainty* (Master's thesis). Cambridge, MA: Massachusetts Institute of Technology.

Griffin, J. (2015, January). A more flexible fleet. *Proceedings Magazine, 141/1/1,343*.

Hoffman, F. (2006, August). The fleet we need: A look at alternative—and affordable—futures for the U.S. Navy. *Armed Forces Journal*. Retrieved from http://www.armedforcesjournal.com/the-fleet-we-need

Hoffman, F. (2008, November 10). From preponderance to partnership: American maritime power in the 21st century. Center for a New American Security. Retrieved from https://www.cnas.org/publications/reports/from-preponderance-to-partnership-american-maritime-power-in-the-21st-century

Housel, T. J., & Bell, A. H. (2001). *Measuring and managing knowledge*. Boston, MA: McGraw–Hill/Irwin.

Housel, T. J., El Sawy, O., Zhong, J., & Rodgers, W. (2001, December). *Models for measuring the return on information technology: A proof of concept demonstration* (p. 13). Presented at 22nd International Conference on Information Systems, City, ST.

Howe, K. (2011, August 30). Secretary of Navy visits Naval Postgraduate School, addresses energy independence. *The Herald*, Monterey County. Retrieved from http://www.montereyherald.com/local/ci_18786371

Higgins, S. (2007, March 14). Ship check data capture 37% cheaper, 39% faster with 3D laser scanning, NSRP and Electric Boat report. Spar3D. Retrieved from http://www.spar3d.com/news/related-new-technologies/ship-check-data-capture-37-cheaper-39-faster-with-3d-laser-scanning-nsrp-and-electric-boat-report/

Jolliff, J. V. (1974, October). Modular ship design concepts. *Naval Engineers Journal*, 11–30.

Knight, J. T. (2014). *A prospect theory-based real option analogy for evaluating flexible systems and architectures in naval ship design* (Doctoral dissertation). Ann Arbor, MI: University of Michigan.

Knight, J. T., & Singer, D. J. (2014, April). *Applying real options analysis to naval ship design.* Paper presented at American Society of Naval Engineers Day. Retrieved from https://www.researchgate.net/publication/272165642_Applying_Real_Options_Analysis_to_Naval_Ship_Design

Koenig, P. C. (2009, April). *Real options in ship and force structure analysis: A research agenda.* Paper presented at American Society of Naval Engineers Day. Retrieved from http://navalengineers.net/Proceedings/AD09/Papers/ASNEoptionspaper.pdf

Koenig, P. C., Czapiewski, P. M., & Hootman, J. C. (2008). Synthesis and analysis of future naval fleets. *Ships and Offshore Structures, 3*(2), 81–89.

Komoroski, C. L. (2005). *Reducing cycle time and increasing value through the application of Knowledge Value Added methodology to the U.S. Navy shipyard planning process* (Master's thesis). Monterey, CA: Naval Postgraduate School.

Komoroski, C. L., Housel, T., Hom, S., & Mun, J. (2006). *A methodology for improving the shipyard planning process: Using KVA analysis, risk simulation and strategic real options* (NPS-AM-06-017). Monterey, CA: Naval Postgraduate School.

Laser Design. (2007). Laser scanning helps Navy save $250,000 by enabling competitive bidding [Press release]. Retrieved from http://www.laserdesign.com/story-NUWC.htm

Markowitz, H. (1952). Portfolio selection. *Journal of Finance, 7*(1), 77–91.

Matthews, W. (2015). New surface ship designs must be flexible, adaptable. Seapower. Retrieved from http://www.seapowermagazine.org/stories/20150413-ships.html

Mun, J. (2015). *Modeling risk: Applying Monte Carlo simulation, real options analysis, forecasting, and optimization techniques* (3rd ed.). Thomson-Shore.

Mun, J. (2016). *Real options analysis: Tools and techniques* (3rd ed.). Thomson-Shore.

National Defense University. (2015, Spring). *Final report: Shipbuilding.* Retrieved from http://es.ndu.edu/Portals/75/Documents/industry-study/reports/2015/es-is-report-shipbuilding-2015.pdf

Office of the Director, Operational Test and Evaluation (DOT&E). (2013). *DDG 51 Flight III Destroyer/Air and Missile Defense Radar (AMDR)/Aegis Modernization.* Retrieved from http://www.dote.osd.mil/pub/reports/FY2014/pdf/navy/2014ddg51.pdf

Neches, R., & Madni, A. M. (2013). Towards affordably adaptable and effective systems. *Systems Engineering, 16*(2), 224–234.

Office of the Chief of Naval Operations. (2015, March). *Report to Congress on the annual long-range plan for construction of naval vessels for Fiscal Year 2016*. Retrieved from https://news.usni.org/2015/04/03/document-navys-30-year-shipbuilding-plan-to-congress-for-fiscal-year-2016

Office of the Deputy Under Secretary of Defense (Logistics and Material Readiness). (2006). *DOD maintenance, policy, programs and resources fact book*. Retrieved from http://www.acq.osd.mil/log/mrmp/factbooks/FACT_BOOK_2006_09_06_06.pdf

O'Rourke, R. (2005). *Navy ship acquisition: Options for lower-cost ship designs—Issues for Congress* (Order Code RL32914). Retrieved from https://www.fas.org/sgp/crs/weapons/RL32914.pdf

O'Rourke, R. (2010, Autumn). Programs vs. resources: Some options for the Navy. *Naval War College Review, 63*(4), 25–37.

Page, J. (2011). *Flexibility in early stage design of US Navy ships: An analysis of options* (Master's thesis). Cambridge, MA: Massachusetts Institute of Technology.

Schank, J. F., Savitz, S., Munson, K., Perkinson, B., McGee, J., & Sollinger, J. M. (2016). *Designing adaptable ships: Modularity and flexibility in future ship designs.* Retrieved from http://www.rand.org/pubs/research_reports/RR696.html

Seaman, N. (2007). *The use of collaborative and three-dimensional imaging technology to increase value in the SHIPMAIN environment of the Fleet Modernization Plan* (Master's thesis). Monterey, CA: Naval Postgraduate School.

Service Cost Estimating Organizations. (2007). *Improving ERP cost estimating in the DOD* [PowerPoint presentation]. Retrieved from https://acc.dau.mil/CommunityBrowser.aspx?id=149301

Siegel, A. B. (2005a). *Navigating the perfect storm: Perspectives on prospects for shipbuilding* [PowerPoint presentation]. Retrieved from http://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=10&ved=0ahUKEwjuIbzpqfMAhUEcz4KHZefAG8QFghaMAk&url=http%3A%2F%2Fwww.northropgrumman.com%2FAboutUs%2FAnalysisCenter%2FDocuments%2Fppts%2FNavigating_the_Perfect_Storm_b.ppt&usg=AFQjCNGpUZCvBS94sivd4ut5_uoEURjlVw

Siegel, A. B. (2005b, August 22). Surviving a perfect storm: U.S. Navy needs more punch from budget dollar. *Defense News*. Retrieved from http://www.northropgrumman.com/AboutUs/AnalysisCenter/Documents/pdfs/Surviving_a_Perfect_Storm_Def_.pdf

Simmons, J. L. (1975, April). Design for change: The impact of changing threats and missions on system design philosophy. *Naval Engineers Journal*, 120–125.

SparPoint. (2007). Capturing existing conditions with terrestrial laser scanning. Retrieved from http://sparllc.com/cec.php

Stout, R., & Tilton, B. (2007, March 27). *U.S. Navy leverages 3D scanning with design and technical data management.* Paper presented at the Spar View Conference, Houston, TX.

Sturtevant, G. (2015). *Flexible ships: Affordable relevance over the ship's life cycle* [PowerPoint presentation]. Retrieved from http://www.asne-tw.org/asne/events/presentation/2015-01Sturtevant.pdf

UGS Corporation. (2007). UGS Teamcenter. Retrieved from http://www.ugs.com/products/teamcenter/

Office of the President of the United States. (n.d.). The National Security Council. Retrieved from http://www.whitehouse.gov/nsc/nss.pdf

Wilson, S. (2014, August 1). Condition sinking: Navy faces shipbuilding crisis. Mississippi Watchdog. Retrieved from http://watchdog.org/162322/u-s-navy/

Work, R. O. (2004, Fall). Small combat ships and the future of the Navy. *Issues in Science and Technology, 21*(1). Retrieved from http://issues.org/21-1/work/

# Biographies

## Johnathan Mun, PhD, MBA, MS, BS, CQRM, CFC, FRM, MIFC

### EDUCATION

Lehigh University, Doctor of Philosophy, Finance and Economics, 1998

Nova Southeastern University, Master of Business Administration, 1995 (Summa Cum Laude)

University of Miami, Bachelor of Science, 1994 (Magna Cum Laude)

### EXPERIENCE

| | |
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| 2005–Present: | Research Professor, Naval Postgraduate School, Monterey, California |
| 2005–Present: | Chairman and CEO, Real Options Valuation, Inc., Dublin, California |
| 2001–2010: | Visiting Professor, University of Applied Sciences and Swiss School of Management, Switzerland |
| 2001–2004: | Vice President of Analytics, Decisioneering-Oracle, Denver, Colorado |
| 1999–2001: | Senior Manager and Economist, KPMG Consulting, California |
| 1998–2001: | Adjunct Professor, Golden Gate Univ. and St. Mary's College, California |
| 1998–1999: | Manager, Viking, Inc. (FDX Corporation), California |

### PUBLISHED BOOKS

- *Modeling Risk: Applying Monte Carlo Risk Simulation, Strategic Real Options Analysis, Stochastic Forecasting, and Portfolio Optimization,* Third Edition, Thompson-Shore (2015).
- *Modeling Risk: Applying Monte Carlo Risk Simulation, Strategic Real Options Analysis, Stochastic Forecasting, and Portfolio Optimization,* Second Edition, Wiley Finance (2010).
- *Credit Engineering for Bankers,* Elsevier Academic Press (2010).
- *Advanced Analytical Models: Over 800 Models and 300 Applications from Basel Accords to Wall Street,* Wiley (2008).
- *The Banker's Handbook on Credit Risk: Implementing Basel II and Credit Risk,* Elsevier and Academic Press (2008).

- *Modeling Risk: Applying Monte Carlo Simulation, Real Options Analysis, Stochastic Forecasting, and Optimization,* Wiley Finance (2006).
- *Real Options Analysis: Tools and Techniques for Valuing Strategic Investments and Decisions,* Second Edition, Wiley (2005).
- *Valuing Employee Stock Options: Under 2004 FAS 123,* Wiley Finance (2004).
- *Applied Risk Analysis: Moving Beyond Uncertainty,* Wiley Finance (2003).
- *Real Options Analysis Course: Business Cases and Applications,* Wiley Finance (2003).
- *Real Options Analysis: Tools and Techniques for Valuing Strategic Investments and Decisions,* Wiley Finance (2002).

## ACADEMIC PUBLICATIONS

- "A New Theory of Value: The New Invisible Hand of Altruism," in *Intellectual Capital in Organizations,* Routledge (2015).
- "A Risk-Based Approach to Cost-Benefit Analysis: Monte Carlo Risk Simulation, Strategic Real Options Analysis, Knowledge Value Added, and Portfolio Optimization," Chapter 11 in *Military Cost-Benefit Analysis,* Taylor & Francis (2015).
- "Real Options in Practice," Chapter 2 in H. B. Nembhard and M. Aktan (Editors), *Real Options in Engineering Design, Operations, and Management,* CRC Press (2012).
- "Hands-on Applications of Real Options SLS," Chapter 15 in H. B. Nembhard and M. Aktan (Editors), *Real Options in Engineering Design, Operations, and Management,* CRC Press (2012).
- "Capturing the Strategic Flexibility of Investment Decisions through Real Options Analysis," Article #5 in U. Hommel et al. (Editors), *The Strategic CFO: Creating Value in a Dynamic Market Environment,* Springer, Berlin (2011).
- "Monte Carlo Risk Simulation," Chapter 17 in J. B. Abrams, *Quantitative Business Valuation: A Mathematical Approach for Today's Professionals,* Second Edition, Wiley (2010).
- "Real Options," Chapter 18, J. B. Abrams, *Quantitative Business Valuation: A Mathematical Approach for Today's Professionals,* Second Edition, Wiley (2010).
- "Real Options and Monte Carlo Simulation versus Traditional DCF Valuation in Layman's Terms," Chapter 6 in K. B. Leggio (Editor), *Managing Enterprise Risk,* Elsevier (2006).
- "Strategic Real Options Valuation," Chapter 7 in R. Razgaitis, *Deal Making Using Real Options,* Wiley (2003).
- "Managing Bank Risk," in *Bank Risk,* Morton Glantz, Academic Press (2003).
- "Make or Buy: An Analysis of the Impacts of 3D Printing Operations, 3D Laser Scanning Technology, and Collaborative Product Lifecycle Management on Ship Maintenance and Modernization Cost Savings," *Acquisitions Research,* 2015.

- “Applying Fuzzy Inference Systems, ASKE, Knowledge Value Added, and Monte Carlo Risk Simulation to Value Intangible Human Capital Investments,” *AIP (American Institute of Physics) Conference Proceedings,* 2013.
- “Naval Ship Maintenance: An Analysis of Dutch Shipbuilding Industry Using the Knowledge Value Added, Systems Dynamics, and Integrated Risk Management Methodologies,” *Acquisitions Research* (U.S. Department of Defense) 2013.
- “Applying Fuzzy Inference Systems, ASKE, Knowledge Value Added, and Monte Carlo Risk Simulation to Value Intangible Human Capital Investments,” Math and Science Symposium in Malaysia, December 2012.
- “Human Capital Valuation and Return of Investment on Corporate Education,” *Journal of Expert Systems with Applications* Vol. 39, No. 15, 11934–11943, Nov. 2012.
- “Integrated Risk Management: A Layman’s Primer” (in Russian), *Journal of Economic Strategies,* No. 6-7, 48–62, 2012.
- “Application of Real Options Theory to Department of Defense Software Acquisitions,” *Defense Acquisition Research Journal* Vol. 18, No. 1, 81, Jan. 2011.
- “AEGIS Weapons System and Advanced Concept Builds for the U.S. Navy,” Acquisitions Symposium, 2010.
- “Advanced Capability Builds: Portfolio Optimization, Selection and Prioritization, Risk Simulation, KVA, and Strategic Real Options Analysis,” *Acquisitions Research* (U.S. Department of Defense) Sept. 2009.
- “Application of Real Options Theory to Software Engineering for Strategic Decision Making in Software Related Capital Investments in the U.S. Department of Defense,” *Acquisitions Research* (U.S. Department of Defense) Feb. 2009.
- “Ship Maintenance and Project Lifecycle Management,” Acquisitions Symposium (U.S. Department of Defense) 2008.
- “A Primer on Integrated Risk Management for the Military,” Acquisitions Symposium (U.S. Department of Defense) 2007.
- “AEGIS Platforms: The Potential Impact of Open Architecture in Sustaining Engineering,” *Acquisitions Research* (U.S. Department of Defense) Oct. 2007.
- “Return on Investment in Non-Revenue Generating Activities: Applying KVA and Real Options to Government Operations,” U.S. Department of Defense, HICSS, 2007.
- “AEGIS and Ship-to-Ship Self-Defense System Platforms: Using KVA Analysis, Risk Simulation and Strategic Real Options to Assess Operational Effectiveness,” *Acquisitions Research* (U.S. Department of Defense) 2006.
- “A Methodology for Improving the Shipyard Planning Process: Using KVA Analysis, Risk Simulation and Strategic Real Options,” *Acquisitions Research* (U.S. Department of Defense) May 2006.
- “Reducing Maintenance Program Costs with Improved Engineering Design Processes Using KVA Analysis, Risk Simulation, and Strategic Real Options,” *Acquisitions Research* (U.S. Department of Defense) 2005.

- “Real Option Analysis: Implementation for Financial Planners,” *Financial Planning Journal,* 2003.
- “A Stepwise Example of Real Options Analysis of a Production Enhancement Project,” Society of Petroleum Engineers (SPE) 13th European Petroleum Conference held in Aberdeen, Scotland, U.K.
- “Using Real Options Software to Value Complex Options,” *Financial Engineering News,* 2002.
- “The Contrarian Investment Strategy: Additional Evidence,” *Journal of Applied Financial Economics,* 2001.
- “Time-Varying Nonparametric Capital Asset Pricing Model: New Bootstrapping Evidence.” *Journal of Applied Financial Economics,* 2000. Paper was presented at the 1999 Southern Finance Association Conference, Key West, Florida.
- “The Contrarian/Overreaction Hypothesis: A Comparative Analysis of the U.S. and Canadian Stock Markets,” *Global Finance Journal* Vol. 11, No. 1–2, 53–72, 2000.
- “Tests of the Contrarian Investment Strategy: Evidence from the French and German Stock Markets,” *International Review of Financial Analysis* Vol. 8, No. 3, 215–234, 1999.
- “Dividend-Price Puzzle: A Nonparametric Approach,” *Advances in Quantitative Accounting and Finance* Vol. 7, 1998.

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## EDUCATION

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California State University, Long Beach, BA in Communication, 1974 (Honors Graduate)

## WORK EXPERIENCE

- Associate Chair and Full Professor of Information Sciences, Naval Postgraduate School
- Associate Professor of Information and Operations Management, University of Southern California, Marshall School of Business, 8/97 – 8/01.
- Visiting Professor of Information and Operations Management, University of Southern California, Marshall School of Business, 8/95 – 8/97.
- Academic Program Director, University of Southern California, Marshall School of Business, 8/98 – 8/01.
- Director (Vice President), Consumer Behavior Research in Telematics and Informatics, Centro Studies. Salvador (Telecom Italia), 1/94 – 8/95.
- Chief Business Process Engineer, Strategic Information Systems Division, Pacific Bell, 10/92 – 1/94.
- Director, Business Development and Domain Engineering, Strategic Information Systems Division, Pacific Bell, 8/91 – 10/92.
- Assistant Professor of Business Communication (clinical), University of Southern California, School of Business Administration, 1982 – 1991.
- Associate Director, Center for Operations Management Education and Research, University of Southern California, 1987 – 1991.
- Associate Director, Center for Telecommunications Management, University of Southern California, 1984 – 1985.
- Assistant Professor, University of Kentucky, College of Communications, 1977 – 1982.

## PUBLICATIONS

- Rodgers, Waymond, and Housel, Thomas J. (2009) “Problems and Resolutions to Future Knowledge-Based Assets Reporting,” *Journal of Intellectual Capital* Vol. 10, No. 4.
- Pfeiffer, K., Kanevsky, V. and Housel, T. (2009) "Testing of Complex Systems: Information-driven Strategies to Reduce Cost and Improve Reliability," *Proceedings of the INFORMS Annual Meeting,* San Diego, Oct. 11-14.
- Cintron, Jose, Rabelo, Luis, and Housel, Thomas J. (2008) “Estimating the Knowledge Value-Added of Information Technology Investments,” *Proceedings of the Industrial Engineering Research Conference,* Vancouver, British Columbia, Canada, May 20.
- Housel, Thomas J. (2008) “Measuring the Value Added by Management,” IC4 Intellectual Capital for Communities in the Knowledge Economy (Refereed Proceedings), Paris, France, May 25.

## AWARDS

Honorable Mention 1994 Planning Forum Case Competition

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