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# Business Case Valuation of Strategic Flexibility in Shipbuilding: Justifying and Assessing the Value of Flexible Ships Design Features in New Navy Ship Concepts

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# Business Case Valuation of Strategic Flexibility in Shipbuilding: Justifying and Assessing the Value of Flexible Ships Design Features in New Navy Ship Concepts

15 November 2017

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# Abstract

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 and value a business case for making strategic decisions under uncertainty.

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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 2017

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# List of Acronyms

| | |
|---|---|
| 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. Accomplishing 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 has included robust features that limit any future capabilities to make requirement changes. For instance, any major requirement changes or upgrades 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 FASO/MAS concepts have been detailed by Jolliff (1974), Simmons (1975), Drewry and Jons (1975), and others. Even as recently as 2015, the Naval Sea Systems Command's (NAVSEA's) Program Executive Office, Ships (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 (former chief of Naval Operations) and VADM Rowden (commander of Naval Surface Forces, U.S. Pacific Fleet) 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 approaches 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 (VLSs) 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, and gun systems).

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 type by using standardized design specifications that allow similar systems to be placed across multiple ship platforms) are all concepts that can be evaluated using 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 applies the same design flexibility models utilizing ROV methods to identify the optimal ship design alternatives.

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 (FSCs). Further, the Navy acknowledges that there is significant potential value in terms of being able to rapidly upgrade FASO ships at a lower cost, while extending the ships' service life, with the added benefit of being able to quickly adapt to changes in both external threats and internal new technologies that offer value-added capabilities. As such, this current research is not meant to identify said FASO/MAS platforms or payloads per se, but, rather, to use previously identified platforms such as the DDG 51 Flight III where there are opportunities to insert flexible ship features. For the purpose of generating a proof of concept example, we limit the analysis to said surface combatants in the capability domain of anti-submarine warfare (ASW).

This current research focuses on applying a series of analytical methodologies, such as ROV, to support development of a business model or business case analysis that supports strategic decision-making in the context of uncertainty. This analysis identifies, models, values, and optimizes the various strategic real options identified for 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) inputs, publicly available information, and a set of basic assumptions or rough order magnitude (ROM) estimates are used. The use of the ROM or SME inputs, while subjective in nature, in no way detracts from the analytical power, efficacy, or applicability of these methods, because the values they supply to the model parameters can be replaced with more objective values as they become available.

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 support creation of a business case for making strategic ship design 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 is collected, reviewed, and used to develop a comprehensive ship design and building process that is generic and applicable in general across the U.S. Navy ship platforms. Second, a collection of the most common types of modular and flexible ship design requirements is identified and reviewed.

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

The recommended decision framework is briefly explained in this section. This framework structures the ROV models and methodology in a way that relates to the various design implementations and facilitates data collection, data analysis, and recommendations, regardless of the design-type alternatives. In addition, the ROV analytical modeling method is reviewed as part of the Integrated Risk Management (IRM) process, where other advanced analytical decision methodologies such as Monte Carlo risk simulation, Knowledge Value Added (KVA), and Portfolio Optimization approaches are included.

### *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 ship design scope of the current study, but can be extended to other DOD acquisition investment decision challenges.

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

This section illustrates the case application of FASO/MAS regarding the anti-submarine warfare domain for the DDG 51 Flight III platform. The case begins with identifying the design options, then covers the framing and valuation of these options, and ends with applying ROV methods within the IRM analytical environment.

### *Conclusions and Recommendations*

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

# Literature Review

## *Flexible and Adaptable Ship Design*

Seventy percent of the world is covered by water. To ensure freedom of navigation, economic independence, and national sovereignty, countries must maintain a highly efficient and technologically advanced fleet. With shrinking defense budgets, the current trend is to build fewer warships but maintain the same operational tempo. To continually meet the demands of a larger operational fleet, these new smaller fleets must be built on flexible and adaptable platforms with decoupled payloads that allow the vessel to accomplish a multitude of mission sets. This type of modular design and build “offers an opportunity for a ship to affordably transform its mission systems over its service life to maintain military relevance” (Doerry, 2012). The design characteristics that allow these fleets to flourish are Modular Adaptable Ships (MAS) and Flexible and Adaptable Ship Options (FASO) (Mun & Housel, 2016). MAS and FASO incorporated designs provide an economical platform for a seagoing navy to build highly effective warships capable of performing various missions in a multitude of environments.

Flexible and adaptable ship designs are centered around a standard hull with modular mission payloads that offer a wide mission set, affordable scalability, reduced operational downtime, increased availability of the ship, and a reduced total number of mission modules for the fleet (Thorsteinson, 2013). For navies with limited budgets, having a flexible and modular platform allows a vessel to perform at times like a frigate and at other times like a corvette (Paris, Brussels & Fiorenza, 2013). These new fleets of multi-mission vessels are already operational in blue-water fleets around the world operated by countries including Denmark, Germany, France, Italy, Australia, and the United States.

Modular build and design has been in use since the mid-20th century. During World War II, Henry Kaiser’s ship yards were able to produce Liberty ships in minimal time due in part to the heavy use of modular construction, and the Germans constructed their Type 21 submarines with modular build principles (Abbott, Levine

& Vasilakos, 2008). Starting in 1979, the German shipyard Blohm & Voss began building modular corvettes and frigates for third-world navies using a modular concept known as MEKO. The MEKO concept has continually evolved with time producing the more mature MEKO A-100, A-200, and now A-400. In 1986 the Royal Danish Navy (RDN) began implementation of a modular concept called STANFLEX for a new class of patrol craft (Abbott et al., 2008) known as the Flyvefisken (SF 300) class. The specific use of modular mission payload within the SF 300s directly translated into the future design and development of the RDN Absalon support ships and Iver Huitfeldt class frigates. The French and Italians have worked together to design a flexible multi-mission frigate known as the FREMM class, while the Australian Royal Navy has the modular Anzac class of frigates and Hobart class of air-warfare destroyers (AWDs).

The U.S. Navy began to look at modular builds in 1975 with the Sea Systems Modification and Modernization by Modularity (SEAMOD) program (Abbott al., 2008). SEAMOD focused on decoupling “the development of the payload from the development of the platform” (Doerry, 2012). This uncoupling provided two major benefits: it allowed the payload to be developed in parallel with the platform versus in series, which allowed the most recent technological systems to be installed onboard at the time the ship was put to sea, and it permitted rapid removal, replacement, or installment of mission payloads, preventing extended maintenance yard periods (Abbott et al., 2008; Doerry, 2012). SEAMOD evolved into the Modular Open Systems Approach (MOSA) and is characterized by “modular design, key interfaces, and the use of open standards for key interfaces where appropriate” (Abbott et al., 2008). These efforts led to the development of the Littoral Combat Ship (LCS) and DDG 1000 for the U.S. Navy (Abbott et al., 2008).

To achieve expected service life, flexible and adaptable ships must be built with payloads that decouple from the platform, be configured with standard interfaces for technical modules, have the ability to reconfigure rapidly, and have allowances for growth margin. Growth margins allow for future technologies to be rapidly implemented into the existing design, preventing the vessel from having to enter into an extended maintenance overhaul period. Growth margins work hand in hand with the parallel development of mature payloads, ensuring that the latest technology can be installed as it is developed because of the standard interfaces.

Over the past 40 years, significant strides have been made by foreign navies with regards to ship designs that incorporated modularity, flexibility, and adaptability. The designs focused heavily on a standard hull with the same engines, but offered a variety of modular payloads for specific mission sets. Ultimately, MAS and FASO incorporated designs provide an economical platform for a seagoing navy to build powerful, multi-task warships.

## *Royal Danish Navy*

The Royal Danish Navy (RDN) has been at the forefront of modular ship design since 1987 when the first of 14 Flyvefisken class or STANFLEX 300 (SF 300) multi-role vessels (MRVs) were commissioned. The design was based on a standard hull that used modular bays to change mission type through use of the Standard Flex (STANFLEX) concept. The Flyvefisken class was ultimately decommissioned in October 2010 ("Flyvefisken Class (SF 300), Denmark," n.d.), but the use of the STANFLEX concept played a fundamental role in the design and development of the larger follow-on modular designs seen in the Absalon class littoral support ships and Iver Huitfeldt class frigates.

### *Flyvefisken Class (SF 300)*

The inception of the Flyvefisken class and Standard Flex resulted from a feasibility study in 1982. The Royal Danish Navy wanted to replace its fleet of 24 mission-specific ships (eight Fast Attack Craft [FAC], eight patrol boats, and eight mine countermeasure vessels) with a smaller number of multi-role vessels (MRVs) (Pike, 2011). The RDN downsized to 14 MRVs and commissioned the SF 300 fleet between1987 and1996. To meet the multi-role vessel mission, the SF 300 was built on a standard hull of non-magnetic fiberglass reinforced plastic (FRP) that measured 54m in length and 9m in beam, the crew varied between 19 and 29 personnel depending on mission type, and the overall tonnage ranged from 320–485 tons specific to payload installed (Pike, 2011).

STANFLEX design capitalized on mission modularity by incorporating four interchangeable mission containers, one forward and three aft. The stainless-steel containers measured 3m by 3.5m by 2.5m and housed all dedicated machinery and electronic payloads connected by a standard interface panel (“Flyvefisken Class (SF 300), Denmark,” n.d.). “Each of these units can be (re)configured at a short notice for different roles, simply by installing the right combination of standard-size equipment containers in the four positions” (Pike, 2011). The ability to quickly and efficiently swap payload allowed these MRVs to serve the following mission sets: anti-air defense (AAW); anti-surface warfare (ASuW); anti-submarine warfare (ASW); electronic warfare (EW); mine countermeasures (MCM); patrol and surveillance; and pollution control (Pike, 2011).

The use of containerized weapon systems permitted the SF 300 to have an open architecture C4I system that allowed “new weapons systems to be added by creating new nodes” (“Flyvefisken Class (SF 300), Denmark,” n.d.). Major technological upgrades were not required for the ship itself, but merely applied to the appropriate container. Containers could be swapped out in 30–60 minutes pier-side using standard civilian cranes, facilitating rapid mission change if necessary (Pike, 2011). Ultimately, 15 different mission modules were developed for the SF 300, which included weaponized containers for the MK48 NATO vertical launch Sea Sparrow surface-to-air missile, Boeing’s Harpoon Block II surface-to-surface missile, and the 76mm Oto Melara Super Rapid gun (“Flyvefisken Class (SF 300), Denmark,” n.d.).

The Flyvefisken class demonstrated that a smaller number of multi-role vessels were capable of meeting the same mission demands of a fleet almost twice its size. STANFLEX and modular payload allowed for containers to be pre-staged for mission flex while simultaneously reducing downtime for upgrades. The success of the SF 300 fleet was the cornerstone for the RDN’s development of the Absalon Littoral Combat Ship.

### ***Absalon Class Support Ships***

The success of STANFLEX propelled the Royal Danish Navy to continue to design seagoing naval vessels with modularity as the core requirement. The Flyvefisken class was a coastal platform capable of performing a mission set designed to protect local waters, but it lacked the endurance to deploy to the Gulf of Aden or the Persian Gulf. The Flyvefisken class served the RDN from the mid-1980s through the early 2000s, but left the Danish lacking a true-blue water navy. With a firm commitment to NATO's Ocean Shield mission to combat piracy off the Horn of Africa, a need arose for a bigger platform capable of reaching distant locations like Somalia (Lundquist, 2012).

To meet the rising need for a blue-water navy, the RDN commissioned two flexible support ships, HDMS *Absalon* in 2004 and HDMS *Exbern Snare* in 2005. Capitalizing on the success of the STANFLEX design and the use of payload modularity, the Absalons were designed with the same containerized weapon packages as the SF 300 but also featured "significant internal volume inside the multipurpose flexible support deck (FSD) to support stern ramps for vehicles and boats" (Lundquist, 2012). The ability to launch and recover small boats or vehicles in conjunction with containerized weapon systems allowed the Absalon to float between two classes of warship: amphibious and combatant (Lundquist, 2012). Under the various configurations, the Absalon class could be "equipped for naval warfare, land attack, strategic sealift missions, emergency disaster relief or as a hospital ship" ("Absalon," n.d.).

The Absalon class was built on a frigate hull and measures a little more than two-and-a-half times the length of the Flyvefisken class at 137m with a beam of 19.5m ("Absalon," n.d.). Total tonnage is between 4,500 tons and 6,300 tons, depending on configuration (Pike, 2016). "The ship design, with 16 watertight sections or compartments and two airtight bulkheads, incorporates survivability and damage limitation including dual redundancy, automated damage control zones, damage detectors and smoke zones" ("Absalon," n.d.). Focusing on long-term cost savings based on crew requirements, the Absalon class was outfitted with a maximum crew of 100, could accommodate 70 additional personnel, could house another 130 in temporary container facilities on the flexible support deck, and has personnel facilities and a galley for up to 300 embarked crew (“Absalon,” n.d.; Pike, 2016).

The Absalon class features five STANFELX container wells located amidships on the weapons deck (Lundquist, 2012; Pike, 2016). As with the SF 300, changing the combination of STANFLEX payloads allowed the Absalon class to easily shift mission. Each of the five individual containers is capable of being loaded with either eight Boeing Harpoon Block II surface-to-surface missiles or 12 surface-to-air RIM-162 Raytheon Evolved Sea Sparrow Missiles (ESSMs) (“Absalon,” n.d.; Pike, 2016). Additionally, the Absalon container wells were configured to handle “any combination of STANFLEX weapon/container suites developed for the Flyvefisken class” (Pike, 2016). By re-using existing containers and ensuring compatibility, the Absalon class created greater flexibility for mission type while proving to be a cost saving.

The modularity of the payload in conjunction with the flexible deck have allowed the Absalon class to be at the forefront of flexible and adaptable warship design. The flexible support deck is 90m long, with 250m of parking lanes, and encompasses 915m$^2$ of total usable space (“Absalon,” n.d.). The FSD is designed for roll-on/roll-off (RO/RO) vehicles, and the reinforced deck “can embark vehicles up to 62t such as the Leopard II Main Battle Tank” (“Absalon,” n.d.). The flexible multipurpose deck can take

> 75% of an Army reconnaissance battalion, a containerized hospital with 40 beds and a capacity for 10 surgeries a day, a containerized command module for a staff of up to 70 personnel, a container accommodation for emergency evacuations, up to 300 mines in modular rails … or facilities for carrying two high-speed insertion craft Swedish Type SRC-90E at 7.4t each. (Pike, 2016)

The ability of the FSD to rapidly reconfigure missions based on the use of containers has allowed the Absalon class to effectively and efficiently meet all of its desired mission types.

Modularity with the Absalon class is not limited to containerized weapons and the flexible support decks. The Combat Information Center (CIC) has a Terma C-Flex combat management system and “virtually any console in CIC can be used interchangeably with the exception of the gun-firing console and Harpoon Block II consoles” (Lundquist, 2012). Finally, the flight deck is equipped with a hangar for two helicopters, rated at 20t, and when not in use for helicopter operation it can store and stack cargo containers (Lundquist, 2012). The Absalon class demonstrated that modularity could be applied to larger combatant ships and was not localized to smaller littoral ships. Continuing to capitalize on the growing success of its modular techniques, the RDN moved forward with designing and building a flexible and adaptable frigate fleet.

### ***Iver Huitfeldt Frigates***

The success of the Absalon class laid the keel for the Iver Huitfeldt class frigates comprising three operational frigates: *Iver Huitfeldt* (F361), *Peter Willemoes* (F362), and *Niels Juel* (F363). The compliment of the Absalon and Huitfeldt class added a true combatant element to an already formidable class of flexible support ships, providing the opportunity for the Royal Danish Navy to assume a more global blue navy posture with extended deployments farther from native waters (Lundquist, 2013).

The Huitfeldt class was designed and built on the same hull used for the Absalon class, creating an 80% shared commonality between the two classes (Lundquist, 2013). The Huitfeldt class is 138.7m in length with a beam of 19.75m, carries a crew of 101, and has accommodations for 165. Where the Huitfeldt class lacks the flexible-support deck found on the Absalon class, it has a more sophisticated AAW capability and quieter acoustic signature for ASW operations, and is twice as powerful (Lundquist, 2013).

The Huitfeldt class was built without the flexible support deck to accommodate the addition of a vertical launch system (VLS). The MK41 32-cell VLS is capable of launching the Standard Missile-2 (SM-2) and the SM-6, as well as the RIM-162

ESSM (Huitfeldt, n.d.). In addition to the VLS, the Huitfeldt class continued with the modular mission payload design. The Huitfeldt class has six slots for weaponized containers that can be loaded with additional ESSMs or Harpoon Block II missiles (Lundquist, 2013). The frigates capitalized on the reuse of design elements, and the stainless-steel containers used on the Huitfeldt are the same containers used on Absalon-updated and modified containers from the Cold War–era Flyvefisken class. When a container is not being utilized, it can be stored, updated, or re-equipped. Using a standardized interface, the weaponized containers represent flexibility and adaptability through their ability to plug and play on any Danish ship (Lundquist, 2013).

The Combat Information Center (CIC) modeled the flexible support ships CIC and utilizes the same Terma C-Flex combat management system (CMS; Lundquist, 2013). “Modularity and the COTS (commercial-off-the-shelf)-based system with an open architecture-approach (OA) makes these ships easy to modify and less time consuming to upgrade” (Lundquist, 2013). Upgrades to IT systems, weapons, communications, and sensors are done through rack replacement on the standard civilian 19-inch racks installed throughout the frigate (Lundquist, 2013). Through the use of IT modularity, the fleet of RDN frigates is capable of upgrading and installing technology faster and more efficiently.

The Iver Huitfeldt class of frigates represents maturity in Danish modular ship design. Powerful and sophisticated, the frigate was built for $325 million (Cavas, 2014), about one-third of the cost of a U.S. Arleigh Burke Flight III class destroyer (GAO, 2016). Cmdr. Senior Grade Per Hesselberg, who is in charge of the Danish frigate program, stated,

> We have built in flexibility from the beginning. It’s not that much more expensive in the beginning, but easier to update later on. It’s the safe, low-risk option. We learned from our flexible support ships to have extra space for containers on the frigates. Modularity makes ships easier and more economical to build. It also makes them more efficient to operate, less expensive to maintain and to modernize. (Lundquist, 2013)

For the last 30 years, the Royal Danish Navy has significantly reduced the size of its fleet and replaced it with a smaller, powerful, cost-effective fleet. The RDN has proven that flexible and adaptable ships with modular payloads can accomplish a multitude of missions and can play a significant role in international waters.

### *German Navy*

At the forefront of modular design for the German Navy is Blohm + Voss. The design concept known as Mehrzweck-Kombination (MEKO), which translates as “multi-purpose combination,” has been utilized in ship construction and design since the 1970s. The success of the MEKO class can be seen in 13 navies worldwide in various corvettes and frigates (Kamerman, 2015). The modular mission payloads in 20ft standardized ISO containers create adaptability and flexibility and allow navies to rapidly reconfigure mission type based on operational needs. Modules can be rotated for upgrades and maintenance or passed between ships, which reduces the number of overall payloads required for the fleet. This simple reduction results in significant cost savings in procurement and maintenance over the life cycle of the ship (“ThyssenKrupp,” n.d.). The MEKO class comprises the MEKO A-100 Corvette and the MEKO A-200 Frigate (“ThyssenKrupp,” n.d.), and is the backbone for the new German frigate class, the Baden-Württemberg (F125).

The German Navy will acquire four Baden-Württemberg class frigates to replace the eight frigates in the Bremen class (F122) commissioned in the 1980s. The Baden-Württemberg frigate design incorporates enhanced survivability capabilities to include floating, moving, and fighting after sustaining damage; to embark and deploy special forces; and to maintain prolonged periods at sea with little maintenance; and it incorporates modular mission capabilities (Kamerman, 2015). The F125 is a new hull design drawing from the MEKO A-200 and the German F124. It measures 149.5m in length with a beam of 18.8m, displaces 7,300 tons at full load, and will carry a crew of 105–120, but can accommodate up to 190 personnel to include a 20-person aircraft detachment and 50 embarked forces (“Baden-Württemberg,” 2017). The first frigate, *Baden-Württemberg* (F222), will be commissioned in 2017, *Nordrhein-Westfalen* (F223) in 2018, *Sachsen-Anhalt* (F224) in 2019, and *Rheinland-Pfalz* (F225) in 2020 (Pape, 2016).

The F125 class is designed to experience prolonged deployment periods of 24 months and increased hours of operation of 5,000h/yr. This extended availability will be accomplished through a two-crew concept with crews swapping every four months in the given operational theater (Kamerman, 2015). Through modernization, automation, and cross-rate training, the crew of the F125 is approximately half the size of the marginally smaller German Sachsen (F124) class frigates that currently deploy for six-month cycles and operate 2,500h/yr. The design flexibility of the F125 will double the availability of the current German frigate fleet (Kamerman, 2015) while simultaneously reducing overhead.

The F125 will take advantage of MEKO technology. MEKO designs rely heavily on modularity that increases the speed at which the ship can be built and facilitates faster upgrades and refits. The F125 will feature weapon modules, electronic modules, mast modules, and a modular combat system with standard interfaces (Kamerman, 2015). Given the flexibility in the design, the F125 readily translates into an exportable frigate design within the MEKO family: the MEKO A-400 Generic Evolved MOTs Multi-Role Frigate. The MEKO A-400 will be built on the same class-standard hull with the same machinery as the F125 frigate, but offers foreign navies the flexibility to specify any combination of combat systems from any supplier, resulting in more than 80% commonality between the two classes of ships (Kamerman, 2015). This commonality creates a larger fleet of ships from which to draw resources, technical knowledge, and maintenance upgrades.

### *French Navy*

Similar to the Royal Danish Navy, the French Navy has made substantial strides over the last decade to replace three separate aging fleets with two smaller, state-of-the-art, flexible and adaptable fleets of frigates. The Frégate Européenne Multi-Mission (FREMM) was a joint venture between the Italian and French navies, built and designed by the Direction des Constructions Navales Services (DCNS, a

French naval defense company) and Orizzonte Sistemi Navali with Fincatieri and Finmeccanica ("FREMM," 2017). These highly modular frigate designs allowed the French, Italians, and potential international clients a choice of equipment with regards to weapons and combat systems (Cavas & Tran, 2016). The newer Frégate de Taille Intermédiaire (FTI), specific to the French Navy, was unveiled in October 2016 (Peruzzi, Scott, & Pape, 2016). Designed by DCNS, it promotes modular design with potential international appeal (Cavas & Tran, 2016).

### *Aquitaine Class*

The Aquitaine class FREMM frigates designed for the French will replace nine D'Estienne d'Orves class avisos (A69 Type Aviso) and nine Tourville and Georges Legues class anti-submarine frigates. The modular design of the FREMM vessels allowed the French Navy to choose between two mission versions: a land attack version with torpedoes, vertical launch system, and cruise missiles or an anti-submarine (ASW) version fitted with torpedoes, vertical launch system, and an active towed array sonar ("FREMM," n.d.). The French government originally committed to 17 FREMMs, but defense budget cuts reduced the class to 11 and then ultimately eight vessels. The French Navy has committed to building two FREMMs in the land attack configuration and six in the anti-submarine configuration. *Aquitaine* (D 650) was commissioned in November 2012, *Provence* (D 652) was commissioned in June 2015, and *Languedoc* (D 653) was commissioned in March 2016, each configured to ASW (Tomkins, 2016).

The French FREMM is 142m in length, has a beam of 20m, displaces 6,000 tons, and carries a crew of 108 ("FREMM," n.d.). "The frigate's layout has been designed to provide sufficient size for operational effectiveness, maintainability and sustained upgrades. The layout incorporates increased headroom between decks, deeper and longer engine compartments and larger equipment pathways for access and maintenance" ("FREMM," n.d.).

Both the land attack and anti-submarine versions of the Aquitaine class feature the MBDA Exocet MM40 Block III for anti-ship and littoral attack capability and the

MBDA Aster 15 and Aster 30 for air defense. The land attack vessels will also be equipped with MDBA SCALP naval cruise missiles. Additionally, both versions of the frigate boast an aft helicopter hangar and deck encompassing 520m$^2$ while the land attack frigates "are fitted for a tactical unmanned air vehicle and have the capability to control long-endurance, medium and high-altitude unmanned air vehicles launched from ground sites or from other platforms" ("FREMM," n.d.).

Similar to the Danish Absalon and Iver Huitfeldt classes, the Aquitaine class Combat Information Center (CIC) features a high-speed data network with an open architecture that will enable future weapon systems to be integrated into the frigates ("FREMM," 2017) With external communication equipment compliant with NATO standards, French FREMMs can operate on Link 11, Link 16, Link 22, and JSAT tactical data link (FREMM, n.d.). This international NATO co-operability has resulted in the Aquitaine and Provence participating in joint exercises with the U.S. Navy's Task Force 50 in the Persian-Arabian Gulf (Tomkins, 2016).

The design features of the FREMM have considered a flexible and adaptable modular build that allows for future growth in technology at a sustainable cost. Given choices between the various mission sets, growth margins for upgrades, and a relatively small and manageable crew size, FREMM is a viable option for a multitude of foreign navies.

#### (1) Italian Bergamini Class

Under the joint FREMM venture with the French, the Italian Navy has committed to the purchase of 10 frigates to replace the Lupo- and Maestrale-class frigates built in the 1970s by Fincantieri ("Italian Navy," 2016). Known as the Bergamini class, *Carlo Bergamini* and *Virginio Fasan* were delivered in 2013, *Carlo Margottini* in 2014, and *Carabinieri* in 2015, and *Alpino* was commissioned in September 2016 (Italian Navy, 2016). The Italian Navy expects to have all 10 frigates delivered by 2020 and will operate four anti-submarine variants and six general-purpose variants of the FREMM class ("Italian Navy," 2016).

#### (2) Foreign FREMM sales

Given the modular choices for combat systems and weapons, smaller crew, and the capability to carry out various mission types, the FREMM class is appealing to foreign navies. Both the Egyptian Navy and Royal Moroccan Navy each operate a FREMM ship in anti-submarine configuration but without a vertical launch system or jamming capabilities (Tomkins, 2016). Built by DCNS, FREMM *Mohammed VI* was delivered to Morocco in 2014, while FREMM *Tahya Misr* was delivered to the Egyptian Navy in 2015 (“Italian Navy,” 2016).

### ***FTI Class***

The success of the FREMM class has pushed the French to continue to tailor their existing fleet into a smaller, more highly effective combatant force. The Frégate de Taille Intermédiaire (FTI) is a medium-sized frigate and will replace the five in-service La Fayette class frigates starting in 2023 (Peruzzi et al., 2016). “The 4,200-ton frigate is a fresh design, different from the preceding FREMM multi-mission frigates, and features an unusual ‘inverted bow’ intended to improve seakeeping in high sea states” (Cavas & Tran, 2016). The FTI will be a formidable platform capable of executing the following:

> anti-submarine, anti-surface, and anti-air warfare capabilities, the ability to deploy special forces projections, capable of supporting operations against asymmetric threats, able to operate as a single vessel or as part of a joint national or combined international task force, provide power projection at distance, conduct maritime interdiction, crisis prevention, and intelligence gathering operations. (Peruzzi et al., 2016)

The FTI will measure 122.25m in length, have a beam of 17.7m, and carry a crew of 125 personnel, including a 15-person aviation detachment, and can accommodate an additional 50 personnel depending on the mission. Each frigate will be equipped with two MBDA Aster 30 launchers, each consisting of four cells as compared to the four launchers on the FREMM class. FTI will be capable of launching the Aster MM-40 Exocet Block III guided anti-ship missiles, and has a 76mm cannon. Finally, the compact frigate will reach speeds of 27 knots with an endurance of 5,000NM on a combined diesel and diesel (CODAD) engine arrangement (Cavas & Tran, 2016). The compliment of the eight FREMM vessels (six anti-submarine configurations and two air defense configuration), five FTIs, and two Horizon class anti-air warfare frigates will make the French Navy a 15-strong frigate force by 2030 (Cavas & Tran, 2016).

The FTI is estimated to cost $840 million, which is still 20–30% less than the 6,000-ton FREMM (Cavas & Tran, 2016). Despite this price tag, DCNS is committed to producing a flexible and adaptable frigate that delivers options to the buyer, be it the French Navy or the international naval community, and estimates it could possibly sell an additional 40 frigates of this design (Cavas & Tran, 2016). At the core of the FTI design are embedded evolutionary and adaptive capabilities based around a modular design (Peruzzi et al., 2016) that offers freedom in a rapidly changing technical world for clients to pick and choose their combat systems and equipment (Cavas & Tran, 2016).

### *Royal Australian Navy*

Currently, the Royal Australian Navy (RAN) utilizes the Anzac class of frigates as its primary anti-submarine warfare platform. Built by Tenix Defense Systems (now part of BAE Systems Australia), eight were commissioned for the RAN between1996 and 2006, and two were commissioned for the Royal New Zealand Navy in 1997 and 1999 ("Anzac," n.d.). "Anzac frigates are long-range escorts with roles that include air defense, anti-submarine warfare and surveillance" (Kerr, n.d.). The Anzac class displaces 3,600 tons fully loaded, has a length of 118m with a beam of 14.8m, and carries a crew of 174 personnel. The design of the Anzac is "based on the Blohm + Voss MEKO 200 modular design which utilizes a basic hull and construction concept to provide flexibility in the choice of command and control, weapons, equipment and sensors" ("Anzac," n.d.). Given the success of the Anzac frigates, the RAN is moving forward with a new class of frigates that will need to incorporate a flexible and adaptable design to meet the growing demand for an efficient, sophisticated, and technologically advanced warship.

The new Future Frigate initiative launched by the Royal Australian Navy is known as the SEA5000 Program. Anticipating an increased military presence in the

Asia-Pacific region from both non-state and state actors by 2035, the RAN will need a frigate capable of deterrence and power projection (Goldsmith, 2016). SEA5000 “will oversee the acquisition of nine high-capability Future Frigates and these major surface combatants will be capable of Anti-Air Warfare (AAW), Anti-Surface Warfare (ASuW), with a strong emphasis on Anti-Submarine Warfare (ASW)” (Goldsmith, 2016).

### *Future Frigate Mandatory Design Characteristics*

Given the anticipated threat in the region, the RAN has stated that five critical capability criteria should be incorporated into the Future Frigate design (Goldsmith, 2016). These five characteristics are essential to the long-term success of a flexible and adaptable RAN warship.

1. Low Crewing Requirement: Due to RAN personnel shortages, the Future Frigates must be capable of safely operating with crew of fewer than 174.

2. RAN Combat Capability Preferences: The Future Frigates must be capable of supporting the CEAFAR S/L/X radar suite with the SAAB 9LV Combat System and Aegis Fire Control System (FCS). It is also inferred that the RAN will insist on the inclusion of the multipurpose MK41 Vertical Launching System (VLS) as the ship’s principal weapons battery.

3. Flexibility: The Future Frigates must be capable of accepting mission-specific modules, as well as providing full hangar and logistics support for two HM-60R helicopters.

4. Ship Survivability: The Future Frigates must be capable of operating in the projected higher-threat environment of future decades, even without access to “external support.” The Future Frigates must also be capable of remaining partially functional even after suffering battle damage, and particularly due to the higher-threat operating environment of future decades. Ship survivability is a pivotal aspect of the Future Frigate design since the RAN major surface combatant fleet is numerically finite and thus cannot lose a single ship without severe repercussions for the RAN’s capacity to sustain ship deployments over protracted periods.

5. Growth Margin: The Future Frigates must have sufficient surplus space, weight, electrical power, and industrial-grade cooling to accommodate new “game-changing” technologies as they mature in the period through 2035. For instance, high-energy directed energy weapons are anticipated to mature over this period and promise to revolutionize naval operations.

(1) Low Crewing Requirement

Due to manning shortages within the RAN, the Australian DOD has stated that the crew size must not exceed that of the current Anzac frigate: 174 personnel. Given that naval personnel account for about 50% of a ship’s operating and sustainment life-cycle costs, it would be advantageous for the RAN to cut long-term costs by building a flexible and adaptable ship that reduces costs through manpower (Goldsmith, 2016).

(2) Growth Margins

Given the rapid growth in technologically advanced weapons over the last two decades, the new Future Frigate must incorporate a design that allows for continued growth without major, costly overhauls. The Future Frigate design must have “sufficient growth margins to accept new technologies as they mature” (Goldsmith, 2016). To accommodate this growth margin, the original design must have “significant surplus space, weight, power and cooling margins” (Goldsmith, 2016).

### ***Potential Designs***

Initial designs were submitted from eight different countries with a history of designing and building flexible and adaptable vessels including France, Germany, Britain, Spain, Denmark, The Netherlands, Italy, and Australia (Kerr, n.d.). Ultimately, Italy (Fincantieri), Spain (Navantia), and British Aerospace (BAE) were selected to “refine their designs and prepare their commercial proposals for the comparative evaluation process (CEP)” (Kerr, n.d.). Fincantieri has built four FREMM frigates for the Italian Navy, with another four in production and two left to build. The RAN variant of the Bergamini class would not require modification to the existing hull design, already has twin helicopter hangars, and would create a large support structure with a family of 19 vessels (Kerr, n.d.). Navantia designed the RAN Hobart class of Air Warfare Destroyers (AWD), and the Future Frigate design would be a modified F-100 Frigate (Goldsmith, 2016) that “would benefit from more than 75 percent of systems commonality with the AWDs and about 40 percent with the Anzac class” (Kerr, n.d.). BAE has designed the Type 26 Global Combat Ship for the British Royal Navy, and the RAN version of the global combat ship stands to benefit from the mature Type 26 design already in production (Kerr, n.d.). Final design selection for the Future Frigate will occur in 2018 (Goldsmith, 2016).

The Royal Australian Navy is pushing the design boundaries of flexible and adaptable ships to meet the evolving needs of a global navy with a deep blue-water reach and shrinking defense budgets. With a clear and concise list of critical capability criteria, the RAN will ensure that the Future Frigate will be able to meet the defense needs of the Australian people.

## *American Navy*

As the U.S. Navy began to phase out its fleet of 51 Oliver Hazard Perry class frigates, its leadership began to look for a high-tech platform that could be used as a replacement (Osborn, 2015). The end result was the Littoral Combat Ship (LCS) in two variants: the trimaran-hull Independence and the mono-hull Freedom. The concept of the LCS was a highly flexible and adaptable ship that would allow the U.S. Navy to operate in littoral areas with a focus on maritime security and anti-piracy (Stashwick, 2016). “The ships were designed to be high-speed (over 40 knots) and highly maneuverable, with the ability to swap out modules to provide mission-specific capabilities like anti-submarine, anti-surface, and mine-clearing” (Stashwick 2016). Both variants of the LCS included a mission bay in the design to house elements of mission packages. Within the LCS class, “mission packages are composed of mission modules, aircraft, and crew detachments to support the mission modules and aircraft” (Doerry, 2012).

### *LCS—Freedom*

Currently, 13 Freedom class littoral combat ships have been ordered, and four have been commissioned. USS *Freedom* (LCS 1) was commissioned in November 2008, USS *Fort Worth* (LCS 3) was commissioned in September 2012, USS *Milwaukee* (LCS 5) was commissioned in November 2015, and USS *Detroit* was commissioned in October 2016) (“Freedom,” 2016).

The Freedom class is built on a steel monohull and is capable of incorporating three mission packages: anti-submarine warfare (ASW), anti-surface warfare (ASuW), and mine countermeasures (MCM). LCS 1 has an overall length of 115.3m, and all subsequent Freedom class vessels are 118.3m to improve through-water performance. The beam of LCS 1 is 17.5m, while the remaining class is 17.6m; the bow of LCS 5 and all subsequent models were modified from LCS 1 and LCS 3. LCS 1 has a maximum tonnage of 3,360 tons and the remaining Freedom class reaches a maximum tonnage of 3,480 tons, and all variants carry a crew of 50 (“Freedom,” 2016).

The flexible design “incorporates a large reconfigurable seaframe to allow rapidly interchangeable mission modules, a flight deck with integrated helicopter launch, recovery, and handling systems and the capability to launch and recover maritime vehicles (manned and unmanned) from the stern side” (“Freedom,” 2016). Modular payload on the LCS comprises three modular weapons stations that can accommodate either a gun (MK46 30 mm gun) or missile module (Lockheed Martin AGM 114L Longbow Hellfire; “Freedom,” 2016).

The low total gross weight allows the LCS class to obtain speeds greater than 40 knots. The design trade-off for speed was sustained battle damage capability. Where other surface combatants could withstand and potentially recover from sustained-high intensity conflict, the Freedom class would likely result in abandonment of the vessel in the same type of conflict (Stashwick, 2016).

### *LCS—Independence*

The Independence class of littoral combat ships has commissioned four ships with another six in construction and four more ordered. USS *Independence* (LCS 2) was commissioned in January 2010, USS *Coronado* (LCS 4) was commissioned in April 2014, USS *Jackson* (LCS 6) was commissioned in December 2015, and USS *Montgomery* (LCS 8) was commissioned in September 2016.

The Independence class was designed on an aluminum trimaran hull form based on a commercial ferry design used by the Norwegian company Fred Olsen (“Independence,” 2016). As with the Freedom class, the Independence is capable of performing three mission packages: anti-submarine warfare (ASW), anti-surface warfare (ASuW), and mine countermeasures (MCM). The Independence class has an overall length of 128.5m (about 10 meters longer than Freedom), with a top speed of 50 knots (“Independence,” 2016). The beam of Independence is 31.6m (approximately twice of Freedom), which can accommodate the MH-5E heavy-lift helicopter (used primarily for mine countermeasures). Full load displacement is 3,188 tons, and it carries a crew of 40 personnel (“Independence,” 2016).

The flexible design incorporates a “reconfigurable seaframe to allow rapidly interchangeable mission modules” that include three modular weapon stations (“Independence,” 2016). “The two-gun modules are each built around a MK46 30mm gun” (“Independence,” 2016) and the missile module has been fielded with the Longbow Hellfire a millimeter wave RF, fire-and-forget, high explosive anti-tank missile. The Independence class features a side-ramp with roll on/roll off capability, and can carry two 11m RHIBs (rigid hull inflatable boat) “available for use by boarding teams carrying small arms” (“Independence,” 2016).

### *Small Surface Combatant*

The U.S. Navy originally contracted 52 littoral combat ships, but in January 2014, Secretary of Defense Chuck Hagel “instructed the Navy that there would be no new contracts awarded for LCS production beyond 32 ships” (Osborn, 2015). In place of the remaining 20 littoral combat ships, the Navy will build a Small Surface

Combatant ship. On January 15, 2015, Secretary of the Navy Mabus stated that a new class of ship was required to have frigate-like capabilities and thus would change the designation of the last 20 ships from LCS to FF (Osborn, 2015).

The new frigate will capitalize on the two existing hull variants used in the Freedom and Independence classes (Eckstein, 2015). Speaking at an American Society for Naval Engineers event, CAPT Dan Brintzinghoffer stated that the new frigate would take the basic LCS design but differ in that it “will be more lethal, more survivable, and will be able to conduct surface warfare and anti-submarine warfare simultaneously, whereas the LCS had to choose only one mission package to work with at any given time” (Eckstein, 2015). In addition,

> it will have a torpedo decoy, variable depth sonar and multi-function towed array permanently onboard, rather than included in a part-time mission package for LCS; will deploy two 7-meter rigid-hull inflatable boats rather than the 11-meter RHIBs on the LCS surface warfare package; and will retain the Mk 50 30mm guns rather converting to the more common 25mm gun. The ship will be upgunned with a SeaRAM anti-ship missile system, a ship-launched Hellfire missile system and an over-the-horizon surface-to-surface missile system. (Eckstein, 2015)

The new class of frigates will trade the high-speed capability of the LCS class in order to accommodate the additional weight created by the heavier armor for increased survivability (Eckstein, 2015). To make the new frigate class cost-efficient, CAPT Brintzinghoffer stated that commonality will be required across both variants, and it will likely need to share some modular aspects with the LCS class or some commonalities with other classes of surface combatants (Eckstein, 2015).

This new class of frigates represents an opportunity for the U.S. Navy to build on an existing hull, capitalizing on cost savings in the early design process, and incorporate more advanced flexible and adaptable modules in the payload design. A proven example of a flexible and adaptable frigate with modular payload with similar tonnage is the MEKO A-200 class frigate. The MEKO class family is designed for sustained battle damage and could provide guidance for enhanced survivability options for this new class of American frigates.

### *Real Options Valuation with Flexible Ships*

The U.S. Navy needs to develop a more sophisticated method for flexible and adaptable ship design if it is going to keep pace with a rapidly evolving worldwide naval threat. In the past, ship design relied on highly experienced naval architects who were well versed in a straight-forward ship design that was fixed and rigid (Caprace & Rigo, 2010). This outdated method of ship design is becoming cost-prohibitive when looking at the lifetime life-cycle cost for upgrades, and overhauls, and drives inflexibility for mission change (Koenig et al., 2008). Due to the rigidity in the build and failure to build with margin, U.S. Navy cruisers and destroyers are failing to meet their designed service lives by almost 10 years (Doerry, 2012).

While ship design needs to incorporate flexibility and adaptability, the possible set of requirements for the design is so great that it is prohibitively expensive to attempt to design a ship including every desired feature. Instead, the ship design needs to incorporate options that can be deferred to the future when the exact requirements are better understood (Doerry, 2012).

> The key to modular adaptable design is incorporating options in the design to be able to defer the exact configuration of the ship to that point in time when the requirements are known, and to have the capability to affordably modify the ship’s configuration to meet the requirements when they become known. (Doerry, 2012)

Moving forward with flexible and adaptable ship design requires sophistication and finesse. One valuable tool on the market to assist the U.S. Navy with evaluating the inherent risk in adaptable and flexible ship design is Real Options Valuation (ROV). ROV is a systematic approach and integrated solution that uses various inputs including modeling, statistics, and economic analysis to provide decision-makers with a varied set of design options from which to choose. ROV is a powerful tool in this situation because traditional return on investment (ROI) design comparison trade-offs cannot defensibly be applied to these assets (Mun & Housel, 2016).

By computing the Knowledge Value Added (KVA) of the ship design, a common unit of output (CUO) value will be developed that will allow decision-makers to assess the actual cost and value of people, systems, or processes within the design. KVA ultimately delivers two metrics—Return on Knowledge (ROK) and Return on Knowledge Investment (ROKI)—that can be used to generate input values for real options analysis (Mun & Housel, 2016). Finally, integrated Risk Management (IRM) builds on the portfolio of options available in the design process by using a quantitative software suite to provide objective quantification of risk, flexibility, strategy, and decision analysis (Mun & Housel, 2016).

Real Options Valuation allows shipbuilders to design for uncertainty. “In the design state, options analysis enables more realistic assessments of technologies and design features that add flexibility during development and adaptability during the post-commissioning life cycle” (Koenig, 2009). ROV creates five standard investment options: option to expand, option to contract, option to wait or defer an investment, option to choose between different assets, and option to vary the mix (Koenig, 2009). Real Options is a quantitative approach to ascertaining the amount of risk in a modular build when the risk is unknown. Using simulation, a portfolio of options can be presented to the design team, allowing for a more flexible build that has margin for growth or mission change. The portfolio of options created using Real Options analysis can be value- and cost-driven or payload-specific, forcing the design to accept some risk in the final product (Mun & Housel, 2016).

By incorporating the theories of Real Options Valuation (ROV), Knowledge Value Added (KVA), and Integrated Risk Management (IRM) into existing design builds, the U.S. Navy can use the DDG 51 Flight III Series to model a business case for making strategic decisions under uncertainty (Mun & Housel, 2016).

Using Monte Carlo simulation, thousands of simulations can be run to determine possible outcomes for flexible and adaptable ship design. Ultimately, ROV, KVA, and IRM can provide naval architects, senior leadership, and decision-makers the opportunity to exercise the strategic ability to either move forward with a portion of the ship design or abandon it because the initial risks have become known over time (Mun & Housel, 2016).

In a U.S. Navy research article, Page (2011) determined that when the design investment 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” (Page, 2011). 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 potential 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 summarize, 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” (Page, 2011).

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 stated that Sea Swap and other initiatives like it are not adequate. In his article, Siegel (2005b) suggested 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) offered 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.” It follows that the U.S. Navy can utilize strategic real options for addressing situations 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” (O’Rourke, 2010).

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* stated 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, p. 9)

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, p. 9)

In "Condition Sinking," Wilson (2014) stated 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, p. xv)

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 et al., 2004, p. xv)

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)

Doerry’s 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 (Hoffman, 2006) 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 current study 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 [i.e., return on assets] 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) stated 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) described 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) stated 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. (Koenig, 2009)

Neches and Madni (2013) delivered 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 were 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.

> 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) stated 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.

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

O'Rourke (2005) also said that 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.

In a research report from Northrop Grumman Analysis Center, the author stated 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) stated 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) also 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 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

This review of the ROV-KVA-IRM approach is intended to provide a concise tutorial context for the specific use of these tools as they are applied to strategic ship design challenges. The examples of the use of ROV in for-profit organizations provide a background of the successful use of the approach in a competitive, market-driven environment. The review of the KVA approach is provided to demonstrate how this approach can be used to generate objective value estimates to feed the ROV estimates in the IRM eight-step framework. The IRM review is intended to demonstrate how the ROV and KVA approaches can be combined to generate value, risk, and optimal portfolio estimates.

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 Real Options Valuation (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 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 the automobile and manufacturing industry, General Motors (GM) applies real options to create *switching options* 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 cyclicity 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 consider not only 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 has been used for approaching the problems of estimating the productivity (in terms of ROI) for military capabilities embedded in processes that are impacted by technology. KVA partially 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 by the following:

- Clinger-Cohen Act of 1996 that mandates the assessment of the cost benefits for information technology investments.
- Government Accountability Office’s (formerly the General Accounting Office) *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’s *Risk Management Guidance Defense Acquisition Guidebook* 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 can be used to monetize the outputs of all assets, including intangible knowledge assets, by generating market-comparable estimates of the price per common unit of output. 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) divided by the cost to produce the CUOs. By capturing the value of knowledge embedded in an organization's core processes, employees, and technology, KVA identifies the cost and value of people, systems, and 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.

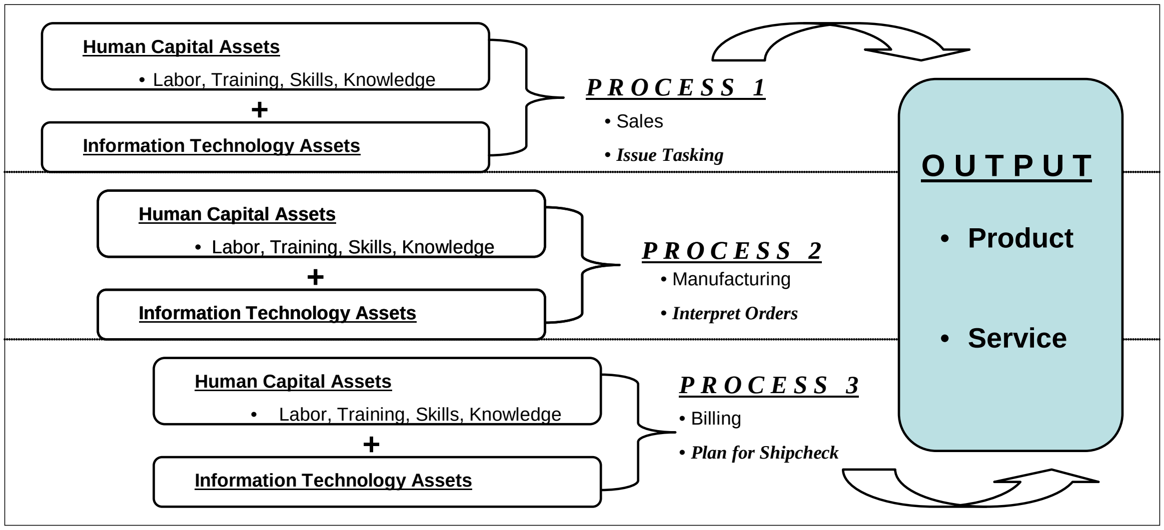


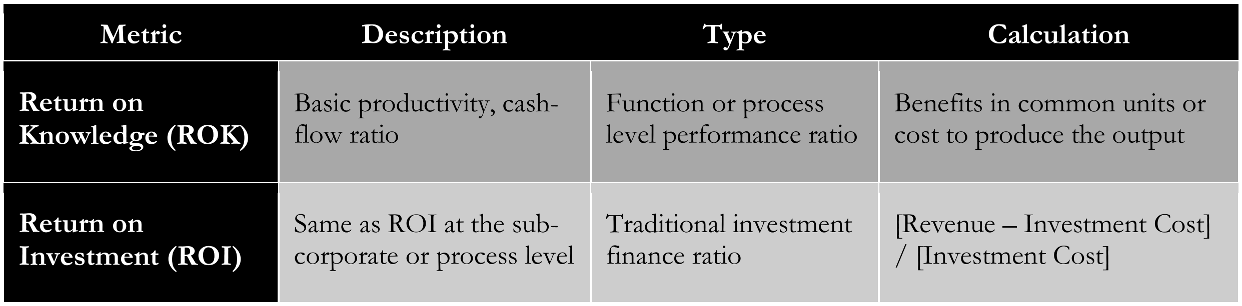
*Figure 1: Measuring Output*

For the purpose of this study, KVA was used to measure the value added by the human capital assets (i.e., military personnel and systems used in executing the processes) and the system assets (e.g., new sensor, weapons system) 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, building, 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

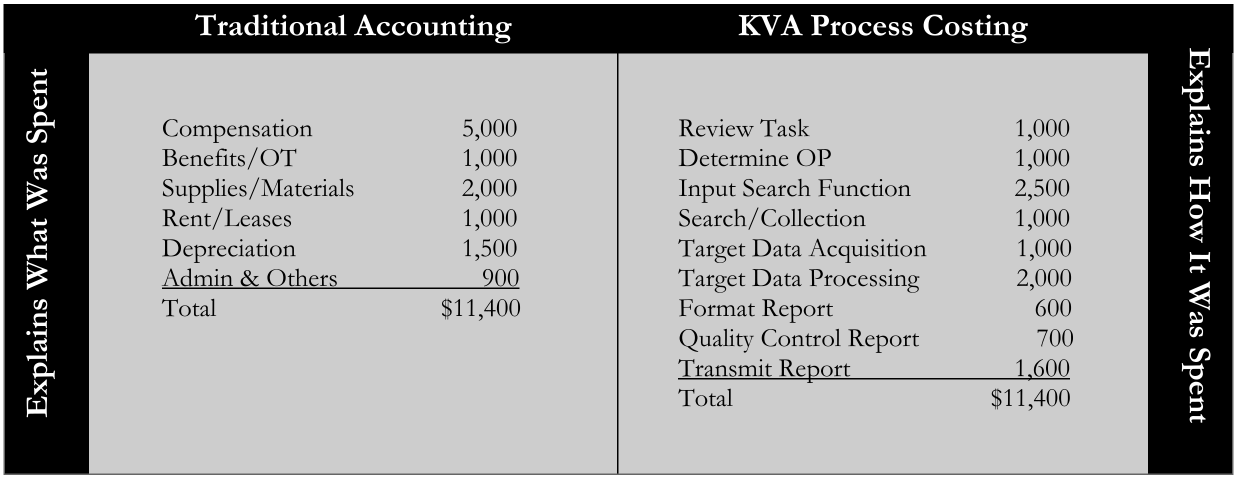
KVA quantifies value in two key productivity metrics: Return on Knowledge (ROK) and Return on Knowledge Investment (ROI). Calculations of these key metrics are shown in Figure 2.



| 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 reflects how well a specific process converts existing knowledge into producing outputs so decision-makers can quantify costs and measure value derived from investments in human capital and information technology 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).



Explains What Was Spent

| Traditional Accounting | |
|---|---|
| Compensation | 5,000 |
| Benefits/OT | 1,000 |
| Supplies/Materials | 2,000 |
| Rent/Leases | 1,000 |
| Depreciation | 1,500 |
| Admin & Others | 900 |
| Total | $11,400 |

| KVA Process Costing | |
|---|---|
| Review Task | 1,000 |
| Determine OP | 1,000 |
| Input Search Function | 2,500 |
| Search/Collection | 1,000 |
| Target Data Acquisition | 1,000 |
| Target Data Processing | 2,000 |
| Format Report | 600 |
| Quality Control Report | 700 |
| Transmit Report | 1,600 |
| Total | $11,400 |

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 or change) 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 at a given point in time. 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 such as 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. These rankings assist 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.

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, life-cycle 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 life-cycle 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 yields 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.

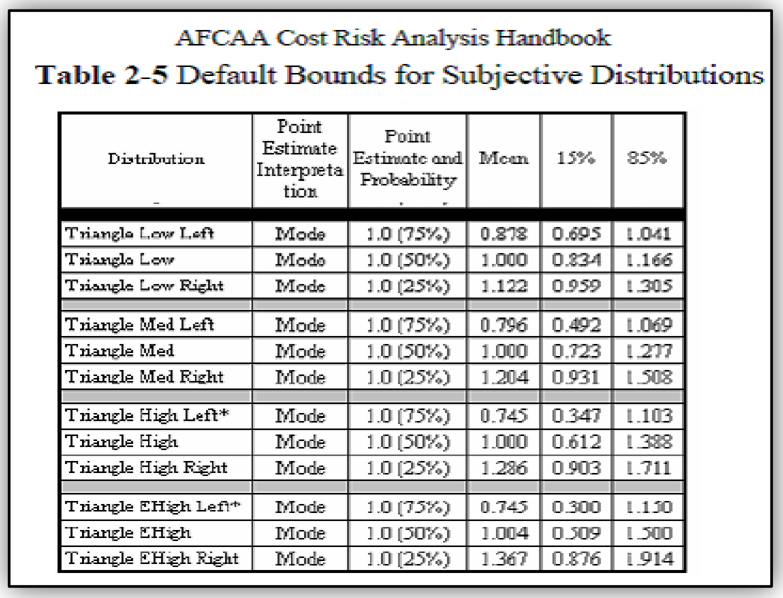
In real options, the analyst assumes that the underlying variable is the future benefit minus the cost of the project. An implied volatility can be calculated through the results of a Monte Carlo risk simulation. The results for the IRM analysis will be built on the quantitative estimates provided by 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.



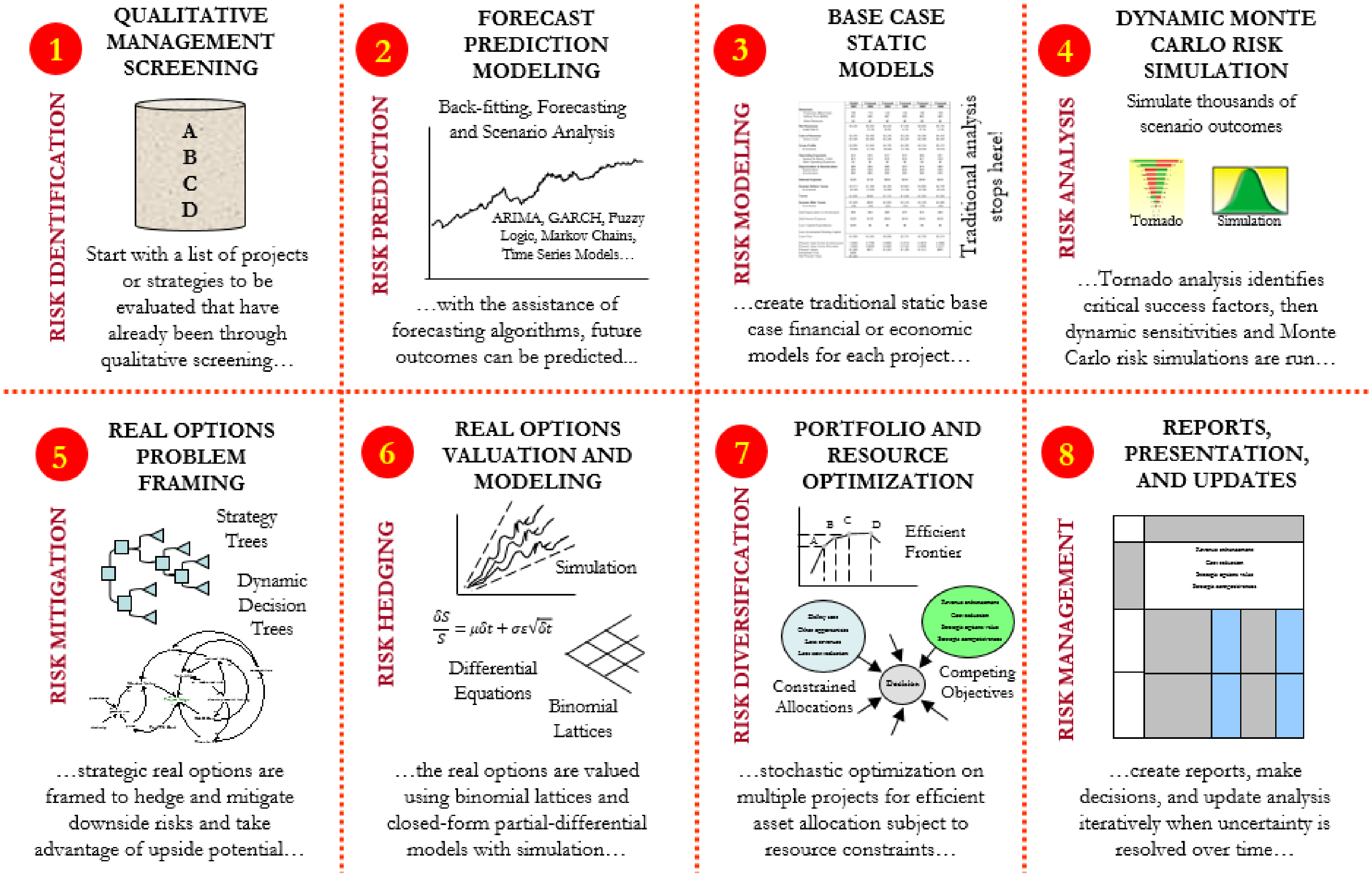
AFCAA Cost Risk Analysis Handbook

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*

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



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

…with the assistance of forecasting algorithms, future outcomes can be predicted...

…create traditional static base case financial or economic models for each project…

…Tornado analysis identifies critical success factors, then dynamic sensitivities and Monte Carlo risk simulations are run…

…strategic real options are framed to hedge and mitigate downside risks and take advantage of upside potential…

…the real options are valued using binomial lattices and closed-form partial-differential models with simulation…

…stochastic optimization on multiple projects for efficient asset allocation subject to resource constraints…

…create reports, make decisions, and update analysis iteratively when uncertainty is resolved over time…

*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 wait and defer allows the holder the option, but not the obligation, to execute a certain strategy when situations make it optimal to do so.

- 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
    - 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
    - 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
    - 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.

- Facilitates the determination of 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 a FASO/MAS 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
    - 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 life-cycle 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 onboard 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 whether 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). 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.

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

The C-17 Globemaster III is a long-range cargo/transport aircraft that has been 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

- 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

  - 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

  - 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 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 also begun to demonstrate some promise 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 MK41 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

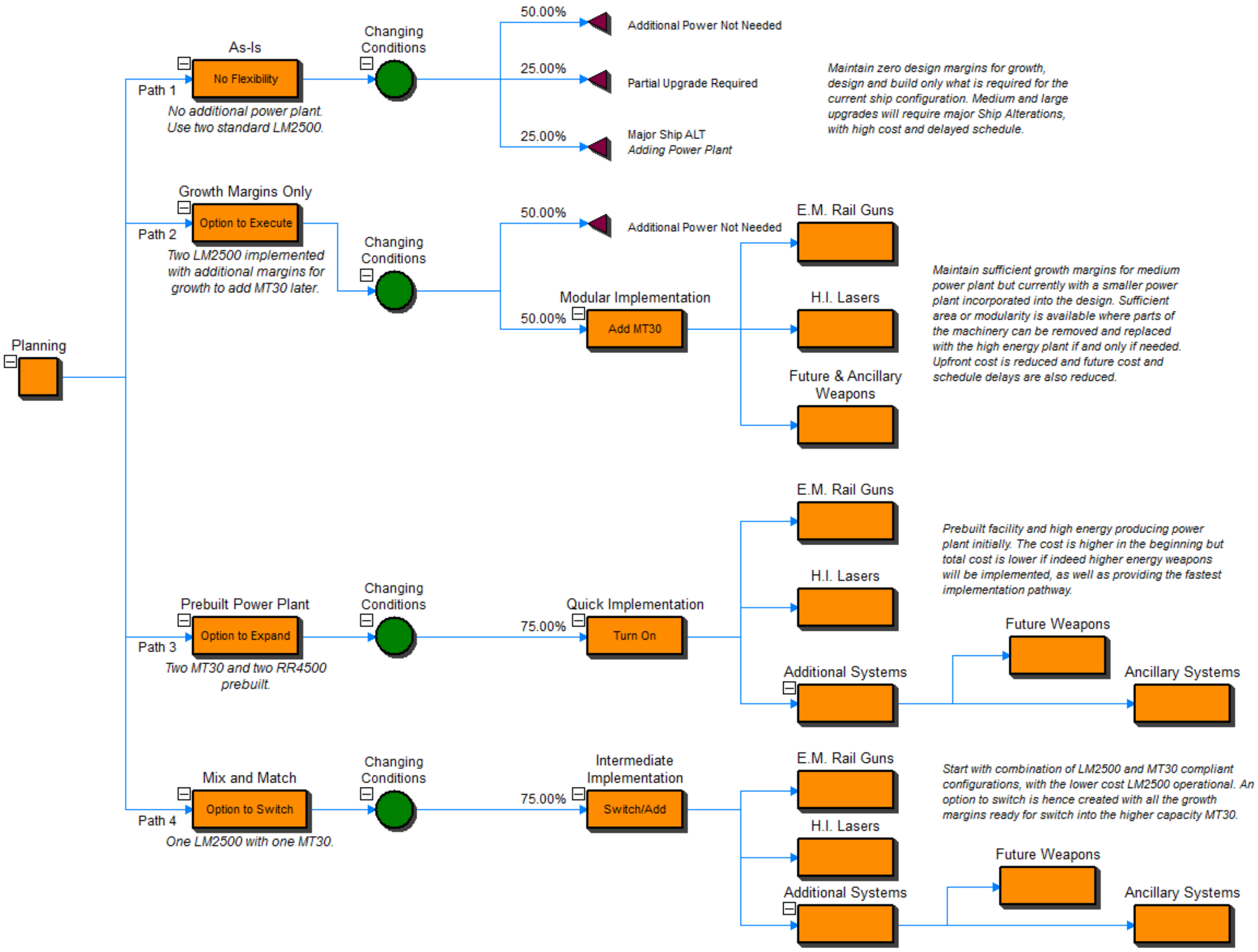
The following provides two high-level examples of identifying and framing strategic flexibility options in the DDG 51 and DDG1000 environments. These are only notional examples with rough order magnitude values to illustrate the options framing approach.

### 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 35.4 MW, and its auxiliary RR4500 Rolls-Royce turbine generators can produce an added 3.8 MW, 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, while 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.



*Maintain zero design margins for growth, design and build only what is required for the current ship configuration. Medium and large upgrades will require major Ship Alterations, with high cost and delayed schedule.*

*Maintain sufficient growth margins for medium power plant but currently 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 high energy plant if and only if needed. Upfront cost is reduced and future cost and schedule delays are also reduced.*

*Prebuilt facility and high energy producing power plant initially. The cost is higher in the beginning but total cost is lower if indeed higher energy weapons will be implemented, as well as providing the fastest implementation pathway.*

*Start with combination of LM2500 and MT30 compliant configurations, with the lower cost LM2500 operational. An option to switch is hence created with all the growth margins ready for switch into the higher capacity MT30.*

*Figure 6: Options Framing on Power Generation*

### *Vertical Launch Systems*

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.

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 it 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 modeling 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 cost 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.

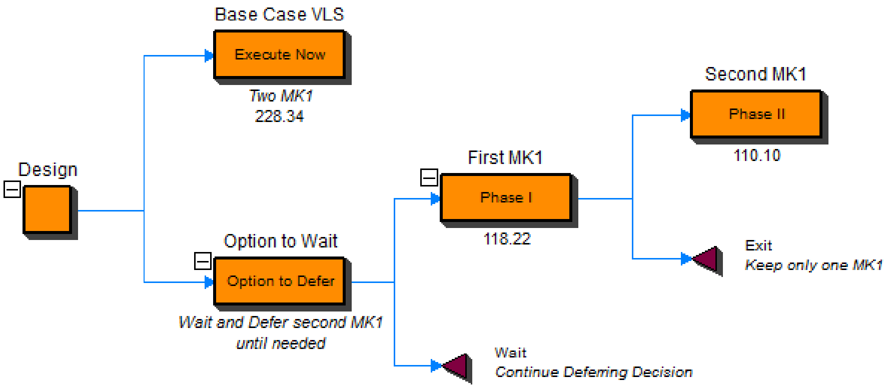
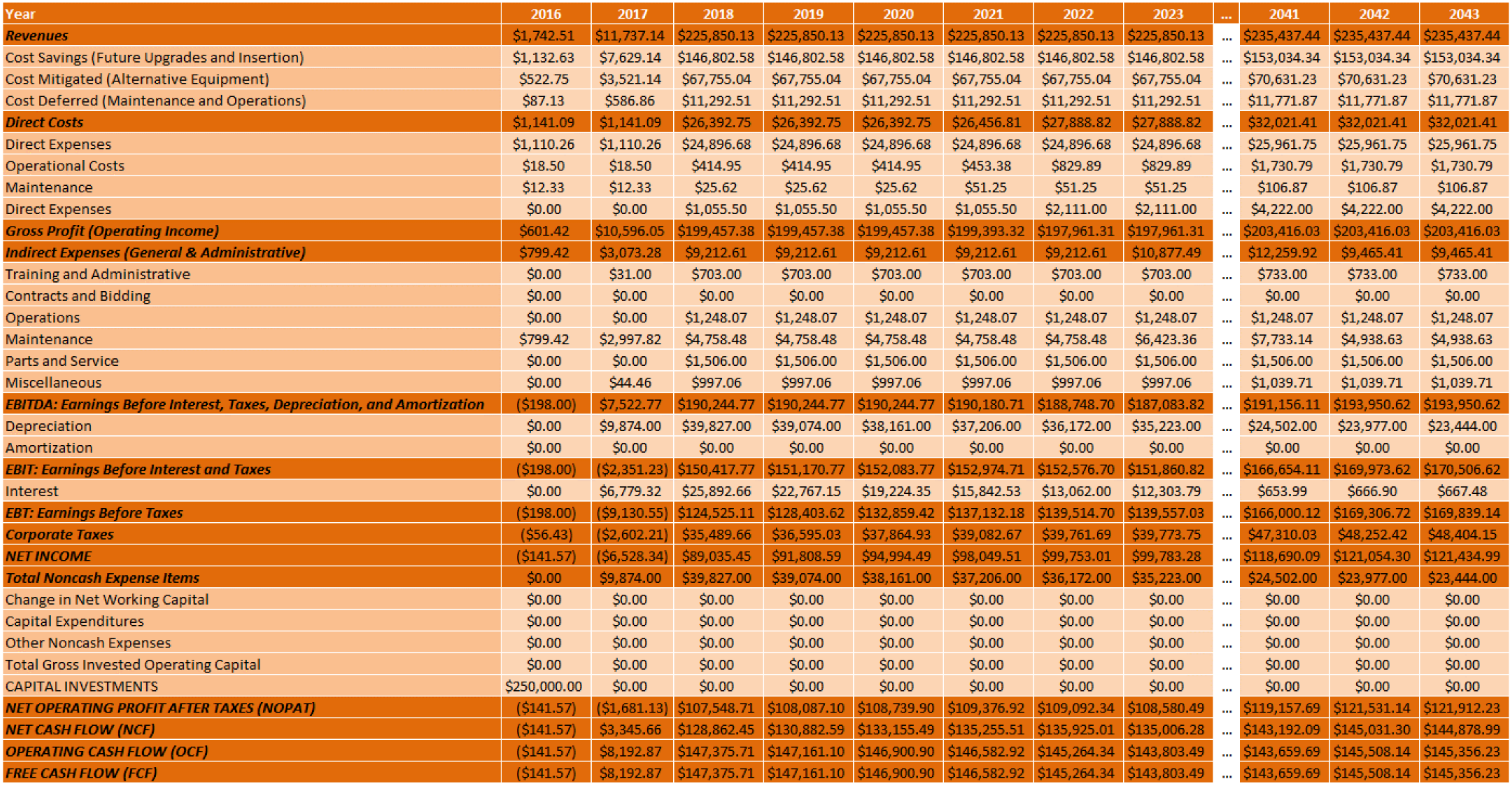


*Figure 7: Options Framing on Vertical Launch Systems*

## *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. Figure 8 shows some examples of shadow revenues (i.e., cost savings from lowered cost of future upgrades and technology insertions; costs mitigated by reducing the need for alternative equipment and lower spare parts; and other costs deferred by reducing the need for maintenance and operating costs) or cost savings, additional direct and indirect costs of implementing the new option, and capital requirements.



| Year | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | ... | 2041 | 2042 | 2043 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ***Revenues*** | $1,742.51 | $11,737.14 | $225,850.13 | $225,850.13 | $225,850.13 | $225,850.13 | $225,850.13 | $225,850.13 | ... | $235,437.44 | $235,437.44 | $235,437.44 |
| Cost Savings (Future Upgrades and Insertion) | $1,132.63 | $7,629.14 | $146,802.58 | $146,802.58 | $146,802.58 | $146,802.58 | $146,802.58 | $146,802.58 | ... | $153,034.34 | $153,034.34 | $153,034.34 |
| Cost Mitigated (Alternative Equipment) | $522.75 | $3,521.14 | $67,755.04 | $67,755.04 | $67,755.04 | $67,755.04 | $67,755.04 | $67,755.04 | ... | $70,631.23 | $70,631.23 | $70,631.23 |
| Cost Deferred (Maintenance and Operations) | $87.13 | $586.86 | $11,292.51 | $11,292.51 | $11,292.51 | $11,292.51 | $11,292.51 | $11,292.51 | ... | $11,771.87 | $11,771.87 | $11,771.87 |
| ***Direct Costs*** | $1,141.09 | $1,141.09 | $26,392.75 | $26,392.75 | $26,392.75 | $26,456.81 | $27,888.82 | $27,888.82 | ... | $32,021.41 | $32,021.41 | $32,021.41 |
| Direct Expenses | $1,110.26 | $1,110.26 | $24,896.68 | $24,896.68 | $24,896.68 | $24,896.68 | $24,896.68 | $24,896.68 | ... | $25,961.75 | $25,961.75 | $25,961.75 |
| Operational Costs | $18.50 | $18.50 | $414.95 | $414.95 | $414.95 | $453.38 | $829.89 | $829.89 | ... | $1,730.79 | $1,730.79 | $1,730.79 |
| Maintenance | $12.33 | $12.33 | $25.62 | $25.62 | $25.62 | $51.25 | $51.25 | $51.25 | ... | $106.87 | $106.87 | $106.87 |
| Direct Expenses | $0.00 | $0.00 | $1,055.50 | $1,055.50 | $1,055.50 | $1,055.50 | $2,111.00 | $2,111.00 | ... | $4,222.00 | $4,222.00 | $4,222.00 |
| ***Gross Profit (Operating Income)*** | $601.42 | $10,596.05 | $199,457.38 | $199,457.38 | $199,457.38 | $199,393.32 | $197,961.31 | $197,961.31 | ... | $203,416.03 | $203,416.03 | $203,416.03 |
| ***Indirect Expenses (General & Administrative)*** | $799.42 | $3,073.28 | $9,212.61 | $9,212.61 | $9,212.61 | $9,212.61 | $9,212.61 | $10,877.49 | ... | $12,259.92 | $9,465.41 | $9,465.41 |
| Training and Administrative | $0.00 | $31.00 | $703.00 | $703.00 | $703.00 | $703.00 | $703.00 | $703.00 | ... | $733.00 | $733.00 | $733.00 |
| Contracts and Bidding | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | ... | $0.00 | $0.00 | $0.00 |
| Operations | $0.00 | $0.00 | $1,248.07 | $1,248.07 | $1,248.07 | $1,248.07 | $1,248.07 | $1,248.07 | ... | $1,248.07 | $1,248.07 | $1,248.07 |
| Maintenance | $799.42 | $2,997.82 | $4,758.48 | $4,758.48 | $4,758.48 | $4,758.48 | $4,758.48 | $6,423.36 | ... | $7,733.14 | $4,938.63 | $4,938.63 |
| Parts and Service | $0.00 | $0.00 | $1,506.00 | $1,506.00 | $1,506.00 | $1,506.00 | $1,506.00 | $1,506.00 | ... | $1,506.00 | $1,506.00 | $1,506.00 |
| Miscellaneous | $0.00 | $44.46 | $997.06 | $997.06 | $997.06 | $997.06 | $997.06 | $997.06 | ... | $1,039.71 | $1,039.71 | $1,039.71 |
| ***EBITDA: Earnings Before Interest, Taxes, Depreciation, and Amortization*** | ($198.00) | $7,522.77 | $190,244.77 | $190,244.77 | $190,244.77 | $190,180.71 | $188,748.70 | $187,083.82 | ... | $191,156.11 | $193,950.62 | $193,950.62 |
| Depreciation | $0.00 | $9,874.00 | $39,827.00 | $39,074.00 | $38,161.00 | $37,206.00 | $36,172.00 | $35,223.00 | ... | $24,502.00 | $23,977.00 | $23,444.00 |
| Amortization | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | ... | $0.00 | $0.00 | $0.00 |
| ***EBIT: Earnings Before Interest and Taxes*** | ($198.00) | ($2,351.23) | $150,417.77 | $151,170.77 | $152,083.77 | $152,974.71 | $152,576.70 | $151,860.82 | ... | $166,654.11 | $169,973.62 | $170,506.62 |
| Interest | $0.00 | $6,779.32 | $25,892.66 | $22,767.15 | $19,224.35 | $15,842.53 | $13,062.00 | $12,303.79 | ... | $653.99 | $666.90 | $667.48 |
| ***EBT: Earnings Before Taxes*** | ($198.00) | ($9,130.55) | $124,525.11 | $128,403.62 | $132,859.42 | $137,132.18 | $139,514.70 | $139,557.03 | ... | $166,000.12 | $169,306.72 | $169,839.14 |
| ***Corporate Taxes*** | ($56.43) | ($2,602.21) | $35,489.66 | $36,595.03 | $37,864.93 | $39,082.67 | $39,761.69 | $39,773.75 | ... | $47,310.03 | $48,252.42 | $48,404.15 |
| ***NET INCOME*** | ($141.57) | ($6,528.34) | $89,035.45 | $91,808.59 | $94,994.49 | $98,049.51 | $99,753.01 | $99,783.28 | ... | $118,690.09 | $121,054.30 | $121,434.99 |
| ***Total Noncash Expense Items*** | $0.00 | $9,874.00 | $39,827.00 | $39,074.00 | $38,161.00 | $37,206.00 | $36,172.00 | $35,223.00 | ... | $24,502.00 | $23,977.00 | $23,444.00 |
| Change in Net Working Capital | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | ... | $0.00 | $0.00 | $0.00 |
| Capital Expenditures | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | ... | $0.00 | $0.00 | $0.00 |
| Other Noncash Expenses | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | ... | $0.00 | $0.00 | $0.00 |
| Total Gross Invested Operating Capital | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | ... | $0.00 | $0.00 | $0.00 |
| CAPITAL INVESTMENTS | $250,000.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | ... | $0.00 | $0.00 | $0.00 |
| ***NET OPERATING PROFIT AFTER TAXES (NOPAT)*** | ($141.57) | ($1,681.13) | $107,548.71 | $108,087.10 | $108,739.90 | $109,376.92 | $109,092.34 | $108,580.49 | ... | $119,157.69 | $121,531.14 | $121,912.23 |
| ***NET CASH FLOW (NCF)*** | ($141.57) | $3,345.66 | $128,862.45 | $130,882.59 | $133,155.49 | $135,255.51 | $135,925.01 | $135,006.28 | ... | $143,192.09 | $145,031.30 | $144,878.99 |
| ***OPERATING CASH FLOW (OCF)*** | ($141.57) | $8,192.87 | $147,375.71 | $147,161.10 | $146,900.90 | $146,582.92 | $145,264.34 | $143,803.49 | ... | $143,659.69 | $145,508.14 | $145,356.23 |
| ***FREE CASH FLOW (FCF)*** | ($141.57) | $8,192.87 | $147,375.71 | $147,161.10 | $146,900.90 | $146,582.92 | $145,264.34 | $143,803.49 | ... | $143,659.69 | $145,508.14 | $145,356.23 |

*Figure 8: Financial and Economic Cost Savings and Cost Averted Cash Flow Model*

### *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.

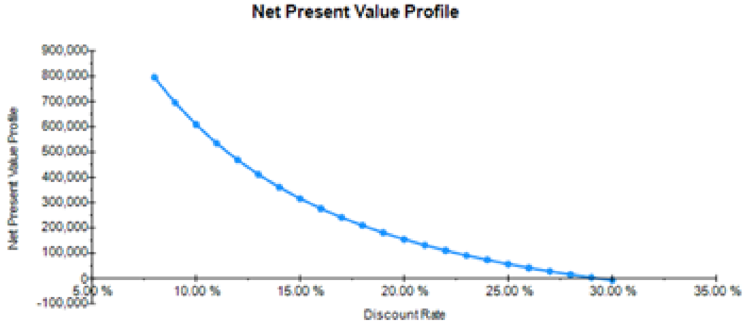
Analysts can also identify and create the various options, and compute the economic and financial results such as net present value (NPV), internal rate of return (IRR), modified internal rate of return (MIRR), profitability index (PI), return on investment (ROI), payback period (PP), and discounted payback (DPP). This is shown in Figures 8 and 9, complete with various charts, cash flow ratios and models, intermediate calculations, and comparisons of the options within a portfolio view, as illustrated in the figure. As a side note, the term *Option* is used 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 10 illustrates the *Economic Results* of each project. This figure 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 in the figure, where different discount rates and their respective NPV results are shown and charted.

| Year | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | ... | 2040 | 2041 | 2042 | 2043 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| EARNINGS BEFORE INT, TAX, DEP, AMORT (EBITDA) | -198 | 7,522.77 | 190,244.77 | 190,244.77 | 190,244.77 | 190,180.71 | 188,748.70 | 187,083.82 | 188,393.60 | ... | 193,775.67 | 191,156.11 | 193,950.62 | 193,950.62 |
| EARNINGS BEFORE INTEREST AND TAXES (EBIT) | -198 | -2,351.23 | 150,417.77 | 151,170.77 | 152,083.77 | 152,974.71 | 152,576.70 | 151,860.82 | 153,915.60 | ... | 168,829.67 | 166,654.11 | 169,973.62 | 170,506.62 |
| NET INCOME (NI) | -141.57 | -6,528.34 | 89,035.45 | 91,808.59 | 94,994.49 | 98,049.51 | 99,753.01 | 99,783.28 | 101,776.23 | ... | 120,236.60 | 118,690.09 | 121,054.30 | 121,434.99 |
| NET OPERATING PROFIT AFTER TAXES (NOPAT) | -141.57 | -1,681.13 | 107,548.71 | 108,087.10 | 108,739.90 | 109,376.92 | 109,092.34 | 108,580.49 | 110,049.65 | ... | 120,713.21 | 119,157.69 | 121,531.14 | 121,912.23 |
| NET CASH FLOW (NCF) | -141.57 | 3,345.66 | 128,862.45 | 130,882.59 | 133,155.49 | 135,255.51 | 135,925.01 | 135,006.28 | 136,254.23 | ... | 145,182.60 | 143,192.09 | 145,031.30 | 144,878.99 |
| OPERATING CASH FLOW (OCF) | -141.57 | 8,192.87 | 147,375.71 | 147,161.10 | 146,900.90 | 146,582.92 | 145,264.34 | 143,803.49 | 144,527.65 | ... | 145,659.21 | 143,659.69 | 145,508.14 | 145,356.23 |
| FREE CASH FLOW (FCF) | -141.57 | 8,192.87 | 147,375.71 | 147,161.10 | 146,900.90 | 146,582.92 | 145,264.34 | 143,803.49 | 144,527.65 | ... | 145,659.21 | 143,659.69 | 145,508.14 | 145,356.23 |
| RETURN ON INVESTED CAPITAL (ROIC) | -0.11% | -1.31% | 83.68% | 84.09% | 84.60% | 85.10% | 84.88% | 84.48% | 85.62% | ... | 93.92% | 92.71% | 94.55% | 94.85% |
| ECONOMIC VALUE ADDED (EVA) | -12,994.67 | -14,534.23 | 94,695.61 | 95,234.00 | 95,886.80 | 96,523.82 | 96,239.24 | 95,727.39 | 97,196.55 | ... | 107,860.11 | 106,304.59 | 108,678.04 | 109,059.13 |
| TIMES INTEREST EARNED (TIE) | 0 | -0.35 | 5.81 | 6.64 | 7.91 | 9.66 | 11.68 | 12.34 | 13.3 | ... | 253.27 | 254.83 | 254.87 | 255.45 |
| NET PROFIT MARGIN (NPM) | -8.12% | -55.62% | 39.42% | 40.65% | 42.06% | 43.41% | 44.17% | 44.18% | 45.06% | ... | 51.07% | 50.41% | 51.42% | 51.58% |
| OPERATING PROFIT MARGIN (OPM) | -8.12% | -14.32% | 47.62% | 47.86% | 48.15% | 48.43% | 48.30% | 48.08% | 48.73% | ... | 51.27% | 50.61% | 51.62% | 51.78% |
| EARNINGS PER SHARE (EPS) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | ... | 0 | 0 | 0 | 0 |
| INVENTORY TURNOVER (IT) | 2.58 | 17.35 | 333.8 | 333.8 | 333.8 | 333.8 | 333.8 | 333.8 | 333.8 | ... | 347.97 | 347.97 | 347.97 | 347.97 |
| DAYS SALES OUTSTANDING (DSO) | 841.22 | 124.89 | 6.49 | 6.49 | 6.49 | 6.49 | 6.49 | 6.49 | 6.49 | ... | 6.23 | 6.23 | 6.23 | 6.23 |
| TOTAL ASSET TURNOVER (TAT) | 1.19% | 7.99% | 153.74% | 153.74% | 153.74% | 153.74% | 153.74% | 153.74% | 153.74% | ... | 160.27% | 160.27% | 160.27% | 160.27% |
| BASIC EARNING POWER (BEP) | -0.13% | -1.60% | 102.39% | 102.91% | 103.53% | 104.13% | 103.86% | 103.38% | 104.78% | ... | 114.93% | 113.45% | 115.71% | 116.07% |
| PRICE TO EARNINGS RATIO (PE) | -215,961,301.34 | -4,683,215.98 | 343,387.27 | 333,015.05 | 321,846.49 | 311,818.41 | 306,493.42 | 306,400.46 | 300,400.60 | ... | 254,279.00 | 257,592.21 | 252,561.37 | 251,769.63 |
| RETURN ON ASSET (ROA) | -0.10% | -4.44% | 60.61% | 62.50% | 64.67% | 66.75% | 67.90% | 67.93% | 69.28% | ... | 81.85% | 80.80% | 82.41% | 82.66% |
| RETURN ON EQUITY (ROE) | -0.20% | -9.26% | 126.24% | 130.17% | 134.69% | 139.02% | 141.43% | 141.48% | 144.30% | ... | 170.48% | 168.28% | 171.64% | 172.17% |

*Figure 9: Financial and Economic Performance Ratios*

| ECONOMIC INDICATORS | RESULTS |
|---|---|
| Net Present Value (NPV) | $608,388.34 |
| Net Present Value (NPV) with Terminal Value | $726,488.77 |
| Internal Rate of Return (IRR) | 29.31% |
| Modified Internal Rate of Return (MIRR) | 15.07% |
| Profitability Index (PI) | 3.43 |
| Return on Investment (ROI) | 243.36% |
| Payback Period (PP) | 3.80 |
| Discounted Payback Period (DPP) | 4.80 |



| NPV PROFILE | |
|---|---|
| DISCOUNT % | NPV |
| 8.00% | $794,590.13 |
| 9.00% | $694,674.49 |
| 10.00% | $608,388.34 |
| 11.00% | $533,487.10 |
| 12.00% | $468,141.66 |
| 13.00% | $410,854.85 |
| 14.00% | $360,395.93 |
| 15.00% | $315,748.74 |
| 16.00% | $276,070.74 |
| 17.00% | $240,660.35 |
| 18.00% | $208,930.96 |
| 19.00% | $180,389.99 |
| 20.00% | $154,622.20 |
| 21.00% | $131,276.09 |
| 22.00% | $110,052.97 |
| 23.00% | $90,698.01 |
| 24.00% | $72,993.02 |
| 25.00% | $56,750.42 |
| 26.00% | $41,808.40 |
| 27.00% | $28,026.89 |
| 28.00% | $15,284.18 |
| 29.00% | $3,474.16 |
| 30.00% | ($7,495.93) |

*Figure 10: Economic Results*

The *Economic Results* shown are for each individual project, whereas the *Portfolio Analysis* (see Figure 11) 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 the 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 11 illustrates the *Portfolio Analysis* of multiple *Projects*. This Portfolio Analysis 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* 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* 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.).

| Economic Results | Option 1 | Option 2 | Option 3 | Option 4 | Option 5 | Option 6 | Option 7 | Option 8 | Option 9 | Option 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Net Present Value (NPV) | $608,388.34 | $427,132.76 | $40,765.22 | $41,613.74 | ($10,610.44) | ($23,774.85) | $728,339.38 | $554,258.99 | $31,837.41 | $46,377.25 |
| Net Present Value (NPV) with Terminal Value | 72648877.00% | 54046710.00% | 7033594.00% | 6615455.00% | 1525722.00% | 2718633.00% | 112457959.00% | 74402419.00% | 16876439.00% | 12973950.00% |
| Internal Rate of Return (IRR) | 29.31% | 11.17% | 16.21% | 19.21% | 8.55% | 6.76% | 11.20% | 13.74% | 9.29% | 14.77% |
| Modified Internal Rate of Return (MIRR) | 0.15 | 0.10 | 0.12 | 0.13 | 0.09 | 0.08 | 0.10 | 0.11 | 0.07 | 0.10 |
| Profitability Index (PI) | 343.00% | 114.00% | 137.00% | 154.00% | 90.00% | 86.00% | 109.00% | 129.00% | 134.00% | 176.00% |
| Return on Investment (ROI) | 2.43 | 0.14 | 0.37 | 0.54 | -0.10 | -0.14 | 0.09 | 0.29 | 0.34 | 0.76 |
| Payback Period (PP) | 3.80 | 10.82 | 6.38 | 5.45 | 10.32 | 9.78 | 9.98 | 7.87 | 9.19 | 7.30 |
| Discounted Payback Period (DPP) | $4.80 | $22.81 | $9.80 | $7.84 |  |  | $22.35 | $13.79 | $12.18 | $9.21 |
| Show on Charts |  |  |  |  |  |  |  |  |  |  |

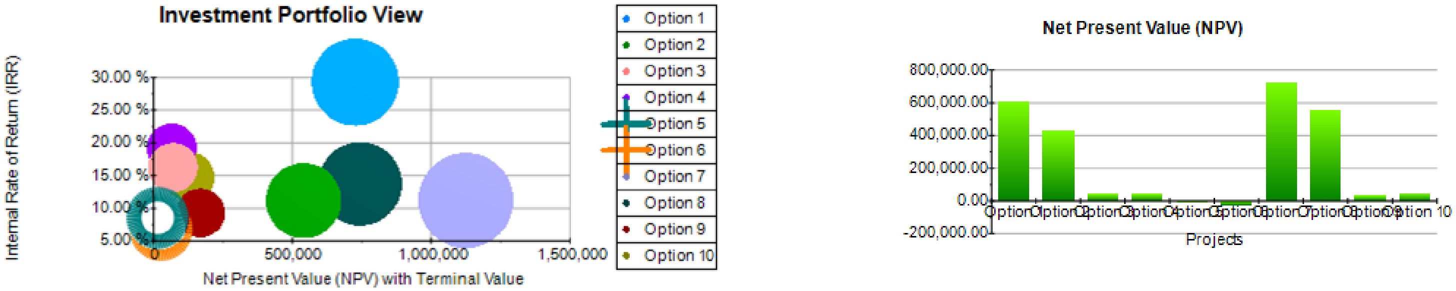


*Figure 11: Static Portfolio Analysis*

## *Step 4: Tornado and Sensitivity Analytics*

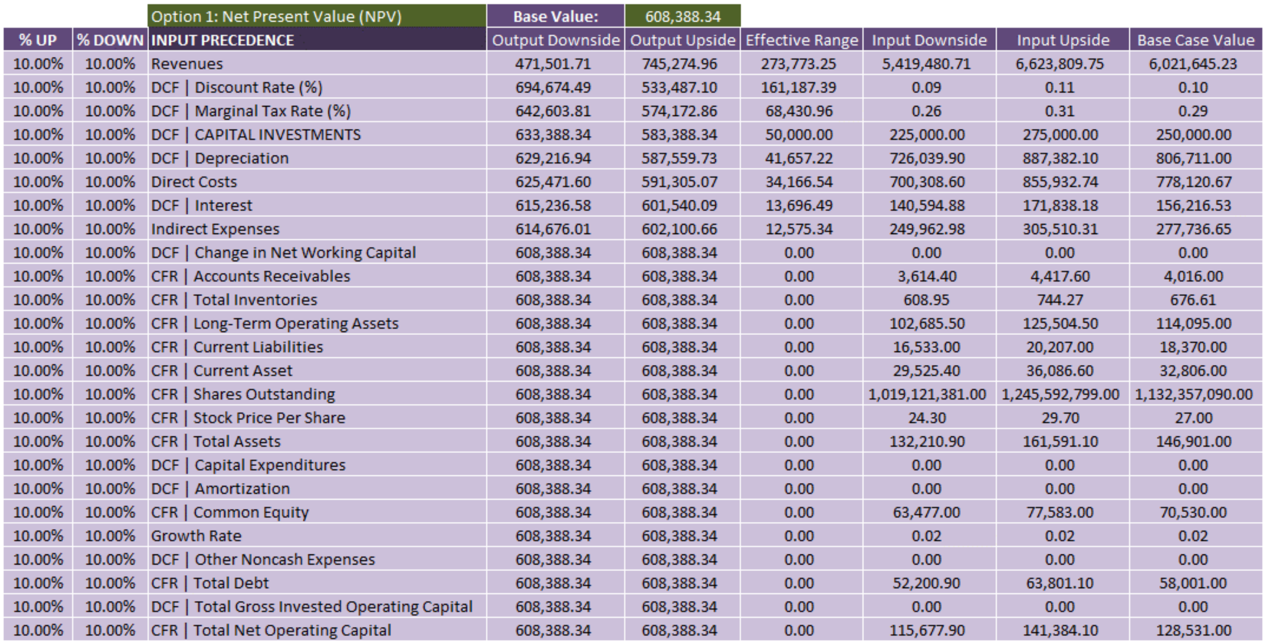
Figure 12 illustrates the *Applied Analytics* results, which allows analysts to run *Tornado Analysis* and *Scenario Analysis* on any one of the projects previously modeled—the analytics cover all the various projects and options. We can, therefore, run tornado or scenario analyses on any one of the projects or options. 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. We can start the analysis by first choosing the output variable to test.

We used the default sensitivity settings of ±10% on 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 run was based on the input assumptions as unique inputs, but the inputs can also be grouped as a line item (all individual inputs on a single line item are assumed to be one variable), or the analysis can be run as variable groups (e.g., all line items under *Revenue* will be assumed to be a single variable). 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).



| | | Option 1: Net Present Value (NPV) | Base Value: | 608,388.34 | | | | |
|---|---|---|---|---|---|---|---|---|
| % UP | % DOWN | INPUT PRECEDENCE | Output Downside | Output Upside | Effective Range | Input Downside | Input Upside | Base Case Value |
| 10.00% | 10.00% | Revenues | 471,501.71 | 745,274.96 | 273,773.25 | 5,419,480.71 | 6,623,809.75 | 6,021,645.23 |
| 10.00% | 10.00% | DCF \| Discount Rate (%) | 694,674.49 | 533,487.10 | 161,187.39 | 0.09 | 0.11 | 0.10 |
| 10.00% | 10.00% | DCF \| Marginal Tax Rate (%) | 642,603.81 | 574,172.86 | 68,430.96 | 0.26 | 0.31 | 0.29 |
| 10.00% | 10.00% | DCF \| CAPITAL INVESTMENTS | 633,388.34 | 583,388.34 | 50,000.00 | 225,000.00 | 275,000.00 | 250,000.00 |
| 10.00% | 10.00% | DCF \| Depreciation | 629,216.94 | 587,559.73 | 41,657.22 | 726,039.90 | 887,382.10 | 806,711.00 |
| 10.00% | 10.00% | Direct Costs | 625,471.60 | 591,305.07 | 34,166.54 | 700,308.60 | 855,932.74 | 778,120.67 |
| 10.00% | 10.00% | DCF \| Interest | 615,236.58 | 601,540.09 | 13,696.49 | 140,594.88 | 171,838.18 | 156,216.53 |
| 10.00% | 10.00% | Indirect Expenses | 614,676.01 | 602,100.66 | 12,575.34 | 249,962.98 | 305,510.31 | 277,736.65 |
| 10.00% | 10.00% | DCF \| Change in Net Working Capital | 608,388.34 | 608,388.34 | 0.00 | 0.00 | 0.00 | 0.00 |
| 10.00% | 10.00% | CFR \| Accounts Receivables | 608,388.34 | 608,388.34 | 0.00 | 3,614.40 | 4,417.60 | 4,016.00 |
| 10.00% | 10.00% | CFR \| Total Inventories | 608,388.34 | 608,388.34 | 0.00 | 608.95 | 744.27 | 676.61 |
| 10.00% | 10.00% | CFR \| Long-Term Operating Assets | 608,388.34 | 608,388.34 | 0.00 | 102,685.50 | 125,504.50 | 114,095.00 |
| 10.00% | 10.00% | CFR \| Current Liabilities | 608,388.34 | 608,388.34 | 0.00 | 16,533.00 | 20,207.00 | 18,370.00 |
| 10.00% | 10.00% | CFR \| Current Asset | 608,388.34 | 608,388.34 | 0.00 | 29,525.40 | 36,086.60 | 32,806.00 |
| 10.00% | 10.00% | CFR \| Shares Outstanding | 608,388.34 | 608,388.34 | 0.00 | 1,019,121,381.00 | 1,245,592,799.00 | 1,132,357,090.00 |
| 10.00% | 10.00% | CFR \| Stock Price Per Share | 608,388.34 | 608,388.34 | 0.00 | 24.30 | 29.70 | 27.00 |
| 10.00% | 10.00% | CFR \| Total Assets | 608,388.34 | 608,388.34 | 0.00 | 132,210.90 | 161,591.10 | 146,901.00 |
| 10.00% | 10.00% | DCF \| Capital Expenditures | 608,388.34 | 608,388.34 | 0.00 | 0.00 | 0.00 | 0.00 |
| 10.00% | 10.00% | DCF \| Amortization | 608,388.34 | 608,388.34 | 0.00 | 0.00 | 0.00 | 0.00 |
| 10.00% | 10.00% | CFR \| Common Equity | 608,388.34 | 608,388.34 | 0.00 | 63,477.00 | 77,583.00 | 70,530.00 |
| 10.00% | 10.00% | Growth Rate | 608,388.34 | 608,388.34 | 0.00 | 0.02 | 0.02 | 0.02 |
| 10.00% | 10.00% | DCF \| Other Noncash Expenses | 608,388.34 | 608,388.34 | 0.00 | 0.00 | 0.00 | 0.00 |
| 10.00% | 10.00% | CFR \| Total Debt | 608,388.34 | 608,388.34 | 0.00 | 52,200.90 | 63,801.10 | 58,001.00 |
| 10.00% | 10.00% | DCF \| Total Gross Invested Operating Capital | 608,388.34 | 608,388.34 | 0.00 | 0.00 | 0.00 | 0.00 |
| 10.00% | 10.00% | CFR \| Total Net Operating Capital | 608,388.34 | 608,388.34 | 0.00 | 115,677.90 | 141,384.10 | 128,531.00 |

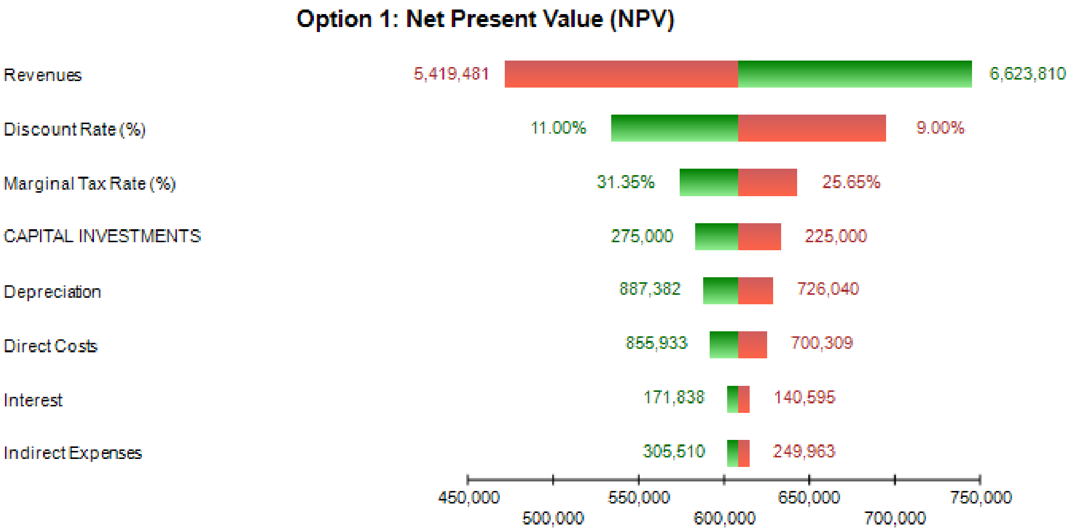
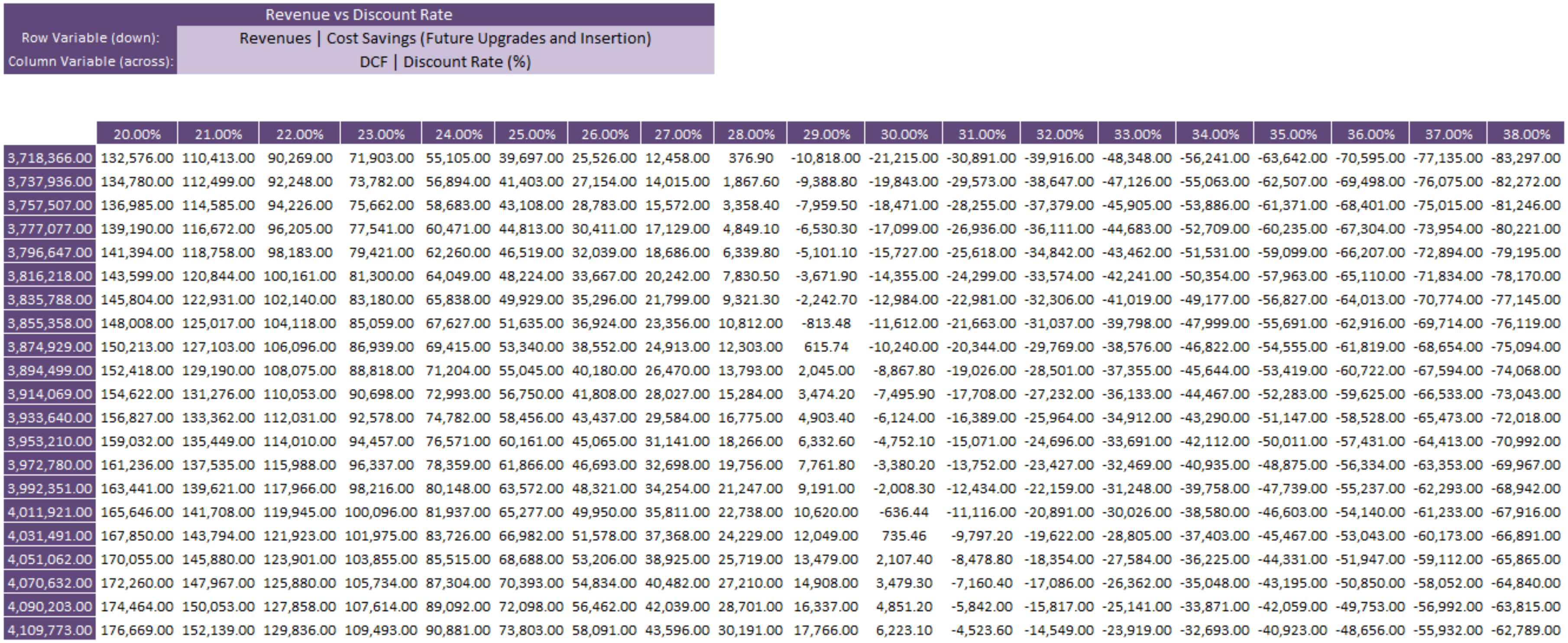


*Figure 12: Applied Analytics—Tornado Analysis*

Figure 13 illustrates the *Scenario Analysis* results, 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*, 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.



| | |
|---|---|
| Revenue vs Discount Rate | |
| Row Variable (down): | Revenues \| Cost Savings (Future Upgrades and Insertion) |
| Column Variable (across): | DCF \| Discount Rate (%) |

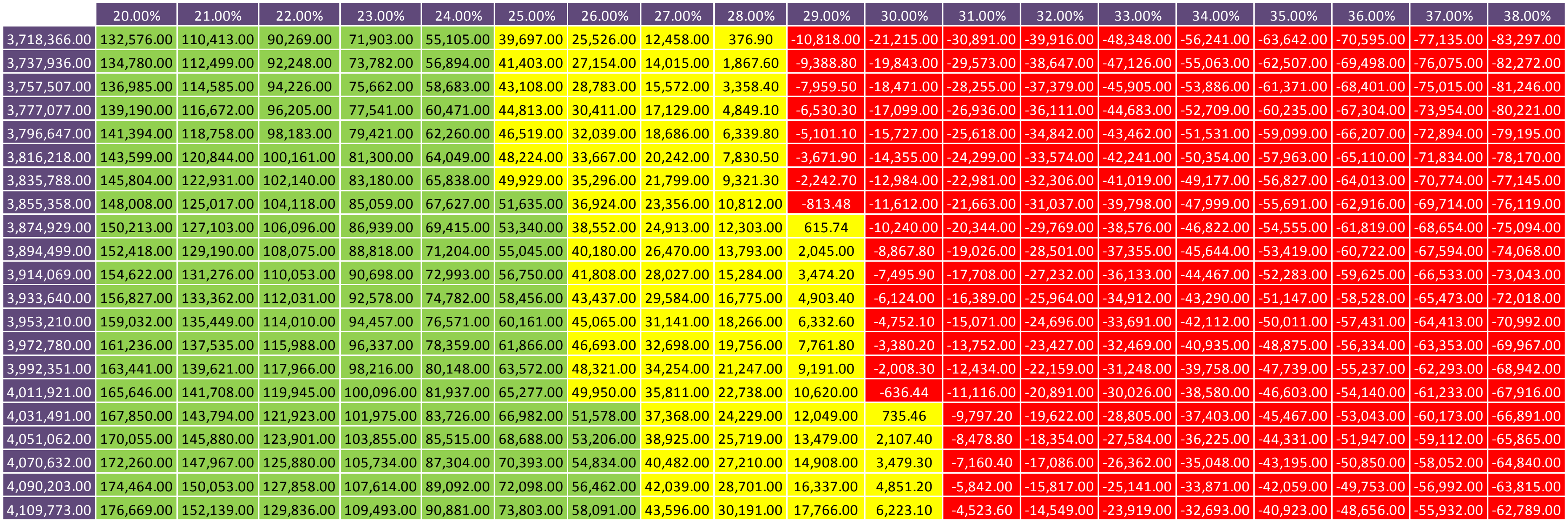
| | 20.00% | 21.00% | 22.00% | 23.00% | 24.00% | 25.00% | 26.00% | 27.00% | 28.00% | 29.00% | 30.00% | 31.00% | 32.00% | 33.00% | 34.00% | 35.00% | 36.00% | 37.00% | 38.00% |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3,718,366.00 | 132,576.00 | 110,413.00 | 90,269.00 | 71,903.00 | 55,105.00 | 39,697.00 | 25,526.00 | 12,458.00 | 376.90 | -10,818.00 | -21,215.00 | -30,891.00 | -39,916.00 | -48,348.00 | -56,241.00 | -63,642.00 | -70,595.00 | -77,135.00 | -83,297.00 |
| 3,737,936.00 | 134,780.00 | 112,499.00 | 92,248.00 | 73,782.00 | 56,894.00 | 41,403.00 | 27,154.00 | 14,015.00 | 1,867.60 | -9,388.80 | -19,843.00 | -29,573.00 | -38,647.00 | -47,126.00 | -55,063.00 | -62,507.00 | -69,498.00 | -76,075.00 | -82,272.00 |
| 3,757,507.00 | 136,985.00 | 114,585.00 | 94,226.00 | 75,662.00 | 58,683.00 | 43,108.00 | 28,783.00 | 15,572.00 | 3,358.40 | -7,959.50 | -18,471.00 | -28,255.00 | -37,379.00 | -45,905.00 | -53,886.00 | -61,371.00 | -68,401.00 | -75,015.00 | -81,246.00 |
| 3,777,077.00 | 139,190.00 | 116,672.00 | 96,205.00 | 77,541.00 | 60,471.00 | 44,813.00 | 30,411.00 | 17,129.00 | 4,849.10 | -6,530.30 | -17,099.00 | -26,936.00 | -36,111.00 | -44,683.00 | -52,709.00 | -60,235.00 | -67,304.00 | -73,954.00 | -80,221.00 |
| 3,796,647.00 | 141,394.00 | 118,758.00 | 98,183.00 | 79,421.00 | 62,260.00 | 46,519.00 | 32,039.00 | 18,686.00 | 6,339.80 | -5,101.10 | -15,727.00 | -25,618.00 | -34,842.00 | -43,462.00 | -51,531.00 | -59,099.00 | -66,207.00 | -72,894.00 | -79,195.00 |
| 3,816,218.00 | 143,599.00 | 120,844.00 | 100,161.00 | 81,300.00 | 64,049.00 | 48,224.00 | 33,667.00 | 20,242.00 | 7,830.50 | -3,671.90 | -14,355.00 | -24,299.00 | -33,574.00 | -42,241.00 | -50,354.00 | -57,963.00 | -65,110.00 | -71,834.00 | -78,170.00 |
| 3,835,788.00 | 145,804.00 | 122,931.00 | 102,140.00 | 83,180.00 | 65,838.00 | 49,929.00 | 35,296.00 | 21,799.00 | 9,321.30 | -2,242.70 | -12,984.00 | -22,981.00 | -32,306.00 | -41,019.00 | -49,177.00 | -56,827.00 | -64,013.00 | -70,774.00 | -77,145.00 |
| 3,855,358.00 | 148,008.00 | 125,017.00 | 104,118.00 | 85,059.00 | 67,627.00 | 51,635.00 | 36,924.00 | 23,356.00 | 10,812.00 | -813.48 | -11,612.00 | -21,663.00 | -31,037.00 | -39,798.00 | -47,999.00 | -55,691.00 | -62,916.00 | -69,714.00 | -76,119.00 |
| 3,874,929.00 | 150,213.00 | 127,103.00 | 106,096.00 | 86,939.00 | 69,415.00 | 53,340.00 | 38,552.00 | 24,913.00 | 12,303.00 | 615.74 | -10,240.00 | -20,344.00 | -29,769.00 | -38,576.00 | -46,822.00 | -54,555.00 | -61,819.00 | -68,654.00 | -75,094.00 |
| 3,894,499.00 | 152,418.00 | 129,190.00 | 108,075.00 | 88,818.00 | 71,204.00 | 55,045.00 | 40,180.00 | 26,470.00 | 13,793.00 | 2,045.00 | -8,867.80 | -19,026.00 | -28,501.00 | -37,355.00 | -45,644.00 | -53,419.00 | -60,722.00 | -67,594.00 | -74,068.00 |
| 3,914,069.00 | 154,622.00 | 131,276.00 | 110,053.00 | 90,698.00 | 72,993.00 | 56,750.00 | 41,808.00 | 28,027.00 | 15,284.00 | 3,474.20 | -7,495.90 | -17,708.00 | -27,232.00 | -36,133.00 | -44,467.00 | -52,283.00 | -59,625.00 | -66,533.00 | -73,043.00 |
| 3,933,640.00 | 156,827.00 | 133,362.00 | 112,031.00 | 92,578.00 | 74,782.00 | 58,456.00 | 43,437.00 | 29,584.00 | 16,775.00 | 4,903.40 | -6,124.00 | -16,389.00 | -25,964.00 | -34,912.00 | -43,290.00 | -51,147.00 | -58,528.00 | -65,473.00 | -72,018.00 |
| 3,953,210.00 | 159,032.00 | 135,449.00 | 114,010.00 | 94,457.00 | 76,571.00 | 60,161.00 | 45,065.00 | 31,141.00 | 18,266.00 | 6,332.60 | -4,752.10 | -15,071.00 | -24,696.00 | -33,691.00 | -42,112.00 | -50,011.00 | -57,431.00 | -64,413.00 | -70,992.00 |
| 3,972,780.00 | 161,236.00 | 137,535.00 | 115,988.00 | 96,337.00 | 78,359.00 | 61,866.00 | 46,693.00 | 32,698.00 | 19,756.00 | 7,761.80 | -3,380.20 | -13,752.00 | -23,427.00 | -32,469.00 | -40,935.00 | -48,875.00 | -56,334.00 | -63,353.00 | -69,967.00 |
| 3,992,351.00 | 163,441.00 | 139,621.00 | 117,966.00 | 98,216.00 | 80,148.00 | 63,572.00 | 48,321.00 | 34,254.00 | 21,247.00 | 9,191.00 | -2,008.30 | -12,434.00 | -22,159.00 | -31,248.00 | -39,758.00 | -47,739.00 | -55,237.00 | -62,293.00 | -68,942.00 |
| 4,011,921.00 | 165,646.00 | 141,708.00 | 119,945.00 | 100,096.00 | 81,937.00 | 65,277.00 | 49,950.00 | 35,811.00 | 22,738.00 | 10,620.00 | -636.44 | -11,116.00 | -20,891.00 | -30,026.00 | -38,580.00 | -46,603.00 | -54,140.00 | -61,233.00 | -67,916.00 |
| 4,031,491.00 | 167,850.00 | 143,794.00 | 121,923.00 | 101,975.00 | 83,726.00 | 66,982.00 | 51,578.00 | 37,368.00 | 24,229.00 | 12,049.00 | 735.46 | -9,797.20 | -19,622.00 | -28,805.00 | -37,403.00 | -45,467.00 | -53,043.00 | -60,173.00 | -66,891.00 |
| 4,051,062.00 | 170,055.00 | 145,880.00 | 123,901.00 | 103,855.00 | 85,515.00 | 68,688.00 | 53,206.00 | 38,925.00 | 25,719.00 | 13,479.00 | 2,107.40 | -8,478.80 | -18,354.00 | -27,584.00 | -36,225.00 | -44,331.00 | -51,947.00 | -59,112.00 | -65,865.00 |
| 4,070,632.00 | 172,260.00 | 147,967.00 | 125,880.00 | 105,734.00 | 87,304.00 | 70,393.00 | 54,834.00 | 40,482.00 | 27,210.00 | 14,908.00 | 3,479.30 | -7,160.40 | -17,086.00 | -26,362.00 | -35,048.00 | -43,195.00 | -50,850.00 | -58,052.00 | -64,840.00 |
| 4,090,203.00 | 174,464.00 | 150,053.00 | 127,858.00 | 107,614.00 | 89,092.00 | 72,098.00 | 56,462.00 | 42,039.00 | 28,701.00 | 16,337.00 | 4,851.20 | -5,842.00 | -15,817.00 | -25,141.00 | -33,871.00 | -42,059.00 | -49,753.00 | -56,992.00 | -63,815.00 |
| 4,109,773.00 | 176,669.00 | 152,139.00 | 129,836.00 | 109,493.00 | 90,881.00 | 73,803.00 | 58,091.00 | 43,596.00 | 30,191.00 | 17,766.00 | 6,223.10 | -4,523.60 | -14,549.00 | -23,919.00 | -32,693.00 | -40,923.00 | -48,656.00 | -55,932.00 | -62,789.00 |

*Figure 13: Applied Analytics—Scenario Analysis Input*

Figure 14 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 following 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).

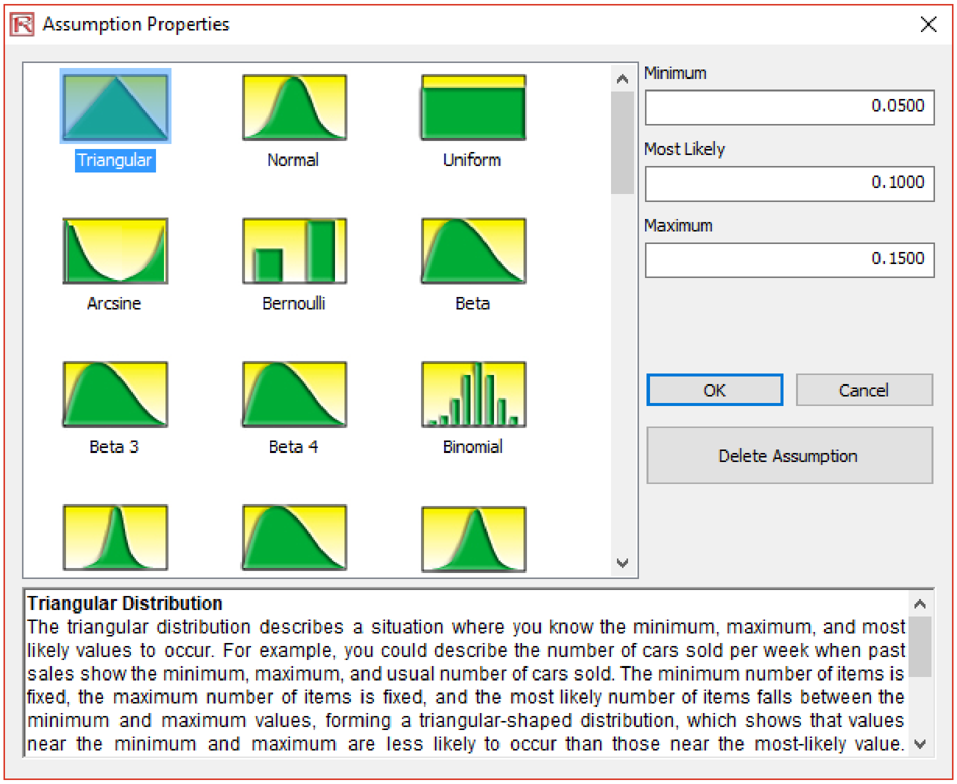


| | 20.00% | 21.00% | 22.00% | 23.00% | 24.00% | 25.00% | 26.00% | 27.00% | 28.00% | 29.00% | 30.00% | 31.00% | 32.00% | 33.00% | 34.00% | 35.00% | 36.00% | 37.00% | 38.00% |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3,718,366.00 | 132,576.00 | 110,413.00 | 90,269.00 | 71,903.00 | 55,105.00 | 39,697.00 | 25,526.00 | 12,458.00 | 376.90 | -10,818.00 | -21,215.00 | -30,891.00 | -39,916.00 | -48,348.00 | -56,241.00 | -63,642.00 | -70,595.00 | -77,135.00 | -83,297.00 |
| 3,737,936.00 | 134,780.00 | 112,499.00 | 92,248.00 | 73,782.00 | 56,894.00 | 41,403.00 | 27,154.00 | 14,015.00 | 1,867.60 | -9,388.80 | -19,843.00 | -29,573.00 | -38,647.00 | -47,126.00 | -55,063.00 | -62,507.00 | -69,498.00 | -76,075.00 | -82,272.00 |
| 3,757,507.00 | 136,985.00 | 114,585.00 | 94,226.00 | 75,662.00 | 58,683.00 | 43,108.00 | 28,783.00 | 15,572.00 | 3,358.40 | -7,959.50 | -18,471.00 | -28,255.00 | -37,379.00 | -45,905.00 | -53,886.00 | -61,371.00 | -68,401.00 | -75,015.00 | -81,246.00 |
| 3,777,077.00 | 139,190.00 | 116,672.00 | 96,205.00 | 77,541.00 | 60,471.00 | 44,813.00 | 30,411.00 | 17,129.00 | 4,849.10 | -6,530.30 | -17,099.00 | -26,936.00 | -36,111.00 | -44,683.00 | -52,709.00 | -60,235.00 | -67,304.00 | -73,954.00 | -80,221.00 |
| 3,796,647.00 | 141,394.00 | 118,758.00 | 98,183.00 | 79,421.00 | 62,260.00 | 46,519.00 | 32,039.00 | 18,686.00 | 6,339.80 | -5,101.10 | -15,727.00 | -25,618.00 | -34,842.00 | -43,462.00 | -51,531.00 | -59,099.00 | -66,207.00 | -72,894.00 | -79,195.00 |
| 3,816,218.00 | 143,599.00 | 120,844.00 | 100,161.00 | 81,300.00 | 64,049.00 | 48,224.00 | 33,667.00 | 20,242.00 | 7,830.50 | -3,671.90 | -14,355.00 | -24,299.00 | -33,574.00 | -42,241.00 | -50,354.00 | -57,963.00 | -65,110.00 | -71,834.00 | -78,170.00 |
| 3,835,788.00 | 145,804.00 | 122,931.00 | 102,140.00 | 83,180.00 | 65,838.00 | 49,929.00 | 35,296.00 | 21,799.00 | 9,321.30 | -2,242.70 | -12,984.00 | -22,981.00 | -32,306.00 | -41,019.00 | -49,177.00 | -56,827.00 | -64,013.00 | -70,774.00 | -77,145.00 |
| 3,855,358.00 | 148,008.00 | 125,017.00 | 104,118.00 | 85,059.00 | 67,627.00 | 51,635.00 | 36,924.00 | 23,356.00 | 10,812.00 | -813.48 | -11,612.00 | -21,663.00 | -31,037.00 | -39,798.00 | -47,999.00 | -55,691.00 | -62,916.00 | -69,714.00 | -76,119.00 |
| 3,874,929.00 | 150,213.00 | 127,103.00 | 106,096.00 | 86,939.00 | 69,415.00 | 53,340.00 | 38,552.00 | 24,913.00 | 12,303.00 | 615.74 | -10,240.00 | -20,344.00 | -29,769.00 | -38,576.00 | -46,822.00 | -54,555.00 | -61,819.00 | -68,654.00 | -75,094.00 |
| 3,894,499.00 | 152,418.00 | 129,190.00 | 108,075.00 | 88,818.00 | 71,204.00 | 55,045.00 | 40,180.00 | 26,470.00 | 13,793.00 | 2,045.00 | -8,867.80 | -19,026.00 | -28,501.00 | -37,355.00 | -45,644.00 | -53,419.00 | -60,722.00 | -67,594.00 | -74,068.00 |
| 3,914,069.00 | 154,622.00 | 131,276.00 | 110,053.00 | 90,698.00 | 72,993.00 | 56,750.00 | 41,808.00 | 28,027.00 | 15,284.00 | 3,474.20 | -7,495.90 | -17,708.00 | -27,232.00 | -36,133.00 | -44,467.00 | -52,283.00 | -59,625.00 | -66,533.00 | -73,043.00 |
| 3,933,640.00 | 156,827.00 | 133,362.00 | 112,031.00 | 92,578.00 | 74,782.00 | 58,456.00 | 43,437.00 | 29,584.00 | 16,775.00 | 4,903.40 | -6,124.00 | -16,389.00 | -25,964.00 | -34,912.00 | -43,290.00 | -51,147.00 | -58,528.00 | -65,473.00 | -72,018.00 |
| 3,953,210.00 | 159,032.00 | 135,449.00 | 114,010.00 | 94,457.00 | 76,571.00 | 60,161.00 | 45,065.00 | 31,141.00 | 18,266.00 | 6,332.60 | -4,752.10 | -15,071.00 | -24,696.00 | -33,691.00 | -42,112.00 | -50,011.00 | -57,431.00 | -64,413.00 | -70,992.00 |
| 3,972,780.00 | 161,236.00 | 137,535.00 | 115,988.00 | 96,337.00 | 78,359.00 | 61,866.00 | 46,693.00 | 32,698.00 | 19,756.00 | 7,761.80 | -3,380.20 | -13,752.00 | -23,427.00 | -32,469.00 | -40,935.00 | -48,875.00 | -56,334.00 | -63,353.00 | -69,967.00 |
| 3,992,351.00 | 163,441.00 | 139,621.00 | 117,966.00 | 98,216.00 | 80,148.00 | 63,572.00 | 48,321.00 | 34,254.00 | 21,247.00 | 9,191.00 | -2,008.30 | -12,434.00 | -22,159.00 | -31,248.00 | -39,758.00 | -47,739.00 | -55,237.00 | -62,293.00 | -68,942.00 |
| 4,011,921.00 | 165,646.00 | 141,708.00 | 119,945.00 | 100,096.00 | 81,937.00 | 65,277.00 | 49,950.00 | 35,811.00 | 22,738.00 | 10,620.00 | -636.44 | -11,116.00 | -20,891.00 | -30,026.00 | -38,580.00 | -46,603.00 | -54,140.00 | -61,233.00 | -67,916.00 |
| 4,031,491.00 | 167,850.00 | 143,794.00 | 121,923.00 | 101,975.00 | 83,726.00 | 66,982.00 | 51,578.00 | 37,368.00 | 24,229.00 | 12,049.00 | 735.46 | -9,797.20 | -19,622.00 | -28,805.00 | -37,403.00 | -45,467.00 | -53,043.00 | -60,173.00 | -66,891.00 |
| 4,051,062.00 | 170,055.00 | 145,880.00 | 123,901.00 | 103,855.00 | 85,515.00 | 68,688.00 | 53,206.00 | 38,925.00 | 25,719.00 | 13,479.00 | 2,107.40 | -8,478.80 | -18,354.00 | -27,584.00 | -36,225.00 | -44,331.00 | -51,947.00 | -59,112.00 | -65,865.00 |
| 4,070,632.00 | 172,260.00 | 147,967.00 | 125,880.00 | 105,734.00 | 87,304.00 | 70,393.00 | 54,834.00 | 40,482.00 | 27,210.00 | 14,908.00 | 3,479.30 | -7,160.40 | -17,086.00 | -26,362.00 | -35,048.00 | -43,195.00 | -50,850.00 | -58,052.00 | -64,840.00 |
| 4,090,203.00 | 174,464.00 | 150,053.00 | 127,858.00 | 107,614.00 | 89,092.00 | 72,098.00 | 56,462.00 | 42,039.00 | 28,701.00 | 16,337.00 | 4,851.20 | -5,842.00 | -15,817.00 | -25,141.00 | -33,871.00 | -42,059.00 | -49,753.00 | -56,992.00 | -63,815.00 |
| 4,109,773.00 | 176,669.00 | 152,139.00 | 129,836.00 | 109,493.00 | 90,881.00 | 73,803.00 | 58,091.00 | 43,596.00 | 30,191.00 | 17,766.00 | 6,223.10 | -4,523.60 | -14,549.00 | -23,919.00 | -32,693.00 | -40,923.00 | -48,656.00 | -55,932.00 | -62,789.00 |

*Figure 14: Applied Analytics—Scenario Tables*

## *Step 5: Monte Carlo Risk Simulation*

Figure 15 illustrates the *Risk Simulation* analysis, 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.



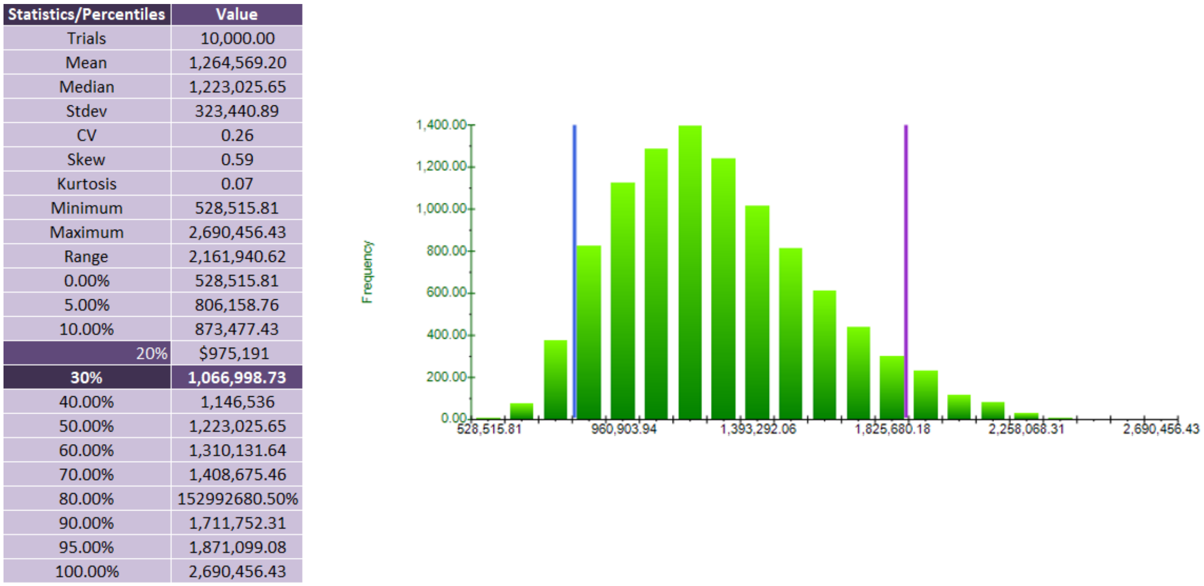
Minimum: 0.0500
Most Likely: 0.1000
Maximum: 0.1500

**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 15: Risk Simulation Input Assumptions*

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

Figure 16 illustrates the *Risk Simulation* results. The simulation forecast chart is shown on the right, while percentiles and simulation statistics are presented on the left.



| Statistics/Percentiles | Value |
|---|---|
| Trials | 10,000.00 |
| Mean | 1,264,569.20 |
| Median | 1,223,025.65 |
| Stdev | 323,440.89 |
| CV | 0.26 |
| Skew | 0.59 |
| Kurtosis | 0.07 |
| Minimum | 528,515.81 |
| Maximum | 2,690,456.43 |
| Range | 2,161,940.62 |
| 0.00% | 528,515.81 |
| 5.00% | 806,158.76 |
| 10.00% | 873,477.43 |
| 20% | $975,191 |
| **30%** | **1,066,998.73** |
| 40.00% | 1,146,536 |
| 50.00% | 1,223,025.65 |
| 60.00% | 1,310,131.64 |
| 70.00% | 1,408,675.46 |
| 80.00% | 152992680.50% |
| 90.00% | 1,711,752.31 |
| 95.00% | 1,871,099.08 |
| 100.00% | 2,690,456.43 |

*Figure 16: Risk Simulation Results*

### *Probability Distribution Overlay Charts*

Figure 17 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.

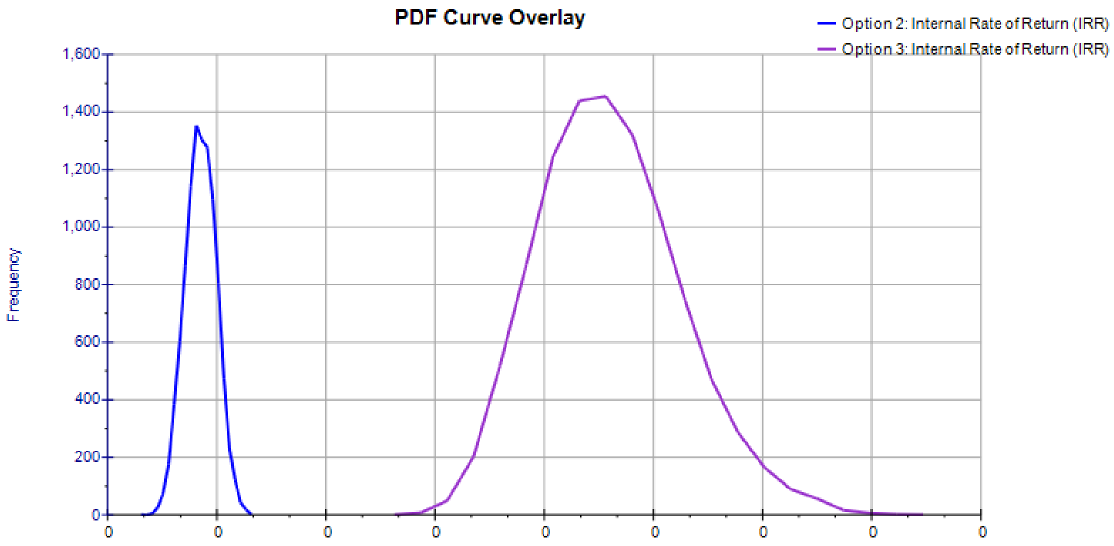


*Figure 17: Simulated Overlay Results*

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

Figure 18 illustrates the *Analysis of Alternatives* results. Whereas the *Overlay Results* shows the simulated results as charts (PDF/CDF), the *Analysis of Alternatives* 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 standard approach is to run an analysis of alternatives to compare one project to another, but analysts can also choose to analyze the results on an *Incremental Analysis* basis.

Figure 19 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 be performed only 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.

| OPTIONS | Option 1 | Option 2 | Option 3 | Option 4 | Option 5 | Option 6 | Option 7 | Option 8 | Option 9 | Option 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Acronym | | | | | | | | | | |
| Mean | 1,264,569.20 | -129,548.71 | 115,517.52 | 104,069.16 | 186,548.19 | 50,886.00 | 982,026.93 | 2,222,255.83 | 120,139.43 | 115,842.87 |
| Median | 1,223,025.65 | -269,130.82 | 111,946.33 | 101,647.69 | 182,533.06 | 48,903.31 | 809,951.34 | 2,125,984.32 | 118,821.08 | 113,873.98 |
| Stdev | 323,440.89 | 756,980.40 | 33,246.01 | 27,242.55 | 42,751.66 | 24,260.40 | 1,841,083.18 | 774,387.88 | 22,748.49 | 26,884.24 |
| CV | 25.58% | 584.32% | 28.78% | 26.18% | 22.92% | 47.68% | 187.48% | 34.85% | 18.94% | 23.21% |
| Skew | 0.59 | 0.83 | 0.50 | 0.46 | 0.46 | 0.41 | 0.48 | 0.64 | 0.31 | 0.38 |
| Kurtosis | 0.07 | 0.42 | -0.06 | -0.02 | -0.05 | -0.06 | 0.18 | 0.29 | -0.06 | -0.02 |
| Minimum | 528,515.81 | -1,612,389.19 | 33,915.58 | 34,781.88 | 72,360.45 | -13,544.30 | -4,062,019.59 | 409,940.95 | 53,294.46 | 45,687.22 |
| Maximum | 2,690,456.43 | 3,186,736.54 | 238,613.77 | 208,832.14 | 361,534.33 | 150,216.66 | 8,105,902.62 | 5,492,144.74 | 213,754.98 | 234,987.45 |
| Range | 2,161,940.62 | 4,799,125.72 | 204,698.19 | 174,050.27 | 289,173.87 | 163,760.96 | 12,167,922.22 | 5,082,203.79 | 160,460.52 | 189,300.23 |
| 0% Percentile | 528,515.81 | -1,612,389.19 | 33,915.58 | 34,781.88 | 72,360.45 | -13,544.30 | -4,062,019.59 | 409,940.95 | 53,294.46 | 45,687.22 |
| 5% Percentile | 806,158.76 | -1,126,810.37 | 66,833.21 | 63,341.55 | 123,647.00 | 14,407.25 | -1,721,563.12 | 1,118,422.25 | 85,021.02 | 74,880.17 |
| 10% Percentile | 873,477.43 | -985,321.30 | 75,292.44 | 70,536.07 | 134,523.19 | 21,061.66 | -1,234,281.88 | 1,308,170.97 | 91,480.18 | 82,478.56 |
| 20% Percentile | 975,191.16 | -787,408.29 | 86,592.52 | 80,551.23 | 149,044.20 | 29,596.95 | -575,471.45 | 1,553,575.46 | 100,319.83 | 92,352.05 |
| 30% Percentile | 1,066,998.73 | -607,802.26 | 95,258.85 | 87,689.17 | 160,430.73 | 36,309.09 | -88,078.13 | 1,756,505.72 | 107,072.89 | 100,314.71 |
| 40% Percentile | 1,146,536.48 | -435,048.39 | 103,478.90 | 94,871.67 | 171,896.55 | 42,716.18 | 366,415.18 | 1,937,629.66 | 113,197.08 | 106,958.95 |
| 50% Percentile | 1,223,025.65 | -269,130.82 | 111,946.33 | 101,647.69 | 182,533.06 | 48,903.31 | 809,951.34 | 2,125,984.32 | 118,821.08 | 113,873.98 |
| 60% Percentile | 1,310,131.64 | -70,640.29 | 120,924.23 | 108,733.13 | 193,556.04 | 55,280.95 | 1,260,274.23 | 2,321,587.17 | 124,955.05 | 121,112.91 |
| 70% Percentile | 1,408,675.46 | 168,159.10 | 130,549.63 | 116,448.61 | 206,334.42 | 62,431.52 | 1,795,294.68 | 2,549,885.15 | 131,348.03 | 128,934.06 |
| 80% Percentile | 1,529,926.80 | 474,006.49 | 143,040.93 | 127,054.19 | 222,193.22 | 71,595.89 | 2,464,689.40 | 2,848,749.31 | 139,239.82 | 138,456.24 |
| 90% Percentile | 1,711,752.31 | 956,928.86 | 161,722.53 | 141,005.97 | 245,083.83 | 83,760.91 | 3,475,890.85 | 3,275,508.70 | 150,031.84 | 151,426.79 |
| 95% Percentile | 1,871,099.08 | 1,333,426.70 | 177,165.94 | 153,294.40 | 263,658.89 | 93,827.83 | 4,368,679.78 | 3,668,268.40 | 159,781.91 | 163,466.89 |
| 100% Percentile | 2,690,456.43 | 3,186,736.54 | 238,613.77 | 208,832.14 | 361,534.33 | 150,216.66 | 8,105,902.62 | 5,492,144.74 | 213,754.98 | 234,987.45 |

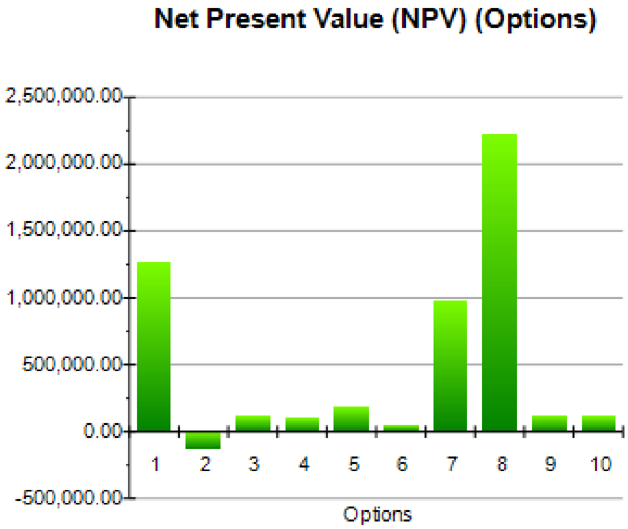


*Figure 18: Simulated Analysis of Alternatives*

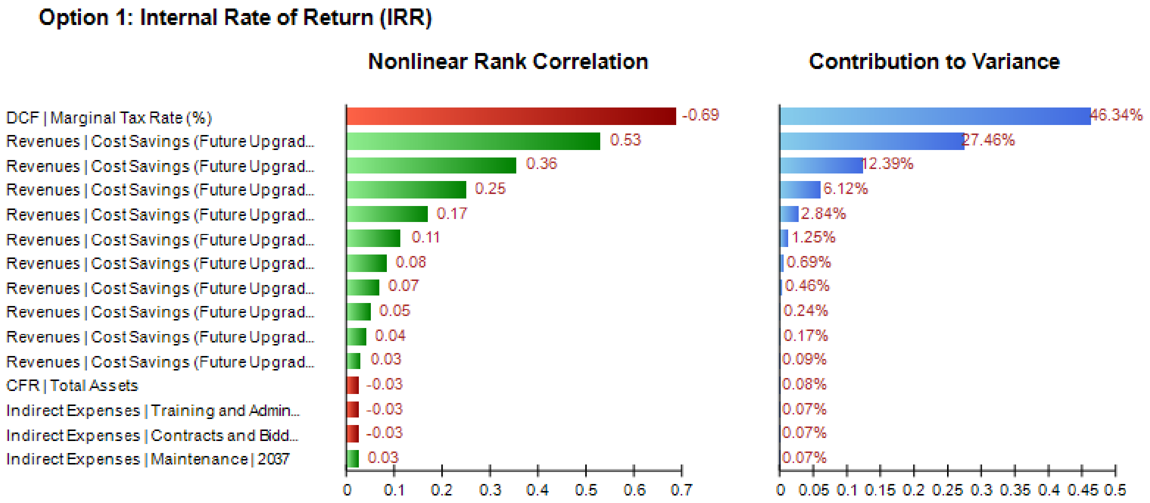


*Figure 19: Simulated Dynamic Sensitivity Analysis*

## *Step 6: Strategic Real Options Valuation Modeling*

Figure 20 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 analysis 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 20.

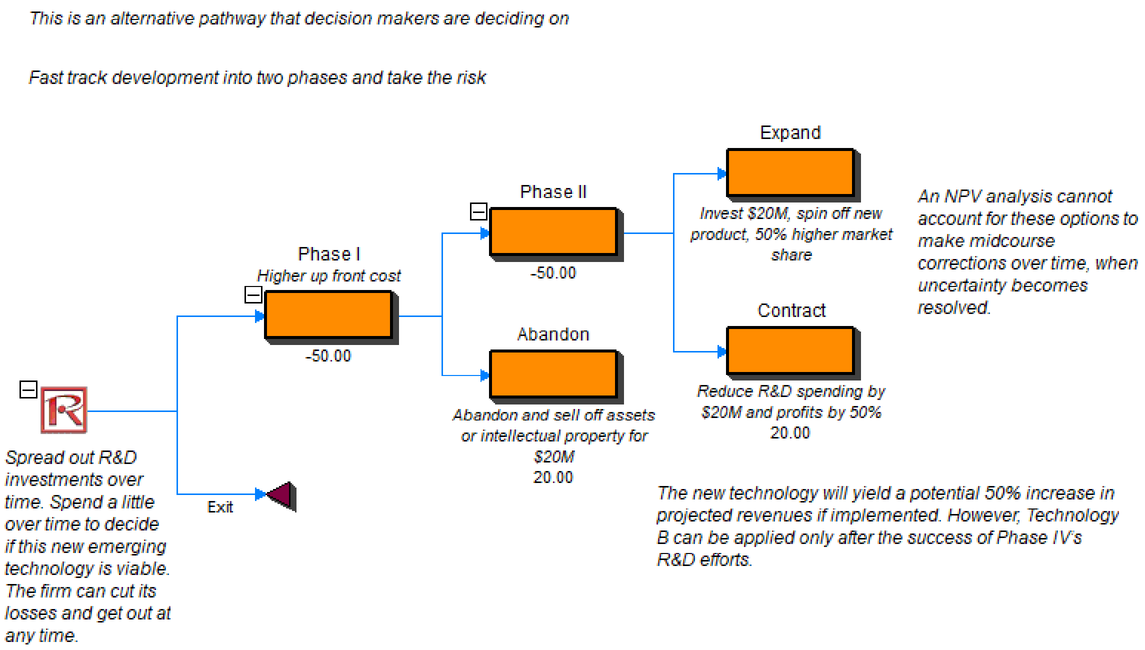
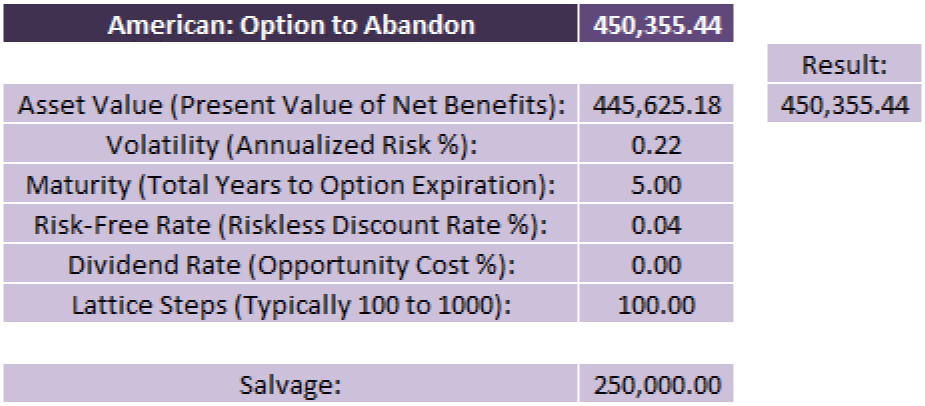


*Figure 20: Options Strategies*

## *Real Options Valuation Modeling*

Figure 21 illustrates the *Options Valuation* and the *Strategy View*. This part of the analysis performs the calculations of real options valuation models. Analysts must understand the basic concepts of real options before proceeding. This analysis internalizes the more sophisticated Real Options SLS software (see Chapter 13 of Mun's *Modeling Risk* book [2015]). 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.



| American: Option to Abandon | 450,355.44 |
|---|---|
| Asset Value (Present Value of Net Benefits): | 445,625.18 |
| Volatility (Annualized Risk %): | 0.22 |
| Maturity (Total Years to Option Expiration): | 5.00 |
| Risk-Free Rate (Riskless Discount Rate %): | 0.04 |
| Dividend Rate (Opportunity Cost %): | 0.00 |
| Lattice Steps (Typically 100 to 1000): | 100.00 |
| Salvage: | 250,000.00 |

| Result: |
|---|
| 450,355.44 |

*Figure 21: 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 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. It 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 $q_i = \dfrac{S_{i-1} - S_{down}}{S_{up} - S_{down}}$

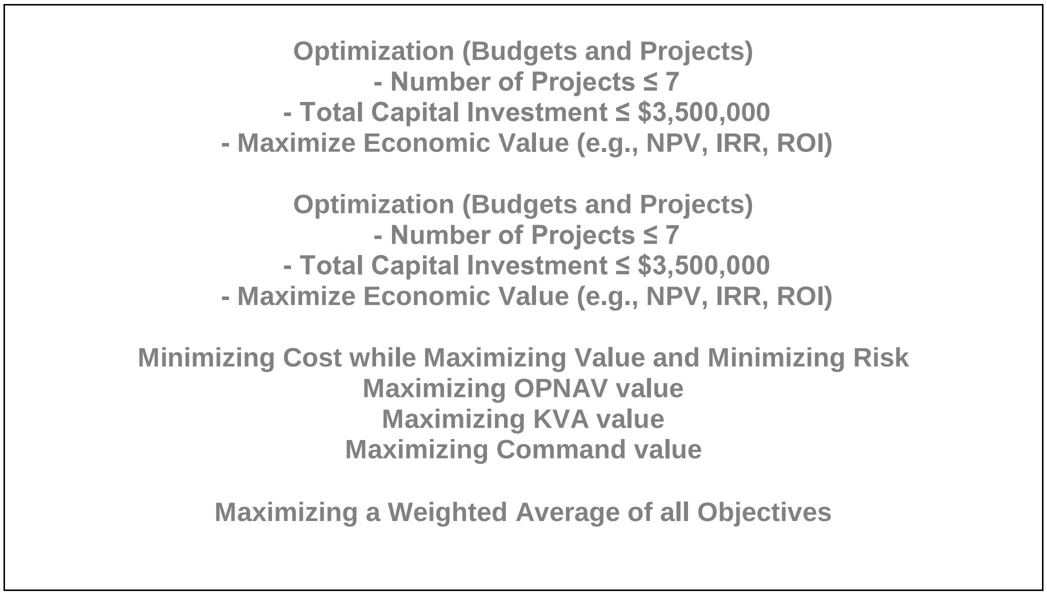
Additional methods using closed-form solutions, binomial and trinomial lattices, and simulation approaches, as well as dynamic simulated decision trees are used in computing the relevant option values of each strategic pathway as previously indicated. Fortunately, Navy analysts do not have to be experts in advanced mathematics to run these models, as they have all been preprogrammed in PEAT, as illustrated in Figure 21.

### *Step 7: Portfolio Optimization*

Figure 22 illustrates the *Portfolio Optimization's Optimization* settings. 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 within the ROV software 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, run the Optimization.



**Optimization (Budgets and Projects)**
**- Number of Projects ≤ 7**
**- Total Capital Investment ≤ $3,500,000**
**- Maximize Economic Value (e.g., NPV, IRR, ROI)**

**Optimization (Budgets and Projects)**
**- Number of Projects ≤ 7**
**- Total Capital Investment ≤ $3,500,000**
**- Maximize Economic Value (e.g., NPV, IRR, ROI)**

**Minimizing Cost while Maximizing Value and Minimizing Risk**
**Maximizing OPNAV value**
**Maximizing KVA value**
**Maximizing Command value**

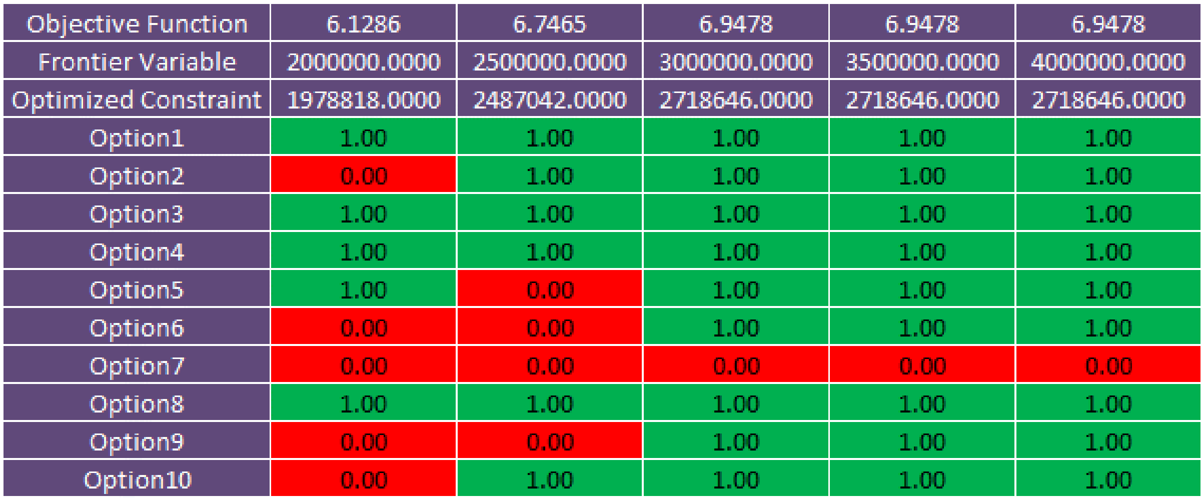
**Maximizing a Weighted Average of all Objectives**

*Figure 22: Portfolio Optimization Settings*

Figure 23 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 portion of the figure 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 23 and 24 provide examples of the critical results for decision-makers as they allow flexibility in designing their own portfolio of options. For instance, Figure 23 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 is subject to a budget constraint. The colored columns on the right in Figure 23 show the various combinations of budget limits and maximum number of options allowed. For instance, if a program office in the Navy allocates only $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 biggest 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 23 shows the efficient frontier where the constraints such as number of options allowed and budget were varied to determine the efficient portfolio selection, Figure 24 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, and would hence be considered first, followed by options with counts of 4, 3, 2, and 1.



| Objective Function | 6.1286 | 6.7465 | 6.9478 | 6.9478 | 6.9478 |
|---|---|---|---|---|---|
| Frontier Variable | 2000000.0000 | 2500000.0000 | 3000000.0000 | 3500000.0000 | 4000000.0000 |
| Optimized Constraint | 1978818.0000 | 2487042.0000 | 2718646.0000 | 2718646.0000 | 2718646.0000 |
| Option1 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| Option2 | 0.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| Option3 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| Option4 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| Option5 | 1.00 | 0.00 | 1.00 | 1.00 | 1.00 |
| Option6 | 0.00 | 0.00 | 1.00 | 1.00 | 1.00 |
| Option7 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Option8 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| Option9 | 0.00 | 0.00 | 1.00 | 1.00 | 1.00 |
| Option10 | 0.00 | 1.00 | 1.00 | 1.00 | 1.00 |

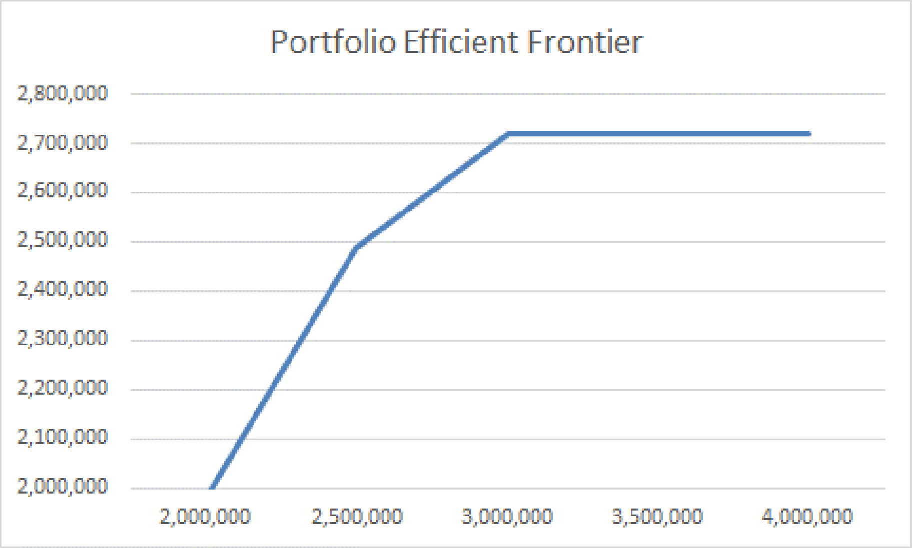
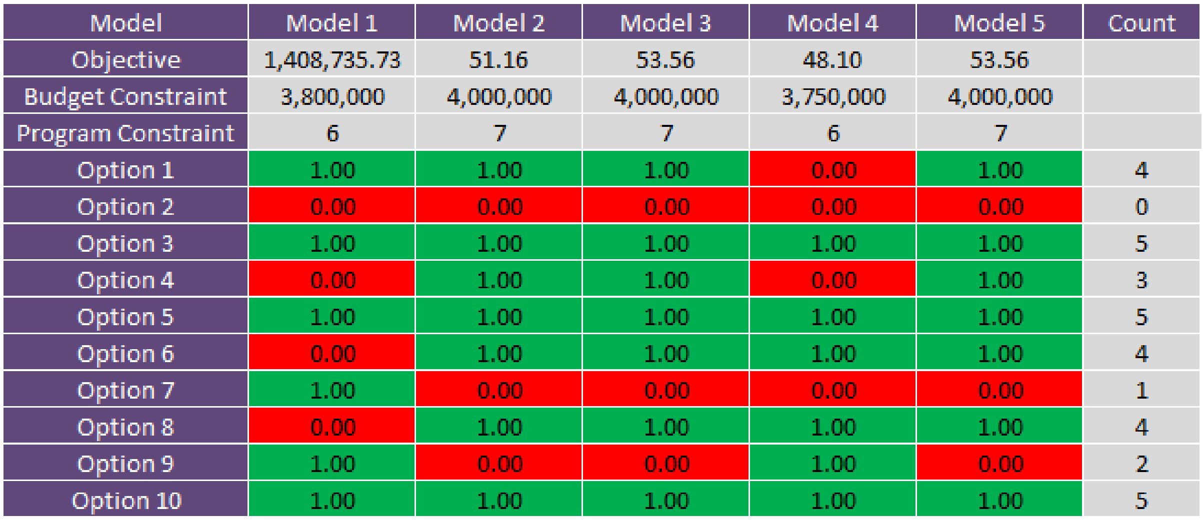


*Figure 23: Portfolio Optimization Results*



| Model | Model 1 | Model 2 | Model 3 | Model 4 | Model 5 | Count |
|---|---|---|---|---|---|---|
| Objective | 1,408,735.73 | 51.16 | 53.56 | 48.10 | 53.56 | |
| Budget Constraint | 3,800,000 | 4,000,000 | 4,000,000 | 3,750,000 | 4,000,000 | |
| Program Constraint | 6 | 7 | 7 | 6 | 7 | |
| Option 1 | 1.00 | 1.00 | 1.00 | 0.00 | 1.00 | 4 |
| Option 2 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| Option 3 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 5 |
| Option 4 | 0.00 | 1.00 | 1.00 | 0.00 | 1.00 | 3 |
| Option 5 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 5 |
| Option 6 | 0.00 | 1.00 | 1.00 | 1.00 | 1.00 | 4 |
| Option 7 | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1 |
| Option 8 | 0.00 | 1.00 | 1.00 | 1.00 | 1.00 | 4 |
| Option 9 | 1.00 | 0.00 | 0.00 | 1.00 | 0.00 | 2 |
| Option 10 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 5 |

*Figure 24: 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

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

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

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 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:

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

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

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

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

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 fewer 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. Estimate the starting point 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.

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# Conclusions and Recommendations

## Key Conclusions and Next Steps

Strategic real options valuation (ROV) provides the decision-maker 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 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. Second, 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 calculating 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––**Using the correct tools is 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 real options experts in the world, who truly

understand the complex theoretical underpinnings of the models as well the practical applications, it follows that care should be taken in choosing the correct team. A team of competent real options users is vital in the success of the initiative. The Navy 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 initial team of individuals. This is why training is vital for the core Navy real options analysts' team. 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.

- **Senior Decision-Maker Buy-In**—The analysis buy-in must be top-down where Navy 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. Someone in Navy leadership should be the champion of the move to incorporate real options analysis within the acquisitions business case development.

## *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, volatility (a measure of risk and uncertainty) is zero because everything is certain and the real options value is zero. In this case, 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.

- *Navy leadership must have strategic flexibility or options* to make midcourse corrections when actively managing acquisition projects. Otherwise, do not apply real options analysis when there are no options or management flexibility to value.
- *Navy management must be able 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 trained Navy ROV 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's 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, as previously stated, 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 not merely another set of numbers.

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| 2001–2010: | Visiting Professor, University of Applied Sciences and Swiss School of Management, Switzerland |
| 2001–2004: | Vice President of Analytics, Decisioneering-Oracle, Denver, Colorado |
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- “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.
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## EDUCATION

University of Utah, PhD in Communication, 1980 (Magna Cum Laude)

University of Wyoming, MA in Communication, 1975 (Summa Cum Laude)

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

First Prize Winner, 1986 Society for Information Management Paper Competition

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