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

Johnathan C. Mun—is a research professor at NPS and teaches executive seminars in quantitative risk analysis, decision sciences, real options, simulation, portfolio optimization, and other related concepts. He received his PhD in finance and economics from Lehigh University. He is considered a leading world expert on risk analysis and real options analysis. Dr. Mun has authored 12 books and is the founder and CEO of Real Options Valuation Inc. [jcmun@realoptionsvaluation.com]

Thomas J. Housel—specializes in valuing intellectual capital, knowledge management, telecommunications, information technology, value-based business process reengineering, and knowledge value measurement in profit and non-profit organizations. He is a tenured full professor for the Information Sciences (Systems) Department at NPS. He has conducted over 80 knowledge value added (KVA) projects within the non-profit, Department of Defense (DoD) sector for the Army, Navy, and Marines. Dr. Housel also completed over 100 KVA projects in the private sector. The results of these projects provided substantial performance improvement strategies and tactics for core processes throughout DoD organizations and private sector companies. [tjhousel@nps.edu]

LCDR Lauren B. Majchrzak, USN

Abstract

To successfully implement the Surface Navy's Flexible Ships concept, Program Executive Office–Ships (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 (ROV) 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.

Introduction

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

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

The concept of FASO is not new to the Navy. In fact, benefits of MAS/FASO concepts have been detailed by Jolliff (1974), Simmons (1975), Drewry 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 the 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, Admiral Greenert (Chief of Naval Operations) and Vice Admiral Rowden (Commander of Naval Surface Forces) echoed the idea that the ability to quickly change payloads and have modularity on ships would maximize the service life of ships and allow faster and more affordable upgrades to combat systems and equipment.

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

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

This current research acknowledges that the U.S. Navy has sought out the ability to incorporate FASO and MAS capabilities in its ship design of Future Surface Combatants (FSC). Further, the Navy acknowledges that there is significant value in terms of being able to rapidly upgrade FASO ships at a lower cost while extending the ships' service life, all the while being able to quickly adapt to changes in both external threats and internal new technologies. As such, this current research is not meant to identify said FASO/MAS platforms or payloads per se, but to use previously identified platforms such as the DDG 51 Flight III, where there are opportunities to insert flexible ship features, and we limit the analysis to said surface combatants in the domain of Anti-Submarine Warfare (ASW).

This current research focuses on a series of recommended analytical methodologies to establish a business model or business case analysis that supports strategic decision-making under uncertainty, specific to identifying, modeling, valuing, and optimizing the various strategic real options in flexible ship designs. Currently, there is only a limited set of real-life applications of FASO/MAS in ship design, and they are classified; therefore, actual empirical data is not used in this research. In addition, because the objective of this research is to illustrate in detail the business case modeling process and analytical methodologies such that the method and process can be replicated and used in all future FASO/MAS design decisions, subject matter expert (SME) opinions, publicly available information, and certain basic assumptions or rough order magnitude (ROM) estimates are used. The use of said ROM or SME inputs in no way detracts from the analytical power, efficacy, or applicability of these methods.

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

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

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 MAS and FASO (Mun & Housel, 2016). MAS- and FASO-incorporated designs provide an economical platform for a sea-going 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 et 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 machines but offered a variety of modular payloads for specific mission sets. Ultimately, MAS- and FASO-incorporated designs provide an economical platform for a sea-going navy to build powerful, multi-task warships.

Royal Danish Navy

The RDN has been at the forefront of modular ship design since 1987, when the first of 14 Flyvesfisken 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 Flyvesfisken class was ultimately decommissioned in October 2010 (“Flyvefisken Class,” 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 Flyvesfisken class and STANFLEX resulted from a feasibility study in 1982. The RDN 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 between 1987 and 1996. 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 54 m in length and 9 m 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 3 m by 3.5 m by 2.5 m and housed all dedicated machinery and electronic payloads connected by a standard interface panel (“Flyvefisken Class,” 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 warfare (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,” 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 (Pike, 2011), facilitating rapid mission change if necessary. 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 76 mm Oto Melara Super Rapid gun ("Flyvefisken Class," 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.

German Navy

At the forefront of modular design for the German Navy is the Blohm + Voss model. 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 20-ft 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 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 Marine Systems, n.d.). The MEKO class is comprised of the MEKO A-100 Corvette and the MEKO A-200 Frigate (ThyssenKrupp Marine Systems, 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 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 149.5 m in length with a beam of 18.8 m, 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 5,000 hr/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 2,500 hr/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 RDN, 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 Finmeccania ("FREMM European," 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 European," 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 142 m in length, has a beam of 20 m, displaces 6,000 tons, and carries a crew of 108 ("FREMM European," 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 European," 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 520 m2 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 European," 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 European," n.d.) 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 European," 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 taken into account 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.

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 between 1996 and 2006, and two were commissioned for the Royal New Zealand Navy in 1997 and 1999 ("Anzac Class Frigate," 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 118 m with a beam of 14.8 m, 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 Class Frigate," 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).

FASO/MAS at PEO-SHIPS: Flexibility on 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 [ODOT&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 ASW role with their towed sonar array, anti-submarine rockets, and ASW helicopter; the 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 (ODOT&E, 2013).

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

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

Step 1: Identification of FASO/MAS Options

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

Power Plant Options

This real options example illustrates the implications of the standard LM2500 GE Marine Gas Turbines for DDG 51 FLT III ships versus the Rolls-Royce MT30 Marine Gas Turbine Engines for the Zumwalt DDG 1000, where the latter can satisfy large power requirements in warships. The LM2500 provides 105,000 shaft hp for a four-engine plant. In comparison, the MT30 can generate upwards of 35.4 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 1 illustrates a real options strategy tree with four mutually exclusive paths. Additional strategies and pathways can be similarly created, but these initial strategies are sufficient to illustrate the options framing approach. Path 1 shows the As-Is strategy, where no additional higher capacity power plant is used; that is, only two standard LM2500 units are deployed, maintain zero design margins for growth, and only the requirements for the current ship configuration are designed and built. Medium and large upgrades will require major ship alterations, with high cost and delayed schedule. Path 2 implements the two required LM2500 units with additional and sufficient growth margins for one MT30 power plant but currently only with a smaller power plant incorporated into the design. Sufficient area or modularity is available where parts of the machinery can be removed and replaced with the higher energy production unit if needed. Upfront cost is reduced, and future cost and schedule delays are also reduced. Path 3 is to have two prebuilt MT30s and RR4500s initially. While providing the fastest implementation pathway, the cost is higher in the beginning, but total cost is lower if indeed higher energy weapons will be implemented. Path 4 is an option to switch whereby one LM2500 is built with one MT30 unit. Depending on conditions, either the LM2500 or MT30 will be used (switched between units). When higher-powered future weapons such as electromagnetic railguns (E.M. Rail Guns) or high-intensity lasers (H. I. Lasers) as well as other similarly futuristic weapons and systems are required, the MT30 can be turned on.

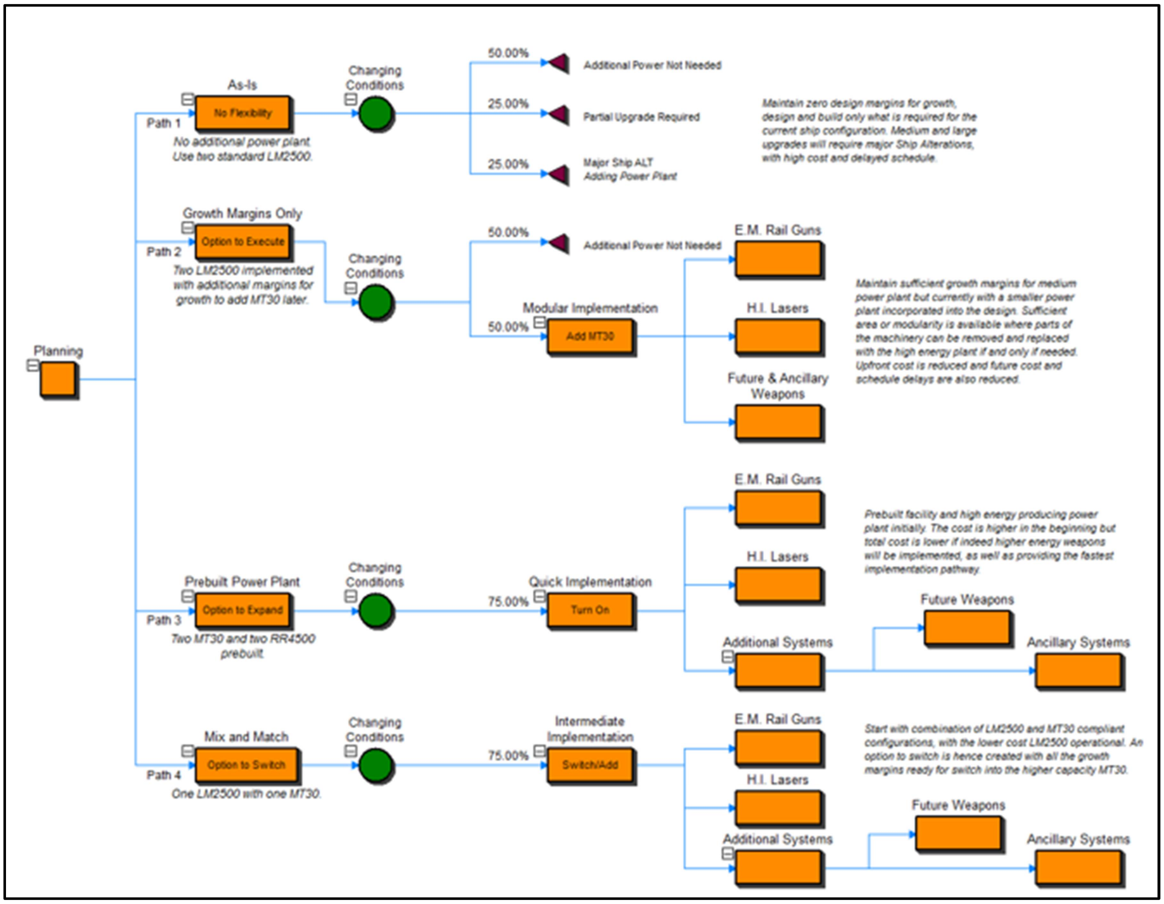
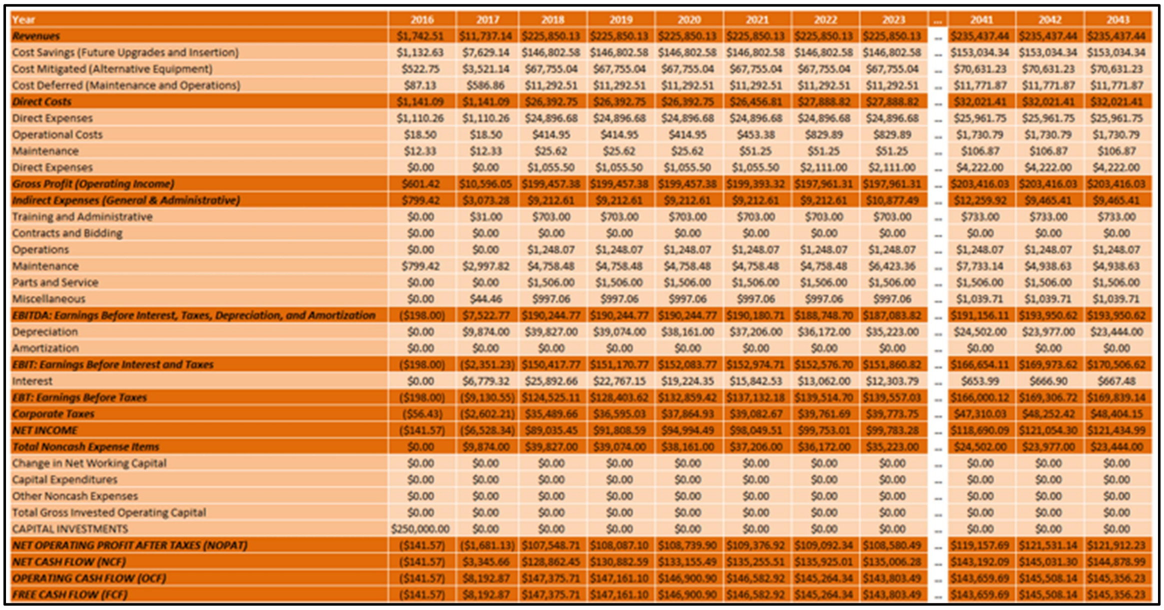


Figure 1. Options Framing on Power Generation

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.

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 2 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 costs 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 2. Financial and Economic Cost Savings and Cost Averted Cash Flow Model

Step 3: Financial Modeling

The *Discounted Cash Flow* section, shown in Figure 3, is at the heart of the input assumptions for the analysis. Additional time-series inputs are entered in the data grid as required, while some elements of this grid are intermediate computed values.

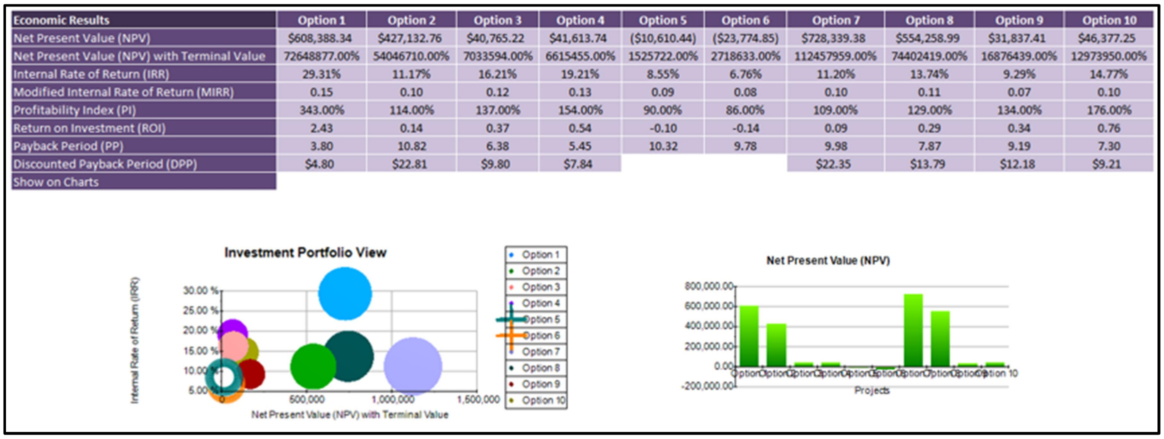
Year	2016	2017	2018	2019	2020	2021	2022	2023	2024	...	2040	2041	2042	2043
EARNINGS BEFORE INT, TAX, DEP, AMORT (EBITDA)	-198	7,522.77	190,244.77	190,244.77	190,244.77	190,180.71	188,748.70	187,083.82	188,393.60	...	193,775.67	191,156.11	193,950.62	193,950.62
EARNINGS BEFORE INTEREST AND TAXES (EBIT)	-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 3. Financial and Economic Performance Ratios

Static Portfolio Analysis and Comparisons of Multiple Projects

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 Figure 4, 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 4 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* (Level 3) subtabs show the individual project's economic and financial indicators, whereas this Level 2 *Portfolio Analysis* view shows the results of all projects' indicators and compares them side by side. There are also two charts available for comparing these individual projects' results. The *Portfolio Analysis* 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).



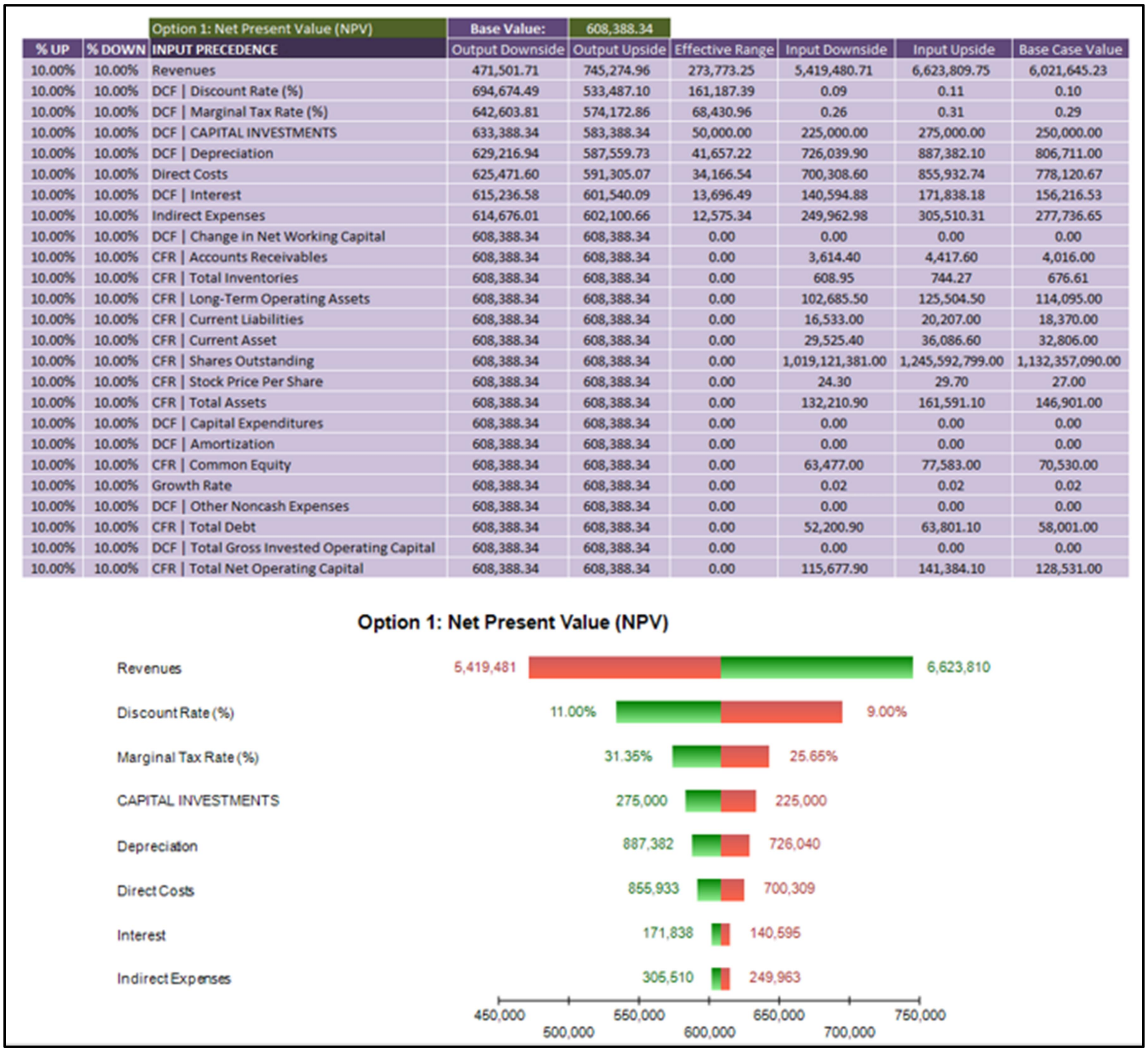
Economic Results	Option 1	Option 2	Option 3	Option 4	Option 5	Option 6	Option 7	Option 8	Option 9	Option 10
Net Present Value (NPV)	$608,388.34	$427,132.76	$40,765.22	$41,613.74	($10,610.44)	($23,774.85)	$728,339.38	$554,258.99	$31,837.41	$46,377.25
Net Present Value (NPV) with Terminal Value	72648877.00%	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 4. Static Portfolio Analysis

Step 4: Tornado and Sensitivity Analytics

Figure 5 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). 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).

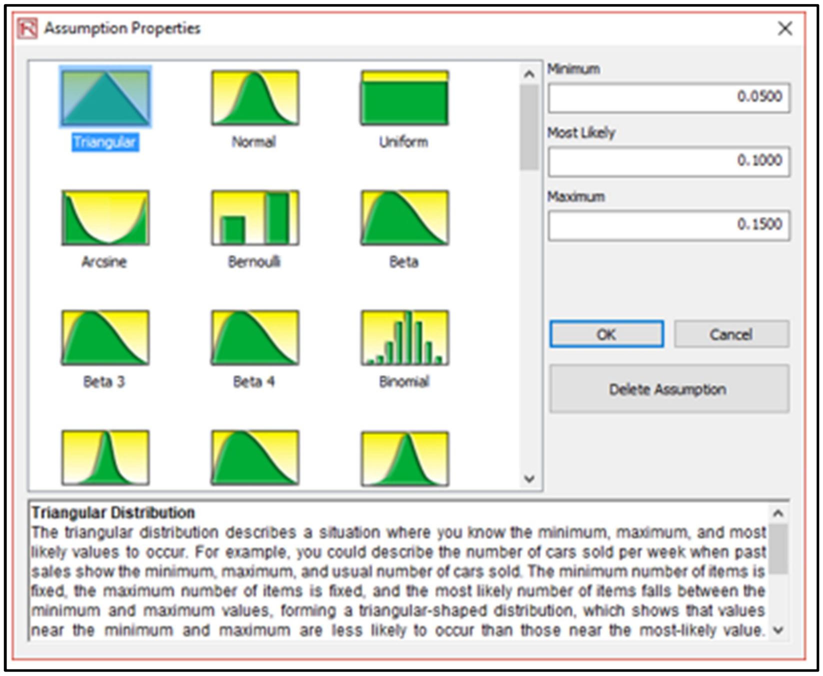


		Option 1: Net Present Value (NPV)	Base Value:	608,388.34				
% UP	% DOWN	INPUT PRECEDENCE	Output Downside	Output Upside	Effective Range	Input Downside	Input Upside	Base Case Value
10.00%	10.00%	Revenues	471,501.71	745,274.96	273,773.25	5,419,480.71	6,623,809.75	6,021,645.23
10.00%	10.00%	DCF | Discount 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 5. Applied Analytics—Tornado Analysis

Step 5: Monte Carlo Risk Simulation

Figures 6 and 7 illustrate 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

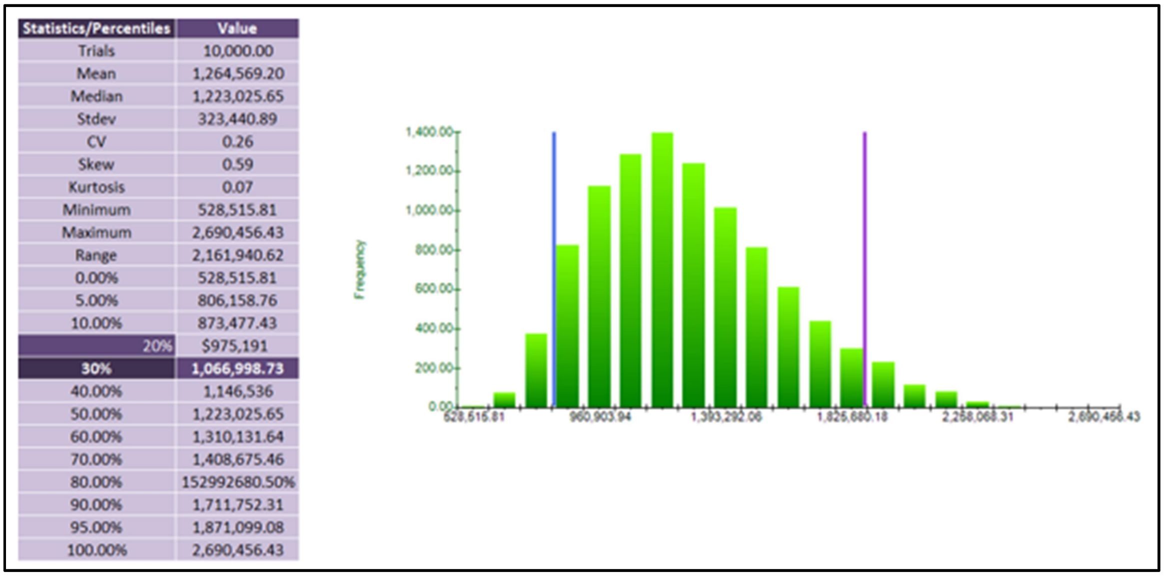
Most Likely 0.1000

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 6. Risk Simulation Input Assumptions

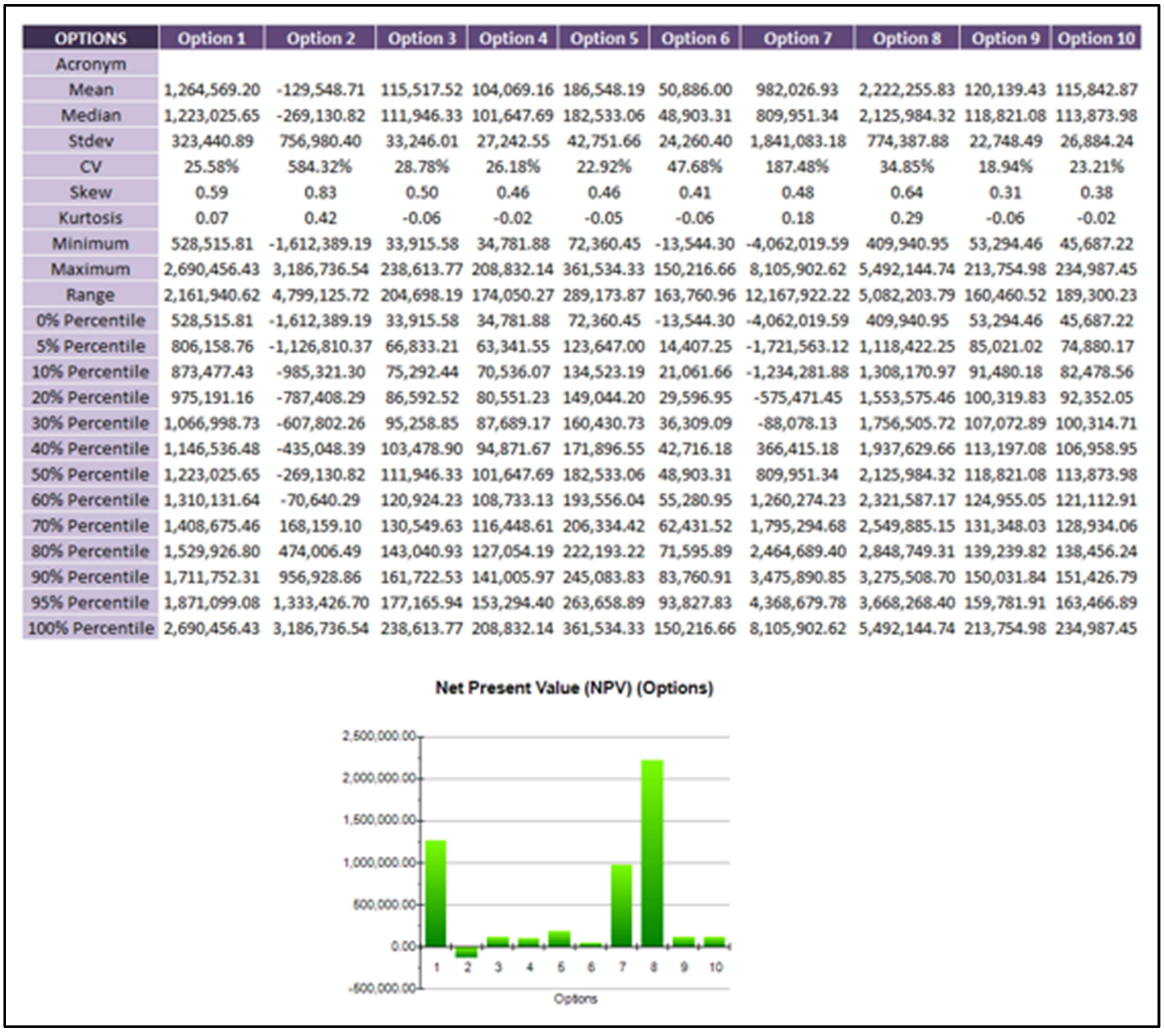


Statistics/Percentiles	Value
Trials	10,000.00
Mean	1,264,569.20
Median	1,223,025.65
Stdev	323,440.89
CV	0.26
Skew	0.59
Kurtosis	0.07
Minimum	528,515.81
Maximum	2,690,456.43
Range	2,161,940.62
0.00%	528,515.81
5.00%	806,158.76
10.00%	873,477.43
20%	$975,191
30%	1,066,998.73
40.00%	1,146,536
50.00%	1,223,025.65
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 7. Risk Simulation Results

Analysis of Alternatives and Dynamic Sensitivity Analysis

Figure 8 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 versus another, but analysts can also choose to analyze the results on an *Incremental Analysis* basis.



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 8. Simulated Analysis of Alternatives

Figure 9 illustrates the *Dynamic Sensitivity Analysis* computations. Tornado analysis and scenario analysis are both static calculations. Dynamic sensitivity, in contrast, is a dynamic analysis, which can only be performed after a simulation is run. Analysts start by selecting the desired project's economic output. Red bars on the *Rank Correlation* chart indicate negative correlations, and green bars indicate positive correlations for the left chart. The correlations' absolute values are used to rank the variables with the highest relationship to the lowest, for all simulation input assumptions. The *Contribution* to *Variance* computations and chart indicate the percentage fluctuation in the output variable that can be statistically explained by the fluctuations in each of the input variables.

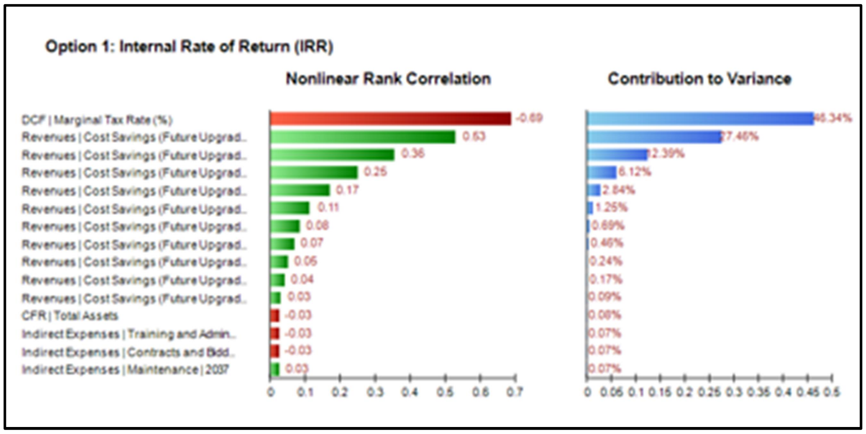
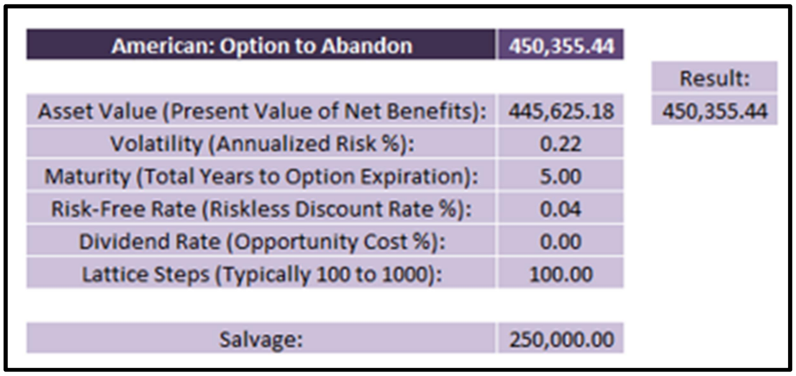


Figure 9. Simulated Dynamic Sensitivity Analysis

Step 6: Strategic Real Options Valuation Modeling

Figure 10 illustrates the *Options Valuation* and the *Strategy View.* This part of the analysis performs the calculations of ROV models. Analysts must understand the basic concepts of real options before proceeding.



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

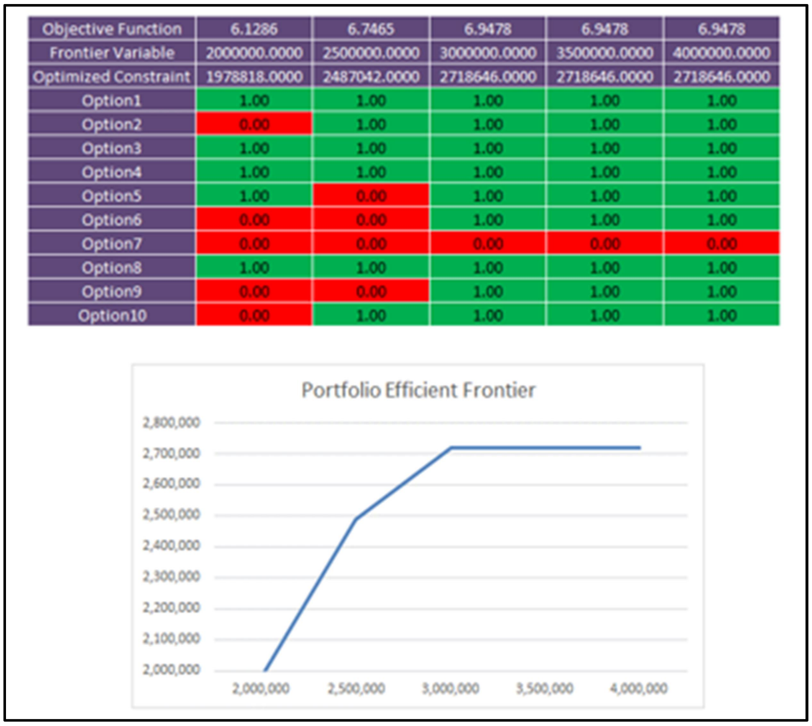
Figure 10. Options Valuation

Step 7: Portfolio Optimization

Figure 11 illustrates the *Portfolio Optimization's Optimization* settings and assumptions. In the Portfolio Optimization analysis, 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 may even be 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).

Analysts start by deciding on 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.

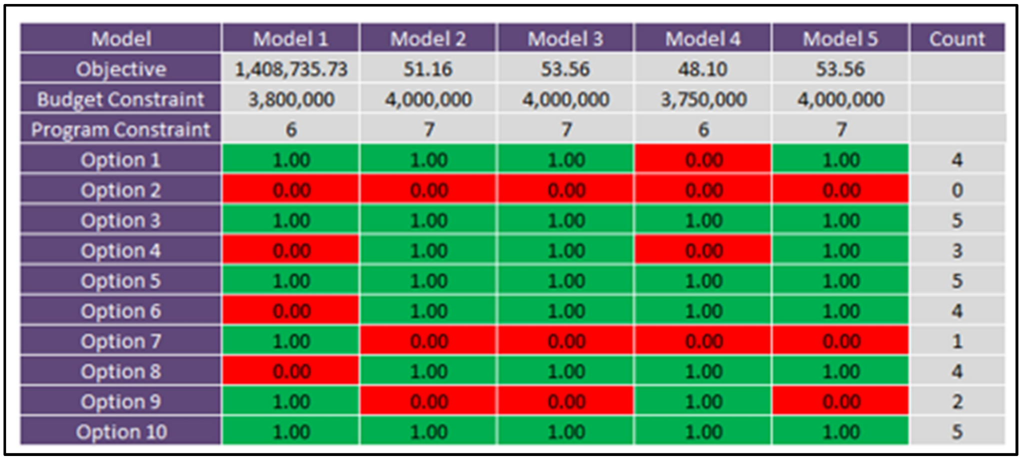
Figure 11 illustrates the *Optimization Results*, which return the results from the portfolio optimization analysis. The main results are provided in the data grid, showing the final *Objective Function* results, final *Optimized Constraints*, and the allocation, selection, or optimization across all individual options or projects within this optimized portfolio. The typical optimization results 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).



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 11. Portfolio Optimization Results

Figures 11 and 12 provide examples of the critical results for decision makers as they allow flexibility in designing their own portfolio of options. For instance, Figure 11 shows an efficient frontier of portfolios, where each of the points along the curve are optimized portfolios subject to a certain set of constraints. In this example, the constraints were the number of options that can be selected in a ship, and the total cost of obtaining these options are subject to a budget constraint. The colored columns on the right in Figure 12 show the various combinations of budget limits and maximum number of options allowed. For instance, if a program office in the Navy only allocates $2.5 million (see the Frontier Variable located on the second row) and no more than four options per ship, then only options 3, 7, 9, and 10 are feasible, and this portfolio combination would generate the highest bang for the buck while simultaneously satisfying the budgetary and number of options constraints. If the constraints were relaxed to, say, five options and a $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.



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 12. Multi-Criteria Portfolio Optimization Results

While Figure 11 shows the efficient frontier where the constraints such as number of options allowed and budget were varied to determine the efficient portfolio selection, Figure 12 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.

Conclusions and Recommendations

Key Conclusions and Next Steps

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

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