

Design and Analysis of US Navy Shipbuilding

Contract Architecture

by

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B.S., Massachusetts Institute of Technology (2004)

Submitted to the Department of Mechanical Engineering
and

Engineering Systems Division

in partial fulfillment of the requirements for the degrees of
Naval Engineer

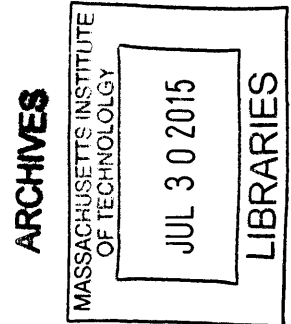
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Abstract

Contracting for US Navy ship procurement is complex due several factors such as budgetary and political concerns, sole or near sole source environments, and long lead-time construction. In the current climate of shrinking budgets, it is especially important to set programs up for financial success. One potential area for cost management improvement in acquisition programs is with the initial contract and incentive structure. If shipbuilding contracts could be described in engineering architectural terms, then perhaps that architecture could provide better clarity of contract options. Further, if contracting can be described as an engineering architecture, then perhaps that architecture could be optimized for a given result. These are the central questions of this thesis. To answer them, interviews were conducted with several experienced individuals from both industry and the government. Additionally, past shipbuilding contracts in both the US and Canada were examined.

These insights were then used to form a contract architecture concept in accordance with the Tradespace engineering paradigm. From the concept definition came the design vector definition which included variables such as shareline definition, incentives, and contracted profit percentage. The tradespace was then populated by manipulating the design vector parameters. The Palisade tool @Risk was used to conduct the design vector manipulation and tradespace population. @Risk is an excel plug in that allows uncertain variables to be defined by probability distributions. The tradespace of contract outcomes was then evaluated against utilities such as cost, profit, and risk. Although the factors affecting the contracting environment are complex, and not all are modeled, quantitative modeling allows the architect to roughly evaluate different approaches, vice just basing the contract on past models. It also

gives the government the ability to check whether shipbuilder furnished predicted costs are reasonable for a given contract structure.

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1 Introduction and Background

“Shipbuilding is America’s greatest pride, and in which, she will in time excel the whole world.” Thomas Paine, *Common Sense*, 1776.

The U.S. Shipbuilding industry accounts for over \$36 billion annually[8] (FY 2011 USD). The U.S. Navy accounts for a large share of the national shipbuilding. Figure 1.1 displays the revenue by product type for the US shipbuilding and repair industry for 2012.

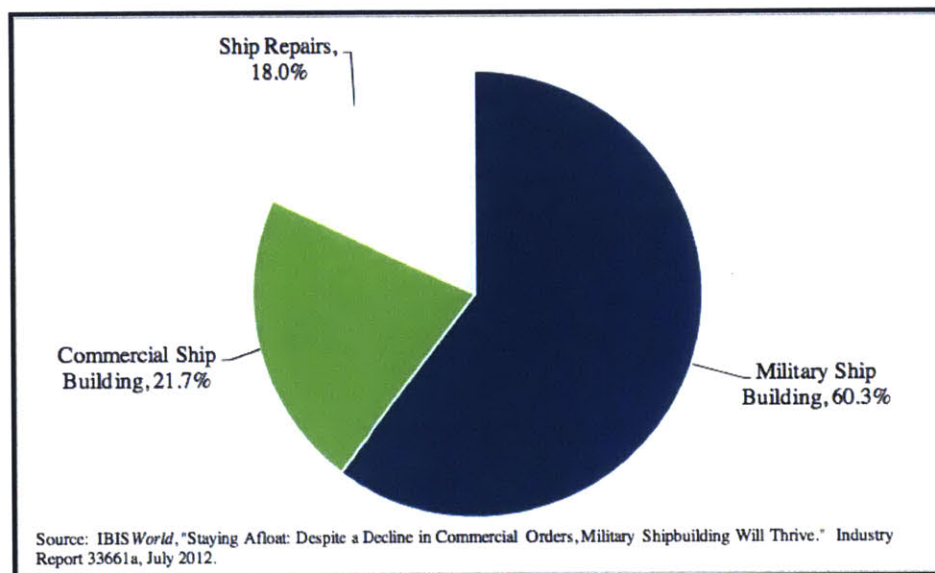


Figure 1.1: Industry Revenue by Product Type, 2012[1]

In June of 2014, the Report to Congress on the Annual Long-Range Construction of Naval Vessels for FY 2015 described the need to increase the force size from 289 ships to 306 ships by 2020. The report estimates that the cost for this procurement is an annual investment of 17.2 billion USD (FY14), which is up from the historical average annual spending of approximately 13 billion USD. With so much money being spent on ship procurement in a tight fiscal climate, it is of particular importance to ensure these programs remain on track. Increasing costs could result in the 306 ship target

not being met. One area for cost control is in the build contracts and construction of the Navy ships, which is all done at private shipyards. This thesis looks at how U.S. Navy shipbuilding contracts are negotiated and written, and whether these contracts can be described in terms of engineering architecting principles. Further, if they can be, can they be modeled quantitatively, and if so, optimized for a specific outcome—i.e. low cost, or high contractor profit?

A recent report by the Maritime Administration on the economic importance of the U.S. shipbuilding industry listed 31 shipyards in the U.S. capable of the construction of mid to large sized naval vessels. U.S. shipyards are largely categorized into three types: (1) private shipyards that build commercial ships; (2) private shipyards that build military ships; (3) U.S. government-owned naval shipyards that conduct maintenance, repairs, and upgrades on Navy and Coast Guard ships[9]. The second category of shipyards represents a unique relationship between the U.S. government and the private company that owns the shipyard. In some cases, as with aircraft carriers built by Newport News Shipbuilding which is owned by Huntington Ingalls Industry (HII), the private shipyard is the sole source provider of the shipbuilding capability. In other cases, as with Bath Iron Works and Electric Boat owned by General Dynamics, and HII's Newport News and Pascagoula shipyards, the U.S. government is the sole customer. The U.S. military shipbuilding programs are long lead time programs, subject to constantly changing budgetary climates, as well as to threat environments. These fluctuating conditions add large amounts of uncertainty and risk to both parties. This risk and uncertainty is a constant challenge in writing shipbuilding contracts. Poorly managed risk and uncertainty can result in program failures or large cost overruns. Is there a way to change how contracts are written to better manage this risk and uncertainty for program success?

Canada has recently taken a hard look at how it does military shipbuilding and changed its approach. The government of Canada has recently announced and begun the transition to a new National Shipbuilding Procurement Strategy (NSPS) that is aimed at revitalizing the military and commercial shipbuilding industry. The new strategy is to select a single private shipyard for all Navy combatant shipbuilding and one for all Navy Auxiliary and Coast Guard shipbuilding rather than to compete each shipbuilding contract between existing shipyards. Under this new arrangement the government and shipbuilder both agree to the sole source, sole customer environment at the beginning and all contracting is done with that arrangement in mind. The NSPS tackles the risk associated with longterm shipbuilding capability from both the standpoint of the shipyard, and government. With this new strategy, the government hopes to avoid the waste associated with the previous “boom and bust” nature of shipbuilding contracts[10]. By preselecting a single shipyard for all new military shipbuilding, Canada is hoping to leverage different contract incentives and potentially drive the overall cost of the programs down. The case study of NSPS provides some insights into quantifying risk in contracts, as well further information about the nature of shipbuilding contract architectures.

The unique relationship between the U.S. government and private shipbuilders leads to unique contracting practices. Different acquisition programs are handled by different government program offices, and result in different contracting structures. In April 2014, the U.S. Naval Sea System Command awarded the single largest contract in U.S. Navy history to General Dynamic Electric Boat for the Block IV Virginia class attack submarines (VCS) [11]. The \$17.8 billion contract for ten submarines is a “fixed-price incentive fee, multiyear procurement contract with economic order quantity.” In contrast, the DDG 1000 contract is a cost plus incentive fee for the overall construction and the development of the new vertical launch

system. There are some "normal" rules of thumb for basic contracting types, i.e. stable, mature designs work well with fixed-price architectures, whereas; new designs or technologies lend themselves better to cost-plus architectures. These overarching contract type norms, however, do not represent a cohesive set of rules for contracting architecture, nor do they necessarily demand specific incentive structures. An example of this variance is seen between the different blocks of the same VCS program, which each have a unique special incentive architecture. With such variance in contract structure, it is difficult to know if the structure being used is the best one for program cost performance.

A good contract architecture can set a program off on the right foot. It can incentivize positive behavior and desired outcomes for both parties. A poorly constructed contract, however, can unintentionally incentivize negative behavior or lead to "gaming the system." A contracting expert from the VCS program office commented on this effect during an interview about the contract negotiations for the different VCS Blocks. She remarked that the contracting office had to be careful with labor and material incentives because they can encourage contractors to game the incentive with use of overtime or subcontractors, rather than targeting the overall cost reduction goal that the program office was aiming for.

In an era of increasing program costs, and shrinking budgets, having the correct framework for success- starting with the right contract- is essential. The Department of Defense has demonstrated recent trouble with cost management in acquisition programs. The Government Accountability Office (GAO) reported on FY 2008 Department of Defense major acquisition programs, and found that of the 96 major programs, 64 saw cost growth[12]. The cost growth reported totaled \$296 billion, clearly signaling the need for improvement, especially when that growth is compared

to the \$696.4 billion FY 2008 Department of Defense total budget authorization [13].

In the 2014 Better Buying Power 3.0, the Honorable Frank Kendall, Undersecretary of Defense Acquisition, Technology & Logistics, addresses the need for improvement in defense acquisition. One initiative described in the paper is to incentivize productivity in industry and government by aligning profitability more tightly with Department goals. He writes, “Our data analysis shows clearly that the way we structure business deals affect how industry performs.[14]” The guide goes on to say that the use of incentive-type contracts should be expanded. Referencing a previous report published in the “Annual Report on the Performance of the Defense Acquisition System,” the guide concludes that there is a high correlation between incentives and better cost and schedule performance. This performance is specifically referring to Cost-Plus-Incentive and Fixed-Price-Incentive contract vehicles, where cost overruns and under runs are shared between the government and shipbuilder in such a way as to elevate the contractor’s stake in the outcome.

One potential area for cost management improvement in acquisition programs is with the initial contract and incentive structure. If shipbuilding contracts could be described in engineering architectural terms, then perhaps that architecture could provide better clarity of contract options. Further, if contracting can be described as an engineering architecture, then perhaps that architecture could be optimized for a given result.

2 Research Process

2.1 Thesis Study Question

In the current climate of shrinking budgets, it is especially important to set shipbuilding programs up for financial success. One potential area for cost management improvement in acquisition programs is with the initial contract and incentive structure. The current process for contract definition does not follow a set, systematic process. Rather, high level guidance is given on the procurement strategy to be used, i.e. profit related to offer, cost plus incentive fee, firm fixed price, etc. This guidance can be specific to the project, or more general, as is published in the Better Buying Guide [14]. Then the program office, i.e. PMS 450 for the Virginia Class Submarine (VCS) program, translates that guidance into a contract. The program office will get input from various stakeholders and attempt to craft a contract that is agreeable to both the shipbuilder and the government. This process is highly dependent on the individuals involved and their past experiences. Senior NAVSEA officials have expressed the concern that it is difficult to hold on to top contracting officials, due to their highly desirable contract experience. Since these individuals are such a key part of the process, losing them means potentially losing valuable lessons learned. Each contract is also highly individualized for for the specific shipbuilding project. Factors such as current work in the shipbuilder's yard, or the shipbuilder's past performance in cost areas like labor or materials may dictate that specific contract clauses be included. The overall effect is one that makes shipbuilding contracting seem like a fairly ad hoc process, even if it is ultimately successful in producing a product on time and budget. This thesis examines whether a more scientific approach can be applied to the contracting process.

The principles, processes, and tools of system architecting have been successfully used

to describe and manage complex engineering systems and programs. Architecture is the embodiment of concept, and the allocation of physical information function to the elements of form, and definition of the relationships among the elements and with the surrounding context; or more simply: an abstract description of the entities of a system and the relationship between those entities [15] . If shipbuilding contracts could be described in engineering architectural terms, then perhaps that architecture could provide better clarity of contract options. Further, if contracting can be described as an engineering architecture, then perhaps that architecture could be optimized for a given result. These are the central questions of this thesis.

2.2 Research Process Overview

Both a qualitative and a quantitative approach was taken to answer the thesis research questions. First, past case studies in military shipbuilding were studied. Examples of both successful and problematic US Navy programs yielded insights into the contracting process as well as into the general climate of US military shipbuilding. The specific case study of the VCS program was studied in greater detail, as it yielded many lessons on successful contracting and program execution. Additionally, Canadian military shipbuilding was studied for comparison. The case study of the new Canadian National Shipbuilding Procurement Strategy (NSPS) and the recent build contract for the Arctic Offshore Patrol Ship (AOPS) yielded insights into risk sharing and quantification.

Next, interview with experts in the field of shipbuilding were conducted. Contracting individuals in the VCS program office discussed the evolution of the block contracts and how and why incentives were used throughout the different contracts. They also discussed the general approach the office took to contract construction. To gain

insight into the contracting process from the industry perspective, an interview was conducted with the President of Irving Shipbuilding Inc. in Halifax, Nova Scotia. The president discussed the negotiations for the recently signed build contract for the Canadian AOPS as well as being selected to be the combatant shipbuilder under the NSPS. Additionally, two former Commanders of the Naval Sea Systems Command (NAVSEA) were interviewed as well as a senior contracting official from the office of the Assistant Secretary of the Navy (Research, Development and Acquisition.)

The interviews helped to understand the wide range of issues and elements present in the US military shipbuilding environment. This understanding also helped to scope and focus what elements could and should be modeled in a quantitative model. To form the quantitative model, first the concept of the contact model was created. From there, the quantitative model was developed using the Monte Carlo simulation based program @Risk. @Risk is a product from the Palisade Corporation that works with Microsoft Excel. The quantitative model was then run for different project inputs and the outputs were examined.

3 Background and Literature Review

3.1 Current Practice in US Shipbuilding Contracts

Currently U.S. Navy ships are built in public shipyards and maintained in both public and Naval shipyards. Naval Shipyards are located in Norfolk, VA; Portsmouth, NH; Puget Sound, WA; and Pearl Harbor, HI. Private shipyards (Tier 1 and 2) are owned by Huntington Ingalls Industries (HII), General Dynamics (GD), Fincantieri, and Austal USA.

HII's facility in Pascagoula, MS builds surface combatants, amphibious assault and transport vehicles, and provides fleet support for these vessels. Their Newport News Shipbuilding (NNS) facility is the sole builder of U.S. Navy aircraft carriers, and one of two builders of U.S. Navy nuclear submarines. General Dynamics' Marine Systems divisions include Bath Iron Works (BIW), Electric Boat and NASSCO. Bath Iron Works is located in Bath, ME and specializes in U.S. Navy surface combatant design and construction. It is currently building DDG1000 and DDG51 class destroyers. Electric Boat is located in Groton, CT and specialized in the design and construction of U.S. Navy nuclear submarines. NASSCO has shipbuilding locations in San Diego, CA; and Norfolk, VA (repair only) and specializes in auxiliary and support ships for the U.S. Navy. Fincantieri's Marinette Marine shipyard in Wisconsin is building the odd numbered Littoral Combat Ships (LCS) and Austal USA is building the even numbered vessels in it's Mobile, AL facility.

Under Naval Sea Systems Command (NAVSEA), five Program Executive Offices (PEOs) are responsible for all aspects of life-cycle management of their assigned programs. This includes acquisition related matters and contracting. The five PEOs

are as follows: Aircraft Carriers, Integrated Warfare Systems, Littoral Combat Ship, Ships, and Submarines. Within each PEO there is a further division into specific program offices, such as the Virginia Class Submarine (VCS) office under PEO Submarines. Contracting for the VCS project, therefore, is conducted by the VCS program office, which reports to PEO Submarines, which reports directly to the Assistant Secretary of the Navy for Research, Development, and Acquisition. The current NAVSEA organization is shown in Figure 3.1, where the PEOs are shown in orange.

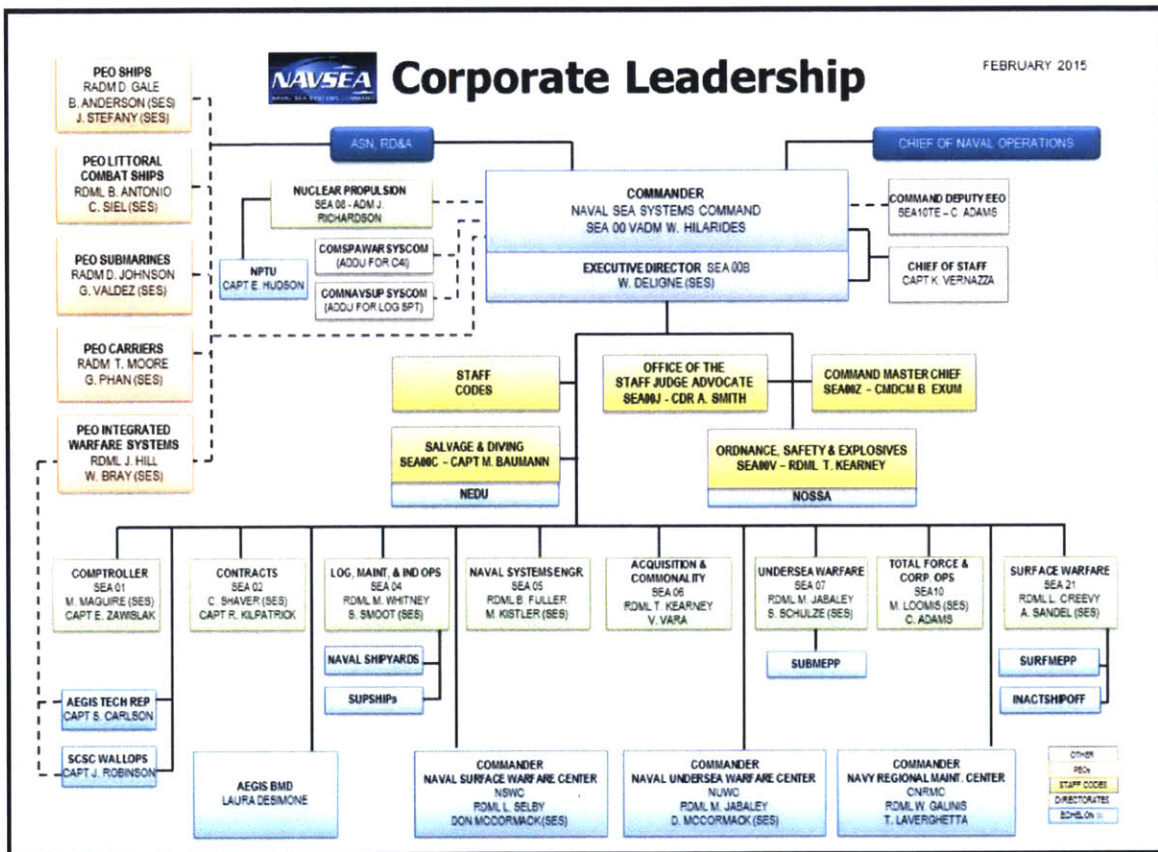


Figure 3.1: NAVSEA Organizational Flow Chart, February 2015

3.1.1 Competition in the current environment

The US shipbuilding industry is unique in that there are a relatively small number of shipbuilders. In many cases there is little or no competition when selecting a shipbuilder for a project. There is only one shipyard- NNS- that is capable of building aircraft carriers. Even when there are multiple shipyards that could be capable of building a ship, there may be only one which is able to do so based on its current workload. Likewise, this single or near single source environment continues past the prime contractor role into the subcontractor arena. For many complex ship systems or technologies there are only a handful of subcontractors that are considered. The subcontractor and supplier environments can be as important, if not more important than the prime, in determining and reducing cost.

Competition, even on a small scale, has shown to be effective at driving down costs. A former Commander of Naval Sea Systems Command relayed the example of the Main Reduction Gear (MRG) for the DDG 51 [16]. On the DDG 51 contract, GE Lynn was the MRG provider. They decided to get out of the MRG business and sold it to Philadelphia Gear. For five of the DDG 51s the MRG was contractor furnished equipment, and when the government did a cost analysis, they found that the prices for the MRGs were skyrocketing. The skyrocketing prices went unchecked because the shipbuilders were continuing to go through Philadelphia Gear who had an effective monopoly on the market. In response, the government said that they were going to compete the design for the MRG. They decided to make the MRG a government furnished item, pull them out of the shipbuilding process, and run a head to head competition for a new design. In turn, Philadelphia Gear significantly reduced the cost to stay the MRG lead supplier. The Aegis Combat System is another example of this strategy. Lockheed Martin was providing the in service

support for the Aegis Combat System and was doing so at a very high cost. The government had to take a few years to get ready to compete that support, but ended up running a competition in which Raytheon submitted an attractive bid. Lockheed Martin was forced to drastically reduce their prices in order to win back the business.

Another trend in current shipbuilding contracts is to use a technique called Profit Related to Offer, or PRO, to inject competition into single or near single source environments. High level strategies such as PRO are communicated via avenues like the Better Buying Guide, written by the ASN (RD&A) office[14]. PRO recognizes a need to maintain an industrial base, and therefore not drive out shipyards by awarding a contract to one and potentially crippling another with lack of work. Some shipyards are being sustained at a constantly critical level of work. HII, for example was awarded one of the DDG 51 restart ships, without having to compete for it, as compensation for the Navy moving DDG 1000 work to BIW, and therefore disrupting the work flow at HII. Decreasing the rate of work, or altering the flow of it, could drive the shipyard out of business. This is part of the “boom and bust” cycle negative effect described above. PRO also allows for some element of competition between two (or potentially more) shipyards that already know they are going to get some piece of a ship construction project. The basic strategy is to say that each yard will get a set number of ships, with the profit subject to some form of competition, and often there is a swing ship also up for competition.

For the DDG 51 restart program, both HII’s NNS facility and GD’s BIW were capable of building the destroyers. If the Navy had competed the contract and given all of the ships to a single yard, they would have risked jeopardizing the other, and losing the capability and learning incurred with having sustained warship production at a yard. Instead a PRO strategy was implemented and saved the Navy approximately

\$300 M over three ships, and earned the David Packard Excellence in Acquisition Award for the innovative approach[17]. Under the PRO system, the Navy had each yard submit a cost to build, vice bid, and the contractor with the lower cost to build got a more favorable profit. The profit formula for the higher bidder was calculated as follows:

$$Profit_{HighBid} = Profit_{LowBid} - .65[Bid_{High} - Bid_{Low}]$$

In order to discourage contractors for submitting unrealistically low bids in an attempt to win the PRO competition, the contract also employed a Fixed-Price Incentive structure. The shareline was set to 50-50 for cost overruns, which means that the contractor was responsible for 50% of expenses above the contracted price.

Although competition can be key for driving down costs, it has the potential to be at odds with collaboration or quality control. A former Commander of Naval Sea Systems Command explained that the contracting and ongoing project environment for nuclear projects is very collaborative due in large to the non-competitive nature of the field. This collaboration, he said, means that everyone- the government, program managers, prime contractors, and subprime contractor are all “under the tent.” The open environment has been instrumental in ensuring the strict quality control standards of the nuclear community have been upheld. Additionally, the collaborative environment is good for finding efficiencies and process improvement opportunities. Negotiations in a competitive environment have to be held at arms length to ensure fairness in competition, and as such, much of that collaborative spirit is lost. As for quality control, he emphasized that the oversight role of SUPSHIP, and other such government agencies is crucial to ensure that even in a competitive environment, that quality does not suffer. It seems clear that the

current environment in Naval shipbuilding is one with limited natural competition, but one where artificially injected competition has the potential, if used properly, to drive down costs.

3.1.2 Incentive Structures

To gain insight into how the contracting process takes place, interviews were conducted with personnel from the VCS Program Office (PMS 450), two former Commanders of Naval Sea Systems Command, and a senior contracting civilian in the office of Assistant Secretary of the Navy (Research, Development and Acquisition.) The PMS 450 group described the contract negotiations as first a gathering of government side stakeholders to decide the relevant priorities. This is when contract goals are considered, such as driving down contractor labor costs or pursuing an aggressive schedule. Different contract structures and incentives are considered in order to achieve these goals. One contracting member described the process for the VCS BLK IV negotiations: “When we were considering our request for proposal (RFP) for BLK IV, we actually gathered a group together of different stakeholders on the government side to talk about incentives, and to strategize about our incentives for BLK IV. We looked at stuff like, for example, where we were having some performance problems with one of the shipbuilders, we try to think of ways to incentivize that[18].” This strategy of tailoring incentives to individual shipbuilders is possible due to the small number of players in the shipbuilding game. Additionally, PMS 450 said that individual contractors have a big influence on what incentives are considered, and in the case of the VCS BLK IV negotiations, the government wanted to streamline the incentives available, but the the shipbuilders pushed for additional incentives to be included in the contract. The inclusion of incentives tied to specific behaviors carries with it the risk of ‘gaming,’ for example including a labor hour incentive which causes the prime contractor to sub contract out to earn the incentive,

but increase overall cost (or potentially decrease quality.) These incentives, therefore, must be carefully worded to ensure it encourages the correct behaviors on the part of the shipbuilder.

This potential for incentivizing the wrong behavior was echoed by the senior contracting civilian in the office of ASN (RD & A. [19]) He cautioned that in addition to incentives within a single contract being gamed, there is the potential for gaming between multiple contracts being executed at a single shipyard. For example, if there is a Firm Fixed Price project, and a Cost Plus project occurring at the same yard, there is a strong motivation on the part of the shipbuilder to have the Cost Plus project assume all of the overhead or excess costs. Further, if one project has a schedule incentive it could draw resources or labor away from other ongoing projects to achieve that incentive, a potentially negative effect for the government. In order to successfully structure incentives, therefore, the contracting authority needs to examine what behaviors are being motivated both by that project's contract structure, as well as by the contract structure of other ongoing or near future projects of the shipbuilder.

The ASN (RD&A) contracting expert also points out that there is a difference between an incentive contract and a contract with incentives. The distinction has everything to do with the distribution of risk. He explained that there was a necessary distinction between cost plus % overrun and cost plus % claimed. Anything other than a strict Firm Fixed Price contract can therefore be viewed as a continuum of risk and incentive, rather than as discreet contract types. For example, with the AOPS contract, the basic contract model would be considered to be a Cost Reimbursable Incentive Fee (CRIF) model, however both parties are insulated from assuming all risks with the 'Sixth Ship' structure, which is described in the AOPS case study.

Additionally, the ASN (RD&A) contracting expert pointed out that incentives are used to do more than motivate cost reductions. Incentives are also used to motivate performance metrics. In these cases relating the cost to the project (potential overrun) to the value gained by increased performance (increased effective power hours, for example) may require more scrutiny. When devising these incentives, the government needs to be ready to assume the majority of the risk, explained one former Commander of Naval Sea Systems Command [20]. He said that if the government is asking the shipbuilder to improve some known performance metric, than that means something has to change. The shipbuilder has to be in control of what is necessary to make that change in order for an incentive to be effective. If the government is unwilling to assume the bulk of the risk (meaning absorb the excess cost, or somehow change design parameters or specifications) than the shipbuilder is likely going to be unwilling or unable to meet the new performance standards, regardless of the contracted incentives.

3.2 The Tradespace Exploration Paradigm

In 2005, MIT's Adam Ross and Daniel Hastings introduced the tradespace paradigm as a way to think about systems. They defined tradespace as “the space spanned by the completely enumerated design variables, which means given a set of design variables, the tradespace is the space of possible design options[21].” The idea is to generate the tradespace using models and simulations and then to do a cost vs. benefits analysis of the options. A Pareto Front is often helpful in further examining best solutions based on optimizing a particular benefit, and the value tradeoffs that exist in the possible solutions. The tradespace analysis also allows for a shift of preferred attributes. When the utility of value changes, the plot will shift. This shift reveals which options are now better, as well as which options are less susceptible to changing requirements, i.e. which options are more robust. As the tradespace is analyzed, it is also possible to glean information about patterns emerging in the design choices.

Recent efforts have been made to create a systematic way to go about tradespace exploration. Figure 3.2 graphically depicts this process. The tradespace database is populated with possible designs and their performances with respect to different elements of a design vector. The performance is expressed in terms of “attributes, metrics of interest to, and chosen by, the stakeholders.[2]”

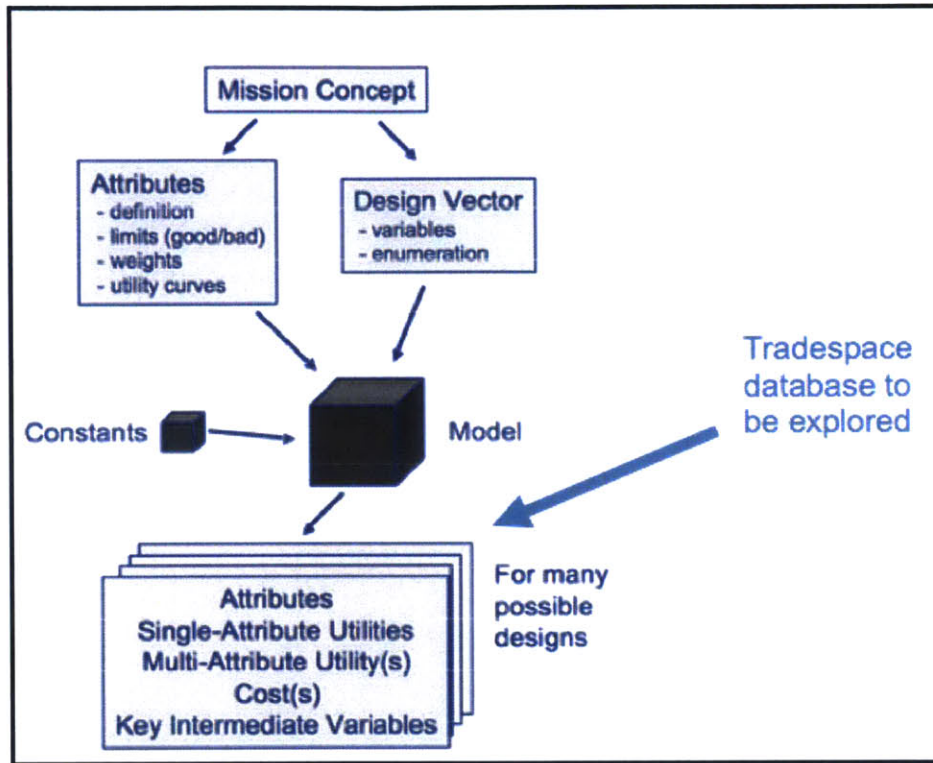


Figure 3.2: Creation of a tradespace[2]

The tradespace concept can be demonstrated using the example of ship design selection. Figure 3.3 is a graph of ship design variants[3]. The variants were generated looking at 12 key design characteristic choices, and assigning a capability and cost to each choice. For example, one choice was to have either one or two helicopters onboard. The capability score for two helicopters was 1, where as for one helicopter it was .5. The cost for two helicopters was not twice that of the cost for one, however, due to the sharing of facilities. This type of analysis was done for all 12 of the design choices and then every combination of choices was created. Each combination represents a design variant. Each variant has a capability and cost score. Those scores were normalized and are graphed in Figure 3.3. The variants in red represent the Pareto Front of the variants. After the Pareto Front was generated highlighted, the design team examined the variants to find that there were some choices that were consistent amongst all or most of the variants. These were the low impact choices.

The team could then focus on the choices that represented a greater decision in terms of cost and capability and make the appropriate choice. As Ross and Hastings described, some patterns were also evident. The upper and lower bands of variants in Figure 3.3 represent the one or two helicopter choice. This makes it obvious that the two helicopter option is always preferred.

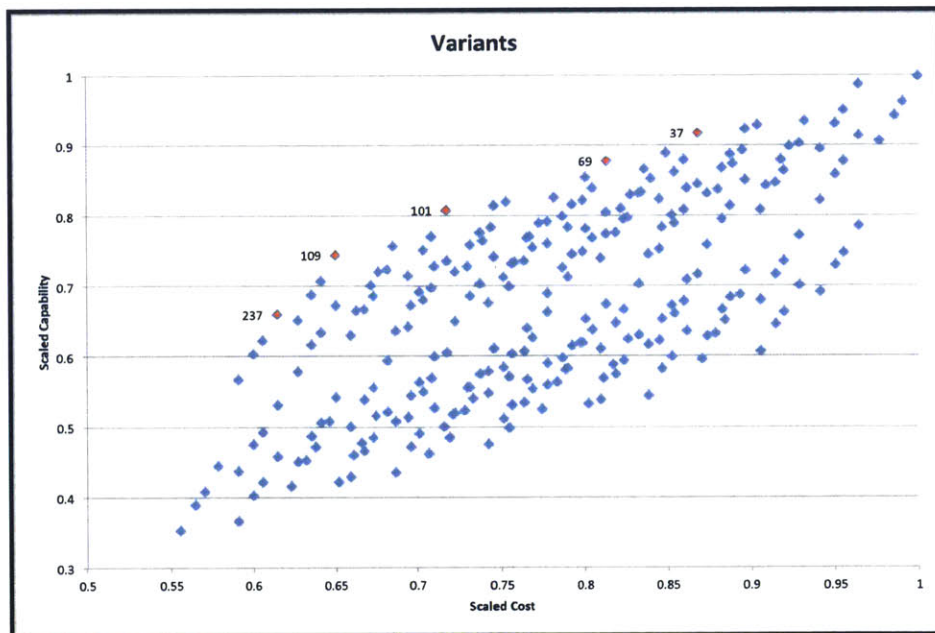


Figure 3.3: Ship Variants[3]

Ross and Hastings describe “Uncertainty” as an advanced tradespace concept. They note that uncertainty is often understood as having a negative connotation and as synonymous with risk. Instead they cite the work of Hasting and McManus for a more general framework for uncertainty management. Hasting and McManus describe the need to understand uncertainty in complex systems, such as airspace systems, “The current environment of rapidly changing technologies and markets on the commercial side, and the rapidly changing technologies, threats, needs and budgets on the defense side, has created a need for a better understanding of these

classes of uncertainties and their effects on complex airspace systems.[4].” They propose a framework for dealing with uncertainty by dividing it into four categories as shown in Figure 3.4: ‘Uncertainties’ which lead to ‘Risks/Opportunities,’ which are dealt with by ‘Mitigations/Exploitations,’ which ideally lead to the intended ‘Outcomes.’

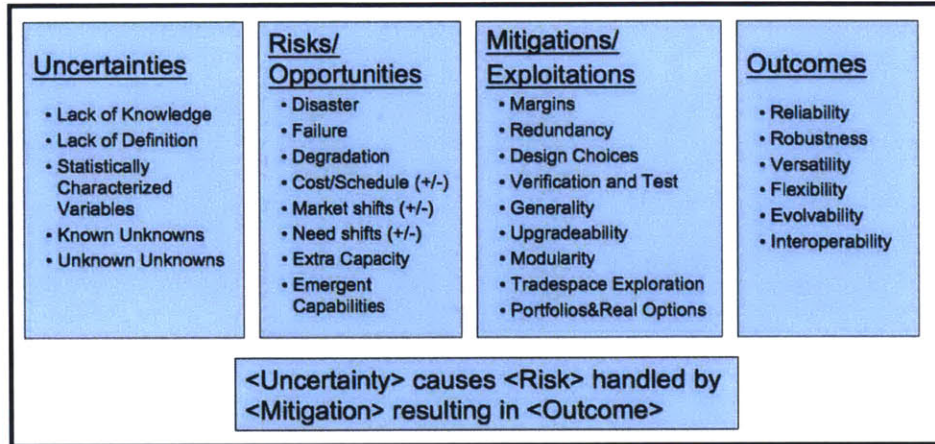


Figure 3.4: Framework for handling uncertainties and their effects. [4]

The outcomes of ‘reliability,’ ‘robustness,’ and ‘flexibility’ are of particular interest when designing shipbuilding contracts.

4 Case Studies

4.1 Virginia Class Submarine Program

4.1.1 Program Overview

The Virginia Class Submarine (VCS) is a nuclear powered fast attack submarine. The program began in the mid 1990's, with construction on the first submarine, the USS Virginia, which was commissioned in 2004. The program was, in part, a response to the over budget, and subsequently canceled, Seawolf program. The VCS program was to reduce the cost from the \$2.8B spent per ship for Seawolf, to \$1.8B. Reductions in price were to come from using commercial off the shelf (COTS) parts as well as improvements in shipbuilding technology. It was originally intended to be a class of 30 ships, and thus far 11 have been commissioned. Each submarine is expected to make 14-15 deployments during a 33 year service life. Figure 4.1 displays the USS John Warner which is expected to commission in September 2015.

The VCS program has been lauded as a fiscal success. The VCS program office has received the David Packard Excellence in Acquisition Award in 1996, 1998, 2008. The award description in 2008 explains that the program office has, since its initiation, “embraced the principles of acquisition reform, and having reduced its total program costs since September 2005, and returning \$48M in FY08-09 Ship Construction Navy funding as a result of improved construction performance.” and that “cumulative savings over the remaining 20 ships will exceed \$3B (FY05\$)[22].”

This success story, however, was not without struggle. From the beginning of the program in the mid-1990's to the present, the total amount of money required to fully fund the construction and delivery of the 30 submarines grew by about one third

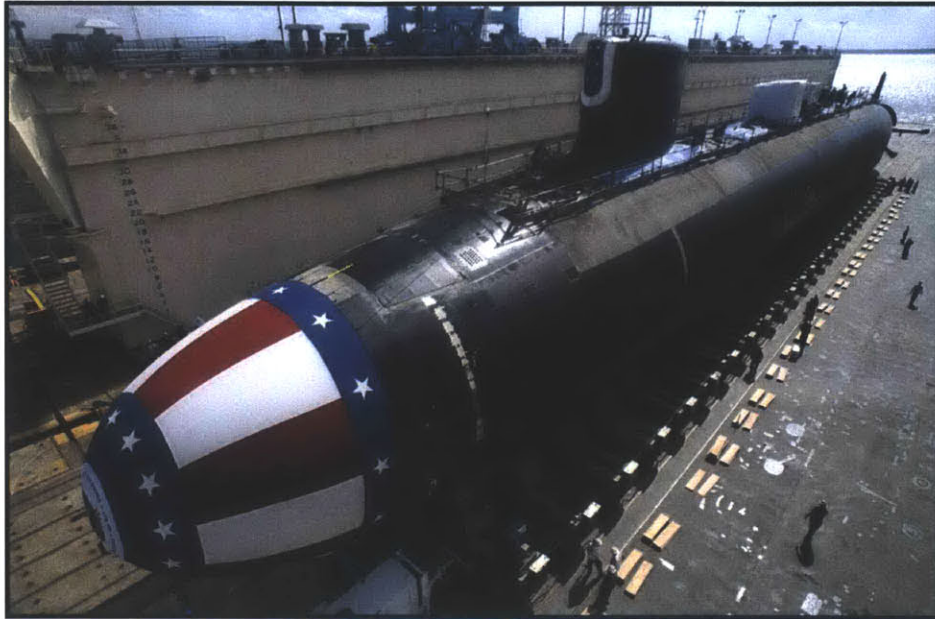


Figure 4.1: Virginia-class submarine Pre-commissioning unit (PCU) John Warner (SSN 785) in dry dock at Newport News Shipbuilding. [5]

[23]. There were several reasons for the cost growth including unexpected material cost growth, and under predicted inflation growth. Additionally, the original plan was to build all of the submarines at a single yard, but in an effort to retain a healthier nuclear shipbuilding base, Congress passed a law requiring both Electric Boat and Newport News to each build parts of every submarine. This problem was compounded when the production rate went from the planned two per year to one per year. The program had originally intended to switch from building one submarine per year to two submarines per year in 2002, but the projected costs were prohibitive and the move to two per year construction was delayed until 2011. Delaying the build increase from one submarine per year to the planned two, meant that the overhead costs were not split and therefore the costs per submarine rose. The reduction in planned work threatened the long term industrial base at both yards and it risked a reduction in the design base capability. Operating below capacity at a shipyard causes a degradation of learning curves, and overall experience. Finally, the reduction of production from the planned two per year to one per year threatened the support

of national security requirements. The VCS program office took steps during that time which enable the cost reduction necessary to resume the plan for two submarine per year construction.

The major push for drastic cost improvement came in September 2005 at the National Defense Industrial Association’s (NDIA) annual Joint Undersea Warfare Technology Conference [6]. Chief of Naval Operations Admiral Michael Mullen announced that the cost of the VCS needed to be reduced to \$2B per submarine (FY05\$) [24]. Both the program office and General Dynamic Electric Boat (lead contractor) went to work to figure out how to reduce costs. Electric Boat hired consulting firm Booz Allen Hamilton to help identify areas for change. Booz Allen developed an approach to Design for Affordability called ISSR- Inherent, Structural, Systemic, Realized, as is visually depicted in Figure 4.2[6]. The cost reduction approach included design,

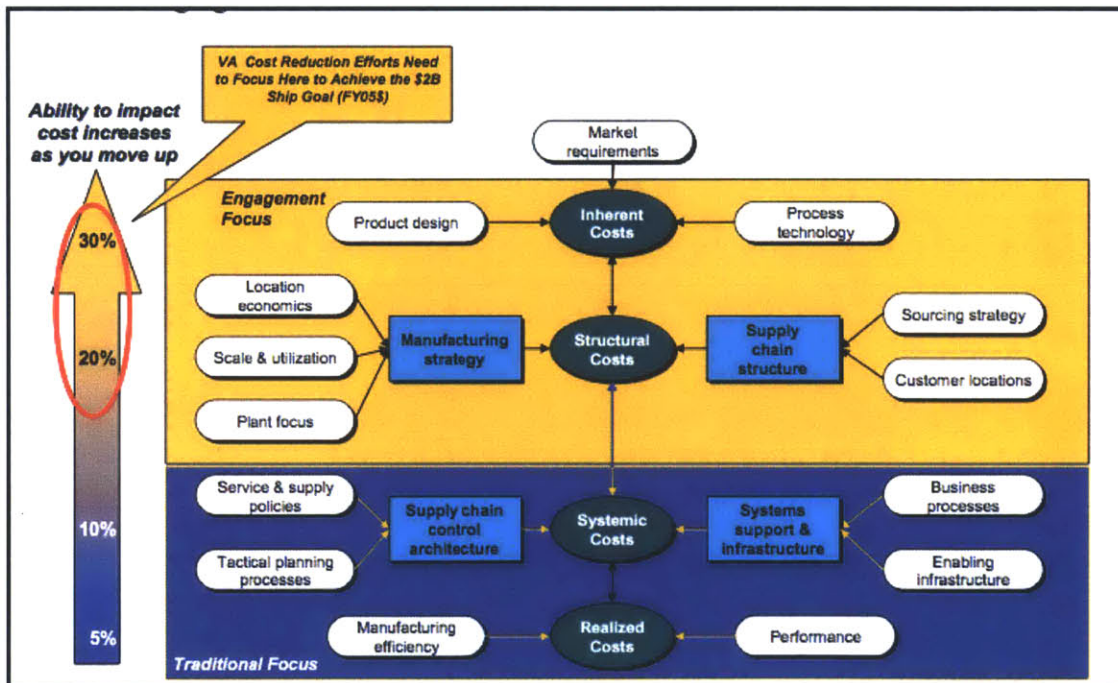


Figure 4.2: ISSR Framework for Virginia Cost Reduction[6]

cycle time, acquisition and sourcing, organizational structure and labor efficiency.

Specifically, Electric Boat was to: determine the cost drivers from construction costs to date, develop target costs, develop a cost framework to guide decisions about cost reduction efforts and establish a plan to integrate and implement these efforts[6]. They presented their findings to the the VCS program office, and by early 2006 a new plan was approved.

The VCS program office reduced costs via a three element strategy. Figure 4.3 visually depicts this strategy [6]. The first of the three cost reduction elements

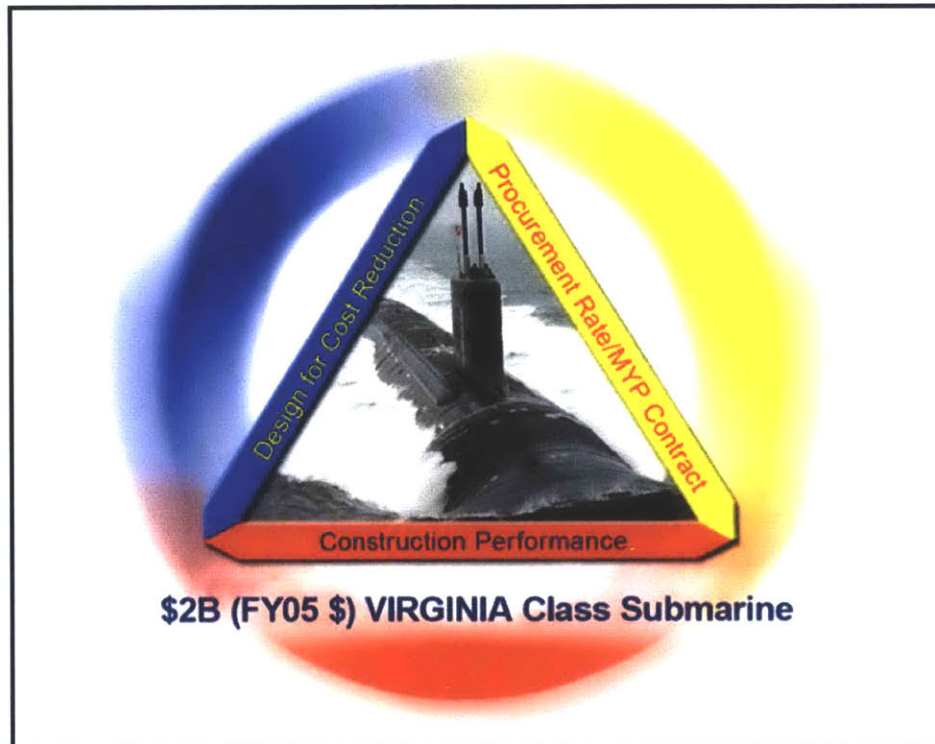


Figure 4.3: Virginia-class submarine Three Element Cost Reduction Strategy [6]

was to design for cost reduction. Portions of the submarine were redesigned to reduce component and constructions costs. The requirement, however, was that each design change was “capability neutral,” meaning that the performance could not be compromised in an effort to reduce costs. The Booz Allen Hamilton recommendations

identified hundreds of design changes, of which 135 were implemented[6]. The torpedo room was electrified, for example, and the approximately 65 hydraulic actuators were replaced with electromechanical parts resulting in a \$3.2M (FY05) savings per ship for the FY12 ships [25].

The second element was to improve construction performance. Specifically, the construction timespan was to be reduced from 84 months to 60 months. One of the ways in which the VCS program office was able to do this was through the Capital Expenditure (CAPEX) program which allowed both shipbuilders to submit business cases for infrastructure and facility upgrades that would result in cost savings. If the program office approved the business case, the Navy funded the first half of costs, and the second half of costs was funded once the cost savings were proved. The \$91M in CAPEX improvements under the Block II contract saved \$400M in acquisition costs, a better than 4 to 1 return on investment [23]. Figure 4.4 shows some of the CAPEX projects under the Block II submarine special incentive clause.

The construction costs were also improved by better streamlining some build and test procedures. Notably the previous submarine construction of ten modules was reduced to four super modules resulting in significant time savings. The cost savings from the first two strategy elements totaled \$200M per submarine, or half of the reductions necessary to get the cost per submarine to \$2B (FY05\$) in FY2012. Figure 4.5 shows the Virginia Class Glide Slope to reap savings from the construction and design savings to reduce cost to \$2B per submarine by FY 2012.

The final element in the three element strategy was the multiyear procurement (MYP) with economic order quantity (EOQ) material in order to achieve labor and material rate benefit. The Block II contract included a clause which allowed, with Congressional approval, the transition from a block buy to a multi-year procurement

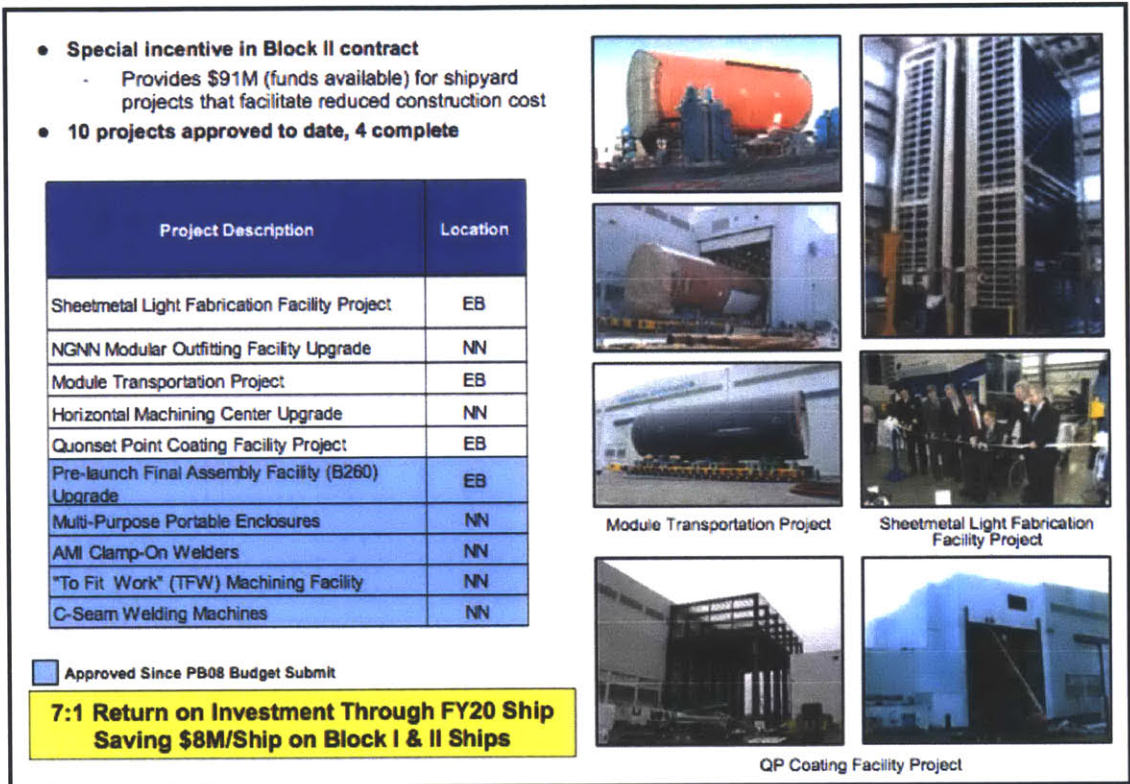


Figure 4.4: CAPEX Projects under Block II VCS [6]

commitment. When the approval was granted, that commitment resulted in further savings. Increasing the production rate to two per year allowed overhead costs to be spread over twice as many submarines and increased efficiencies associated with a better learning curve for the workforce. Both the government furnished equipment (GFE) and the contractor furnished equipment (CFE) saw cost savings with the increased production [6]. The MYP contract EOQ resulted in the projected additional \$200M per ship savings for the Block III submarines, in order to achieve the target price of \$2B per submarine (FY05\$.)

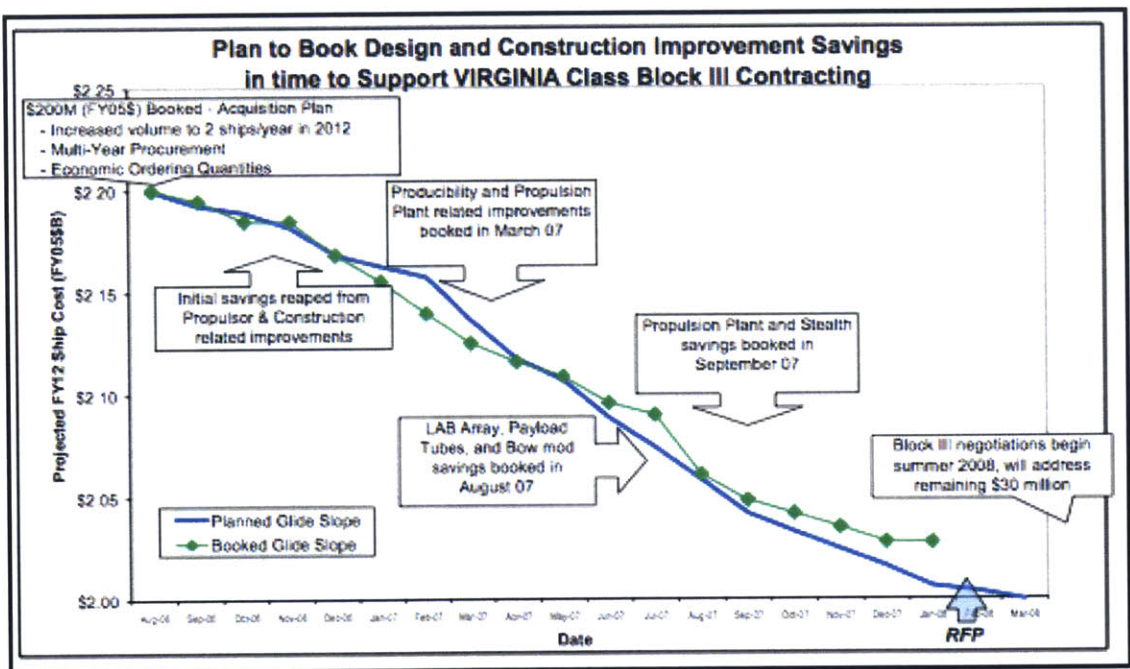


Figure 4.5: Virginia-class submarine Glide Slope [6]

4.1.2 Contracting Process

As the VCS program office worked with Electric Boat and Newport News to reduce program costs, the block contracts evolved. As was previously discussed, Block II included new incentives, such as CAPEX, to help get the project moving in the right direction. As the program office and contractors gained experience, the contract structure and language also matured with the Block III and IV contracts. An interview with VCS contracting personnel illuminated the negotiation process and how it changed over time [18].

For the Block II contract, the VCS program office wanted to target specific cost saving performance in the areas of material, labor and total cost. To do this, five special incentives were included. The contractor could earn three of the five offered incentives: labor cost, material cost, total cost, schedule, and CAPEX. The total pool of money allocated for special incentives equated to earning three of the five. The addition of CAPEX and schedule incentives were included to incentivize the contractor to make improvements in order to become more efficient in the construction.

As time went on with the Block III contract, the program matured. The program office felt that the labor and material incentives were no longer needed, but the other three were kept. Additionally, the way the CAPEX incentive was treated also changed. In the Block II contract the shipbuilder submitted a business case for the project and the Navy reviewed it, and if accepted, the project was funded the first 50%. Then when the savings were proven, the second half of the funding was approved. Under the Block III contract, the program office used a net present value, or cash flow, model. Under this model the incentive money paid was tied to the

shipbuilder's corporate hurdle rate of return. The program office recognized that if a project didn't meet this hurdle rate the shipbuilder would have no reason to take on the project, as it would destroy shareholder value, even if it was long term beneficial to both the government and the ship builder. If the approved project would result in a net present value of less than \$0 for the shipbuilder, the government is authorized to award a special incentive to achieve the pre-documented corporate hurdle rate for that specific ship builder. This change to the CAPEX incentive program was continued into the Block IV contract structure.

When it came time to negotiate the Block IV contract, the VCS program was much more mature. To tackle the new contract writing, the program office enlisted the help of other government stakeholders to devise a contract strategy. The group wanted to streamline the incentive process to remove the possibility of gaming the incentive system. The rationale was that if the shipbuilder controlled the labor and material costs, for example, that savings would be reflected by an advantageous shareline split and an additional incentive was not needed. The program office, therefore, wanted to remove all incentives with the exception of the CAPEX program, and to use the shareline as the the only "incentive" for good performance. The shipbuilders pushed back and wanted to keep the previous incentives, presumably because they become more proficient at earning them. In the end the Block IV contract included the CAPEX incentive structure as well as a schedule centered incentive called the "Module Delivery Challenge." Previous schedule incentives were tied to gates such as individual module deliveries and total ship delivery. The Module Delivery Challenge is an effort to reduce the construction span by having much shorter duration incentive timeframes.

The Block IV contract is also different in its ship award structure. Both General

Dynamics Electric Boat and Huntington Ingalls Industry Newport News Shipbuilding build Virginia-class submarines, but Electric Boat is the prime contractor and Newport News is considered a major subcontractor. When the request for proposal (RFP) went out for the Block IV contract of 10 ships there were two options considered: an even five-five split, and an uneven six-four split. Ultimately, the option that was the cheapest and won out was the uneven six-four split with Electric Boat delivering the larger number. Electric Boat was a major driver of improved cost and schedule performance in the first two blocks and continued those efforts in the Block IV boats. They worked out a deal with Newport News, that was later codified by the program office with contract modifications, where Newport News could “win back” the fifth ship. The provisions of the ship were divided into three gates that had to all be met. They were:

1. Newport News Labor Hour Variance on all Block III Hulls are less than or equal to 2.5M hours.
2. Newport News delivery hours on 787 are less then or equal to Electric Boat hours on 786 plus 100.
3. The estimated cost of Newport News delivery on 801 (the tenth Block IV boat) is less than the Electric Boat delivery cost estimate.

If all gates are met, the shipbuilders can submit a request to the Navy by March 15, 2017 for reassignment. While this new strategy did not originate with the program office, it has the potential to save the Navy acquisition cost and earn the ship builders increased shareline profit for overall cost reduction. The unique structure of the deal artificially injects competition into the otherwise non competitive environment in much the same way the Profit Related to Offer (PRO) contract structure does.

The use of special incentives across the three contracts is shown in Table 4.1. As

Table 4.1 shows, the structure of the incentives changed from Block II to Block III, but the total amount available in special incentives remained fairly constant on a per ship basis. As would be expected, as performance increased, and the program matured, less total incentive money was needed in the Block IV contract to keep the program on track.

<i>Average Available per Ship</i>	<i>Block II</i>	<i>Block III</i>	<i>Block IV</i>
Max Labor Incentive	\$21,997,598.00	N/A	N/A
Max Material Incentive	\$15,511,020.60	N/A	N/A
Max Schedule Incentive	\$15,511,020.60	\$14,319,221.38	\$17,919,073.50
Max Total Cost Incentive	\$15,511,020.60	\$14,139,393.88	\$9,005,745.00
Max CAPEX	\$18,855,084.20	\$21,658,659.38	\$10,366,350.80
Max Total Incentive Available	\$46,533,062.80	\$50,117,274.63	\$37,291,169.30

Table 4.1: Special Incentive \$ Available in VCS contracts

4.2 Canadian Shipbuilding: A Study in Risk Quantification and Distribution

The Canadian National Shipbuilding Procurement Strategy (NSPS) represents a significant change in the way that Canada does shipbuilding. The NSPS streamlines the shipyard construction options in an effort to focus efforts on long term industry growth and sustainment via a select few large shipyards vice a multitude of smaller yards subject to a boom and bust cycle of infrequent work. The process by which shipyards were chosen under the NSPS gives insight into how the government of Canada evaluated and quantified risk.

Once a shipyard was chosen to build Canada's combatant ships, the contract negotiations started for the first of those vessels to be built- the Arctic Offshore Patrol Ship (AOPS.) The final build contract for the AOPS was signed in late 2014. The contract negotiation process for the AOPS also focused heavily on the distribution of risk between the government of Canada (customer) and Irving Shipbuilding (the shipbuilder/contractor.) New insights on ways to quantify and distribute the project risk emerged from those negotiations.

4.2.1 NSPS Bidding Process

The Canadian National Shipbuilding Procurement Strategy (NSPS) was announced in 2010 as an initiative to "foster the development and sustainability of Canada's shipbuilding industry.[7]" The idea behind the NSPS was to divide major shipbuilding into two packages: a combatant work package and a non-combatant work package. The combatant work package includes construction of 6 Arctic Offshore Patrol Ships and 15 Canadian Surface Combatants. The non-combatant work package includes Joint Support Ships, an icebreaker, and some science vessels. The NSPS was to

select a single shipyard for each package in order to achieve stability and growth in the shipbuilding industry. In early 2011 a Request for Proposal (RFP) went out for both work packages.

The RFP stipulated terms under which the shipyards could bid and be evaluated for the two work packages, and provides some insight into the goals and concerns of the government. If selected for one of the two work packages, the winning shipyard would have to agree to the following:

1. Build all ships in Canada. (to include fabrication of the hull, decks, superstructure, masts. Any modules making up those items, whether completed, unassembled, disassembled, unfinished or incomplete, will be conducted in a facility in Canada and that the vessel will be assembled in Canada.)
2. Agree to meet a Target State. (outlined in the RFP, and mainly deals with shipyard facilities and productivity metrics)
3. Allow free third party access to its premises to be periodically (every 2-3 years) benchmarked against an established Target State and to accept the results of the benchmarking.
4. Comply with Canada's Industrial and Regional Benefits (IRB) policy which requires prime contractors to undertake business activities in Canada valued at 100% of the contract value, thereby ensuring a dollar for dollar investment in the Canadian economy.
5. Agree to a Value Proposition obligation of .5% of the Contract Price, to be spent furthering the long term growth and sustainment of the Canadian maritime industry. The plan for how to spend the money and manage the program were evaluated as part of the NSPS bidding process.

In addition to those stipulations, the shipbuilders competing for the work packages had to provide a long list of information to the Canadian government. That information was scored and used to evaluate the perspective shipbuilders. The five main evaluation areas used to score and rank the shipyards were:

1. Mandatory Requirements (listed above, all must be met to be considered in the bidding)
2. Shipyard's Current State and Plans
3. Cost to Canada for Upgrades and Improvements
4. Shipyard's Financial Situation
5. Value Proposition

The latter four categories were scored according to a given formula and the scores were used to select the winning shipyard. The categories were not weighted equally, and Figure 4.6 depicts the point breakdown. From this graphic, it is clear that the current state and plans for the shipyard was the area of greatest concern for the government. The two winning shipyards both wanted to score maximum points in these categories. To do this, they agreed to fully modernize the yards to world class benchmark standards and to not charge the capital expenditure to the government of Canada, including depreciation. The result was two modern shipyards upgraded at no cost to Canada, and therefore the cost per ship to Canada of ships built at these yards is lower.

The current state and plans for the shipyard involved an evaluation an independent third party- First Marine International (FMI). FMI established a "Target State" across a number of different areas, called benchmarking and capability groups, and evaluated where these shipyards stood in relation to that target state. The shipyards then had to submit a plan for achieving the target state, if not already there. What

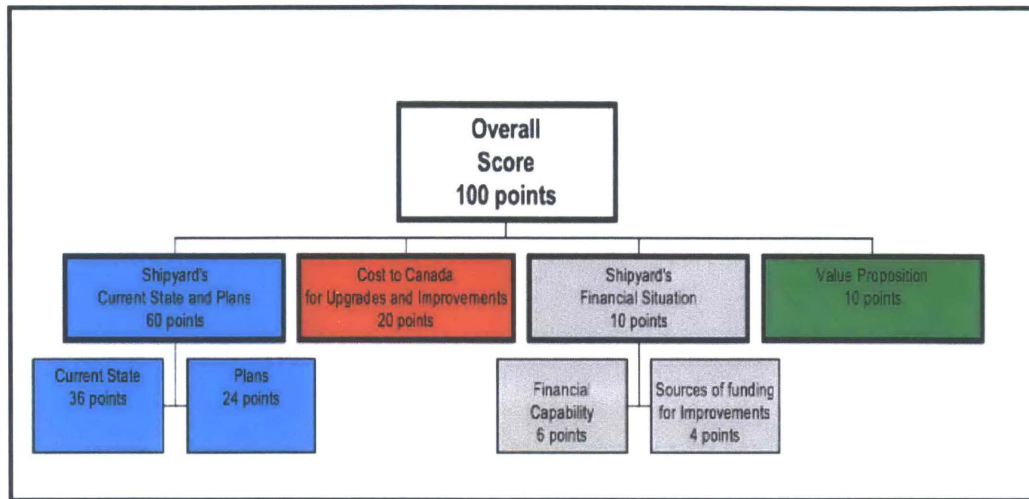


Figure 4.6: NSPS Shipyard Selection Framework [7]

is interesting about this process, is how the government assessed the risk of not achieving the target states. For each element, a probability of failure and an impact of failure was assessed. These two variables make up the x and y axis of Figure 4.7.

Impact of Failure	Severe	Significant	High	High	Very High	Very High
	Major	Medium	Significant	High	High	Very High
	Moderate	Low	Medium	Significant	Significant	High
	Minor	Low	Low	Medium	Medium	Significant
	Insignificant	Low	Low	Low	Medium	Medium
		Rare	Unlikely	Possible	Likely	Almost Certain
		Probability of Failure				

Figure 4.7: NSPS RFP Risk Matrix [7]

The impact of failure for each benchmark and capability group was given in the RFP. Figure 4.8 gives the Impact of Failure Qualifiers for these groups. Group F, Design Engineering and Production Engineering is further broken down later in the RFP.

Finally, comes the task of evaluating the probability of failure. The probability of failure of shipbuilder plans reaching the target states for a particular element

Benchmarking Groups	“Impact of Failure” Qualifiers
A. Steelwork Production	Major
B. Outfit Manufacture and Storage	Major
C. Pre-Erection Activities	Severe
D. Ship Construction and Outfitting	Severe
E. Shipyard Layout and Environment	Severe
F. Design, Engineering and Production Engineering	See Annex C
G. Organization and Operating Systems	Major
H. Human Resources	Major
I. Purchasing and Supply Chain	Moderate
J. Marketing	Minor
K. Performance Improvement	Major
Capability Groups	“Impact of Failure” Qualifiers
A. Structural Production	Severe
B. Outfit Manufacturing	Severe
C. Storage and Logistics	Severe
D. Ship Construction and Outfitting	Severe
E. Facilities	Severe
F. Design, Engineering and Production Engineering	See Annex C
G. Organization and Management Systems	Major
H. Human Resources	Major
I. Purchasing and the Supply Chain	Severe
J. Logistics Support	Major

Figure 4.8: Impact of Failure Qualifiers [7]

were determined after looking at Resource Considerations, Schedule Considerations, and Performance Considerations as are listed in Figure 4.9. After evaluating the considerations for each element the probability of failure is assigned a value of ‘rare,’ ‘unlikely,’ ‘possible,’ ‘likely,’ or ‘almost certain.’ With the x value (the probability of failure) and the y value (the impact of failure) determined, Figure 4.7 is used to determine a Risk Qualifier.

The Risk Qualifier is then transformed into a Risk Coefficient for calculation purposes, as shown in Figure 4.10. The coefficients for each element are added and normalized and a final score is given to each shipbuilder.

Resources Considerations	Schedule Considerations	Performance Considerations
Facility Management	Realistic Scheduling	Legal Requirements
Business Planning	Project Sequencing	Physical Constraints
Design and Engineering	Investment Phasing	Sub-Contracting
Material Management	Scheduling Contingency	Training and Education
Production Management	Key Approvals	Communications Plan
Skilled Labour	Concurrent Activities	Marketing
Quality Assurance		Customer Satisfaction
Cost		Metrics and Measures
Equipment Supply Chain		
Infrastructure Environment		
Information Systems		
Integrated Logistic Support		

Figure 4.9: Probability of Failure Criteria Considerations [7]

Risk Qualifier	Risk Coefficient
Low	0.35
Medium	0.56
Significant	0.67
High	0.91
Very High	1.00

Figure 4.10: Risk Coefficient Conversion [7]

4.2.2 Arctic Offshore Patrol Ship Program Overview

The Canadian Arctic Offshore Patrol Ship (AOPS) is a small, multipurpose, ice-capable ship. The 6500 tonne, 103.6 meter long ship design is based on existing ship technology. It is capable of providing an increase in Canadian presence in the the Arctic region and operational capability further into the season between June and October.

The AOPS concept definition started in 2007 when it was announced that Canada would purchase six to eight Polar Class 5 ships, meaning they would be capable of breaking ice in the Arctic. At the time, the budget for AOPS was set to \$3.1B. The design was to be based on the Norwegian Svalbard class. In 2011, Irving Shipbuilding Inc. in Halifax, Nova Scotia was announced as the AOPS shipbuilder as part of the National Shipbuilding Procurement Strategy (NSPS). In December of 2014 the final



Figure 4.11: AOPS design[1]

build contract for the the AOPS was signed between Irving Shipbuilding and the government of Canada. The final contract reflected a budget increase to \$3.5B, with the build contract worth \$2.3B and the additional funding from the Department of National Defense's accrual envelope. The build contract is for six ships, with a guarantee to build five ships. Should costs increase to the point where they would exceed the established ceiling cost, then the program will complete at five ships vice six. Construction of the AOPS will begin in 2015, and the first ship is expected to deliver in 2018. Irving Shipbuilding is currently undergoing major shipyard construction and improvement effort exceeding \$350M to prepare for the AOPS program. Irving Shipbuilding secured a \$260M construction loan from the Province (separate from the build contract) to make the improvements. The loan is interest bearing and has provisions for balance reductions if certain employment targets are met.

As part of the NSPS, Irving Shipbuilding Inc. was chosen as the sole shipyard for all large combatant ships. NSPS was announced in 2010 in an effort to revitalize Canadian shipbuilding. The concept was to select a single shipyard for large combatant work and a single shipyard for large commercial shipbuilding and in this way avoid the "boom and bust" cycles of shipbuilding. After a competitive bidding process,

Irving Shipbuilding won the bid for the large combat shipbuilding work, and with it the chance to build the AOPS, and then the Canadian Surface Combatant (CSC.) The CSC is expected to be an even larger project in terms of scope, number of ships, and budget than the AOPS. Part of the NSPS, 1/2% of all contract cost (paid by the shipbuilder) will be invested to further the future of the maritime industry in Canada. Additionally, there are provisions to incentivize and require a certain amount of work to be done in Canada and by Canadian vendors. Unlike the United States, Canada does not have a Jone's Act or equivalent, but the goals of the NSPS are similar.

4.2.3 AOPS Build Contract Process

After months of negotiation, the final build contract for the AOPS was announced on January 16, 2015. Irving Shipbuilding leadership characterized the negotiations as “Interest-based” vice “Position-based.” This means that both sides focused on the “why” behind the figure, and then translated those interests into contract terms and conditions vice either side coming to the table with a fixed figure or structure in mind. Irving shipbuilding leadership describes the evolution of the contract structure as an innovative and new approach, born out of spending time with the customer (Canadian government) and understanding what was important to them. An interview with the President of Irving Shipbuilding, conducted in January 2015 provided enormous insight into the contracting process. In reference to the overall contracting approach, “It came from understanding the customer and what they wanted. They were really focused on being able to contain cost, and get a guarantee that they would get something. You could have a cost reimbursable incentive fee (CRIF) contract and go through all the cost and deliver no ships at the end. That’s an extreme example, but they [Canadian government] couldn’t be in that position or explain to the public that was even a remote possibility.[16]” Ultimately the contract

was a blend of fixed price and cost plus contract architectures that balanced both sides' need for risk mitigation.

An interesting insight came from examining the contract negotiation process from the perspective of the shipbuilder vice the government. From the government's perspective the focus tends to be getting the right product, for the right price, at the right time. For the shipbuilder there are other concerns. The President of Irving Shipbuilding Inc. explained how important the "T's and C's," or terms and conditions, were to the contract negotiation. Here, he said, is where they spent a majority of negotiation time. The terms and conditions include things like insurance, indemnity, warranty, and intellectual property clauses. These items all come with an associated cost and risk. Insurance is a big issue in Canada where, unlike the United States, the government of Canada is not self insured. Irving Shipbuilding had to seek outside, private insurance. This insurance is not cheap, and the Insurance limits, deductible, coverage, and fee for managing the insurance program is part of the negotiation. The intellectual property clause can be a sticking point, for example, if the government demands all intellectual property associated with the design of the ship, and one of the subcontractors or strategic partners of the main contractor are adverse to that clause. During the AOPS negotiations, this was an issue. As the president explained, when speaking about intellectual property there are two types: Foreground and Background. Foreground is all of the discovery and intellectual property associated with the execution of that specific contract. Background is all of the trade knowledge and product that it took to get to the point where they are starting the contract. It is, in his words, the "secret sauce" of the company. As an example, if MAN Engines is supplying the diesel engines for the AOPS then the foreground property is all of the tech specs and manuals associated with the specific diesel engines for AOPS. Background is all of the technology advances and

research that the company has in making engines. The government of Canada was very concerned with retaining all of the intellectual properties rights associated with the AOPS, especially as it pertained to items for the eventual maintenance contracts. Irving Shipbuilding agreed to flow all intellectual property they acquired to Canada. The problem was that the government also wanted them to impose this agreement on all of the vendors and subcontractors working with Irving for all hardware AND software. This would mean that the government would have all of the intellectual property for Microsoft Windows, if that operating system existed on the ship. It simply wasn't going to happen. It took some time to hammer out the final details and make sure that the solution was executable and satisfactory to each side.

5 Model of a Contract

The transition from a qualitative understanding of the contracting process to a contract architecture and then to a quantitative model was a challenge. The design variables and attributes of the architecture came from the previous research and interview insights into the US shipbuilding industry. This qualitative understanding was essential to understanding what quantitative aspects should be included in the contract tradespace, especially as it pertained to drawing the boundary between contract architecture and acquisition strategy. The challenge was to limit the scope of the contract architecture tradespace enough that it can be mathematically modeled, but not so much as to oversimplify and therefore degrade the value of the model.

5.1 Contract Mission Concept

Using the Tradespace Paradigm previously described, the contracting tradespace can be defined by first defining the mission concept of a contract. From this mission concept flow the Attributes and Design Variables which, along with constraints, are inputs to the quantitative model. Figure 5.1 graphically depicts the contracting mission concept. Here, the design variables are shown as elements of the contract concept. They are: Basic Contract Structure, Incentives Used, Terms and Conditions, Risk Sharing, Long Term Concerns and Other Program Tools. Long Term Concerns, Terms and Conditions, and Other Program Tools are depicted here to show that they are present in the contract concept, but will not be modeled for consideration in the tradespace analysis. The attributes by which to evaluate the contract designs are represented in the Contract and Customer Concerns blocks.

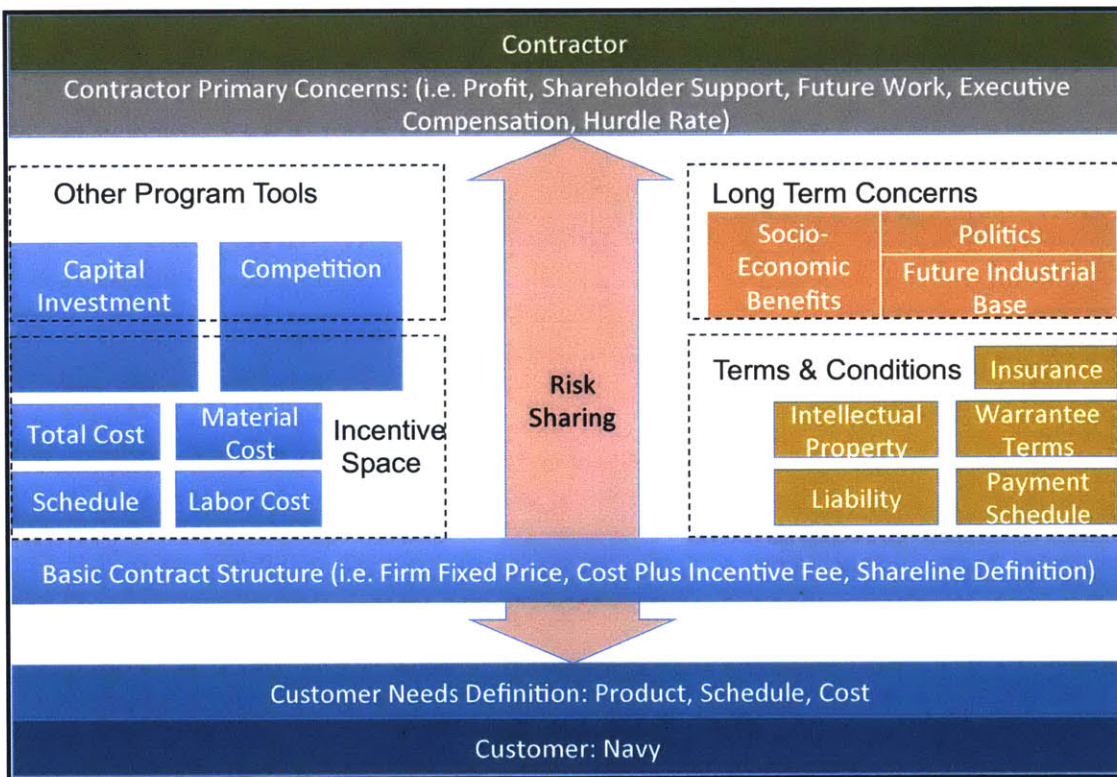


Figure 5.1: Contract Concept

5.2 Design Variables

5.2.1 Basic Contract Structure

In the contracting process, the design variables are the elements of the contract. They start with the definition of the basic contract structure. Here the contract architect chooses whether the contract will be a firm fixed price, cost plus incentive fee, profit related to offer (PRO), etc. The architecture chosen will generally focus the overall structure of the contract and usually dictate which elements are present. A firm fixed price (FFP) contract architecture, for example, typically includes a target cost and target fee, and possibly a shareline definition (although a true FFP does not have a shareline, just a fixed price.) It may or may not include other incentives and provisions. A cost plus incentive fee (CPIF) contract, sometimes referred to as a cost reimbursable incentive fee (CRIF) will also often include a shareline definition, but may rely much more heavily on an incentive fee structure to motivate behavior. The penalties associated with cost overruns on the shareline definition (from the perspective of the contractor) may also be less than in the FFP contract since the CPIF structure assumes a less reliable target price. A CPIF model, unlike the FFP model, will not usually have a ceiling price associated with it. Since the model is designed as having customizable modules, it is able to be adapted. The PRO contract architecture, as was discussed earlier, is less about the specifics of the contract, and more about an acquisition strategy tied to injecting competition in an otherwise single or near single source environment. For this reason the PRO architecture was not specifically modeled. There is not a rigid definition for what constitutes a CPIF contract vice a FFP, but rather those titles refer to a spectrum of contracting options. For example, it is rare that there is really a firm fixed price, without some contingency for under runs and overruns. It is, therefore, less important to label the contract as a certain type, than it is to adjust the design variable to best fit the project.

The shareline definition is an important aspect of the design variable specification. The shareline definition is one way for the two parties to decide on the distribution of risk in the contract. It also reflects the level of confidence in the target price. As the VCS program matured, and the government gained confidence in the cost performance of the ship builders, they moved towards streamlining the contract language towards the shareline as the main incentive driver. The shareline is the amount that each party is responsible for if the cost is above or below the target cost. This percentage can be, but does not have to be, the same for cost overruns and under runs. The definition of the shareline in conjunction with the target cost, can have one of the largest single impacts on contractor motivation. The basic model includes a single inflection point for the shareline (at the target cost,) but several inflection points are possible. From speaking with contracting professionals at NAVSEA, it is common to have regions of zero slope along the shareline in addition to inflection points of slope changes.

A ceiling price may also be defined above which the contractor is wholly responsible for the cost overrun. A ceiling price may be a hard ceiling, or may be one where the contractor comes back to the customer to renegotiate terms. This can be a place where those variables not modeled, such as politics or future industrial base, are important. There have been some cases where cost overruns have been so bad that the customer (government) has had to pay the contractor for large overruns, just to get the project completed. This was the case in the early 90's with the AOE-6 class of ships. NASSCO San Diego was contracted to build 4 ships of the class, but encountered problems during construction, most specifically with one of there subcontractors- Cincinnati Gear. Cincinnati Gear was contracted to build the reversing reduction gear, but problems with the design and manufacture of this

product lead to large delays and cost overruns on the overall construction projects. Ultimately NASCCO claimed that the overruns were beyond their control, that there were close to filing Chapter 11 under their current projections, and that the reduction gears should be government furnished equipment (GFE) and renegotiated under a separate contract. The government had little choice at that point than to renegotiate the GFE contract and to continue to fund the NASCCO construction in order to finish the project. The fourth ship was canceled and the money reallocated to finish the first three. Clearly in this situation it was not the construction of the original contract that drove the money allocation, nor was the original ceiling price enforced.

The basic contract architecture depends largely on the nature of the project. Typically projects with low technical and industrial risk are compatible with the firm fixed price (FFP) contract structure. This is because there is good historical precedent for what the cost and schedule of the project should be. The Virginia Class Submarine (VCS) program, for example, is a FFP contract structure since the program and construction process are both mature. Conversely, the AOPS program has a high degree of industrial risk since the facilities, people and processes are all new. The design, while low in technical risk, is also new. For these reasons, the AOPS build contract is a Cost Plus Incentive Fee structure. In the CPIF structure for AOPS risk is shared between the two parties in ways that are additional to the strict shareline structure with a firm ceiling price for five ships but shareline incentives to reduce costs to allow for building a sixth ship at the ceiling price. In both cases the label of the contract, FFP or CPIF, is not as important as the specific clauses of it.

5.2.2 Incentive Space

The incentive space is where the two parties can really tailor the contract structure to the specific project. As was the case in the VCS contract blocks, the focus of

the project and areas for improvement may change over time, causing a change in the incentive structure from block to block. The shareline incentive may be the only incentive above the negotiated contractual profit, or may be used in conjunction with other incentives to motivate contractor performance. Incentives may be focused on cost reduction in a specific area, overall cost reduction, schedule performance, or on some other performance metric. The VCS program office was able to effectively use the labor and material incentives in the Block II contract to motivate contractor performance in these areas. It is important to note, however, that these incentives were not randomly chosen. They were a result of the program office's investigation into where the costs were, and where they could be improved. Outside consultant firms like Booz Allen Hamilton and A.T. Kearney were used by both the government and ship builder to identify areas for improvement. These areas were then specifically incentivized in the contract.

The incentive space of a contract requires a good understanding by the contract architect of what motivates the ship builder. It is important to understand that the incentive for the contract being written has to be viewed in the whole context of the ship builders frame of reference. For example, consider a CPIF contract that includes special incentives for labor and material savings. If that ship builder has ongoing work on a FFP project, it is possible that any material or labor reductions offered in the CPIF will be negated by the ship builder desire to have the CPIF absorb cost from the FFP. The idea of competing incentives need to be considered not just for incentives within the single contract, but also within the context of all of the ship builder's projects.

Finally the incentive space has the possibility of being gamed by the ship builder if not properly constructed. Here again, the whole context of the ship builder's

business needs to be considered. If for example there is a labor incentive for man hours to be reduced, and the main contractor has the ability to contract out work to a subcontractor at a higher price and bill these costs as material cost. They might be able to earn the labor incentive without actually reducing cost to the government. The construction of special incentives must be done carefully to achieve the desired outcome.

5.2.3 Terms and Conditions

The terms and conditions of the contract should not be overlooked. The current president of Irving Shipbuilding, VADM (ret.) Kevin McCoy, was formerly the NAVSEA Commander. He emphasized how important these terms and conditions are to the private sector, a fact that is sometimes overlooked by their government counterparts[16]. The government contractors care about the bottom line cost, product, and schedule, but the shipbuilders have many other concerns. McCoy explained that on the contract definition for AOPS, the terms and conditions section took up a large percentage of negotiation effort. Pay schedules, warrantee terms, and indemnity terms are among a few of the items that were of great concern to the shipbuilder during those discussion. Pay schedules are integral to ensuring a positive cash flow, and can go a long way to make a contract attractive, or unattractive to a shipbuilder. Since Irving Shipbuilding was already financing the expensive shipyard renovations necessary to complete the project, it was critical to the company to maintain a steady pay schedule with the government. Irving was concerned about cash flow, not just profit.

Additionally, the Indemnity and Warrantee terms come down to putting a monetary value on risk. McCoy described the process: “If we [Irving Shipbuilding] design and build the AOPS here in Nova Scotia and they [Government of Canada] take it to the

Arctic and then the extreme cold causes the welds to start cracking, but we had no way of discovering that here- What is our liability? It [terms and condition] is all of those things that could cause the destruction of the business. A shipyard will go into the negotiation wanting maximum protection. The government, on the other hand, will want that protection in case the welds start cracking, etc. A contract negotiation is about much more than price. “It’s about how much skin you have in the game.” In this way the terms and conditions can drive the negotiations of the contract, but in the end come down to quantifying risk. For this reason the terms and conditions are not directly modeled, but can be indirectly handled in the risk definition section.

5.2.4 Other Program Tools

Other program tools are other strategies at the program office’s disposal that are not necessarily direct incentives. CAPEX is an example of one such tool. Since the CAPEX investment has implications beyond the current project, it is not included in the incentives space. As the VCS program office stated, the CAPEX incentive is now being granted to programs that have future project benefit even if not for the project under which it is granted. This is a good way for the ship builder and government to build a better more productive relationship and industrial base. Although there is no minimum return on investment (ROI) necessary to make a CAPEX project attractive to the government, there have been many successes thus far. The VCS program office reported an ROI on Block II CAPEX project of over 6 to 1.

Competition is a second program tool. Competition can be created via mechanisms such as the PRO contract architecture, but can also be stimulated in other smaller ways. The Electric Boat/Newport News competition for the tenth Block IV VCS is an example of this competition. As is also demonstrated in that example, the

competition does not have to come from only the government. Competition can be used between the contractors and their subcontractors or vendors to stimulate better cost performance. Since both CAPEX and competition tools encompass acquisition strategy and are bigger than just the project contract, they are not included in the scope of the qualitative model.

5.2.5 Long Term Concerns

As was previously mentioned, long term concerns were not included in the quantitative model but are important design variables in the acquisition strategy of a project. Concern for socio-economic benefits can be reflected in contract language. Under the Canadian NSPS, for example, the Value Proposition clause states that .5% of any contract price must be spent by the contractor to “further the long term growth and sustainment of the Canadian maritime industry.” In addition to spending the money, the AOPS build contract had to include details on how the money would be spent and how that process was to be managed. The Industrial and Regional Benefits (IRB) policy in Canada also aims to further the long term advancement of Canadian national economic growth by requiring a dollar for dollar investment back into the Canadian economy for all money spent on national shipbuilding.

In the United States, there is also concern with the long term socio-economic impacts to the shipbuilding industry when drafting contracts. In the VCS Block II contract, for example, there is a small business subcontracting incentive. The reason for the incentive is written in the contract: “The Virginia Class Program office is committed to the increasing small business subcontracting participation in submarine construction efforts consistent with cost/benefit considerations and attainment of acquisition objectives.” The incentive specifically targets small businesses, woman owned small businesses and small disadvantaged business. While these concerns are

relevant to the whole of the acquisition and contracting picture, they are considered out of the scope of the contract architecture for quantitative modeling purposes. Their importance in the qualitative sense, however, should not be overlooked.

5.2.6 Risk Sharing

Perhaps the most challenging and intricate of the design variables is the risk sharing element. Risk and risk quantification is at the heart of the contract negotiation. The type of contract architecture (CPIF or FFP) is often driven by the expectation of project risk. The shareline definition says something about what each side believes the risk to be and who they believe should own that risk (and therefore potential rewards or penalties.) Risk well understood and defined can be mitigated, as was done with the swing sixth ship on the AOPS build contract. For the purposes of modeling it is important to characterize the types of risk involved in a shipbuilding project. For simplicity of discussion, risk will be divided into technical risk, industrial risk, and schedule risk.

Technical risk has to do with specific project design. If it is a new design or has challenging design aspects that could be considered a high technical risk project. Included in this category would be new technologies that have not been completely developed at the time of acquisition. As an example of technical risk, the AOPS project represents low technical risk because the design, while new, is based on existing commercial designs.

The second category of risk is industrial risk. Industrial risk encompasses the shipbuilder's ability to control the people, processes, and facilities necessary to complete the project. Uncertainty in labor or material costs, for example would be included in industrial risk. While the AOPS project represents a low technical

risk, it represents a high industrial risk because all of the facilities and processes will be new. Industrial risk also includes the capacity of the shipyard to do the work. Working under and over capacity are both bad. If there the shipyard has a lot of other ongoing projects there is the potential for a conflict with the sharing of labor or materials. Conversely if the yard is operating under capacity it risks losing part of its experienced workforce or its learning curve earned on previous projects.

Finally there is risk associated with the project schedule. High schedule risk can be the result of an aggressive schedule or of a highly coordinated integration schedule. Managing the schedule risk was of particular concern of the VCS program since the module integration had to be highly coordinated and was a source of increased construction time and cost.

5.3 Design Attributes

The design attributes are the metrics in which to evaluate the goodness or badness of the contract. The attributes are the metrics of concern to either the contractor or the government. As is shown in Figure 5.1, the attributes of importance to the government are typically the product quality, total cost, and schedule. The attributes of importance to the ship builder can be more complex. The contractor often cares not just about the total project profit, but also about the cash flow and corporate hurdle rate throughout the project. There may also be concerns about being a position to win future work. Executive compensation may also be a concern, and shareholder support is always at least in the background of the ship builder's concerns.

As one would expect, the attributes of importance to the government are not necessarily the same as those of importance to the contractor. The obvious difficulty with this

situation is that those can be competing objectives. When this is the case, there needs to be a conscious effort by the government to quantify the relative importance of the product, cost and schedule and to set threshold limits that must be met or not exceeded. Sometimes there are different concerns, as was the case in the AOPS negotiation, when assumed levels of risk by each party were a primary concern as an attribute and not just as a variable. Here, too, there must be a way to rank and quantify the attributes of concern.

The attributes of concern of the contractor are likely more varied and potentially changing than those of the government. Profit is always a concern, and is akin to the government attribute of total cost. There are industry standard of profit that a shipyard can expect to make. Rough NAVSEA numbers for profit were obtained from speaking to individuals who had worked on a number of contracts. If a shipyard does a decent job, over time they should expect a 10% profit. If at least a 10% profit were not obtained, the shareholders would likely remove the leadership and ultimately divest from the shipbuilding business. If a yard doesn't do a good job, it can expect a 7-8% (or less) profit. An extremely successful project could earn a yard profits in the high teens, although this is a rarer case. As was pointed out by one of NAVSEA's senior contracting officials, profits in large excess of these numbers, even if they represent an overall savings to the government for a project job well done would be seen as politically unacceptable. There would be expected backlash for not having better estimated the target cost at the outset if the ship builder were able to reduce costs so much as to see a profit in large excesses of established norms.

6 Contract Model Simulation using @Risk

Once the contract architecture was expressed as a concept, that concept was turned into a quantitative model in @Risk (Figure 6.1), a Monte Carlo simulation tool by Palisade Corporation. @Risk is a Microsoft Excel plug in that allows uncertain variables to be defined by probability distributions. Those distributions are then able to be manipulated and analyzed. It allows the user to not only see the range of possible outcomes, but also how likely each of those outcomes is to occur, and what the sensitivity the outcomes have to various inputs. For this analysis, the student version of the @Risk Decision Suite was used. Each simulation represents 5000 iterations and the results can be set to return all possible values, or statistical values.

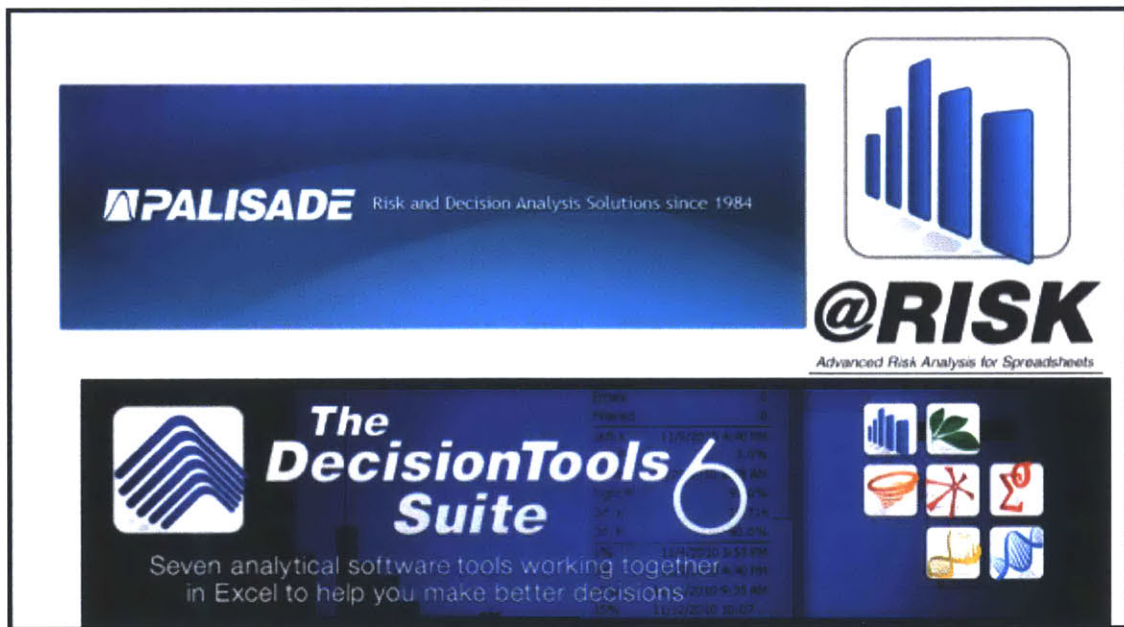


Figure 6.1: @Risk and the DecisionTools Suite, Palisade Corporation products

6.1 Model Overview

The model in @Risk takes user inputs about the contract architecture and project details and from those user inputs creates variable input distributions. The input distributions are then inputs into the distribution for the Actual Cost to Build, which is, as it sounds, the actual cost to complete the project. This distribution then dictates the outputs such as total cost to the government and overall contractor profit. Figure 6.2 shows this model overview.

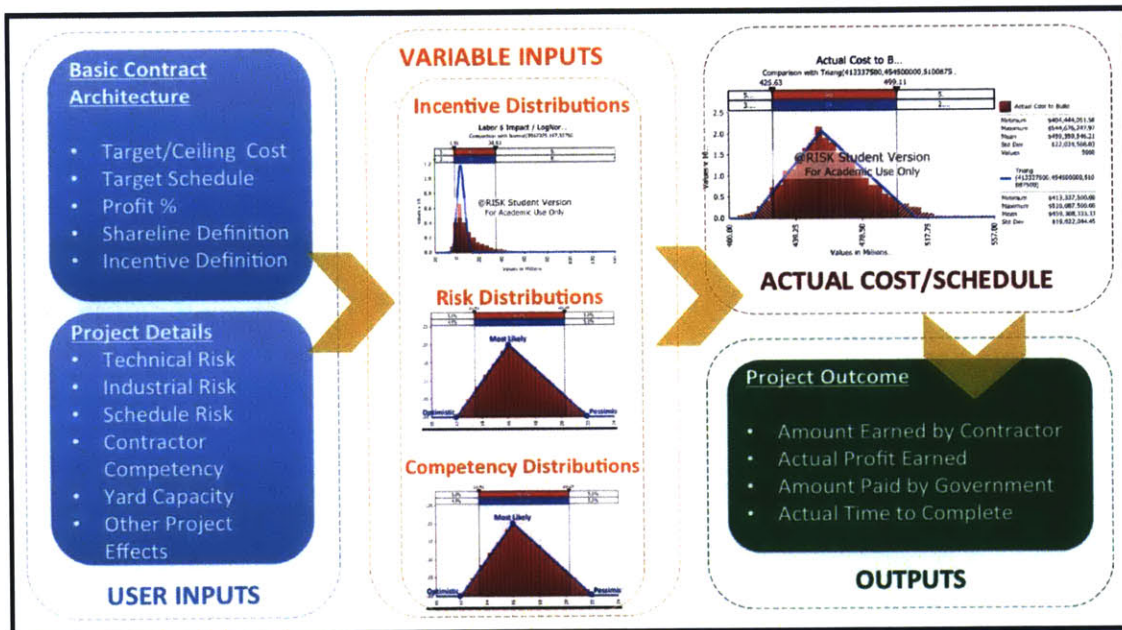


Figure 6.2: Overview of Contract Model in @Risk

6.2 Assumptions

Before a quantitative model could be defined some simplifying assumptions had to be made about the nature of contract negotiations, ship building projects, ship builder performance and motivation, and risk factors. These assumptions are described below:

1. A basic contract has basic and knowable input elements. These elements include the shareline definition, the target cost (TC), target schedule (TS), ceiling cost (CC), contracted profit, and incentive structure.
2. The contract drafter (in the case of US military shipbuilding, this is the government) is able to make some sort of prejudgement about the competency of the contractor. This can be based on based experience with and performance of the shipbuilder or by any other means.
3. Contractor Competency can be expressed as a percent which is determined by a triangular distribution for higher competency contractors and by a randomly generated percent for lower competency contractors.
4. The contract drafter is able to make some sort of prejudgement about the capacity of the shipyard at the time of contract drafting. The capacity of the shipyard is assessed as 'at, over, or under' capacity after considering the new project work in conjunction with other ongoing work or near term work.
5. The contract drafter is able to make some sort of prejudgement about the influence of other ongoing or near future contracts, as they pertain to incentive conflicts, at the time of contract drafting.
6. The ship builder likelihood to improve cost performance is driven by the incentive to make money (via shareline incentive or other incentive means) to a degree that is correlated to the competency of that contractor, the incentive available, and the influence of other ongoing or near future contracts.
7. This cost reduction impact of a special incentive can be expressed as a lognormal distribution.
8. Project Risk can be broken into industrial risk, technical risk, and schedule risk.

9. The contract drafter is able to make some sort of prejudgement about the levels of risk for the three categories at the time of contract drafting.
10. A project can be characterized as being “high” or “low” risk in each of those three categories.
11. Risk can be expressed as a triangular distribution as a percentage of the TC.
12. Technical and Industrial Risk affect the actual cost to build, as does schedule risk, but to a lesser extent. Higher risk in these areas skews the actual cost to build to the right.
13. Schedule Risk impacts the time to complete the project.
14. Absent or incentives or risk quantification, the actual cost to build (ACB) of a project can be expressed as a triangular distribution which favors the right, (cost overruns are more likely than under runs.)
15. The ACB distribution is additionally impacted by the Risk, Contractor Competency, and Incentive Impact distributions.

6.3 Model Inputs

6.3.1 User Inputs

The model has both user defined inputs and distribution generated inputs. Figure 6.3 visually depicts these inputs are modules in a bus type architecture. The main bus is comprised of inputs about the basic contract structure. In addition to the main bus there is a risk definition module and a contractor performance module.

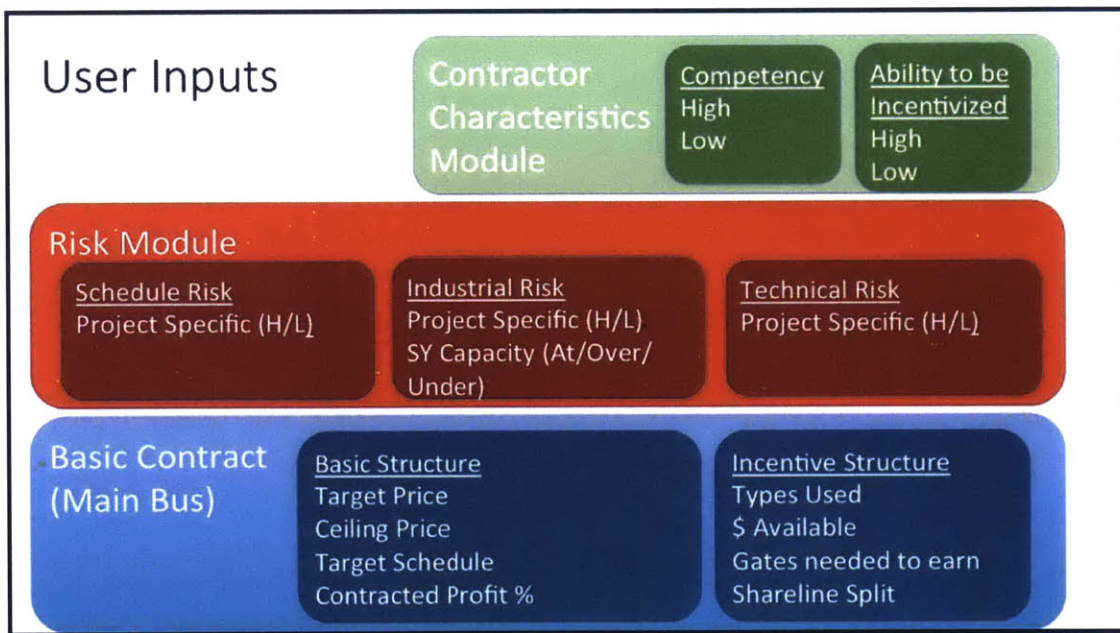


Figure 6.3: Model User Inputs as a bus architecture

The following are user defined inputs:

1. Target Cost (TC). TC is the target cost of the project. This can be based on the ship builder estimates, or by the governments own assessment. TC is often based on past similar projects.
2. Target Schedule (TS). TS is the target schedule of the project. This can be expressed in months or some other unit of time. Like the TC, it is often based

on past similar projects and may be based on either contractor or government estimates.

3. Ceiling Cost (CC). CC is the cost above which the contractor is wholly responsible for the additional costs. This also may be used as a cost above which additional cost negotiation is necessary. For the purposes of the model, it is treated as the cost above which the contractor is responsible for all costs.
4. Profit %. This is the contracted contractor profit as a percentage of the final cost to build. Profit may also be defined as a fixed fee, but for the model it is set as a percentage of final cost to build.
5. Shareline Above %. This is the percentage of costs above the TC that the contractor is responsible for paying.
6. Shareline Below %. This is the percentage of costs below the TC that are returned to the contractor. Currently the model is set up with one shareline inflection point (at TC) but additional points of inflection could easily be added for future models.
7. Project Risk. Risk is defined as either “high” or “low”, as assessed by the user. The three types of project risk assessed are:
 - (a) Technical Risk
 - (b) Industrial Risk
 - (c) Schedule Risk
8. Contractor Competency. Contractor competency is defined as either “high” or “low”, as assessed by the user. This is the contractor's competency with regard to executing a contract as agreed and will most likely be based on past performance.

9. Shipyard Capacity. Capacity is defined as “At,” “Over,” or “Under,” as assessed by the user. The capacity is considered for the time when the new project work is started in conjunction with any other ongoing or near term work (work to be done at the same time as the new project.)
- (a) Shipyard Labor Capacity. This input applies specifically to the shipyard’s labor resources.
 - (b) Shipyard Material Capacity. This input applies specifically to the shipyard’s material resources.
 - (c) Shipyard Facilities Capacity. This input applies specifically to the shipyard’s facilities resources.
10. Competing Incentive Structure. This is a “Yes” or “No” input for the categories of labor, material and facilities incentives. Here the user makes a determination as to whether there are other ongoing projects whose nature (either that projects importance or incentive structure) makes for a situation where the ship builder would have a competing reason to not achieve incentive or improved performance in the categories of labor, material or incentives. An example of this is if another ongoing project has a high schedule incentive, there may be a competing interest for the shipbuild to divert labor, material or facility resources to that project to meet the schedule incentive.
11. Incentive Structures. The amount available for different incentives, as well as the different “gates” which have to be achieved in order to earn the incentive is a user defined input. The model is built to allow for a material, labor, schedule, and total cost incentive. The first two incentives have the ability to have two gates for earning a portion of the incentive. The amount available to earn can be expressed as a fixed amount or as a percentage of the total cost.

6.3.2 Variable Inputs

Variable inputs are generated from the user inputs. These variable inputs are the result of different distributions generated in @Risk. The variable inputs and their associated distribution setting are described below. Figure 6.4 is an example of the triangular distribution which is used frequently throughout the model.

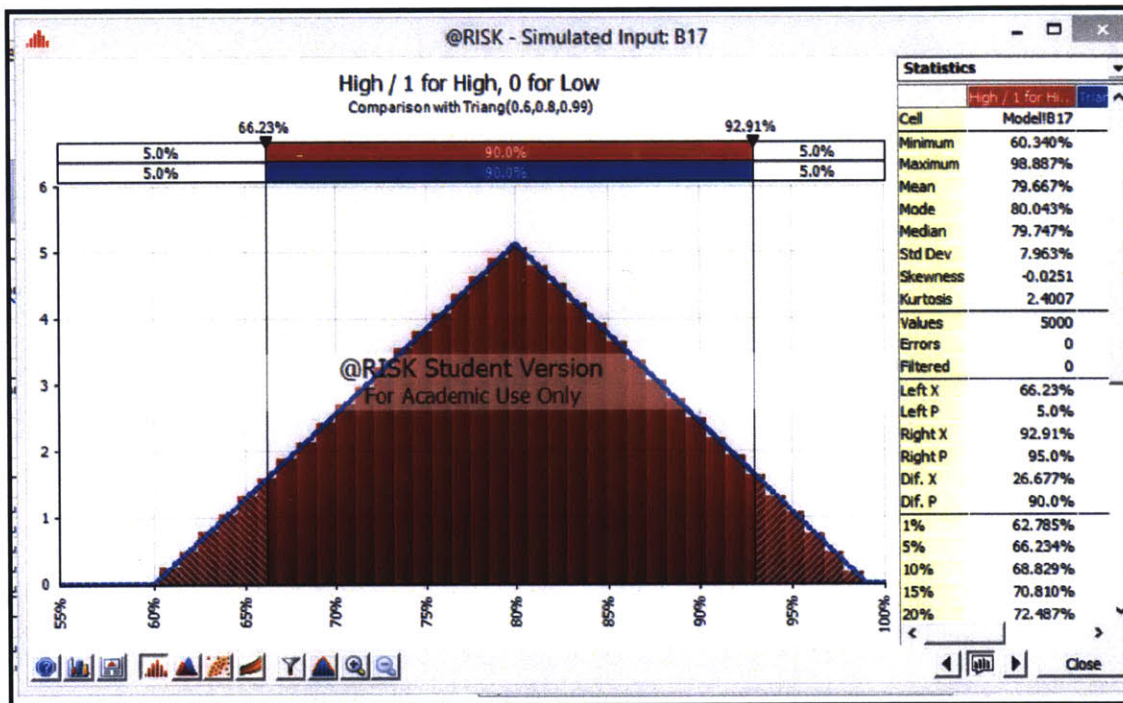


Figure 6.4: Contractor Competency Triangular Distribution

1. Contractor Competency Factor (CCF). From the user defined “high/low” competency, a contractor competency factor is generated. The competency factor is a multiplicative factor from zero to one, with one being the best possible competency. The CCF for a high competency contractor is generated from a triangular distribution with an expected value of .8, a minimum value of .6 and a maximum value of .99. The CCF for a low competency contractor is a randomly generated number between zero and .5.

2. Ability to Incentivize Contractor Behavior. The ability to incentivized contractor behavior is broken up into the categories corresponding to specific special incentives. This model uses special incentives for labor and material costs, but other incentives could be modeled in the same way. The distributions are generated based on the user response to the “Competing Incentives” question. In either case they are lognormal distributions. If there are competing incentives then the ability to incentivize is lognormal distribution with a mean of 30% and a standard deviation of 30%. If there are no competing incentives the mean is 80% with a standard deviation of 30%. The output percentage is the percentage ability that the contractor is able to be incentivized in that particular area, with 100% being the best possible ability to be incentivized.

(a) Labor Incentive Ability. Ability of contractor to be incentivized to earn the labor special incentive fee, from 0-100%.

(b) Materials Incentive Ability. Ability of contractor to be incentivized to earn the materials special incentive fee, from 0-100%.

3. Incentive Impacts. The incentive impacts distribution is lognormal distribution that returns the amount by which the associated incentive reduces (or impacts) the actual cost to build. The distribution is influenced by both the CCF and the associated incentive ability distribution. It also takes inputs from the user defined amount available for the incentive and the performance necessary to earn the incentive. The dollar value output of this distribution is used as an input for the ACB distribution.

(a) Labor Cost Impact. The amount by which the labor cost special incentive reduces the ACB.

(b) Materials Incentive Impact. The amount by which the materials special incentive reduces the ACB.

- (c) Total Cost Impact. The amount by which the total cost special incentive reduces the ACB.
4. Capacity Risk Distributions. The capacity risk distributions are lognormal distributions that are generated from the user input about the shipyard capacity. The mean is set to 5% for a response of “At Capacity” and to 70% for “Under Capacity” or “Over Capacity.” In both cases the standard deviation is 20%. The three types of capacity risk are then averaged to form the Total Industrial Risk Impact of Capacity which is an input to the Industrial Risk distribution.
- (a) Labor Capacity Risk. The amount of risk, expressed as a percentage with 100% being maximum risk, and zero being minimum risk, to the project’s labor costs associated with operated at some non-perfect capacity.
 - (b) Materials Capacity Risk. The amount of risk, expressed as a percentage with 100% being maximum risk, and zero being minimum risk, to the project’s materials costs associated with operated at some non-perfect capacity.
 - (c) Facilities Capacity Risk. The amount of risk, expressed as a percentage with 100% being maximum risk, and zero being minimum risk, to the project’s facilities costs associated with operated at some non-perfect capacity.
5. Total Risk Distributions. The total risk distributions are triangular distributions. The three different types of risk: technical, industrial, and schedule, each have their own distribution. They then combine to form a Risk Impact to Cost and a Risk Impact to Schedule. These risks are expressed as a percentage value of TC.
- (a) Technical Risk. Technical Risk is expressed as a triangular distribution

with an expected value of 20% for a high risk project (based on user input) and a value of 5% for a low risk project. The maximums for are 25% and 7% for high and low risk projects respectively and the minimums are 5% and 0%.

- (b) Industrial Risk. Industrial Risk is also expressed as a triangular distribution and has the same parameters as the technical risk distribution, but to those parameters is added the contribution from the Total Industrial Risk Impact of Capacity (see above.)
- (c) Schedule Risk. Schedule risk is expressed as a triangular distribution with the same parameters as the technical risk distribution based on the user inputs about the project's schedule risk.
- (d) Risk Impact to Cost. The Risk Impact to Cost is the total impact the ACB from the three types of risk. It is also a triangular distribution whose parameters are the sum of the industrial and technical risk parameters and half of the schedule parameters. The reason for this is that the schedule indirectly affects the cost.
- (e) Risk Impact to Schedule. The Risk Impact to Schedule is the sum of the schedule risk and half of the Total Industrial Risk Impact of Capacity. The reason for this is that the industrial risk also has an indirect impact on the schedule.

6.4 Actual Cost to Build Distribution

The Actual Cost to Build (ACB) is described by a triangular distribution. Before any risk or contractor incentive is taken into account, the triangular distribution is skewed slightly to the right, based on historic project trends, i.e. the likelihood that a project will be completed for less than the target price is not equally as likely as it will be to complete for more than the target price. The ACB distribution is defined by the expected value, the maximum value, and the minimum value.

Expected Cost to Build (ECB). The ECB, or expected value of the distribution, before risk and incentive factors are added, is the TC. The addition of risk shifts the expected value to the right and a large incentive impact shifts the value to the left. Therefore, a highly incentivized low risk project has an expected value less than TC, a low risk project without incentives has an expected value of TC, and a high risk project has an expected value greater than TC.

Minimum Cost to Build (MinCB). The MinCB is shifted to the left by some constant percentage of the TC. This constant percentage is less than the constant percentage that the maximum value is shifted to the right. This constant percentage gives the ACB distribution its general shape. In addition the percentage of ACB, the MinCB is affected by the risk to the project (which shifts the value to the right), shareline definition (both above and below the TC), and the incentives impact.

Maximum Cost to Build (MaxCB). The MaxCB is shifted to the right by some percentage (greater than the percentage used for MinCB) of the TC. The MaxCB is also shifted by the shareline definition (both above and below the TC) and the impact of special incentives.

6.5 Model Outputs

The outputs of the model depend directly on the ACB, shareline definition, incentive structure, and contracted shipbuilder profit percentage. The outputs values generated by the model are:

1. Total Amount Paid by Government. This amount is the total amount paid for both the project and contractor incentives/contracted profit.
2. Total Earned by Contractor. This is the amount the contractor receives from the government for both the project and earned incentive/contracted profit.
3. Actual Profit Earned. This is the amount of profit that the contractor actually earned based on the ACB and the Total Earned by Contractor values.
4. Actual Time to Complete. This is the actual schedule based on the risk and incentive impacts to the TS.

6.6 Model Validation

Although most shipbuilding data is proprietary, it is possible to use some existing data to see if the model returns results that are at least reasonable. For a validation test the VCS Block III data was used. The amount of incentives available are shown in Table 4.1. These are the average values for the ships in the block. For the model validation the CAPEX incentive money was not considered, as it is outside the scope of the model. The target cost (TC) is given in the contract, as is the necessary cost to achieve the Total Cost incentive. The TC given, however, represents the desired cost, not the likely cost without incentives. Since the Total Cost incentive value was not framed as a reduction in TC, but rather as an incentive for meeting the TC (up to $1.03 \times \text{TC}$) the model algorithm had to be adjusted accordingly. It is important to note that the costs discussed in the contract are much less than the \$2B (FY05\$) that is discussed in the media because the \$2B amount includes government furnished equipment (GFE) which is outside the scope of the contract. Below are a list of the other parameters used in the validation run:

- TC: \$1.24B
- CC: \$1.55M (125% of TC was used, although no data in contract was given for CC)
- Contracted Profit %: 10%
- Shareline Above %: 50%
- Shareline Below%: 50%
- Other Incentives: Total Cost
- Project Risk: Low (all categories)
- Contractor Competency: High

- Shipyard Capacity: At Capacity (all categories)

The results of the model are as follows:

- ACB: \$1.275B
- Total Paid by Government: \$1.416B
- Total Earned by Contractor: \$125M
- Actual Profit Earned by Contractor: 10%
- Incentives Earned: Total Cost

Figure 6.5 shows the ACB distribution generated by the @Risk model. The ACB

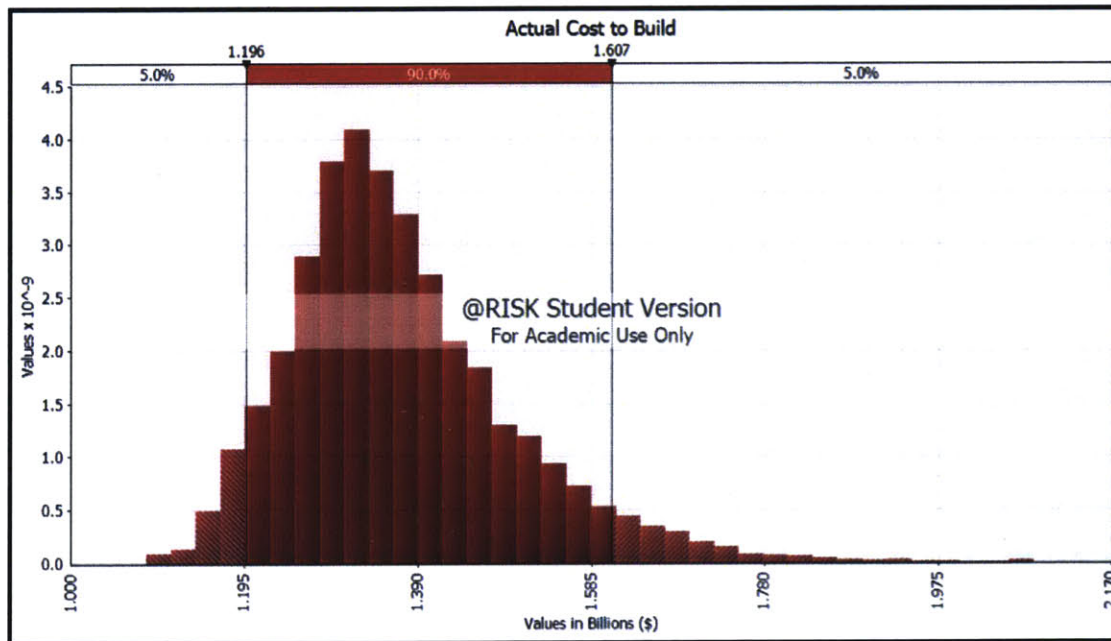


Figure 6.5: VCS Block III ACB Distribution for Model Validation Run

distribution says that there is a 5% chance that the the project costs less than \$1.2B and more than \$1.6B, information that could be useful to the program office. The total cost incentive was earnable if the final cost was less than or equal to the TC +

3%, or \$1.28B, so although the ACB was above the TC, the incentive was still earned.

So what does this mean? The total paid by the government in reality for the program was more than 2\$ per submarine because that amount includes government furnished equipment (GFE), however the contractor did earn the Total Cost incentive as the model predicted. This means that the costs generated by the model had to be close to the comparable costs in reality. What it does point out is that there are other costs besides those in the contract (such as GFE) that drive the cost per submarine up. Although the data for what the contractor's actual profit percentage and the ACB was not available, the fact that the model predicted the earning of the Total Cost Incentive, and that the Total Cost Incentive criteria was fairly narrow (TC+3%) means that the model is at least in the realm of the reasonable.

6.7 Model Results

6.7.1 Fixed Price Incentive Fee

The model results vary by inputs conditions. The first input condition tested was one representing a Fixed Price Incentive Fee (FPIF) contract structure. Since the FPIF structure is used most with low risk projects, the user definition for all categories of risk was set to "Low" and the contractor competency was set to "High". For this test, the project was given only a shareline definition and no additional special incentives. The first step was to verify that the ACB distribution was reasonable. For this run the shareline was given a 50/50 shareline split, meaning that the overrun and under runs were shared evenly between the contractor and the government. The following input parameters were used:

- TC: \$450M

- CC: \$562.5M (125% of TC)
- Contracted Profit %: 10%
- Shareline Above %: 50%
- Shareline Below%: 50%
- Other Incentives: None
- Project Risk: Low (all categories)
- Contractor Competency: High
- Shipyard Capacity: At Capacity (all categories)

For these parameters the ACB generated the following values:

- ECB: \$454.5M
- MinCB: \$413M
- MaxCB: \$510M
- ACB: \$459M

These results seem appropriate, if not a little a high. The ECB is within 1% of the TC, and the ACB is within 2%.

The more interesting results come from varying the shareline definition to see if there is a solution that is advantageous for both the contractor and the government. Both the Shareline Above and Shareline Below % were varied from 10% to 90%. Figure 6.6 shows the results for this test. This graphic represents 45k simulation results. Here the total amount paid by the government is seen in orange and the shipbuilder profit is in blue. The horizontal axis is the actual profit percentage earned by the contractor. The red lines indicate points of inflection change on the graph where the CC and the TC are reached. In each case the amount corresponding to what the government would pay (cost + contracted profit) is shown. For the ACBs less than the TC, the fan structure shown depicts the varying shareline percentages where each fan branch is a different Shareline Below % split.

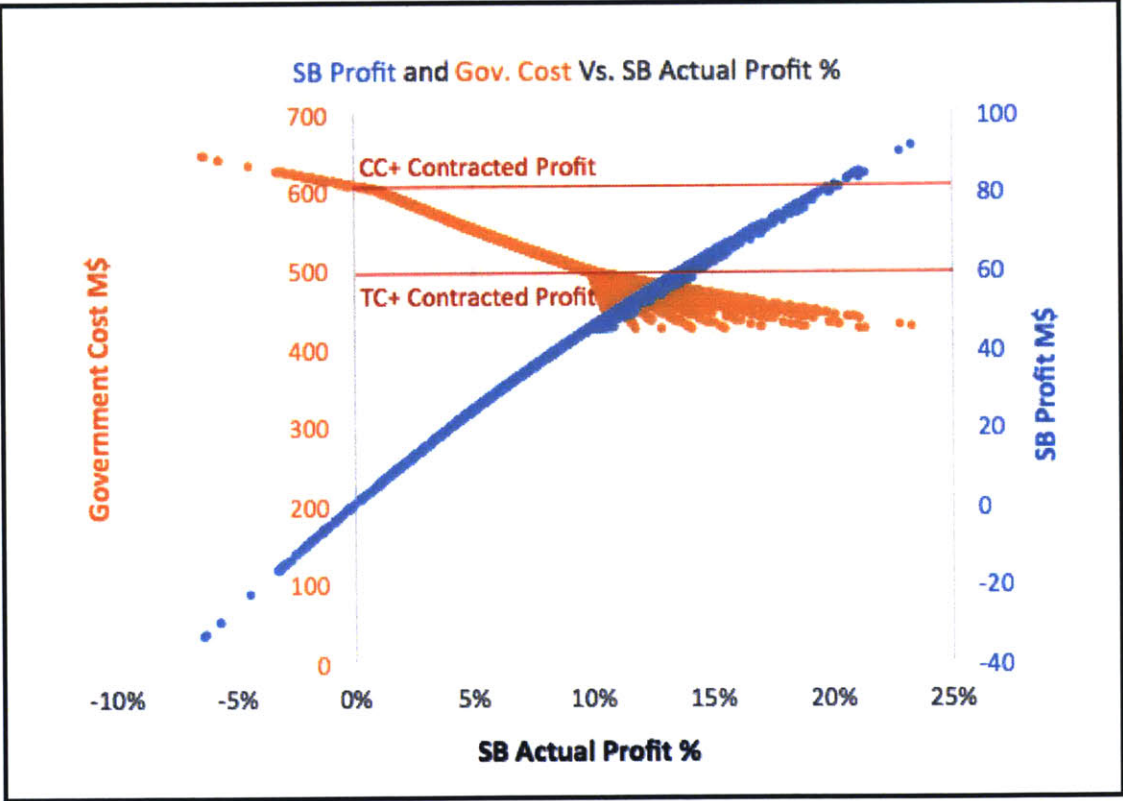


Figure 6.6: Shipbuilder Profit and Government Cost for A FPIF Contract with Varying Sharline Definition

Figure 6.7 shows the same graph zoomed in to include only those desirable solutions where the ACB is less than TC. Here it is apparent that the cost to the government and the profit to the shipbuilder both improve as the the shareline split favors shifting risk to the ship builder. The highest profit and lowest government cost occurs when the the shareline split is 90/90 with the shipbuilder assuming almost all overruns and earning almost all of under runs.

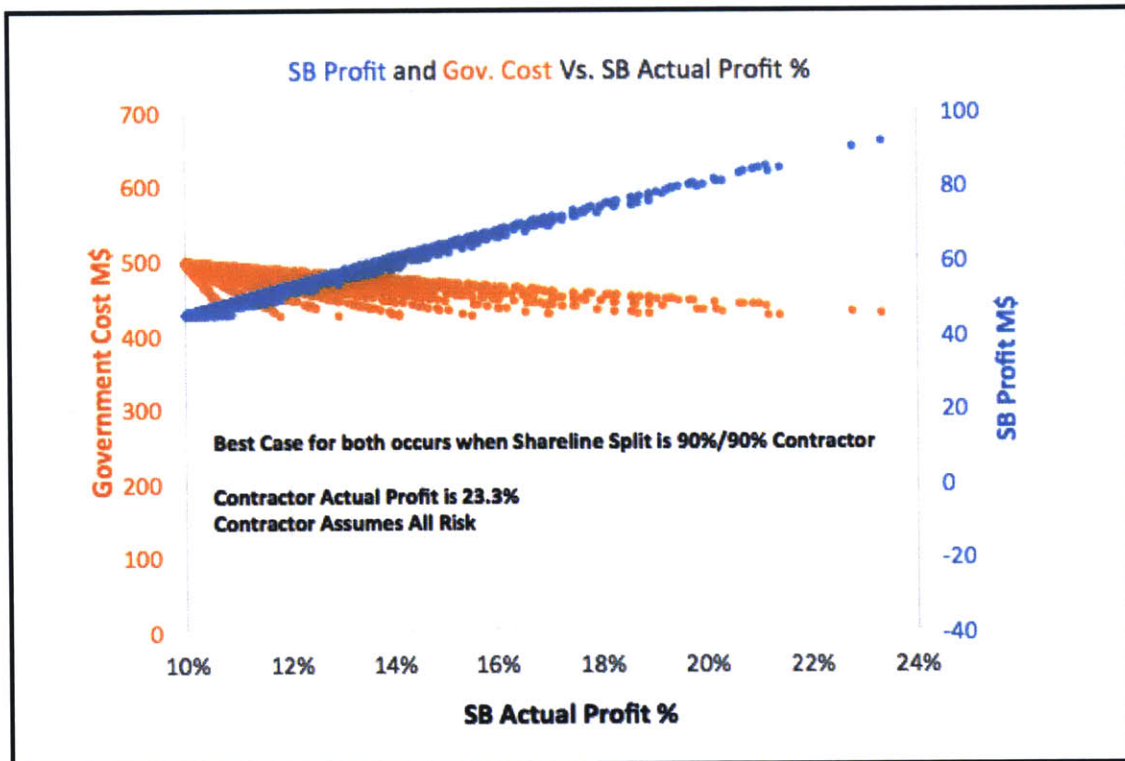


Figure 6.7: Shipbuilder Profit and Government Cost for A FPIF Contract with Varying Sharline Definition- ACB less than TC

6.7.2 Cost Plus Incentive Fee

To simulate a Cost Plus Incentive Fee type contract, special incentives were added to the FPIP model above. The goal of these simulations was to see what factors had the greatest influence on the total amount paid by the government and the actual profit percentage of the contractor. For the analysis on the cost to the government the inputs remained the same as in the FPIF run with the following exceptions:

1. The Contractor Competency was allowed to vary (High or Low with equal likelihood)
2. The Shareline % were allowed to vary from 10-90% both above and below
3. The Project Risk was allowed to vary (High or Low with equal likelihood)
4. The Competing Incentive Structure was allowed to vary (Yes or No with equal likelihood)
5. The amount available for each incentive was varied as a percentage of a set amount
6. Workload Factors were set to "At Capacity."

Figure 6.8 is a tornado graph showing the relative importance of the factors affecting the cost to the government. As would be expected, the largest single factor is the actual cost to build (ACB). After the ACB (which is itself affected by many factors) the impact of special incentives (other than total cost incentive) cost reductions have the greatest effect. Following those factors are the amounts of money available for special incentives. Finally the shareline definition for cost under runs had a significant affect (although the definition for overruns did not) as did the amount available for the total cost incentive. Of note, the cost reduction impact of the total cost incentive did not make the list.

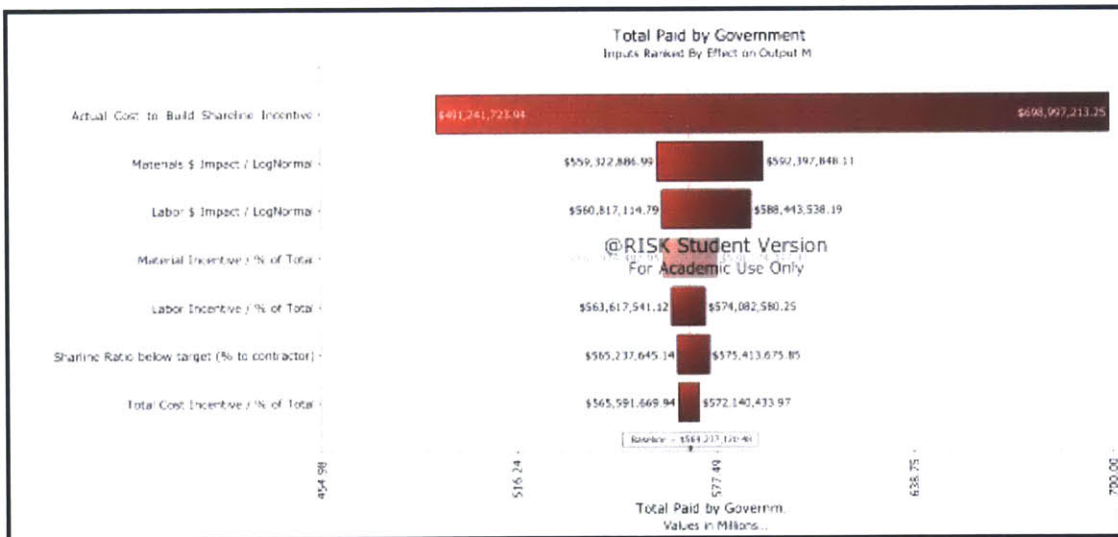


Figure 6.8: Factors Affecting Government Cost for A CPIF Contract

The contractor profit percentages were analyzed using the same inputs as above with one exception. The contractor competency was set to either high or low and the analysis was run for both cases. Figure 6.9 shows the factor results for the case of high contractor competency. Figure 6.10 shows the results for the case of low contractor competency.

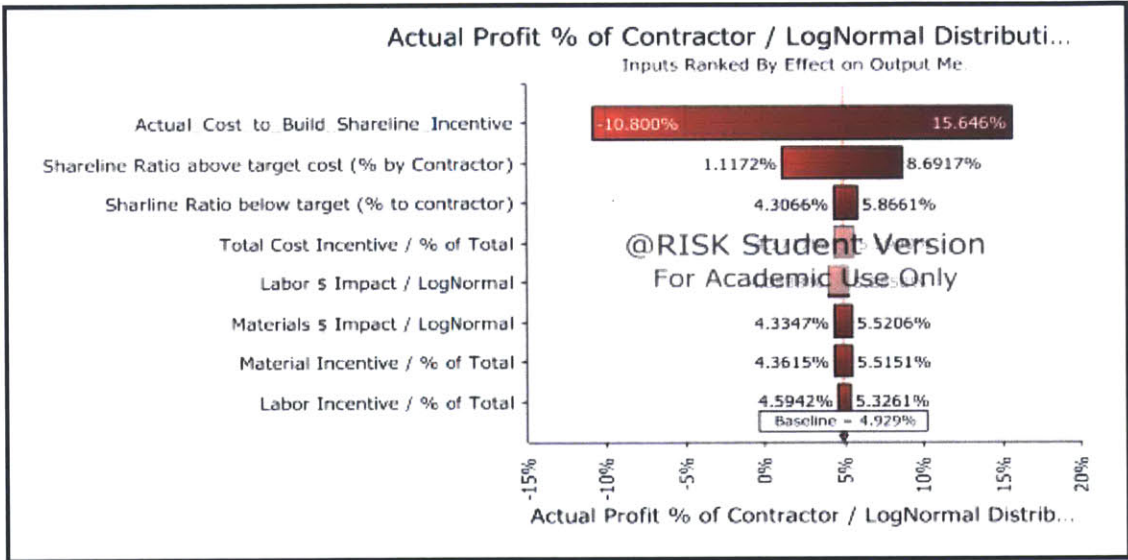


Figure 6.9: Factors Affecting Shipbuilder Profit for A CPIF Contract with High Contractor Competency

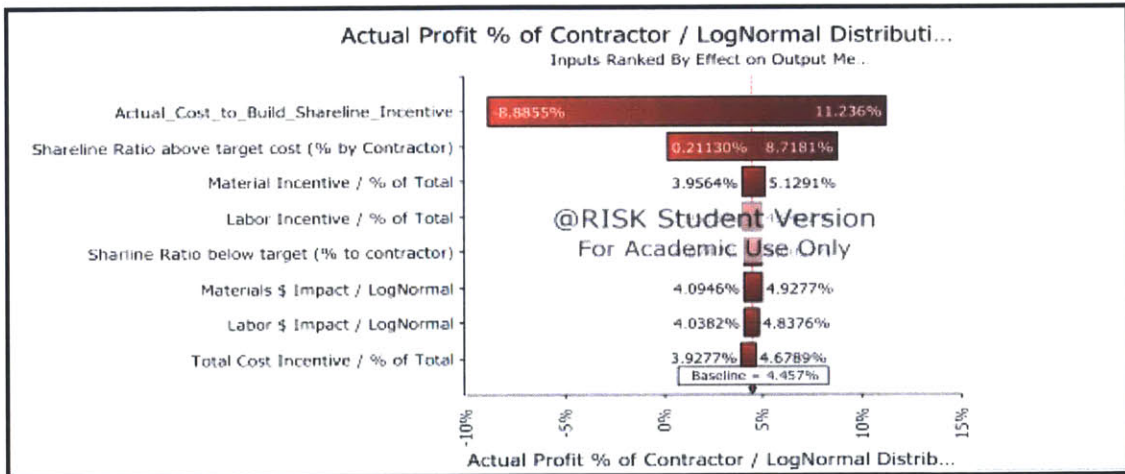


Figure 6.10: Factors Affecting Shipbuilder Profit for A CPIF Contract with Low Contractor Competency

Here again the greatest single factor for both cases is the ACB. What is interesting is where the two graphs differ. Both have the shareline overrun definition as the next largest factor, but only the highly competent contractor has the under run definition as the next most important. The highly competent contractor also had the total cost incentive money available as more important than the low competency contractor.

6.8 Discussion of Results

6.8.1 Fixed Price Incentive Fee (FPIF)

The results for the FPIF suggest that the best solution for both the government and the contractor occurs when the contractor assumes all of the risk and is able to reduce the actual cost to build (ACB) enough to earn increased profits on a favorable shareline split. A matter of political concern arises here, however. After speaking with several NAVSEA officials it was clear that there would be a political outcry for contractor profits in the 20% range. The reasoning is that if such a cost performance were possible, the target cost (TC) should not have been set so high in the first place. Large contractor profits shed doubt on the government's ability to cost estimate. Therefore this caps the amount of increased performance that the government can really incentivize the contractor to achieve. If there is no added benefit to assuming increased risk, due to the capping of profit percentage the contractor may be adverse to doing so. Alternatively, the target cost could be artificially reduced in anticipation of SB cost reduction performance. This would take credit for the reductions ahead of time and thus result in lower actual profit percentages. In any case, the shareline split for overruns had a much smaller affect on the range of government cost solutions than the split for under runs. This suggests that possibly the government negotiation team could give up a few points here to make the contract more attractive to the contractor without really adversely changing their outcome.

6.8.2 Cost Plus Incentive Fee (CPIF)

The results for the CPIF focused on which factors had the greatest impact on the outcome, since there were so many more factors to examine. The obvious winner is the ACB. In order to fully understand the affect of ACB, the same tornado analysis

performed on Cost and Profit was performed on the ACB distribution. The results found that the incentive structure had the greatest impact on the minimum cost to build (MinCB) and the maximum cost to build (MaxCB.) The MaxCB, however, was dominated by project risk. The shareline distribution did not affect the expected cost to build (ECB), but did shift the MinCB to the left if favorable to the contractor. Overall the ability to be incentivized was more important than the amount available for the incentive. Finally the Total Cost Incentive hurdle was set to high to be effective when modeled as 75% of TC as was suggested in interviews. This suggests that it is better used in cases (such as with the VCS program) where there is specific research about where and how drastic cost saving measures are possible. Blindly applying a total cost incentive without evidence that it is achievable is unlikely to improve cost performance. Being able to accurately estimate costs at the outset of the project, as well as knowing specifically where and how those costs can be improved, has the best chance for success for each side.

Incentives are a good way to reduce the cost to the government regardless of the competency of the contractor, as long as the contractor is able to be incentivized (i.e. no competing incentive structures.) This suggests that the incentives should be specifically set up to target areas where the contractor can and is willing to make improvements, meaning that some understanding of the contractors situation and motivations is needed at the time of contract drafting. As in the case for the FPIF model, shareline savings returned to the contractor did not significantly impact the cost to the government, but did impact the profit to the contractor-especially in the case of the high competency contractor. Likewise, the shareline overrun split had a larger affect on the contractor profit than it did the government cost- a result that could impact contract negotiations.

7 Conclusion and Areas for Further Research

The quantitative modeling is a good tool for cost validation or improvement, but most likely insufficient for cost prediction. The reason for this is that there are so many factors involved in shipbuilding programs, such as the political environment and other ongoing contracts, that are either not modeled or modeled insufficiently. As captured in the contract concept in Figure 5.1 the contract space is populated by more than just the basic structure and incentive structure. The question is, however, whether we can hope to control these factors, and if so, how? Politics, for example certainly affects the outcome of a project, but is most likely a factor outside of the control of the contract framer. If those factors can't be controlled, then it is better to focus efforts on making improvements in those which are within the ability of the program offices to improve. When creating the quantitative model, the decision about where to draw the boundary between what is part of the acquisition strategy and what was to be included in the contract architecture was difficult. Certainly one affects the other, but they should not be treated as the same thing. There are many places, such as is the case with PRO contract, where that seam is less definitive. PRO is an acquisition strategy that dictates a certain contract architecture and that architecture is not well modeled in this quantitative assessment. This leads to the conclusion that cost prediction is a complex problem with factors outside the control of the contract drafter. That does not mean, however, that there is no value to focusing on optimizing those factors that are able to be affected by the contract structure. The quantitative model as written suggests that there is ability to improve the cost performance of a program with well written incentives. Since the ability of a contractor to be incentivized is relevant to the contract success, this probably requires a more thorough and accurate modeling than just a high/low scheme. This is another complex area with factors impacting the outcome that are outside of the

control of the contract writer such as other ongoing projects, what is happening with the workforce, etc. For example in Canada, much of the labor force has historically split its time between working on oil projects in Alberta and shipbuilding in Halifax. A boom or bust in one sector can create a surge or deficit in the other. These forces are also not modeled but are seemingly significant, and while the contract writer can't necessarily control them, they can seek to better understand them in order to craft a more successful incentive structure. The attempt at creating the boundaries for the quantitative model only served to highlight the complexity of the US military shipbuilding business.

In order to improve the fidelity of the quantitative model more validation testing would be necessary. A first pass validation with the VCS data was used, but the data was incomplete. This validation proves difficult since so much of the model depends on the ACB- a number that is proprietary shipbuilder information. When interviewing the president of Irving Shipbuilding Inc., even the expected ACB and profit percentages were treated as business sensitive and confidential. Additionally more focus should be given to the bounds of the distributions used. A final area for further research is to extend the quantitative simulation process to other areas of the acquisition process. Extending the scope of the model could help to improve the fidelity by including more of the factors of importance. Specifically, how the CAPEX incentive affects the contract and acquisition structures is not currently modeled and could make for good future work. CAPEX is a unique incentive since it's reach is beyond just a single project, and it's value to the contractor is not just a profit percentage. Finally, this thesis looked only at cost performance. As the technological challenges of modern warfare change and grow, so must our responses to them. This demands increased product performance. Motivating increased product performance has it's own challenges, such as specification management. Adding

product performance to cost performance would increase the value of a future quantitative model.

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