# From Shipyard to Sea: A Flexible System Design Approach to the Transition from Shipbuilding to Operations

A Case Study Using the United States Coast Guard Offshore Patrol Cutter Program

By

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## Abstract

The United States Coast Guard faces significant challenges transitioning new ships from shipbuilding to operations. Historically the low volume and irregular pace of major ship deliveries, combined with diverse homeporting factors, have resulted in anomalous post-delivery requirements. Today, a growing fleet, personnel shortages, and sweeping technological advancements are amplifying the complexity of post-delivery activities. At the same time, the Coast Guard is engaged in its largest shipbuilding effort since World War II, with seven acquisition programs scheduled to deliver 134 new ships over the next 15 years. In light of these factors the current approach, which places significant strain on crews, escalates costs, and delays operational use of the Coast Guard's newest assets, warrants thorough examination. This thesis examines the issue through case study analyses using the Offshore Patrol Cutter (OPC) Program.

The Coast Guard's challenges are driven by three primary factors: the inherent uncertainty in ship construction, sociotechnical system dynamics associated with organizational management of pre-commissioning crews, and the ongoing evolution of technology. To address these challenges, this analysis employs an integrated approach, synthesizing principles and techniques from Architecting Innovative Enterprise Strategy (ARIES), Flexible Engineering Design (FED), and System Design and Management (SDM). This systems thinking approach aims to develop opportunities to reduce costs, improve schedules, and optimize workforce outcomes.

The analysis recommends a three-phased strategy that could yield cost savings on the order of $400 million over the OPC Program's lifespan, significantly mitigate risks associated with unforeseen shipbuilding developments, and enhance organizational outcomes regarding workforce, operational availability, and life cycle sustainment. The staffing of pre-commissioning crews is pinpointed as a pivotal discretionary event that triggers an exponential increase in system complexity and a surge in scope by introducing interdependent yet organizationally disparate requirements. Consequently, major personnel activities are decoupled from highly variable ship construction milestones. This paves the way for a paradigm shift from fixed to flexible approaches, replacing fragmented, ad hoc approaches with a flexible system architecture capable of continuous enterprise learning and improvement. Dynamic post-delivery activities are reimagined as a continuous business line, to professionalize the transition of new ships from shipbuilding to operations.

Thesis Supervisor: Dr. Richard de Neufville, Ph. D. Professor, Engineering Systems

# Acknowledgments

My initial expectations of both the demands, and the rewards, this thesis would offer, fell remarkably short of my actual experience. Its completion was made possible by meaningful contributions from many incredible people, spanning my family, personal network, professional network in the Coast Guard, and academic community at MIT.

To Krystle: everything I accomplish stands on a foundation of your love, wisdom, unwavering support, and selfless dedication. This thesis is a capstone on the larger MIT-sdm experience, which now rests at the top of a list of incredible opportunities and humbling achievements which you have made possible. Thank you. This opportunity required new levels of sacrifice from our family. You put your life on hold and took up my slack without a word of complaint, while keeping our family not just together, but flourishing. I am in awe of your strength, skill, and ability to lead our family, and forever grateful. I love you. To John and Rob: this opportunity required significant sacrifice from both of you as well. You showed strength, character, and understanding far beyond your years, navigating uncertain paths with a significantly reduced presence from dad. Even at a young age, your authentic interest and impressive insights into what I was learning and doing at MIT consistently inspired and energized me. I finally stopped being surprised by each of you intuiting simple but profound truths and principles, that took me more than 40 years and three laps through institutes of higher education to understand. I am bursting with pride, gratitude, and excitement to watch you both continue to grow and contribute to our world.

I consider myself fortunate to be a part of the United States Coast Guard, an organization that has consistently taken the long view and made significant investments in my personal and professional growth. The opportunity to dedicate a full year to thinking and learning at this stage in my career, in the unique environment and community that is MIT, was invaluable. I am deeply grateful to be part of an organization that values the deep learning and growth offered at a place like MIT. The list of mentors and friends across the Coast Guard who provided guidance, perspective, and inspiration continued to grow throughout this process. There are too many Coast Guard men and women who contributed to the substance of this thesis to list here, but the broad willingness to entertain my questions and requests for information was invaluable to my journey and greatly enhanced the depth and quality of the ideas at the heart of this thesis.

To the MIT community: the opportunity to know some of the many amazing individuals that make up MIT faculty, staff, and student body was an absolute highlight of this experience, and a true honor. I was told before I arrived MIT would catalyze my thinking and perspective in ways that transcend the bounds of traditional academic programs, I found that to be true. The people at MIT who shared their time, wisdom, skills, and ideas with me made this experience an inflection point in my life trajectory that I didn't know was possible, both professionally and personally.

Finally, special acknowledgement and thanks to Richard de Neufville, who offered invaluable guidance, knowledge, and wisdom throughout my thesis journey. I am grateful you agreed to advise me, and while the positive impact you had on my thesis was profound- our conversations shaped my thinking and perspective in ways that extend far beyond the bounds of this thesis.

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# List of Acronyms

| | |
|---|---|
| AD | Architectural Decision |
| ARIES | Architecting Innovative Enterprise Strategy |
| AVCERT | Aviation Certification |
| C5I | Command, Control, Communications, Computers, Cyber, and Intelligence |
| C5ISC | Command, Control, Communication, Computer, Cyber, and Intelligence Service Center |
| C5ISR | Command, Control, Communications, Computers, Cyber, Intelligence, Surveillance, and Reconnaissance |
| CART | Combined Assessment of Readiness and Training |
| CDF | Cumulative Distribution Function |
| CG | Coast Guard |
| CGY | Coast Guard Yard |
| CLEAR | Comprehensive Law Enforcement Assessment of Readiness |
| COE | Center of Excellence |
| CSSQT | Combat System Ship Qualification Trials |
| DAFP | Days Away From Homeport |
| DBS | Delivery-Based Staffing |
| DCMS | Deputy Commandant for Mission Support |
| DCO | Deputy Commandant for Operations |
| DHS | Department of Homeland Security |
| DOD | Department of Defense |
| EPM | Enlisted Personnel Management |
| FED | Flexible Engineering Design |
| FRC | Fast Response Cutter |
| GAO | Government Accountability Office |
| IAP | Independent Academic Period |
| IOT&E | Initial Operational Test & Evaluation |
| ISVS | In Service Vessel Sustainment |
| LANT | Atlantic Area |
| LC | Logistics Center |
| MATE | Multi Attribute Tradespace Evaluation |
| NPV | Net Present Value |
| NSC | National Security Cutter |
| OPC | Offshore Patrol Cutter |
| OPM | Officer Personnel Management |
| PAC | Pacific Area |

| | |
|---|---|
| PC&I | Procurement, Construction, and Improvement |
| PD | Post Delivery |
| PDA | Post Delivery Availability |
| PDF | Probability Distribution Function |
| PERSTEMPO | Personnel Tempo |
| PM | Project Management |
| PM | Program Manager |
| PMO | Program Management Office= |
| PRO | Program Resident Office |
| PSC | Polar Security Cutter |
| PSC | Personnel Service Center |
| RFS | Ready For Sea |
| SA | System Architecture |
| SC | Service Center |
| SDM | System Design and Management |
| SDT | Ship Delivery Team |
| SE | System Engineering |
| SFLC | Surface Forces Logistics Center |
| SPS | System Problem Statement |
| STAN | Boat Standardization |
| TCTO | Time Compliant Technical Order |
| TSTA | Tailored Ships Training Availability |
| USCG | United States Coast Guard |
| WCC | Waterways Commerce Cutter |

## Thesis "Sail Plan"

This sail plan lays out the overall strategy and structure of this thesis, which integrates and applies academic principles, techniques, and knowledge from a blend of engineering, business, and systems coursework to address a real challenge of significant complexity and impact. It endeavors to create some knowledge, insights, or applications for the Coast Guard. Thus, the organization of this paper is anchored around the recommendations. This thesis is comprised of four chapters and five appendices: recommendations are featured prominently in the body (Chapter 4) and detailed results of the supporting analyses which informed the development of these recommendations are presented in the appendices.

### Chapter 1. Introduction

This chapter introduces the topic, the author's motivation, the research questions, and the overall research and analytical approach for this thesis.

### Chapter 2. Context

This chapter provides the context necessary to understand the research and recommendations contained in this thesis and introduces contemporary trends that are relevant to these analyses. Three primary topics are addressed: the United States Coast Guard, shipbuilding in the United States, and the time and tasks required to transition a newly built Coast Guard vessel from construction to operations (referred to herein as the "Post Delivery phase").

### Chapter 3. Methodology

This chapter describes the research approach for this thesis. A key premise for the thesis is orienting the Post-Delivery phase of a Coast Guard ship's lifecycle as a complex sociotechnical system. This chapter defines the system and introduces a framework which is referred to and built upon through the reminder of the thesis. A conceptual overview of the methods and key terminology is also provided.

### Chapter 4. Recommendations

This chapter presents the thesis recommendations and implementation considerations.

### Appendix A. Architecting Innovative Enterprise Strategy (ARIES)

ARIES was employed to understand enterprise landscape, stakeholders, and system needs & requirements. This section details the ARIES analyses conducted.

### Appendix B. System Design and Management (SDM)

SDM was employed to design a new system from the bottom-up and understand key tradeoffs using tradespace analyses. This section details the SDM analyses conducted.

### Appendix C. Flexible Engineering Design (FED)

FED was employed to inspire a paradigm shift from a rigid viewpoint which assumes a degree of underlying certainty, to a flexible approach that acknowledges the presence and impact of uncertainty. FED modeled helped develop and analyze several system designs. This section details the FED analyses conducted.

### Appendix D. Stakeholder Multi Attribute Tradespace Exploration (MATE) Packet

This section provides the input sheets used by subject matter experts and stakeholders to develop and fine tune the tradespace model.

# Chapter 1. Introduction

The United States Coast Guard faces significant challenges in fielding new ships and preparing them for operational readiness. Interdependencies between ship construction processes, which inherently possess high schedule uncertainty, and post-delivery organizational activities generate inefficiencies that place significant strain on crews, increase costs, and delay the operational use of the Coast Guard's newest assets. These negative outcomes propagate through the Post-Delivery (PD) phase, resulting in increased costs, schedule delays, and decreased workforce utilization and satisfaction.

The current approach to this transition was developed when major ship deliveries were infrequent, and the post-delivery requirements for making new ships operational were relatively simple. However, this landscape is changing. The Coast Guard is now undertaking the largest shipbuilding endeavor since World War II, with a planned delivery cadence of two major ships per year far exceeding the historical pace. Additionally, the new ships being delivered are significantly more complex and capable than the legacy assets they are replacing, driven by ongoing technological advancements. Modern ships feature increasingly connected and interactive systems of systems with interdependent modern components that require technology refreshes as frequently as every three to four years. The assets these new ships are replacing are comprised of simpler technology: legacy components with refresh cycles that often exceed the 30-year design service life of the overall ship.

This thesis recognizes that contemporary trends have fundamentally transformed the transition of a new military ship from construction to operations. It proposes strategies to develop an enduring organizational capability to meet current and future challenges associated with this important organizational task. By treating the period between shipyard delivery and commencement of unrestricted operations as a dynamic sociotechnical system, characterized by complexity and uncertainty, this thesis applies System Design and Management (SDM), Flexible Engineering Design (FED), and Architecting Innovative Enterprise Strategy (ARIES) principles to identify a range of executable improvement opportunities.

## 1.1 Motivation

The MIT-SDM thesis is an academic exercise to apply and integrate knowledge from engineering, business, and systems coursework to address challenges of substantial complexity and significance. Ideal topics encompass issues where both technical expertise and management strategies are important and interdependent. The topic selection process for this thesis was guided by two factors:

1. United States Coast Guard: an aspiration to orient academic work to create some value, knowledge, or application for the Coast Guard.
2. Deepen learning through practical application: synthesize SDM, engineering, and business coursework into an integrated approach to a complex contemporary topic of interest.

### 1.1.1 Coast Guard Motivation

The author's personal Coast Guard experience to date can be organized into three broad categories: engineering, acquisitions, and personnel management. This thesis is focused on the Post-Delivery system to transition new ships from shipbuilding to operations. This system uniquely sits at the intersection of engineering, acquisitions, and personnel management.

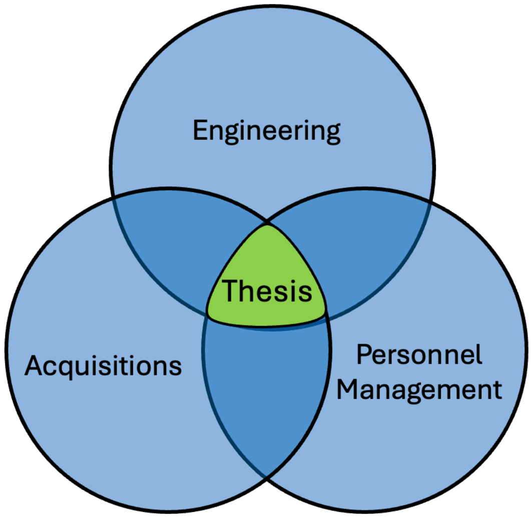



*Figure 1.1. Author's Coast Guard Experience*

At the same time, several contemporary trends that significantly impact these fields are actively shaping the Post Delivery phase, underscoring the foundational opportunity in exploring this topic:

- *A Growing Fleet.* The Coast Guard shipbuilding portfolio plans to deliver 134 new cutters over the next 15 years.
- *Workforce Factors.* The Coast Guard is experiencing significant workforce challenges. Personnel who serve afloat and operate major cutters are of particular interest.
- *Technological Complexity.* Technological evolution is driving increased complexity, capability, and connectivity across the sub-systems, systems, and systems of systems that comprise a major ship.
- *Technology Refresh Cycles.* Technology refresh cycles are getting shorter, interface entanglement across systems is increasing, and reliance on non-government equipment manufacturers is increasing as commercial product owners become more de-centralized and volatile.

Figure 1.2 provides a visualization of the net effect of these four driving forces pressurizing the Post Delivery phase of a modern ship's life cycle.

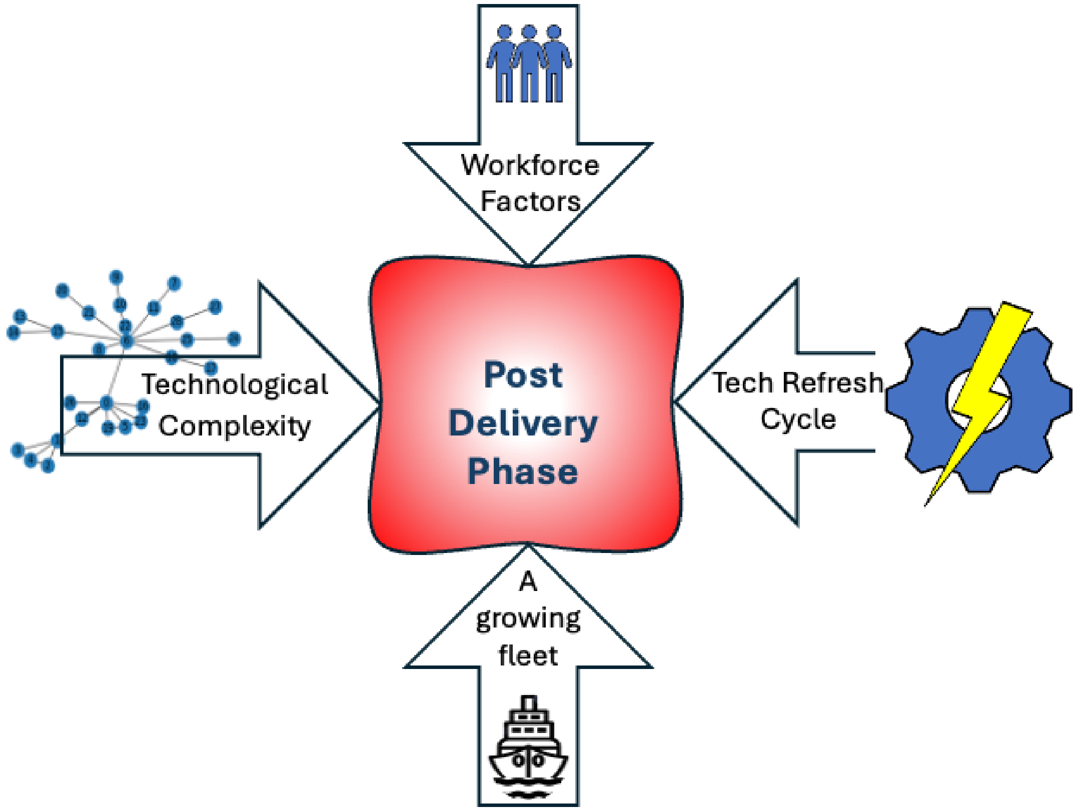



*Figure 1.2. Forces Acting on the Post Delivery Phase*

A key observation that influenced the selection of this topic is the lack of organizational resources and rigor dedicated to Post Delivery challenges and opportunities. Shipbuilding itself is inherently complex and demanding, however the Coast Guard has a robust enterprise with clearly established lines of ownership and well-defined processes for managing those activities. Similarly, the operational phase of a cutter's life has well-established and thoroughly exercised lines of ownership. However, the Post Delivery phase lacks this organizational rigor, not due to its lack of importance, but because the relevant trends and driving forces are emerging in real time. There has simply never been a need for such structure until now.

### 1.1.2 MIT Motivation

This thesis is informed by a comprehensive blend of graduate-level coursework in systems design and management, engineering, and business. Table 1.1 below outlines the specific courses and professors that contributed key principles, techniques, and strategies to the selection and refinement of the thesis topic, as well as the analysis and ideation that shaped the final recommendations.

*Table 1.1. MIT Academic Coursework*

| Course | Title | Semester | Professor |
|---|---|---|---|
| EM.4(series) | System Design and Management | Fall 2023, IAP 2024, Spring 2024 | Bruce Cameron, Eric Rebentisch, Bryan Moser |
| EM.422 | Engineering Systems Analysis for Design | Fall 2023 | Richard de Neufville |
| EM.427 | Technology Roadmapping | Fall 2023 | Olivier L. de Weck |
| 15.871 | System Dynamics | Fall 2023 | Johan Chu |
| 6.928 | Leading Creative Teams | Spring 2024 | David Nino |
| 16.855 | Systems Architecting Enterprises | Spring 2024 | Donna Rhodes |

## 1.2 Thesis Questions

Inspired by all of these factors, this thesis attempts to contribute some knowledge or insights that may be of value to the Coast Guard, by answering the following research questions:

1. How can the Coast Guard improve the transition of new cutters from construction to operations?
2. Are there fundamentally different architectures that could meet the Coast Guard's needs while improving organizational outcomes?
3. Are there executable strategies and processes that are resource-neutral or provide resource savings?

# Chapter 2. Context

The timing of this study seeks to capitalize on a Kairotic moment: an opportune time when conditions are right for the accomplishment of a critical action (Onians, 2011). A recent quote from the Commandant of the Coast Guard provides a compelling backdrop for this thesis, integrating all of the driving forces underpinning it, and issuing a call to action.

> *"…The **pace of change in today's world is accelerating**. Geopolitical competition, economic volatility, climate change impacts, **shifting workforce expectations**, **evolving technologies**, and new enterprises at sea are converging and **driving changes we must make** for our Service. We **must adapt** to ensure the accelerating pace of change will not overtake our ability to protect, defend, and save the American public we serve…"*
>
> *Excerpt from USCG Posture Statement, 2024 Budget Overview (Fagan, 2023)*

This chapter provides essential background information necessary for understanding this thesis. Three key areas are addressed: the United States Coast Guard, shipbuilding in the United States, and the Post-Delivery phase that transitions a new ship from construction to an operational status. Each section of this chapter is comprised of two sub-sections: the first section provides foundational background information, the second discusses contemporary trends relevant to this study.

## 2.1 United States Coast Guard

A basic understanding of the United States Coast Guard's missions, organizational culture, and contemporary trends adds depth and critical context to this analysis. Organization details are presented for the elements of the Coast Guard which are central to this study. Section 2.1.1 details relevant organizational context, and Section 2.1.2 presents contemporary organizational trends that are relevant to this thesis.

### *2.1.1 Coast Guard Organizational Background*

Since 1790, the Coast Guard has safeguarded the American people, promoting national security, maritime safety, and economic prosperity in a complex maritime environment. As a branch of the United States Armed Forces, a regulatory agency, a law enforcement organization, and a first responder, the Coast Guard employs a unique blend of authorities, broad jurisdiction, flexible operational capabilities, and a robust network of partnerships (USCG, 2024). The Coast Guard conducts 11 statutory missions managed within six mission programs spanning the full spectrum of maritime activities:

- **Defense Operations**: Defense Readiness
- **Maritime Law Enforcement**: Migrant Interdiction; Drug Interdiction; Living Marine Resources; Law Enforcement
- **Maritime Response**: Search and Rescue; Marine Environmental Protection
- **Maritime Prevention**: Marine Safety
- **Maritime Transportation System Management**: Aids to Navigation; Ice Operations
- **Maritime Security Operations**: Ports, Waterways, and Coastal Security

Other service responsibilities include Cyber Security, conducting activities and efforts to advance US diplomacy and international relations, Bridge Administration, Great Lakes pilotage, providing products and services for the Intelligence Community, and other Waterways Management functions supplementary to Aids to Navigation.

Coast Guard Publication 1 states, "The true value of the Coast Guard to the Nation is not its ability to perform any single mission, but in its versatile, highly adaptive, multi-mission character" (USCG, 2014). The statistics listed in Figure 2.1 illustrate the breadth and scale of the Coast Guard's multi-mission capabilities and accomplishments.

## On an average day, the Coast Guard:

- Conducts 42 search and rescue cases
- Saves 12 lives.
- Saves $114,000+ in property.
- Seizes 1,253 pounds of cocaine and 172 pounds of marijuana.
- Conducts 133 waterborne patrols of critical maritime infrastructure.
- Interdicts 18 illegal migrants.
- Escorts 9 high-capacity passenger vessels.
- Conducts 13 security boardings in and around US ports.
- Screens 313 merchant vessels for potential security threats prior to arrival in US ports.
- Conducts 19 fisheries conservation boardings.
- Services 45 buoys and fixed aids to navigation.
- Investigates 26 pollution incidents.
- Completes 24 safety examinations on foreign vessels.
- Conducts 162 marine inspections on US vessels and facilities.
- Investigates 17 marine casualties involving commercial vessels.
- Facilitates movement of $15.6 billion worth of goods and commodities through the Nation's Maritime Transportation System

*Figure 2.1. Average U.S. Coast Guard Day (USCG, 2024)*

The Coast Guard's multi mission nature gives rise to an organizational culture that is accustomed to dynamic operations. As the needs of our nation evolve, our mission and demand signals change with them.

The Coast Guard operates a surface fleet of approximately 250 cutters, ranging in size and complexity from 420-foot Heavy Icebreakers to 65-foot Inland Waterways Buoy Tenders. Today more than half of this fleet is operating well beyond its design service life. At the same time, the Coast Guard's services are in great demand, with a steadily growing mission set. To address growing mission demand and an aging fleet, the Coast Guard is currently engaged in its largest shipbuilding effort since World War II. Seven Acquisition programs of record are scheduled to deliver 134 new cutters over the next 15 years, a multi-billion-dollar capital investment to recapitalize the Coast Guard's surface fleet.

#### *2.1.1.1 Coast Guard Surface Acquisitions*

The Coast Guard Acquisition Directorate manages a multibillion-dollar recapitalization investment portfolio of acquisition programs spanning three major domains: surface, aviation, and command, control, communications, computers, cyber, and intelligence (C5I) systems. The surface acquisitions program recapitalizes the fleet's cutters, patrol boats, small boats, and utility craft, and improves the operational availability of legacy platforms. Seven active acquisition programs deliver new and improved platforms with state-of-the-market mission equipment to improve mission capabilities:

- National Security Cutter (NSC): 418 feet length, 4,500 long-ton displacement, with a 148-member crew. Planned fleet size of 11 hulls homeported in California, Hawaii, and South Carolina.
- Fast Response Cutter (FRC): 154 feet length, 353 long-ton displacement, with a 24-member crew. Planned fleet size of 65 hulls, geographically distributed homeporting including Bahrain, Alaska, Hawaii, Puerto Rico, and Guam.
- Offshore Patrol Cutter (OPC): 360 feet length, estimated 3,600 long-ton displacement, with a 125-member crew. Planned fleet size of 25 hulls, eventual homeport locations have yet to be determined.
- In Service Vessel Sustainment (ISVS): identifies and implements cost-effective ways to ensure the Coast Guard has the surface assets necessary to complete its missions. Oriented towards existing cutter fleets, executes Service Life Extension Projects and Major Maintenance Availabilities.

- Polar Security Cutter (PSC): 460 feet length, estimated 22,900 long-ton displacement, crew size yet to be determined. Planned fleet size of up to six hulls eventual homeport locations have yet to be determined.
- Waterways Commerce Cutter (WCC): three variants ranging from 120 to 180 feet length, with a 14-to-17-member crew. Planned fleet size of 30 hulls, eventual homeport locations have yet to be determined.
- Boat Acquisition Program: multiple active cutter acquisitions providing varied levels of capability.

This thesis will focus on the Offshore Patrol Cutter (OPC) Program, as a representative and temporally relevant example of the overall portfolio.

#### *2.1.1.2 Offshore Patrol Cutter (OPC) Program*

The Offshore Patrol Cutter (OPC) is one of the Coast Guard's highest investment priorities, replacing 270-foot and 210-foot medium endurance cutter fleets which range from 30 to 60 years old. The Coast Guard plans to spend $12 billion to acquire a fleet of 25 OPCs, highly capable modern vessels 360-feet in length displacing 3,600 long-tons, over the next 15 years. The OPCs will provide the majority of offshore presence for the Coast Guard's cutter fleet, bridging the capabilities of the 418-foot National Security Cutters, which patrol the open ocean, and the 154-foot Fast Response Cutters, which serve closer to shore. The OPCs will conduct missions including law enforcement, drug and migrant interdiction, search and rescue, and other homeland security and defense operations. Each OPC will be capable of deploying independently or as part of task groups and serving as a mobile command and control platform for surge operations such as hurricane response, mass migration incidents, and other events. The cutters will also support Arctic objectives by helping regulate and protect emerging commerce and energy exploration in Alaska (U.S. Coast Guard, 2023).

Figure 2.2, dated 27 October 2023, shows the christening and launch of the lead ship (first OPC), United States Coast Guard Cutter ARGUS at Eastern Shipbuilding Group in Panama City, Florida. The initial program plan called for delivery in 2021, the current schedule projects delivery in 2025 however the program is actively completing a schedule review which is anticipated to confirm additional delays. Notably, the initial phase of the pre-commissioning crew was assigned to ARGUS in 2020. Many crew members will complete full operational afloat tours of duty without sailing an operational cutter.


*Figure 2.2. USCGC ARGUS Launch, 27 October 2023*

### 2.1.2 Contemporary Coast Guard Trends

Two contemporary Coast Guard trends act as driving forces for this study. The first, referred to herein as a *Growing Fleet*, refers to the $1 billion capital investment to recapitalize the Coast Guard's surface fleet. The second, referred to herein as *Workforce Shortages,* refers to ongoing challenges with recruiting and retention of active-duty service men and women.

1. *A Growing Fleet*. The US Coast Guard is currently engaged in the largest shipbuilding effort in the 234-year history of the service, delivering 134 cutters over the next 15 years ranging in size from 154-foot, 350-long ton fast response patrol boats to 360-foot 23,000-long ton heavy icebreakers. Through this initiative, the total number of hulls comprising the Coast Guard's surface fleet will remain stable, however the overall fleet tonnage will double. The size, technological complexity, and capability of the future CG fleet will bear little resemblance to today's fleet. The increased complexity, scale, and pace of shipbuilding has introduced significant challenges for the Coast Guard; however these same factors also create opportunities.
2. *Workforce Shortages*. The Coast Guard is currently grappling with critical workforce shortages, impacting the service's ability to maintain operational readiness. The shortage is driven by multiple factors, including recruitment challenges, competition with the private sector for skilled labor, retention challenges, and broad shifts in workforce expectations. These challenges have resulted in a significant gap between personnel allowance targets and actual staffing levels across the service. These challenges are not unique to the Coast Guard; over the past year the US Navy has carried an average of more than 18,000 vacant positions on its ships due to recruitment and retention challenges (Serbu, 2024).

## 2.2 Shipbuilding in the United States

This thesis addresses a specific subset of the global shipbuilding industry: the design and construction of United States military vessels via government acquisition programs. Section 2.2.1 details relevant context, and Section 2.2.2 presents contemporary trends that are relevant to this thesis.

### 2.2.1 United States Military Shipbuilding

Shipbuilding is one of the oldest surviving industries in the world. Despite these deep roots, the fundamental nature of ship design and the scale of ship construction make the combination a complex and challenging task filled with uncertainty. In order to maintain levels of production necessary to achieve and sustain an affordable and effective shipbuilding industry, including critical infrastructure and proficient skilled trades, high degrees of governmental protection and subsidies are common in the global market (The Industrial College of the Armed Forces National Defense University, 2004). While the United States has legislation such as the Jones Act that recognizes the strategic need to maintain an industrial shipbuilding base, major shipbuilding subsidies expired in the 1980s (46 United States Code). Today the United States shipbuilding industry is in the throes of a 70-year decline and continues to struggle to compete on a global scale. Measured by gross tonnage, the United States currently builds approximately 0.2% of the world's ocean-going ships; China, Korea, and Japan collectively build over 90% (Frittelli, 2023).

Military shipbuilding constitutes the vast majority of large-scale vessel construction in the United States, and it is a uniquely challenging subset of the overall industry. The military's fundamental need for competitive advantage drives a design bias towards novel, innovative technologies which are developmental and unproven. This stands in stark contrast to the commercial industry, which prioritizes proven design concepts outfitted with high technology readiness level (TRL) equipment. The result is that shipbuilding is a strained and challenging industry. The United States shipbuilding industry struggles to compete on the global stage, and the subset of this dwindling industry that designs and builds military vessels is faced with even more challenge. United States Government acquisition programs to design and build naval vessels have consistently demonstrated a high degree of uncertainty spanning cost, schedule, and scope parameters.

A comprehensive third-party review of military ship construction in the United States conducted in 2022 found that over the past 10 years, active shipbuilding programs have been characterized by schedule delays measured in years versus months, billions of dollars in cost growth, and significant quality and performance shortfalls (Naval Shipbuilding, 18-238).

While these characteristics represent all major shipbuilding programs, ship construction performance is significantly poorer in cases where vessel requirements are novel or particularly complex (such as the Coast Guard's Polar Security Cutter program). Given the high variability in cost, schedule, quality, and system/component-level configuration of major ship deliveries, synchronizing interdependent downstream support and post-delivery activities is extremely challenging.

### *2.2.2 Contemporary Shipbuilding Trends*

Novel design and technology, unstable requirements, concurrent design and build, a contracting strategy anchored in awarding work to the lowest bidder, and the fundamental lack of an organically healthy industrial base combine to make military shipbuilding in the United States extremely uncertain. Three contemporary trends relative to military shipbuilding in the United States act as driving forces for this study. The first is the profound degree of Uncertainty, which negatively impacts non-shipbuilding organizational activities that have interdependencies with the ship construction process. The second trend is ongoing advancements in Technology, and the impacts on construction and sustainment requirements. The third trend is the Geographic location of active and planned Coast Guard shipbuilding programs, which presents some opportunities for efficiencies and economies of scale.

1. *Uncertainty*. Shipbuilding in the United States exhibits significant uncertainty in all dimensions of traditional project management (Government Accountability Office, 2024).

This thesis focuses on schedule uncertainty and scope uncertainty. Figure 2.3 presents the schedule related findings from a Government Accountability Office (GAO) report which analyzed average schedule delays in months for the 10 major Navy shipbuilding programs active in the 2010s (Government Accountability Office, 2018).

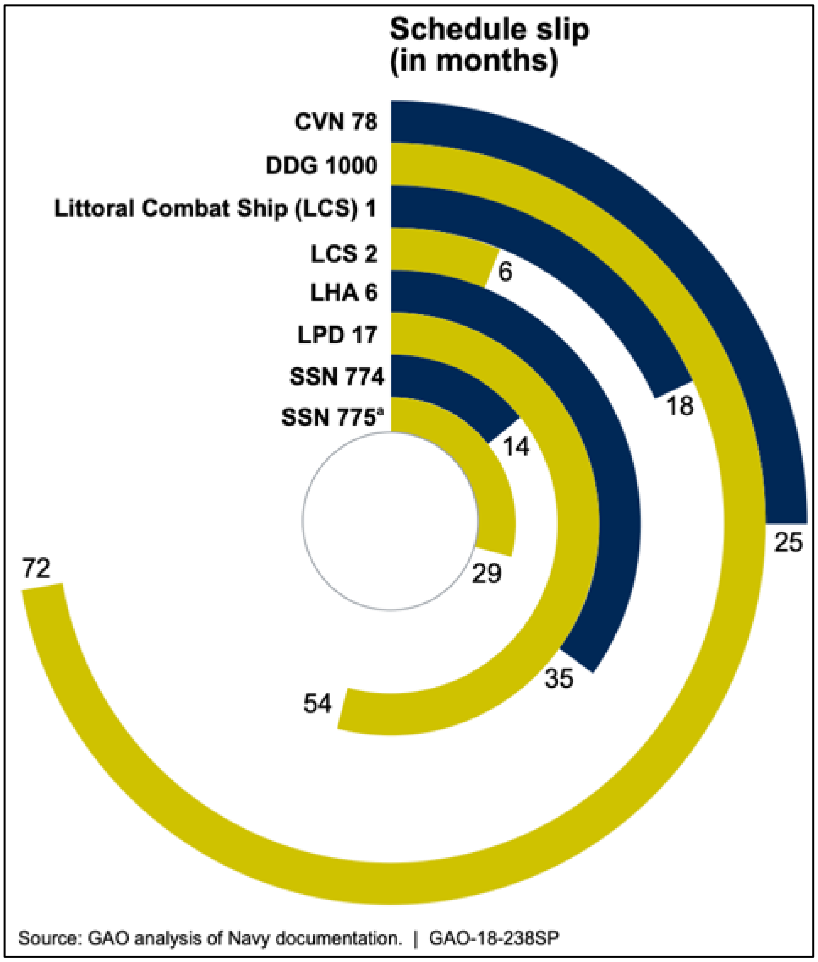



*Figure 2.3. US Shipbuilding Schedule Performance*

2. *Technology*. Technological innovation and complexity have been growing exponentially since the Industrial Revolution (de Weck, 2022).
    a. *Technological Complexity*. The accelerating pace of change has a compounding effect on complexity. Compelling evidence of the speed and scale of this trend may be observed within the current CG fleet: in the same day a CG naval engineer may support one cutter with a “chain and sprocket” propulsion control

architecture that is mechanical pneumatic and requires a wrench to calibrate, and another cutter with a "fly by wire" digital control architecture that requires a laptop to calibrate.

b. *Technology Refresh Cycles*. The exponential increase in technological innovation and complexity is coupled with increasing refresh cycles. Ever-shortening refresh cycles mean decreasing the useful service life of systems, components, and sub-components. Mapped across the systems-of-systems-of-systems that comprise today's military vessels, this trend has significant impact on performance, cost, and supportability.

3. *Geography*. Coast Guard shipbuilding activities are geographically centered in the gulf coast of the United States. Seven major shipbuilding programs are actively under construction, all of them between Panama City, FL and Lockport, LA. Future shipbuilding will further concentrate in the area spanning Pascagoula, MS and Lockport, LA.

## 2.3 Post Delivery Phase

The Post-Delivery phase includes major industrial activities to install or upgrade targeted ship systems and equipment, extensive equipment and system grooms, crew training, and testing and certification events at component, sub-system, system, and system-of-system levels. This thesis defines the Post-Delivery (PD) phase of a ship's lifecycle as the period of time and organizational activities in between ship construction and the designation of ship and crew as Ready For Operations (RFO). Figure 2.4 provides a simplified visualization of the primary phases, this thesis will build upon this construct in analyzing the existing approach and developing a recommended system architecture.


*Figure 2.4. Simplified Ship Delivery Phase Chart*

Two critical phase-gate events define the beginning and end of the Post-Delivery phase, each constituting a ship's transition between phases. Contract Delivery, referred to herein as Delivery, signifies custody transfer of the vessel from the shipbuilder to the Coast Guard, marking the transition from the Construction phase to the Post-Delivery phase. Designation of the ship and crew as Ready For Operations (RFO) signifies the completion of Post Delivery and Testing requirements, marking the transition to the Operations phase. These events are described in further detail in Section 2.3.1. Figure 2.5 overlays these key events on the simplified ship delivery phase chart.

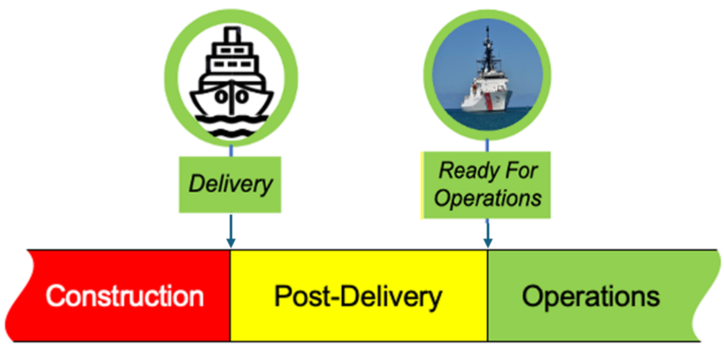



*Figure 2.5. Phase Gate Events on Ship Delivery Phase Chart*

Once the Coast Guard has accepted custody, the primary mission shifts from construction to training, testing, and certification with an ultimate goal of earning RFO designation.

The organizational decision to staff a new vessel's pre-commissioning crew is a major focus of this study. The current approach breaks the crew into two phases, targeting arrival 12 and six months prior to delivery, respectively. Once a crew is assigned, the complexity of all tasks increases significantly. The crew's center of gravity is the cutter's homeport, introducing geographic tension and time pressure. The number of stakeholders increases significantly. Thus this study's area of interest is expanded to include pre-delivery events that have dependencies to staffing decisions and activities. Figure 2.6 provides a visualization of the refined area of interest.

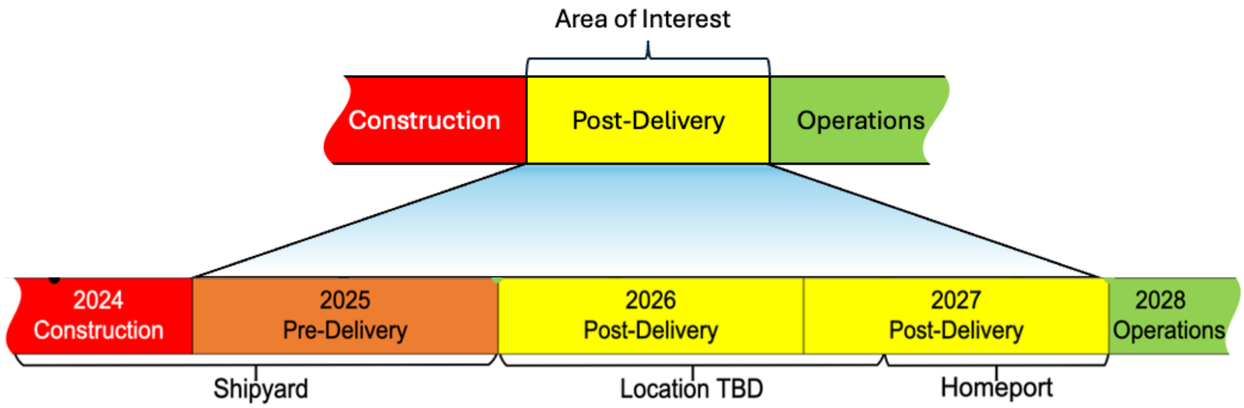



*Figure 2.6. Expanded Area of Interest Phase Chart*

### *2.3.1 Key Events*

There are well over 200 discrete non-construction related tasks (outfitting, training, grooming, upgrades, testing, and certification) required to take a newly constructed modern naval vessel through delivery to a fully operational status. This section defines and discusses key events for context. The PD phase is treated herein as a complex sociotechnical system, rich with complexity, uncertainty, and diverse stakeholders with dynamic relationships and interdependent tasks.

- **Staffing of Pre-Commissioning Crew**. The arrival of a crew of active-duty operational Coast Guard personnel who will ultimately sail and operate the vessel. Phase one includes approximately 13 personnel who arrive 12 months prior to delivery. Phase two includes approximately 91 personnel who arrive six months prior to delivery. Table 2.1 details the composition of a notional Offshore Patrol Cutter pre-commissioning crew.

*Table 2.1. OPC Crew Breakdown (notional)*

| Rank or Rate | Phase 1 | Phase 2 | Total |
|---|---|---|---|
| O5 | 1 | 0 | 1 |
| O4 | 1 | 0 | 1 |
| O3 | 1 | 1 | 2 |
| O2 | 1 | 2 | 3 |
| O1 | 0 | 4 | 4 |
| CWO | 1 | 3 | 4 |
| E8 | 0 | 1 | 1 |
| E7 | 2 | 7 | 9 |
| E6 | 2 | 16 | 18 |
| E5 | 2 | 19 | 21 |
| E4 | 2 | 25 | 27 |
| E3 | | 13 | 13 |
| Total | 13 | 91 | 104 |

- **Delivery**. *Key phase gate event.* The formal custody transfer of a newly constructed vessel from the shipbuilder to the Coast Guard. Delivery constitutes the Coast Guard's official acceptance that the ship has satisfied the contractual and technical requirements established in the contract. Formally the Coast Guard's Vice Commandant, in their capacity as Component Acquisition Executive, accepts each major cutter into the Coast Guard based on recommendations from a multi-layered blend of oversight and program management subject matter experts. The current practice is the Prospective Commanding Officer of the vessel, who has reported for duty 12 months ahead of delivery, assumes custody of the vessel and places it In-Commission (Special) status.
- **Ready For Operations (RFO)**. *Key phase gate event.* The point at which a new cutter and its associated systems are ready to meet the full range of missions outlined in the asset's Capabilities Production Document. The operational commander of the cutter's intended homeport is responsible for designating the ship and crew Ready For Operations when all requirements have been satisfied. All required certifications have been achieved, and ship is available for worldwide deployment.

- **Trials.** Formal events to demonstrate shipbuilder compliance with contractual requirements and facilitate targeted certifications. This category includes Builder's Dockside Trials, Builder's Sea Trials, Acceptance Trials, and Final Contract Trials.
- **Ready For Sea**. Coast Guard certification of the ship itself, the crew, and the outfitting that ensures a minimum level of safe maritime operational capability and redundancy has been satisfied. Certification requires a combination of inport and at sea navigation, engineering, and damage control drills, as well as extensive review of ship systems and outfitting by an independent third party. The Coast Guard requires certification as Ready For Sea (RFS) before a vessel may permanently depart the shipyard.
- **Commissioning**. Transition of vessel status from In-Commission (Special) to In-Commission (Active) and formal assignment to an Operational Commander. The vessel must demonstrate the ability to safely execute restricted operations, however RFO certification is not required for commissioning.
- **Homeport Arrival**. Coast Guard ships are homeported around the globe. In addition to achieving the requirements necessary for commissioning, there are significant infrastructure and logistics requirements that must be met at the host base before the ship arrives.
- **Major Maintenance Events**. Major depot level maintenance is a major component of the Post Delivery phase, typically completed by a third-party commercial contractor in the vicinity of the ships gaining homeport. Some activities are related to the shipbuilding contract, such as equipment discrepancies that were identified through trials and testing which need to be addressed but do not prevent the ship from maintaining Ready For Sea certification. Other activities are not related to the shipbuilder, and are owned by the sustainment support community. These activities include equipment upgrades to address

obsolescence, weapons systems installations, and equipment upgrades or modifications driven by emergent mission demand outside of the configuration baseline.

- **Major Certification Events**. Formal certification events occur throughout the area of interest, key events are highlighted here.
    - Combat System Ship Qualification Trials (CSSQT). DOD certification of crew and installed combat systems, required for RFO.
    - Combined Assessment of Readiness and Training (CART). Basic administrative, materiel, and functional assessment of overall readiness.
    - Boat Standardization (STAN). Cutter boat assessment.
    - Aviation Certification (AVCERT). Aviation assessment of flight deck, aviation outfitting, and aviation operations.
    - Comprehensive Law Enforcement Assessment of Readiness (CLEAR).
    - Tailored Ships Training Availability (TSTA).
- **Initial Operational Test and Evaluation (IOT&E)**. Major acquisition event. Independent third party (Navy Commander Operational Test Force) assesses operational effectiveness and suitability of the ship, including how systems and sub-systems affect mission accomplishment by Coast Guard personnel in actual operating environments. IOT&E is not applicable to all hulls and is typically targeted for the first hull, however successful IOT&E is required for senior Coast Guard and DHD leadership to authorize full rate production of the overall acquisition program.

#### *2.3.1.1 Post Delivery Concept of Operations*

When the Coast Guard accepts delivery of a ship, the primary mission shifts from shipbuilding to preparing for operations. The Coast Guard has 45 days to make the ship and crew Ready For Sea, which is a lower standard than RFO, to depart the shipyard. Figure 2.7 organizes key events along the system phase chart.

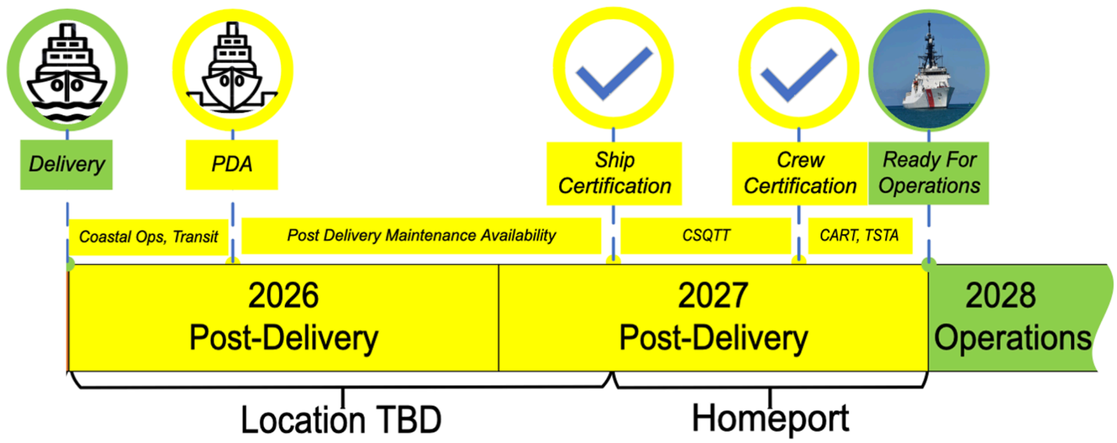



*Figure 2.7. Expanded View of Post Delivery Activities*

Consider the geographic locations of the PD phase: the majority of the time is listed as *To Be Determined,* with the remainder in the vessel's homeport. The current approach places major dependencies between an individual ship's eventual homeport and its complex suite of PD activities, which includes operational testing as well as heavy industrial maintenance contracts with significant infrastructure requirements. Homeporting decisions are complex and have not been finalized for the planned fleet of 25 OPCs, however significant geographic diversity is anticipated including several homeports outside of the continental United States where heavy ship repair industries are not in place.

### 2.3.2 Contemporary Post Delivery Trends

Novel design and technology, unstable requirements, concurrent design and build, a contracting strategy anchored in awarding work to the lowest bidder, and the fundamental lack of an organically healthy industrial base combine to make military shipbuilding in the United States extremely uncertain. Three contemporary trends relative to military shipbuilding in the United States act as driving forces for this study.

1. Uncertainty. Military shipbuilding in the United States exhibits a profound degree of uncertainty, which negatively impacts non-shipbuilding organizational activities that have

interdependencies with the ship construction process. Figure 2.8 demonstrates the range of possible outcomes associated with the Delivery milestone.

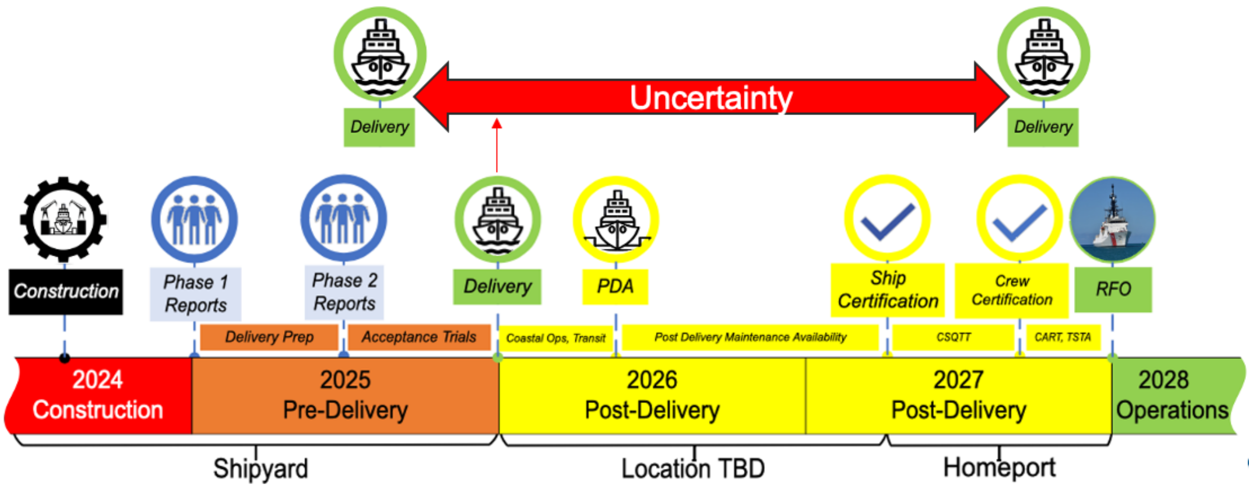



*Figure 2.8. System Uncertainty*

2. Technology. Today's ships are for more complex and connected than the vessels they are replacing. Increasing technological complexity and decreasing technology refresh time are driving broad increases to the scope and complexity of the PD phase.
3. Geographic Location. The third trend is the Geographic location of active and planned Coast Guard shipbuilding programs, which presents some opportunities for efficiencies and economies of scale.

# Chapter 3. Methodology

The MIT-sdm program seeks to arm technical leaders with the ability to manage complexity in dynamic and highly uncertain sociotechnical environments, at the intersection of people and technology. The fundamental idea of this thesis to treat the Post-Delivery phase as a complex sociotechnical system, deserving of a dedicated system architecture to meet the Coast Guard's current and future needs. This thesis integrates principles and techniques from SDM coursework to analyze a novel real-world challenge and develop executable recommendations for improvement.

## 3.1 Integrated Approach

All of the coursework and principles inspire a paradigm shift in thinking. Three courses in particular contributed significant principles and techniques to this analysis: Flexible Engineering Design (FED) introduces a paradigm shift from rigid processes which either ignore uncertainty entirely or assume it cannot be managed, to flexible processes which are capable of effectively interacting with a diverse range of possible scenarios. System Design and Management (SDM) is used primarily to deconstruct and analyze the existing approach and architecting a new PD system. ARIES provides a solid foundation for analysis and ideation through deep stakeholder and enterprise analysis.

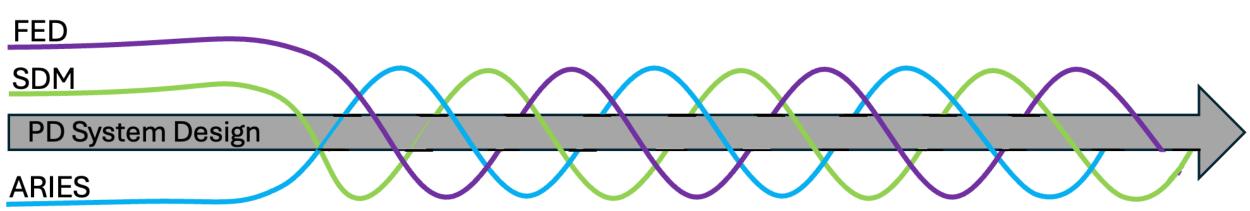



*Figure 3.1. Integrated Systems Design Approach*

The ARIES framework provides a highly effective framework and techniques for systems architecting enterprises. This thesis draws primarily on ARIES approach to analyzing the "as-is" enterprise, to lay the foundation for orienting the PD phase as a system, analyzing the system, and ideating potential alternative architectures. These steps include Enterprise Landscape Analysis, Stakeholder Analysis, and Current Architecture Analysis.

FED enables the modeling of uncertainties and quantification of real options. This thesis employs FED methods to model and evaluate existing and proposed staffing strategies, which the ARIES analysis identified as the key driver of PD system complexity. The FED models also enable efficient, low-cost, high-fidelity exploration of alternative options, playing a significant role in the ideation process. In addition to the mechanics, FED inspires a profound paradigm shifting change from deterministic to probabilistic, which is central to the analysis and recommendations presented in this thesis.

SDM principles, tools, and techniques cover a wide range of potential applications, this thesis utilized system architecture design processes and tradespace exploration to design a flexible and innovative system architecture from the ground up, capable of meeting the Coast Guard's current and future needs.

### *3.1.1 Implementation Considerations*

High level implementation considerations drew heavily on the author's Coast Guard experience, informed by systems thinking and flexible engineering principles, to recommend a time-phased implementation roadmap. This approach is intended to demonstrate a proof of concept with measured improvements, refine the approach and build through additional phases with progressively increasing complexity, cost, and impact. Three specific phases are recommended:

1. *Adopt a flexible approach within the existing system*. Acknowledge that a certain amount of uncertainty is inevitable, giving rise to a paradigm shift from deterministic to

probabilistic thinking. Delivery milestones for new ships are often not met, organizational tasks that are dependent on this milestone should be capable of dealing with this reality.

2. *Invest in the addition of organizational flexibility to the existing system*. Thoughtful investment in organizational flexibility can enable an organization to take advantage of upside opportunities while significantly limiting the negative impacts of downside risks, particularly when attempting to deal with highly uncertain tasks such as shipbuilding schedules. Design and implement a small-scale test intended to achieve a proof of concept.
3. *Invest in the design and implementation of a new post-delivery system architecture.* Progressively refine steps one and two. Build upon targeted improvements to expand to a new organizational capability delivered by a system architecture developed expressly for this purpose.

## 3.2 System Definition

Orienting the time and tasks spanning construction to operations as a complex sociotechnical system is foundational to this study.

### 3.2.1 Transition from Build to Operations as a System

Staffing the pre-commissioning crew is the key event, highly sensitive and highly connected to system complexity downstream. The Coast Guard’s current approach is to establish this crew two phases, one reporting twelve months prior to delivery and the second phase reporting six months before delivery. This necessitates and expansion of this analysis from the post-delivery phase as defined above, to include the pre-delivery phase which encompasses key staffing activities.

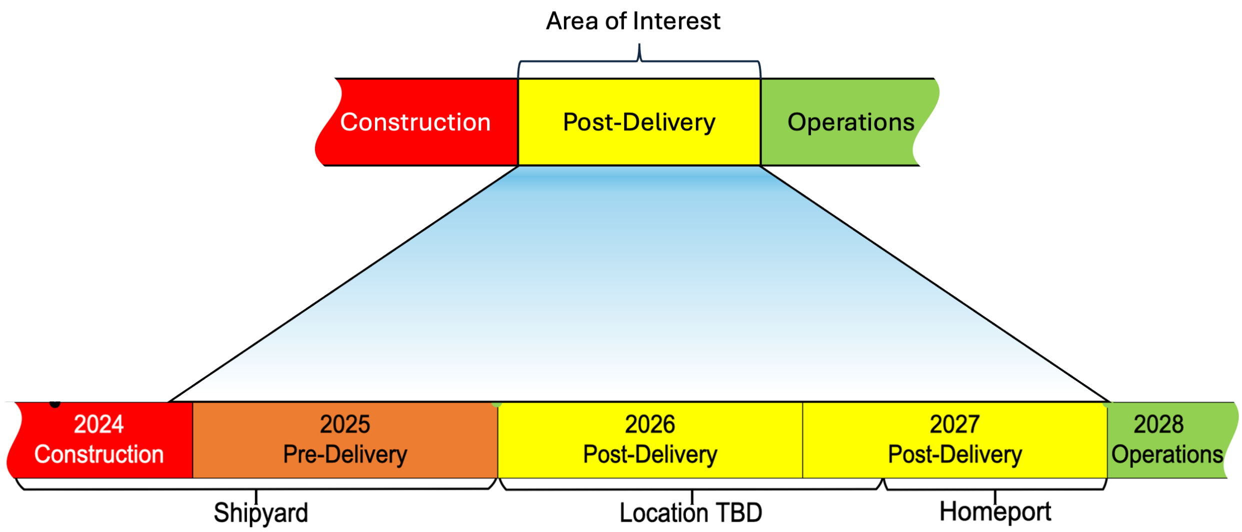



*Figure 3.2. Expanded Area of Interest*

#### *3.2.1.1 Pre Delivery*

Staffing a pre-commissioning crew is a unique activity in the personnel management world. Pre-commissioning crews are new billets and thus lack incumbents, this introduces a unique degree of flexibility by eliminating time pressure to replace incumbents within a larger personnel rotation construct.

#### *3.2.1.2 Post Delivery*

The Post Delivery period is primarily oriented towards training and certification of both the ship and the crew, however there is also a significant amount of heavy industrial maintenance completed during this phase. The tension between technology refresh cycles and acquisition contract timelines increases the obsolescence management requirements during the Post Delivery period.

### *3.2.2 System Composition*

Figure 3.3 below organizes key organizational activities and milestones related to these recommendations, from ship construction through delivery and post-delivery to the accomplishment of Ready for Operations. This image will be utilized as a framework for discussion of the recommended phases.

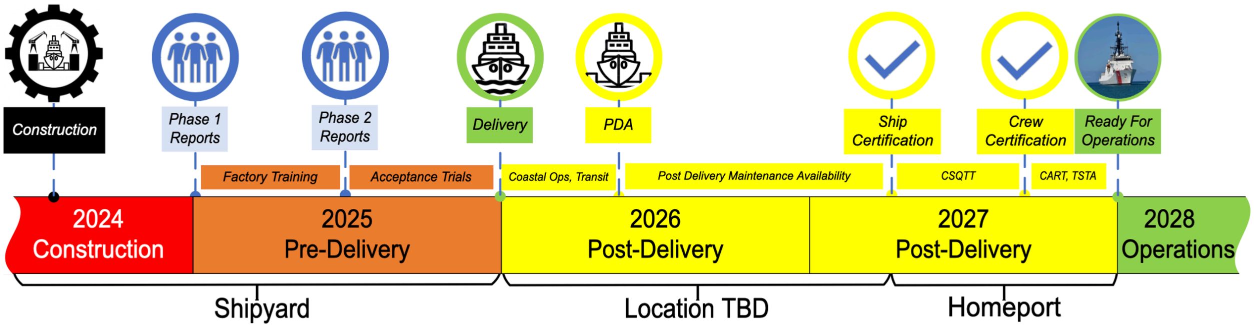



*Figure 3.3. System Framework*

## 3.3 ARIES

The Architecting Innovative Enterprise Strategy (ARIES) framework developed by Nightingale and Rhodes provides and organizes principles, tools, and techniques to enable a holistic approach to enterprise transformation. The ARIES emphasis on a holistic approach ensures architecting considers not just the enterprise itself, but also the environment in which it will operate. Its focus on future states is an acknowledgment of the fundamental uncertainty that makes enterprise architecting challenging. Developed from the knowledge and experience of enterprise leaders, researchers, and architecting teams in more than 100 real-world projects, the ARIES framework pictured in Figure 3.4 is comprised of ten elements, a seven-step process, and a repository of formal and informal techniques for analysis, ideation, modeling, and evaluation (Rhodes, Systems Architecting Applied to Enterprises, 2024).

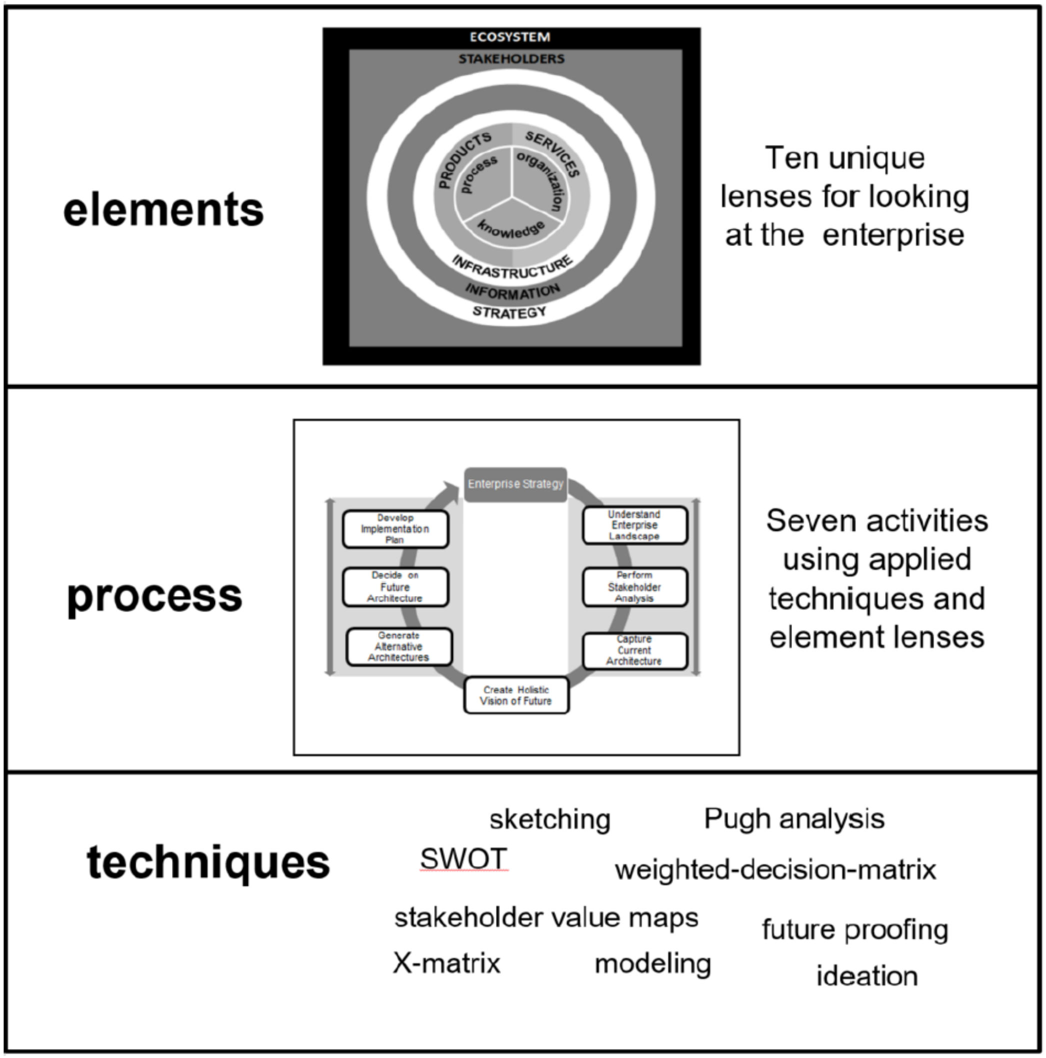



*Figure 3.4. The ARIES Framework*

ARIES may be applied to a range of activities, from the design of a new large-scale organization to a smaller-scale modernization or improvement project. This thesis values the ARIES framework for its emphasis on context, which drives a comprehensive approach to understanding system needs and requirements, and for its focus on uncertainty and future proofing, which underscores a structured but flexible approach to ideation and concept generation.

Rhodes and Nightingale offer seven architecting imperatives, which guided the development of a research strategy for this project. Table 3.1 presents the seven imperatives with a discussion of their application to the development of the recommendations of this thesis (Nightingale & Rhodes, 2015).

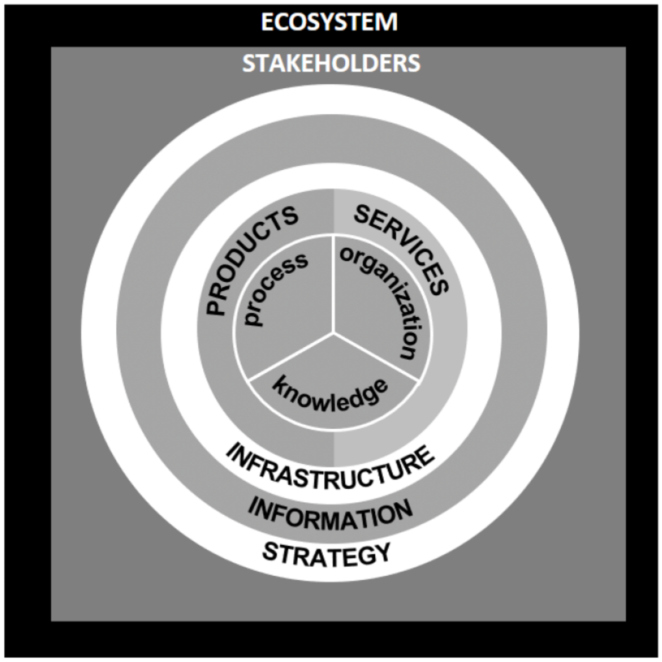
*Table 3.1. Application of ARIES Architecting Imperatives*

| # | Architecting Imperative | Application to Coast Guard Fielding New Ships |
|---|---|---|
| 1 | Make architecting the initial activity in tranformation. | Fundamental premise: evolving context is driving need and opportunity to transform Coast Guard's approach to fielding new ships. |
| 2 | Develop a comprehensive understanding of the enterprise landscape. | Complexity of landscape is central to this topic: mix of government and non-government entities, high degree of uncertainty and change. |
| 3 | Understand what stakeholders value and how that may change in the future. | Post Delivery phase entails a surge of inter-organizational stakeholders. |
| 4 | Use multiple perspectives to see the whole enterprise. | Comprehensive analysis conducted from stakeholder viewpoints, complimented by interviews by representative of key stakeholder groups. |
| 5 | Create an architecting team suited to the transformation challenges. | Included in recommendations. |
| 6 | Engage all levels of leadership in transformation. | Interviews for this thesis span working level, senior leadership, and executive leadership. Recommendations include this imperative. |
| 7 | Architect for the enterprise's changing world. | Uncertainty and change are fundamental to this approach. |

This thesis employs a tailored ARIES approach, drawing extensively from the underlying principles throughout but analytically focusing on the first half of the process to analyze the current approach and serve as a foundation for further work using FED and SDM methods.

### *3.3.1 Ten ARIES View Elements*

The ten elements pictured in Figure 3.5 provide ten unique lenses for approaching the analysis of an enterprise. Collectively they ensure a holistic assessment is achieved. The first two elements, ecosystem, and stakeholders are foundational to any analysis and thus align with the first two process activities: understand the enterprise landscape and perform a stakeholder analysis. Strategy, information, and infrastructure represent the next set of view elements, which are comprehensive, complimentary enterprise elements depicted by the three outer rings of the circle. The final five view elements are products, services, process, organization, and knowledge.




© Nightingale and Rhodes, 2015

*Figure 3.5. ARIES Ten Element Model*

These ten elements may be applied across the full seven-activity process model, a brief discussion of each view element is provided (Rhodes, 2024).

- Ecosystem: the external environment in which the enterprise operates including regulations, political factors, market trends, economic considerations, and broad societal trends.
- Stakeholders: people or entities with an interest or influence on the system and its objectives.
- Strategy: link to overarching enterprise vision and long-term organizational goals and objectives.
- Information: the information and data required for the enterprise to perform as required to execute its mission(s) and deliver value to stakeholders.
- Infrastructure: physical facilities, information technology, and communications technology, and enterprise systems necessary for successful operation of the enterprise.
- Products: item that is produced by the enterprise.

- Services: value-delivering offerings derived from enterprise knowledge, skills, and competencies. Services includes product support.
- Process: Core, leadership, life cycle support, and enabling processes which guide the creation of value by the enterprise.
- Organization: organizational structure and fundamental culture of the enterprise.
- Knowledge: explicit and tacit knowledge, competencies, and intellectual property that is generated and resides within the enterprise.

### *3.3.2 Tailoring the ARIES Approach*

This thesis draws from the first four steps of the ARIES, as indicated by the green highlights in Figure 3.6.

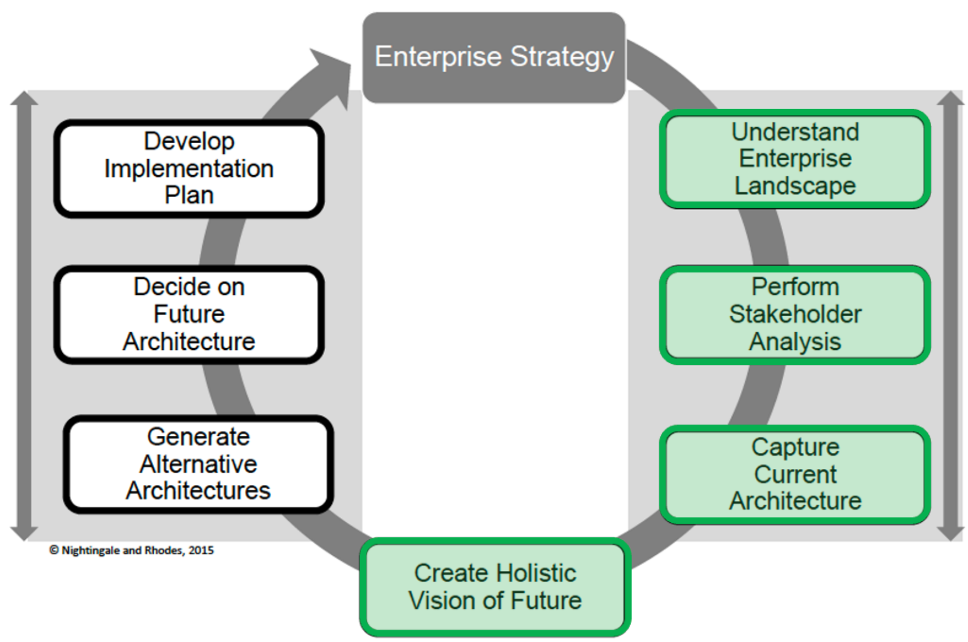



*Figure 3.6. Tailored ARIES Process*

A brief summary of each step is provided:

1. Understand Enterprise Landscape: thorough analysis of both internal and external factors that may affect the enterprise, in both its current and future states. The ten view elements are utilized as different lenses to ensure a holistic analysis is achieved. This step

provides a foundation for decision-making and ideation throughout the systems architecting process.

2. Perform Stakeholder Analysis: thorough analysis of the stakeholders themselves. Stakeholder saliency is analyzed as a function of power, legitimacy, and urgency. These analyses inform the development of robust needs and requirements that are reflective of the enterprise and its stakeholders functioning in their actual operational environment.
3. Capture Current Architecture: deconstruct the existing architecture to provide a baseline from which architecting efforts can be measured or compared. Utilization of the ten view elements ensures a full assessment is completing including processes, technologies, and resources.
4. Create Holistic Vision of Future: the first three steps are all analytical, step 4 is where ideation and creation begin. By integrating the findings and insights of steps one, two, and three, a comprehensive and effective vision for the future may be developed. Notably, this is not a detailed design; subsequent ARIES steps will develop and evaluate alternative architectures; this step is focused on establishing future goals and outcomes.

The first four steps of the ARIES process, paired with the ten view elements provides a comprehensive foundation to embark on the design and architecting of the Coast Guard's system to transition new ships from construction to operations.

## 3.4 FED

The primary concept this thesis draws from Flexible Engineering Design is the recognition that uncertainty is inevitable, and while we can never eliminate or precisely project uncertainty, we can improve outcomes by thinking probabilistically and designing flexibility into our systems. Fundamentally this acknowledgement drives a paradigm shift in thinking from a deterministic approach which treats discrete forecasts as certain, to a probabilistic approach which acknowledges uncertainty and instead of discrete forecasts, considers a range of potential outcomes. Flexible engineering systems can improve outcomes at both ends of the spectrum, by minimizing the downside risk associated with unexpected negative events, and maximizing the ability to take advantage of potential gains associated with unexpected positive events.

### 3.4.1 Uncertainty and Flexibility

By definition uncertainty cannot be precisely accounted for. FED provides a construct to pivot from basing design decisions on discrete projections at the center of the outcomes probability distribution, to basing design decisions on the full range of potential outcomes and associated probabilities i.e. the shape and scale of the probability distribution function itself. This approach trades the perceived precision gained by reducing uncertain projections to a discrete prediction, for significant gains in value by exploring flexible options to improve outcomes.

This approach begins with generating a list of future possibilities, with corresponding ranges of potential outcomes. Different natures of uncertainty may warrant for different approaches. A dynamic model is constructed, informed by historical trends and available information, to estimate this distribution and give shape to the uncertainties impacting a system.

Once uncertainties have been analyzed and prioritized, flexible options are developed which enable the system to deal effectively with the full range of potential outcomes. Having a dynamic model enables effective ideation, by exploring dependencies, costs, and impacts on performance outcomes across a wide range of flexible approaches.

### 3.4.2 Modeling and Monte Carlo Simulation

Monte Carlo simulation is one of several computational methods that enables low-cost, high-speed exploration of a high volume of modeling outcomes. By establishing probability distribution functions for the key uncertainties, we can model a system's performance based on that uncertainty and analyze a range of performance outcomes. The next step is to layer flexible options into the system model, to analyze how this flexibility deals with the full range of uncertain outcomes. Establishing this construct and using Monte Carlo to model a high volume of iterations produces meaningful representations of flexible options within a complex system, operating under real world uncertainty.

## 3.5 SDM

The System Design and Management (SDM) approach integrates principles, tools, and techniques from Systems Architecture (SA), Systems Engineering (SE), and Project Management (PM) to enable effective development and management of complex sociotechnical systems. SDM is designed to enable effective planning and development of complex new products and services, using the latest technologies and methodologies in a global context. The fundamental value propositions of the three core disciplines, as they relate to this thesis, are presented below in Table 3.2.

*Table 3.2. SDM Discipline Summary*

| SDM Discipline | Thesis Value Proposition | Subject Matter Expert |
|---|---|---|
| Systems Architecture (SA) | To effectively describe the architecture of existing systems as well as generate the architecture of new systems. | Bruce Cameron |
| System Engineering (SE) | To effectively transform high level concepts / system architectures into detailed engineering designs for implementation. | Eric Rebentisch |
| Project Management (PM) | To strategically plan, budget, and manage the implementation of product and service projects in a larger organizational and business context. | Bryan Moser |

SDM's integration of SA, SE, and PM is a recognition that decisions regarding complex systems are coupled across all three disciplines. Systems Architecture deals with the thoughtful creation of system concepts, Systems Engineering translates concepts to physical reality, and Project Management enables the realization of the whole effort. A system that is well-designed, wellengineered, and effectively implemented requires consideration of SA, SE, and PM decisions in concert.

The integrated SDM approach is highly iterative. SDM provides a structured framework to admire, analyze, and effectively interact with a problem and its context from multiple perspectives. Assumptions are constantly challenged and refined, opportunities for innovation and novelty are explored with intention, and practical considerations like uncertainty, complexity, interfaces, sociotechnical factors, and temporal considerations are embedded within the analysis. Decomposition of system or decision elements across various levels of abstraction enables meaningful exploration of system complexity, flexibility, and interdependencies amongst components or decisions. Design and analysis products are constantly refined throughout this process as insights sharpen, inform, and clarify the design approach.

The process begins by approaching the problem in its most abstract form and completing ideation and concept generation exercises. Here the rationale and fundamental purpose of the system is explored, with a focus on novel concepts and opportunities for innovation. The system is defined through the development of a System Problem Statement (SPS) and system boundary. Stakeholder analyses inform system needs and requirements, which are followed by a systems architecture concept generation process that deconstructs the design space into a series of architectural decisions (AD). A refined set of ADs for the basis of concept development, enabling the identification and exploration of meaningful tensions and tradeoffs amongst key performance indicators. The range of potential system concepts is mapped to a tradespace diagram to inform the selection of a recommended system concept or concepts. System Engineering tools and principles further develop this concept by layering in uncertainty, complexity, change propagation, value generation, modeling, and lifecycle management. Finally, Project Management considers the implementation and realization of the system by developing a project concept, modeling different development and implementation approaches, and considering tradeoffs between cost, scope, and schedule to inform the integrated system design.

### 3.5.1 System Problem Statement

The SPS is the single assertion of what the system is intended to accomplish in order to deliver value, it defines the high-level goal, establishes boundaries, and divides content from context (Crawley, 2016). The canonical "To-By-Using" framework is recommended by Crawley, Cameron, and Selva, applying the following convention: "***To*** (the statement of (solution-neutral functional) intent), ***By*** (statement of (solution-specific) function), ***Using*** (statement of form).

### 3.5.2 System Boundary

A system boundary not only defines the system, but is essential to understanding key external interfaces, dependencies, and stakeholders. A complex system is only relevant in the context that it is applied, therefore a clear system boundary is fundamental to successful systems architecting. System boundaries in this thesis will be represented with bold red dotted lines.

### 3.5.3 Architectural Decisions

Crawley, Cameron, and Selva define architectural decisions as the subset of design decisions that have the greatest impact on the system; Architectural Decisions determine a system's performance envelope, encode key tradeoffs in the eventual product, and often strongly determine cost (Crawley, 2016).

# Chapter 4. Recommendations

This thesis proposes that sweeping technological advancements have fundamentally transformed the transition of new ships from construction to operations. What was once a fairly straightforward training and certification period has evolved into a challenging organizational task, rich with complexity and uncertainty. By acknowledging the inherent uncertainty in ship construction and treating this transition from construction to operations (referred to herein as the Post Delivery phase) as a dynamic sociotechnical system, systems thinking principles, tools, and techniques are employed to develop executable improvement opportunities. Figure 4.1 presents the reference system architecture, with the system boundary indicated by a red dotted line.

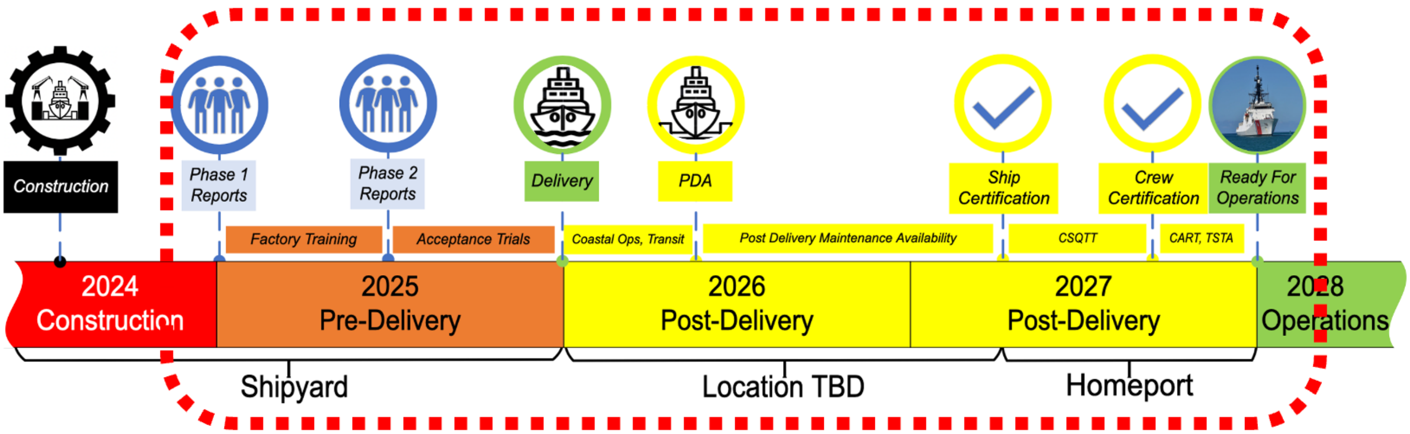



*Figure 4.1. Reference System Architecture: Current Approach*

Architectural decomposition of this system identified one pivotal discretionary event which has an out-sized impact on the complexity and difficulty of the overall endeavor: staffing the ship's pre-commissioning crew. As indicated below in Figure 4.2 the current approach breaks the reporting of pre-commissioning crews into two phases, however functionally the staffing of a pre-commissioning crew is analyzed as a single discretionary event.

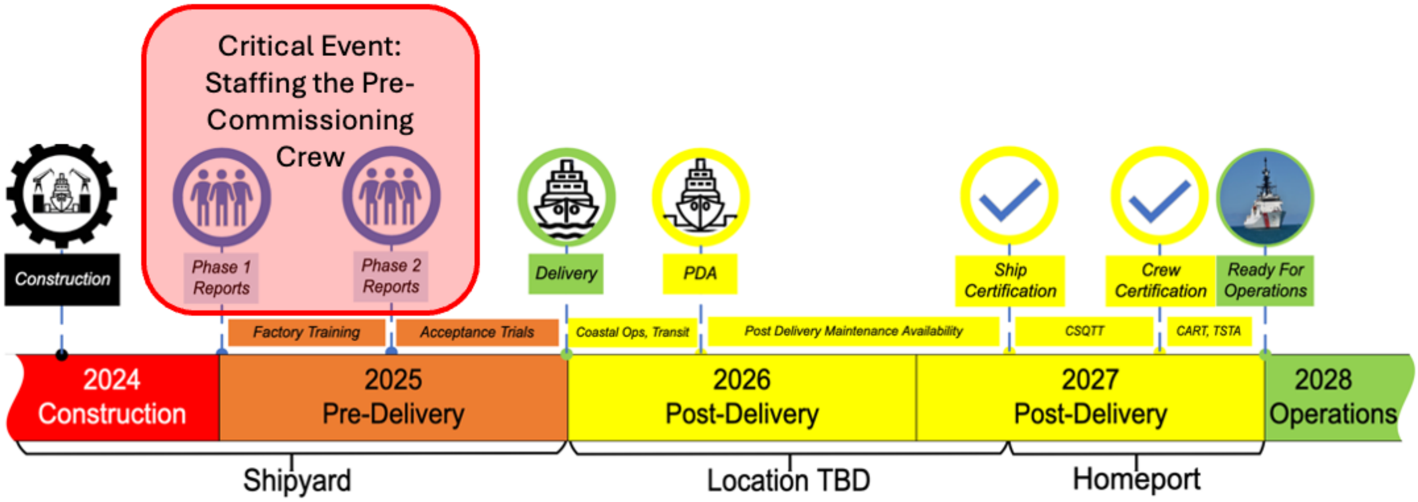



*Figure 4.2. Defining the Staffing of the Pre-Commissioning Crew*

The number and nature of dependencies introduced by staffing an operational crew to a ship that is still under construction propagate complexity throughout downstream tasks. The challenge and impact of this event are heightened by the Coast Guard's current practice which tethers the timing of the decision to staff a pre-commissioning crew to the contract delivery of new ships from the shipbuilder to the Coast Guard- a critical milestone that is rarely met as planned due to extremely high levels of uncertainty. As a result, pre-commissioning crews intended to report six to twelve months before delivery often spend years waiting for the shipbuilding process to catch up. Systemically navigating the gap between planned and actual delivery with a pre-commissioning crew in place places significant strain on key elements of the Coast Guard's workforce, wastes money, and prematurely increases the complexity and difficulty of the organizational tasks necessary to make the ship ready for operations.

The scope and scale of the Coast Guard's current and planned shipbuilding programs underscore the urgent need to enhance its organizational capacity to transition major vessels from construction to operations. This challenge also presents a significant opportunity: the steady cadence of major ship deliveries planned over the next 15 years will make it possible for the Coast Guard to replace fragmented, ad hoc approaches to Post Delivery with a robust, flexible system architecture. Such an architecture would be capable of continuous learning and improvement, ultimately leading to more efficient and effective transitions.

This thesis recommends the Coast Guard develops a dedicated Post Delivery system architecture that professionalizes the transition of new ships from shipbuilding to operations. A three-phased recommendation is presented to address the highest impact issues as quickly as possible while laying the groundwork for implementing more complex, costly, and impactful measures in the future. From a staffing perspective, the current approach treats each new ship as a unique event centered around fixed delivery milestones that are often unreliable, leading to wasted personnel and financial costs. The recommended approach decouples major personnel activities from highly uncertain ship production milestones and treats Post-Delivery activities as a continuous enterprise business line that is flexible, appropriately resourced, and capable of continuous learning as best practices and efficiencies are identified and implemented.

## *4.1 Integrated Strategy*

The strategy recommended here is organized into three complementary phases, pictured in Figure 4.3. These phases: Delivery-Based Staffing, Ship Delivery Teams, and Post Delivery Centers of Excellence, correlate to the three-phased implementation roadmap described in Section 3.1.1 above. This integrated strategy is structured for progressive phase implementation over an extended time horizon. Each phase delivers value independently, the Coast Guard could choose to implement any or all independently however they are designed with a temporal strategy for ease of implementation.

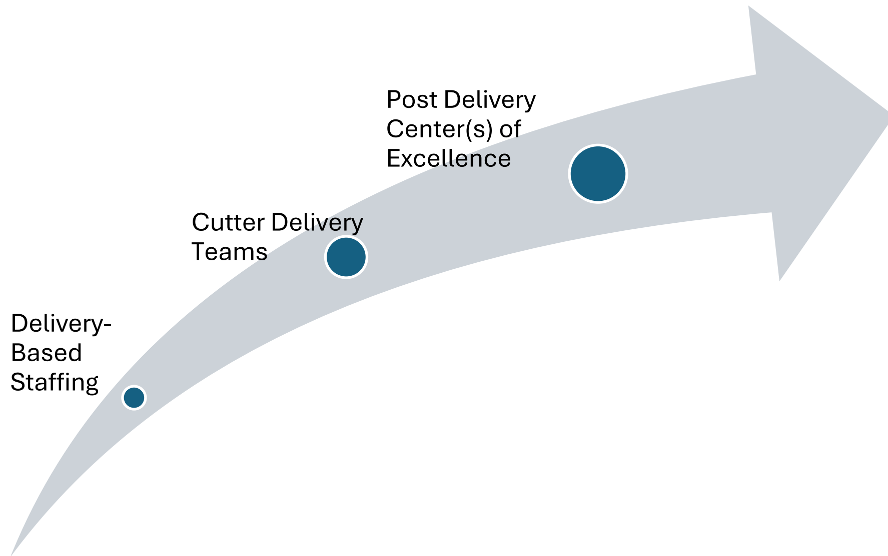



*Figure 4.3. Visualization of Integrated Strategy Recommendation*

Systems complexity analysis identified the crew staffing decision as a critical discretionary event, highly connected and highly sensitive to the larger system; the timing of crew staffing has an out-sized impact on the degree of complexity for the overall Post Delivery system. Therefore, the first two phases are focused on personnel management and resourcing strategies as they relate to ship construction and delivery. The third phase expands the scope to include non-personnel activities such as post-delivery maintenance, training, and certification; this phase requires both cultural change and significant long-term capital investment.

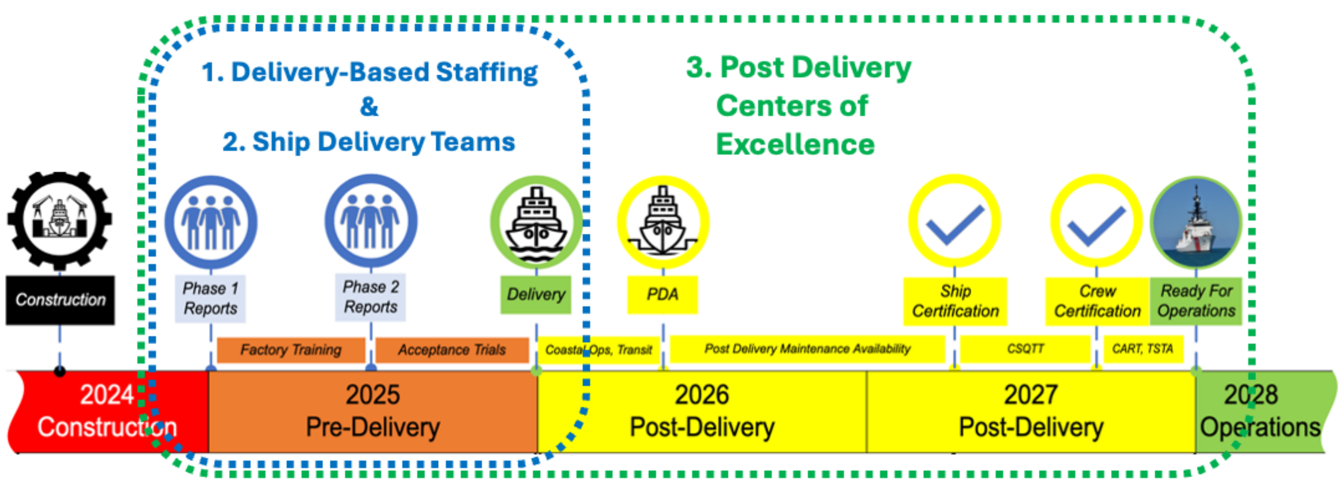



*Figure 4.4. Scope of System Recommendations*

To begin with a common frame of reference, Figure 4.5 presents the current system architecture with key modifications. Schedule uncertainty is illustrated by the red arrow spanning a range of possible outcomes for the actual timing of delivery, and the deterministic approach to staffing the two-phased pre-commissioning crew is illustrated by red lock icons.

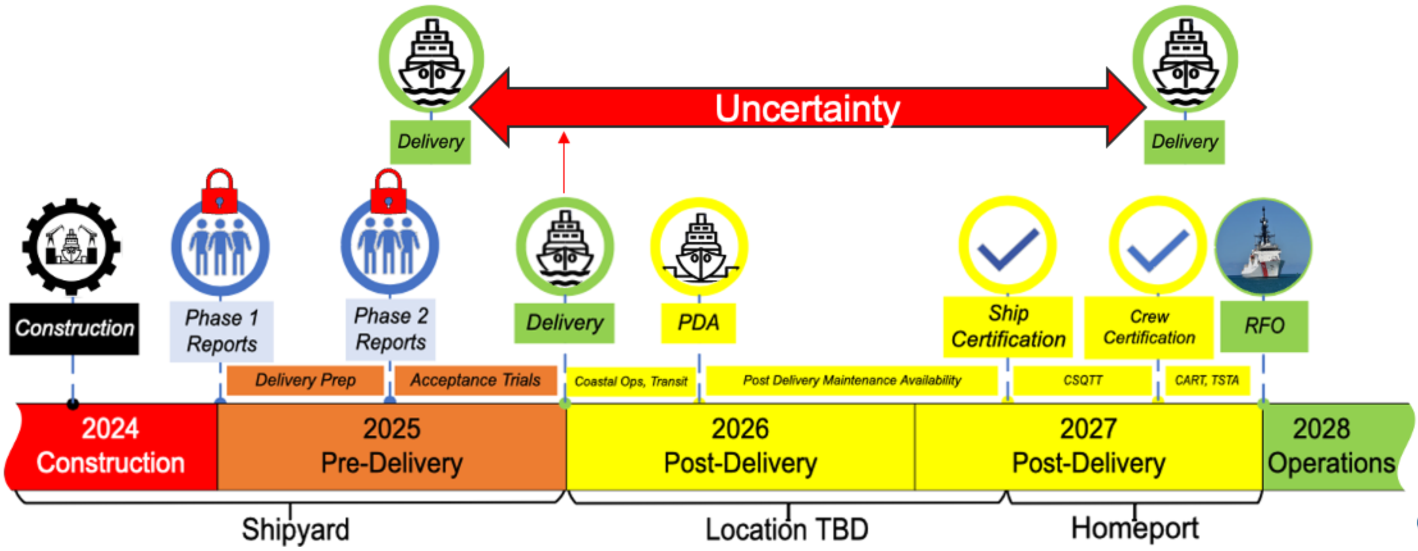



*Figure 4.5. Reference Architecture with Delivery Uncertainty*

A brief summary description of each phase is provided here; detailed descriptions are presented later in this thesis.

1. Delivery-Based Staffing: Tailor reporting timelines for pre-commissioning crews to actual production status. Figure 4.6 provides a visualization of this approach: the red locks are removed from staffing events signifying the shift to a flexible approach, where the range of potential staffing dates is driven by the actual delivery date. This recommendation is presented in detail in Section 4.2.

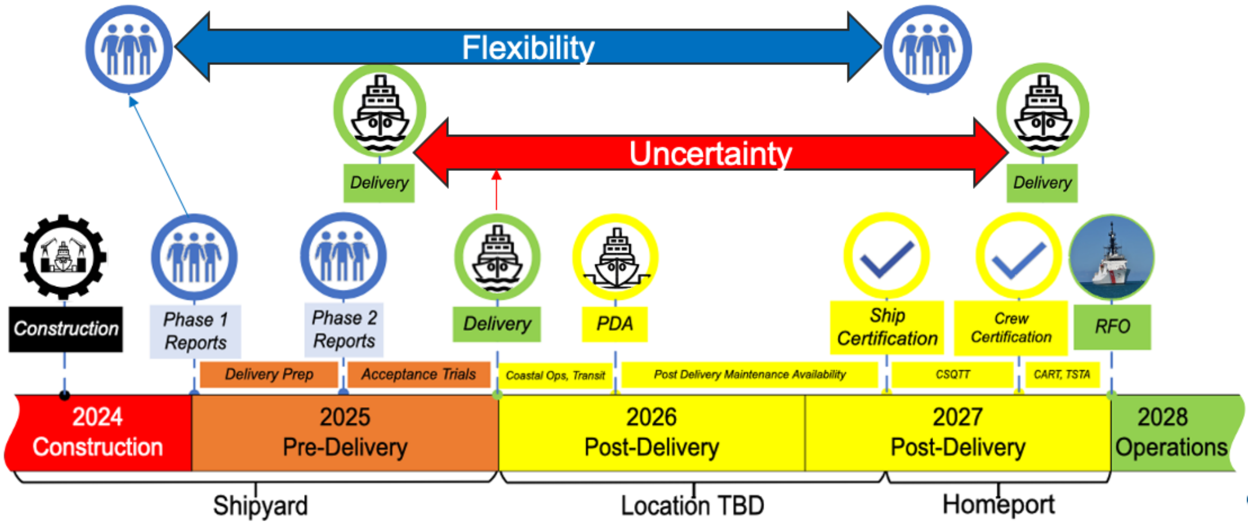



*Figure 4.6. Delivery-Based Staffing*

2. Ship Delivery Teams: Approach pre-delivery tasks currently completed by pre-commissioning crews as recurring elements of a comprehensive shipbuilding program, rather than discrete, ship-specific events. Invest in shore-based personnel permanently located at the shipyard, for the duration of the shipbuilding program. Figure 4.7 provides a visualization of the approach, building on the flexibility from the Deliver-Based Staffing recommendation, additional shore-based personnel are added to unburden operational crews from pre-delivery responsibilities. The Ship Delivery Teams will provide additional organizational flexibility regarding the critical crew staffing event, enabling increased precision illustrated by the tight coupling between crew reporting events and delivery. This recommendation is presented in detail in Section 4.3.

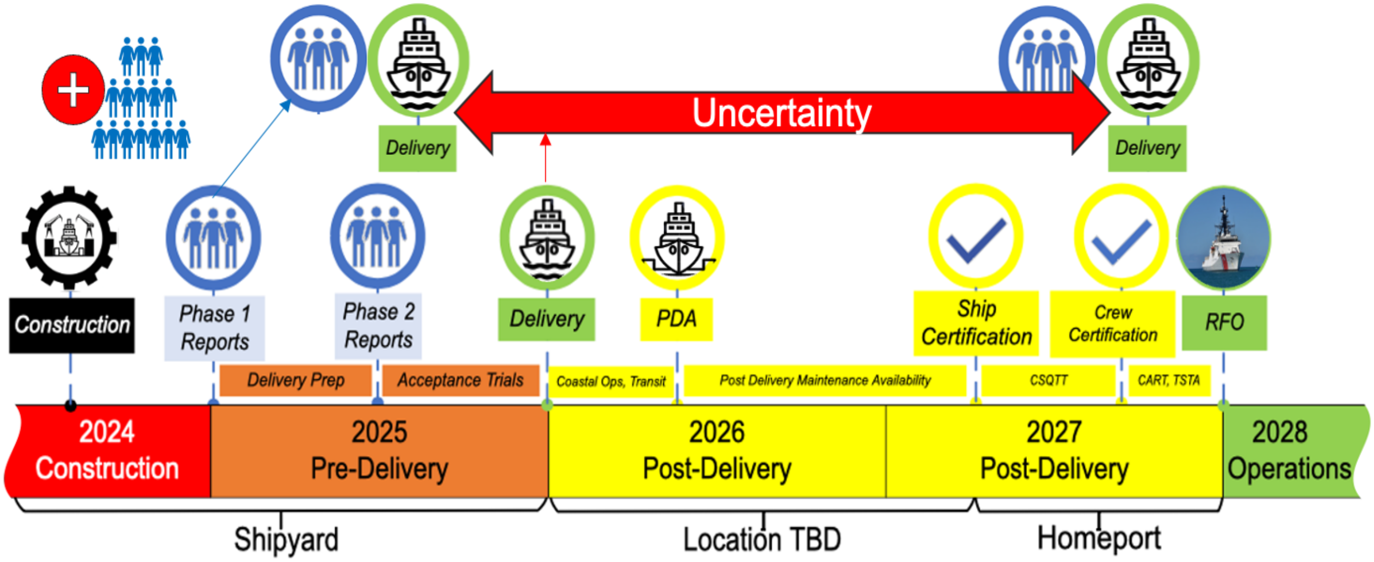



*Figure 4.7. Ship Delivery Teams*

3. Post Delivery (PD) Center of Excellence (COE): re-orient the target for establishing an operational crew from contract delivery. to the completion of post-delivery maintenance and upgrades. Establish long-term centers of excellence to centrally complete all Post Delivery activities. Note in Figure 4.8 that both the pre and post-delivery phases are truncated in duration. The uncertainty regarding delivery remains constant, however complex interdependencies have been removed by shifting the crewing target to after the Post-Delivery requirements have been met. This recommendation requires significant infrastructure investment, and would require non-traditional means of relocating pre-commissioned ships from the shipbuilder to the Post-Delivery Center of Excellence.

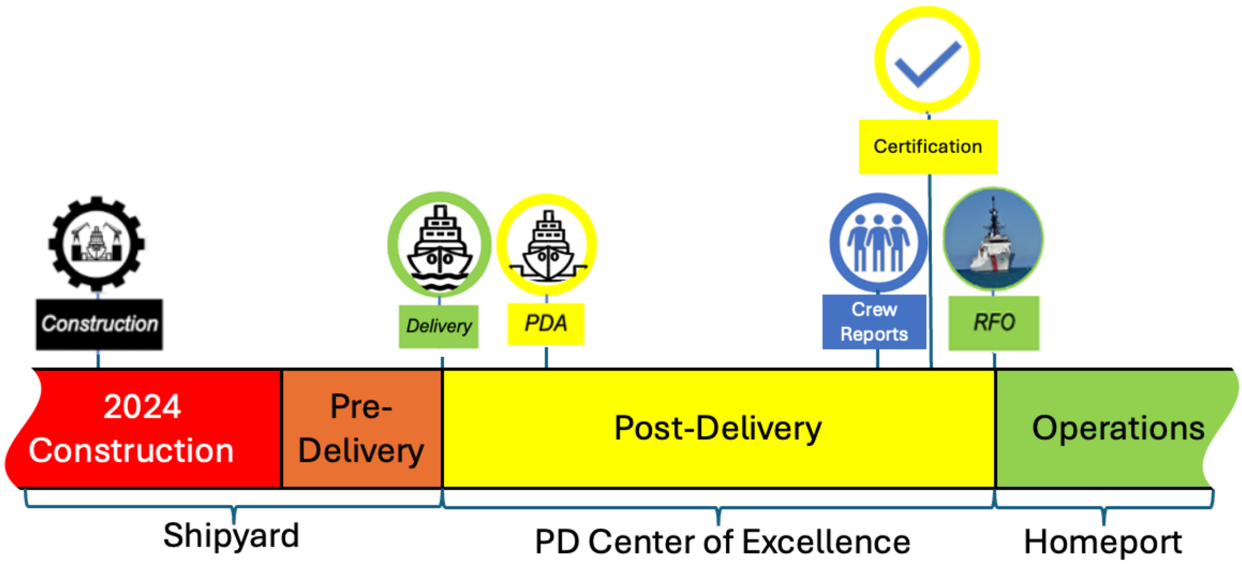



*Figure 4.8. Post Delivery Centers of Excellence*

Upon delivery, new ships will be transported to the appropriate COE based on the ship's eventual homeport. Pre-commissioning crews will report to the COE *after* heavy industrial PDA activities are complete. This recommendation is presented in detail in Section 4.4. This study advocates for the development of a flexible Bicoastal Center of Excellence PD system architecture that can deal knowledgeably with Post-Delivery activities. The Coast Guard faces significant challenges transitioning new ships from shipbuilding to operations. The time and tasks between the shipbuilder's delivery and commencement of operations, referred to herein as the "Post Delivery" (PD) phase, represent a complex organizational endeavor. Interdependencies between delivery and post-delivery make the PD phase particularly susceptible to the uncertainties inherent in the shipbuilding process, leading to broad inefficiencies and significant workforce challenges. Rapid technological advancements are increasing the complexity and scope of the PD phase, transforming it into a substantial and demanding multi-year phase of a ship's life cycle. Historically, the PD phase has not been recognized as a dedicated phase in a military ship's life cycle, but today's PD phase is unprecedented in its demands, and the current trajectory necessitates its acknowledgment as a critical phase with evolving scope, complexity, and scale. Additionally, the Coast Guard's substantial investments in fleet recapitalization will produce a continuous influx of major ship deliveries.

Table 4.1 below presents implementation considerations and organizational benefits associated with each of the three recommended phases.

*Table 4.1. Recommendation Summary Table*

| | Implementation | | Benefit | | | |
|---|---|---|---|---|---|---|
| Phase | Cost | Organizational Change | Costs | Workforce | Operational | Sustainment |
| Deliver-Based Staffing | None | Low | Low | Medium | None | None |
| Ship Delivery Teams | Low | Low | Medium | High | None | None |
| Post Delivery Centers of Excellence | High | High | High | High | Medium | Medium |

## *4.2 Phase One: Delivery-Based Staffing*

The current staffing methodology assigns crews to shipyards based well in advance of the projected milestone. Unfortunately, these milestones are often not met. This approach employed by the Coast Guard for new ships is highly sensitive to the significant schedule uncertainty inherent in the shipbuilding process. The Gap between planned and actual delivery leads to wasted crew time and uncertainty leads to several adverse workforce outcomes, including substantial underutilization of pre-commissioning crews and geographic tension between the ship's eventual homeport and the shipbuilder's location (where crews spend the majority of their time). This study proposes the adoption of a flexible staffing approach, timing crew assignments to actual delivery dates which could markedly enhance workforce outcomes and reduce enterprise costs, with minimal organizational investment.

### 4.2.1 Key Issues

Coast Guard shipbuilding is subject to extreme schedule uncertainty. While the manifestation and impacts of uncertainty are difficult to predict, its presence and general characteristics may be studied and better understood. The Coast Guard resources certain activities that necessarily precede contract delivery, referred to herein as pre-delivery activities, with the personnel who will ultimately operate the ship. This approach introduces dependencies between the shipbuilder's production schedule and the Coast Guard's timing of major personnel activities, such as establishing a new crew. As a result, significant construction delays often unfold after key pre-commissioning personnel are assigned and report, resulting in underutilized personnel spending prolonged periods at a shipyard away from their eventual homeport. Pre-commissioning personnel have completed entire tours of duty while assigned to a ship still under construction. These workforce challenges are compounded by assigning personnel to the ship's eventual homeport, despite them spending the majority of time at the shipyard. This misalignment results in prolonged periods away from homeport, adversely affecting personnel's personal affairs, dependents, pay, entitlements, and benefits.

### 4.2.2 Opportunities

Pre-commissioning crew assignments represent a unique category of personnel activities due to the absence of incumbents in these positions. The vast majority of positions within the Coast Guard are occupied by active-duty personnel, introducing time pressure to provide a replacement as part of a larger enterprise personnel rotation evolution.  Once a billet is occupied, the organizational need for continuity imposes significant constraints on the staffing process. However, pre-commissioning crews are distinguished by their lack of incumbents, providing the Coast Guard with exceptional flexibility. This scenario underscores the critical nature of organizational decisions regarding the assignment of leading-edge pre-commissioning personnel, as it presents a rare opportunity to strategically optimize timing and crew composition without the constraints imposed by incumbent transitions.

#### *4.2.3 Recommendation and Benefits*

Acknowledge the inherent uncertainty in the shipbuilding process and decouple critical personnel activities from construction milestones. The implementation of a flexible strategy for pre-commissioning assignments could yield significant personnel cost savings while markedly improving workforce outcomes.

Delivery-Based Staffing is anticipated to yield substantial benefits in two main areas: workforce management and cost savings.

- Workforce. This strategy is designed to bring about significant benefits at both individual and Coast Guard organizational levels.
    - Individual Level Benefits: at the individual service member level, the strategy aims to reduce uncertainty and increase utilization and engagement for pre-commissioning assignments, by sequencing the arrival of personnel much closer to contract delivery and sail away.
    - Organizational Level Benefits: on a broader scale, the strategy is expected to alleviate resource demands on the Coast Guard’s afloat workforce. The Coast Guard is currently grappling with severe workforce shortages, particularly among the personnel that constitute cutter crews. In October 2023, the severity of these shortages compelled the Coast Guard to take the extraordinary measure of triaging operational assets, specifically cutters and small boat stations. This action was necessitated by a lack of qualified personnel capable of operating these assets safely and effectively. The proposed flexible staffing strategy is expected to

provide some relief on the afloat workforce by ensuring that pre-commissioning assignments are not made until the receiving ships are ready for them.

- Cost Savings: the strategy is expected to yield significant long-term financial benefits. Setting aside the logistical costs associated with staffing an underutilized crew far from their geographic duty station, the net savings across an entire program may exceed $300 million, detailed analyses are presented in Appendix B.

This is a simple strategy that is low cost but high impact and paves the way for a broader paradigm shift towards investing in organizational flexibility.

## *4.3 Phase Two: Cutter Delivery Team(s)*

The Coast Guard faces significant challenges transitioning new ships from shipbuilding to operations. The current strategy, which treats each ship delivery as a unique event, is fundamentally inefficient and highly sensitive to the significant schedule uncertainties inherent in shipbuilding. This approach leads to organizational inefficiencies and workforce challenges, including underutilization of pre-commissioning crew and geographic tension between the ship's future homeport and the shipbuilder's location. This study proposes that the Coast Guard build on the delivery-based staffing approach detailed in Section 4.2 by approaching pre-delivery tasks currently completed by cutter crews, as recurring elements of a comprehensive shipbuilding program rather than discrete, ship-specific events. This paradigm shift would enable highly productive investments in organizational flexibility by allocating shore-based personnel to pre-delivery activities across multiple ships, unburdening pre-commissioning crews and providing the Coast Guard with significant organizational flexibility in managing critical personnel activities. It would also foster continuous learning, best practice development, and the realization of economies of scale.

### 4.3.1 Key Issues

The Pre-Delivery phase is presently managed on a ship-by-ship basis, rather than adopting a broader enterprise approach that could address multiple ships or entire classes of ships. Critical tasks necessary for the shipbuilder to deliver the ship are assigned to the personnel who will ultimately operate the ship (referred to here as pre-commissioning crews). The tasks and responsibilities assigned to pre-commissioning crews are atypical (specific to the delivery of a new ship) and not inherently operational by nature. Historically this approach has been adequate, as the low volume and irregular cadence of major Coast Guard ship deliveries prevented a more streamlined approach and diluted the negative impacts of a fundamentally inefficient approach.

### 4.3.2 Opportunities

Presently the Coast Guard is shifting from dealing with infrequent deliveries to a routine cadence of new ships. It can create systematic line of business to manage this process. The Coast Guard has secured more than $1 billion in capital investments to recapitalize and modernize its surface fleet. Over the next 15 years, the Coast Guard plans to build and deliver more and larger ships than ever before in its history. This sweeping recapitalization effort will produce a volume and steady cadence of major ship deliveries that will enable a transition from a fragmented ship-specific approach to a flexible enterprise approach that is far more effective. A dedicated pre-delivery team would enable the Coast Guard to professionalize pre-delivery tasks, leveraging organizational learning, economies of scale, and flexibility. This approach has the potential to reduce costs, improve operational efficiency, and enhance workforce outcomes.

### 4.3.3 Recommendation and Benefits

This section assumed that Phase One (Delivery-Based Staffing) has already been implemented. Recognize the opportunity to invest in a specialized “ship delivery team” to handle pre-delivery activities currently handled by pre-commissioning crews. This investment would provide further flexibilities and efficiencies in the PD phase.

Ship Delivery Teams are anticipated to yield substantial benefits in two main areas: workforce management and ship delivery.

- Workforce:
  - Individual: Eliminate underutilized periods and prolonged periods of geographic uncertainty.
  - Organization: Alleviate resourcing demands on the afloat workforce and improve the desirability of critical positions operating the newest, most capable assets.
- Ship Delivery: Unlock learning curves, best practices, and the ability to invest in standardized processes and training by having the same personnel execute pre-delivery tasks for every ship.

## 4.4 Phase Three: Post Delivery Centers of Excellence

This study advocates for the development of a flexible Bicoastal Center of Excellence PD system architecture that can deal knowledgeably with Post-Delivery activities. The time and tasks between the shipbuilder's delivery and commencement of operations, referred to herein as the "Post Delivery" (PD) phase, represent a complex organizational endeavor. Interdependencies between delivery and post-delivery make the PD phase particularly susceptible to the uncertainties inherent in the shipbuilding process, leading to broad inefficiencies and significant workforce challenges. Rapid technological advancements are increasing the complexity and scope of the PD phase, transforming it into a substantial and demanding multi-year phase of a ship's life cycle. Historically, the PD phase has not been recognized as a dedicated phase in a military ship's life cycle, but today's PD phase is unprecedented in its demands, and the current trajectory necessitates its acknowledgment as a critical phase with evolving scope, complexity, and scale. Additionally, the Coast Guard's substantial investments in fleet recapitalization will produce a continuous influx of major ship deliveries over the next 15 years. This steady cadence, coupled with increasing PD complexity driven by technological advancements and significant risk exposure to uncertainty, underscores the opportunity for a strategic overhaul of the Coast Guard's PD strategy. This study advocates for the development of a flexible PD system architecture that can adapt to these evolving challenges. Such an architecture would not only improve workforce outcomes and reduce costs by mitigating the uncertainties and inefficiencies of the existing approach, but also produce an organizational capability to efficiently transition new ships into operational service and address the challenges of future PD phases.

### *4.4.1 Key Issues*

The progressively increasing complexity and connectivity of technology, and the speed of its evolution, have amplified the volume and complexity of post-delivery requirements. Delivery-based Staffing addresses issues of uncertainty and flexibility regarding the staffing of new ships. Ship Delivery Teams address the Coast Guard's current approach to pre-delivery activities on a ship-by-ship basis, as opposed to multiple ships via an enterprise approach. Post-Delivery Centers of Excellence builds on these pre-delivery issues and recommendations, and expands the scope to include post-delivery issues as well.

### *4.4.2 Opportunities*

Intensifying technological trends act in tension with the protracted timelines of ship design and construction via the government acquisition process, generating a significant worklist of configuration changes and equipment upgrades necessary after, or "Post", delivery. The assets being designed and delivered are large and complex, exacerbating the increases to PD scope and difficulty. The resulting PD worklist will require significant industrial work before operations commence. The anticipated surge in ship deliveries, coupled with escalating post-delivery requirements driven by technological advancements and the increasing size and complexity of assets, presents an opportunity which this recommendation aims to capitalize on.

# References


14 United States Code, S. 1. (n.d.).

46 United States Code, S. V. (n.d.).

Crawley, C. a. (2016). *System Architecture: Strategy and Product Development for Complex Systems.* Essex: Pearson.

de Neufville, R., & Scholtes, S. (2011). *Flexibility in Engineering Design.* Cambridge: MIT Press.

de Weck, O. L. (2022). *Technology Roadmapping and Development.* Cambridge: Springer.

Department of Homeland Security . (2023). *U.S. Coast Guard Budget Overview, Fiscal Year 2023.* Washington: DHS.

Department of Homeland Security. (2023, 11 29). Retrieved from About DHS: www.dhs.gov/organizational-chart

Department of the Air Force. (2023). *Fiscal Year 2023 Military Personnel Appropriation.* Washington: USAF.

Fagan, L. A. (2023, September). Posture Statement. *2024 Budget Overview*. Washington, DC.

Freeman, R. E. (1984). *Strategic Management: A Stakeholder Approach.* Indianapolis: Pitman.

Frittelli, J. (2023). *U.S. Commercial Shipbuilding in a Global Context.* Washington, DC: Congressional Research Service.

Gates, S. M., & Robbert, A. A. (1998). *Comparing the Costs of DoD Military and Civil Service Personnel.* Washington: National Defense Research Institute, Rand.

Government Accountability Office. (2018). *Naval Shipbuilding, 18-238sp.* Washington: GAO.

Government Accountability Office. (2022). *Navy Shipbuilding. Past Performance Provides Valuable Lessons for Future Investments.* Washington, DC: United States Government Accountability Office.

Government Accountability Office. (2024). *Navy Shipbuilding. Increased Use of Leading Design Practices Could Improve Timeliness of Deliveries.* Washington: US GAO.

Moser, B. (2023, August). Presentation: SDM Overview. Cambridge, MA.

Nightingale, D. J., & Rhodes, D. H. (2015). *Architecting the Future Enterprise.* Cambridge: MIT Press.

OMB. (2023, December 28). Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs. *OMB Circular No. A-94*. Washington, DC.

Onians, R. B. (2011). *The Origins of European Thought: About the Body, the Mind, the Soul, the World, and Fate.* Cambridge: Cambridge University Press.

Pulkkinen, A. (2023, October 31). *AY24 Force Alignment Initiative*. Retrieved from MyCG: https://www.mycg.uscg.mil/News/Article/3575592/coast-guard-adjusts-operations-plan-to-mitigate-2024-workforce-shortage/

Rhodes, D. (2024, May 7). Class Presentation: Architecting the Future Enterprise. *Recap of ARIES Framework and architecting principles*. Cambridge, MA.

Rhodes, D. (2024, Feb 06). Systems Architecting Applied to Enterprises. *Class Slides: Fundamental Concepts and Architectural Thinking*. Cambridge, MA.

Ross, A. M. (2005). The Tradespace Exploration Paradigm. Cambridge, MA.

Serbu. (2024, May 20). *Federal News Network*. Retrieved from Federal News Network: https://federalnewsnetwork.com/navy/2024/05/navy-grapples-with-at-sea-shortages-as-recruiting-lags/#:~:text=you%20to%20stay.%E2%80%9D-,Over%20the%20past%20year%2C%20the%20Navy%20has%20had%2C%20on%20average,goal%20by%20about%207%2C000%20sailors.

The Industrial College of the Armed Forces National Defense University. (2004). *2004 Shipbuilding Industry Study.* Washington: ICAF.

U.S. Coast Guard. (2020, March 16). Offshore Patrol Cutter Deployment Plan. *Version 1.0*. Washington, DC.

U.S. Coast Guard. (2022, August ). Cutter Boats Fact Sheet. Washington , DC.

U.S. Coast Guard. (2022, August). In Service Vessel Sustainment Fact Sheet. Washington, DC.

U.S. Coast Guard. (2022, October). National Security Cutter Fact Sheet. Washington, DC.

U.S. Coast Guard. (2022, November). Washington. DC.

U.S. Coast Guard. (2023, October). Fast Response Cutter Fact Sheet. Washington, DC.

U.S. Coast Guard. (2023, May). Offshore Patrol Cutter Fact Sheet. Washington, DC.

U.S. Coast Guard. (2023, January). Polar Security Cutter Fact Sheet. Washington, DC.

USCG. (2014, February 1). Doctrine for the U.S. Coast Guard. *Coast Guard Publication 1*. Washington, DC.

USCG. (2024, March 9). *About the United States Coast Guard*. Retrieved from United States Coast Guard: www.uscg.mil/About/

# Appendix A. ARIES Enterprise and Stakeholder Analysis

The ARIES approach was selected for this analysis due to its holistic focus on value exchange between the enterprise and stakeholders, which is particularly effective at gaining a deep understanding of the enterprise itself, the ecosystem it will operate in, stakeholders, and the value exchanges amongst these entities. The green highlights in Figure A.1 highlight process steps one through four, which are completed here to form a foundation for subsequent analysis and ideation.

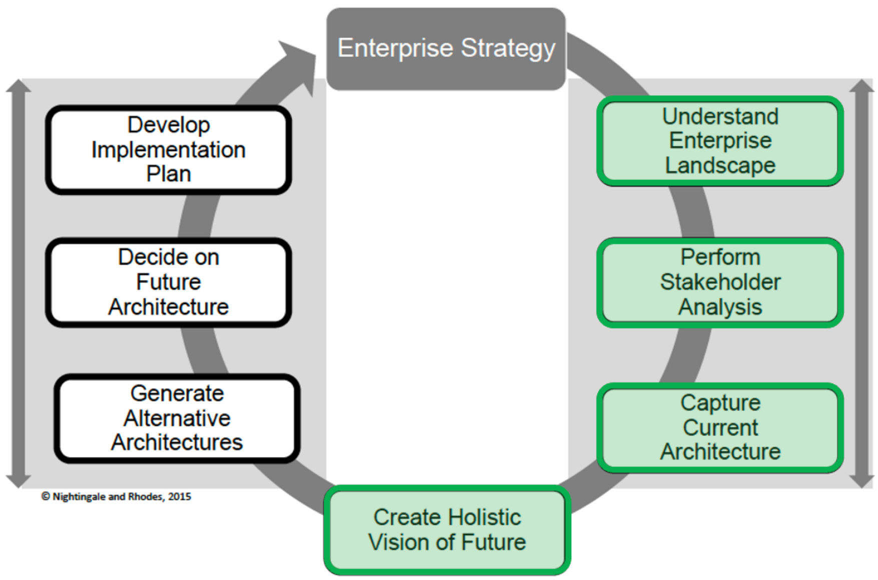



*Figure A.1. Tailored ARIES Process Approach*

Elements from steps five, six, and seven were employed as well, however other methods (Flexible Engineering Design (Appendix B) and System Design and Management (Appendix C)) were employed for the generation of recommended architectures. This appendix will detail the findings from Steps one through four.

## A.1. Understand Enterprise Landscape

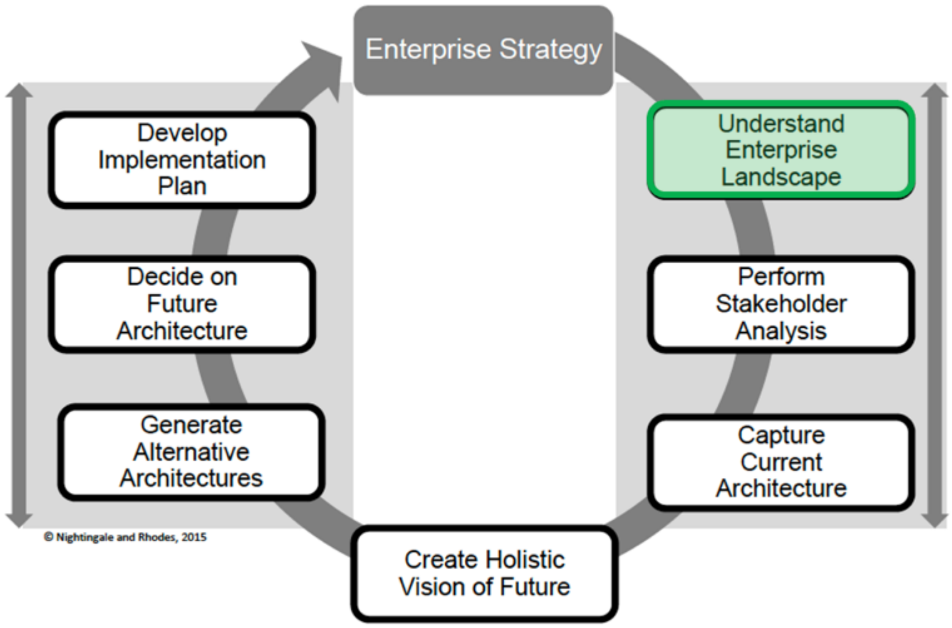



*Figure A.2. ARIES Process Framework: Understand Enterprise Landscape*

As detailed throughout the body of this thesis, sweeping technological advancements have fundamentally transformed the transition of new ships from construction to operations. What was once a fairly straightforward training and certification period has evolved into a challenging organizational task rich with complexity and uncertainty. At the same time, the scope and scale of the Coast Guard's portfolio of shipbuilding programs present a significant opportunity for the Coast Guard to enhance its organizational capacity to transition major vessels from construction to operations. The steady cadence of major ship deliveries planned over the next 15 years will make it possible for the Coast Guard to replace fragmented, ad hoc approaches to Post Delivery with a robust, flexible system architecture. Such an architecture would be capable of continuous learning and improvement, ultimately leading to more efficient and effective transitions.

## A.1.1. Forcefield Analysis

A forcefield analysis was conducted to identify and organize the fundamental driving forces acting on the enterprise landscape as it applies to this study. The results are presented in Figure A.3.

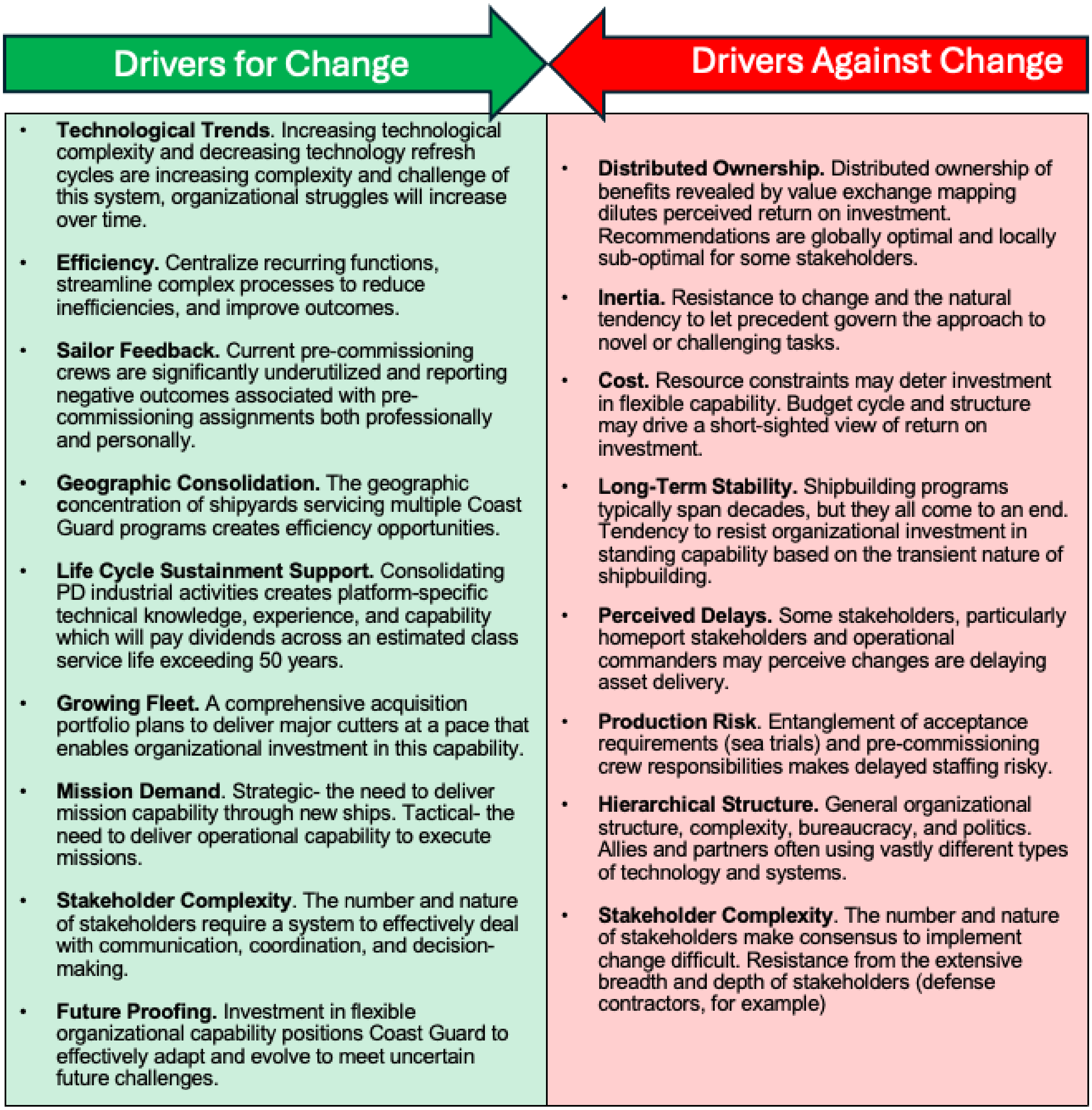



*Figure A.3. Forcefield Analysis*

### A.1.2. Internal Landscape

The internal and external landscapes were both studied through ten specified ecosystem factors. For each factor, an assessment of the level, pace, and potential impact of change is provided. The primary insights produced by this analysis are that workforce and political ecosystem factors demonstrate the highest degree of change impact on the enterprise. Note that each of these factors also display medium to high levels and pace of change. Table A.1 presents the consolidated results of this analysis, with key portions in bold.

*Table A.1. Enterprise Landscape: Internal Ecosystem Analysis*

| Ecosystem Factors (Internal) | Description | Level of Change in Ecosystem | Pace of Change in Ecosystem | Impact of Change |
|---|---|---|---|---|
| Economic | Budgetary constraints and competing allocation priorities within the service. | Low | Med | Med |
| Geopolitical | Internal priorities and focus are influenced by changing geopolitical landscape. | Med | Med | Med |
| Regulatory | Compliance with internal regulations and policy. | Low | Low | Low |
| Market Demand | Internal demand for new capabilities, systems, or processes. | High | Low | Med |
| Competitive Forces | Competing organizational priorities, disparate timelines and objectives. Locally optimal, globally sub-optimal. | Low | Low | Low |
| Demographics | Demographic composition of workforce, including skills and experience. | Med | Low | Low |
| Workforce | **Ship Deliveries are atypical workforce events: highly uncertain, require activation of new billets..** | High | High | High |
| Environmental | Environmental and Sustainability goals may impact PD. | Low | Low | Low |
| Political | **Competing priorities across organizational elements may lead to sub optimal enterprise solutions.** | Med | Med | High |

## A.1.3. External Landscape

The results demonstrate a higher broad sensitivity to external ecosystem factors, as opposed to internal ecosystem factors. Additional insights produced by this analysis are that economic factors, competitive forces, and political factors stand out as notable factors for consideration in the architecting process. Table A.2 presents the consolidated results of this analysis, with key portions in bold.

*Table A.2. Enterprise Landscape: External Ecosystem Analysis*

| Ecosystem Factors (External) | Description | Level of Change in Ecosystem | Pace of Change in Ecosystem | Impact of Change |
|---|---|---|---|---|
| Economic | **Broad economic factors:** labor rates, materials price indices, inflation levels, interest rates, employment trends. | Med | Med | High |
| Geopolitical | Global dynamics impact missions, priorities, and readiness requirements. | Med | High | Med |
| Regulatory | External regulatory dynamics: federal state, local, and maritime. Multiple states may impact. | Low | Low | High |
| Market Demand | Competition amongst industrial base. | Med | Low | Low |
| Competitive Forces | Competition with near peer nations and potential adversaries. | Med | Med | High |
| Demographics | External demographic trends, such as population growth and migration patterns, may impact mission demand. | Low | Low | Low |
| Workforce | State of US industrial base, availability and affordability of skilled labor. | Low | Low | High |
| Environmental | Environmental and sustainability regulations may shape requirements, work methods and efficiencies. | Low | Low | Med |
| Political | Political interest and engagement at federal, state, and local all have significant impact. **Homeporting factors pressurize PD period.** | Med | Low | High |

## *A.2. Perform Stakeholder Analysis*

Freeman defines a stakeholder in an organization as “any group or individual who can affect or is affected by the achievement of the organization’s objectives” (Freeman, 1984).

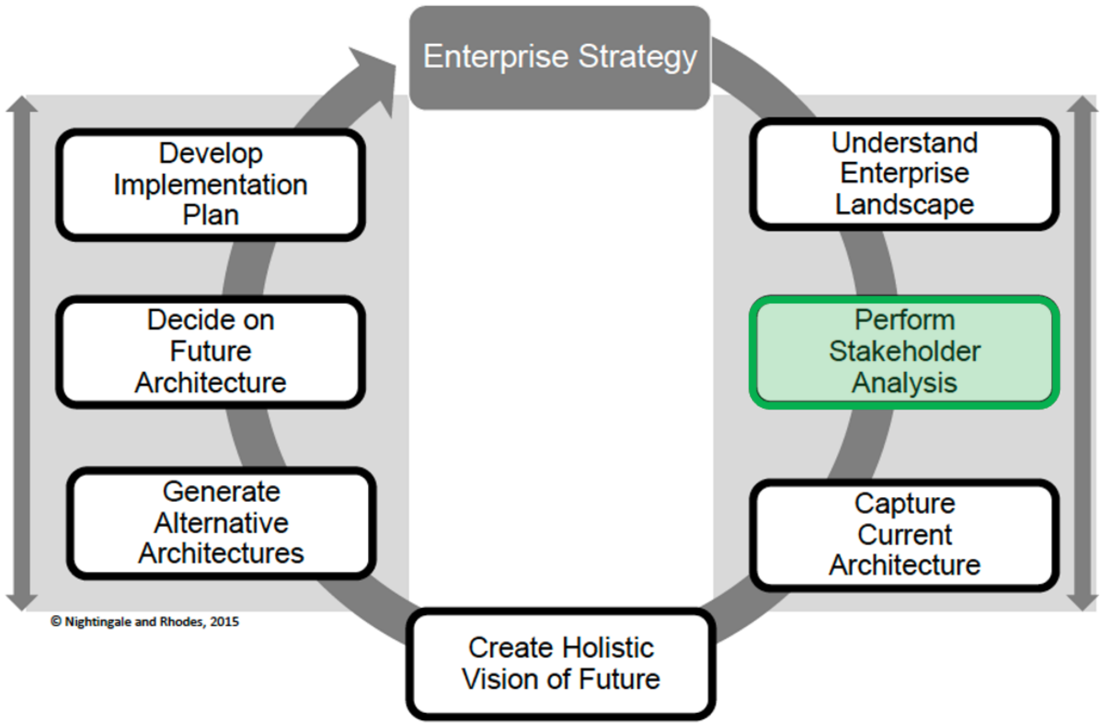



*Figure A.4. ARIES Process Framework: Perform Stakeholder Analysis*

## A.2.1. Stakeholder Roles

Eighteen stakeholders were identified, defined, and analyzed. This section details roles and definitions.

### *A.2.1.1. Department of Homeland Security*

The United States Department of Homeland Security (DHS) is a federal executive department, created in response to the September 11th attacks to secure the United States from the many threats it faces. DHS is now the third largest federal department with more than 260,000 employees, responsible for six overarching homeland security missions:

- Counter Terrorism and Homeland Security Threats
- Secure U.S. Borders and Approaches
- Secure Cyberspace and Critical Infrastructure
- Preserve and Uphold the Nation's Prosperity and Economic Security

- Strengthen Preparedness and Resilience
- Champion the DHS Workforce and Strengthen the Department

Figure A.5 presents the overall organization of DHS, with the U.S. Coast Guard highlighted with a red border.

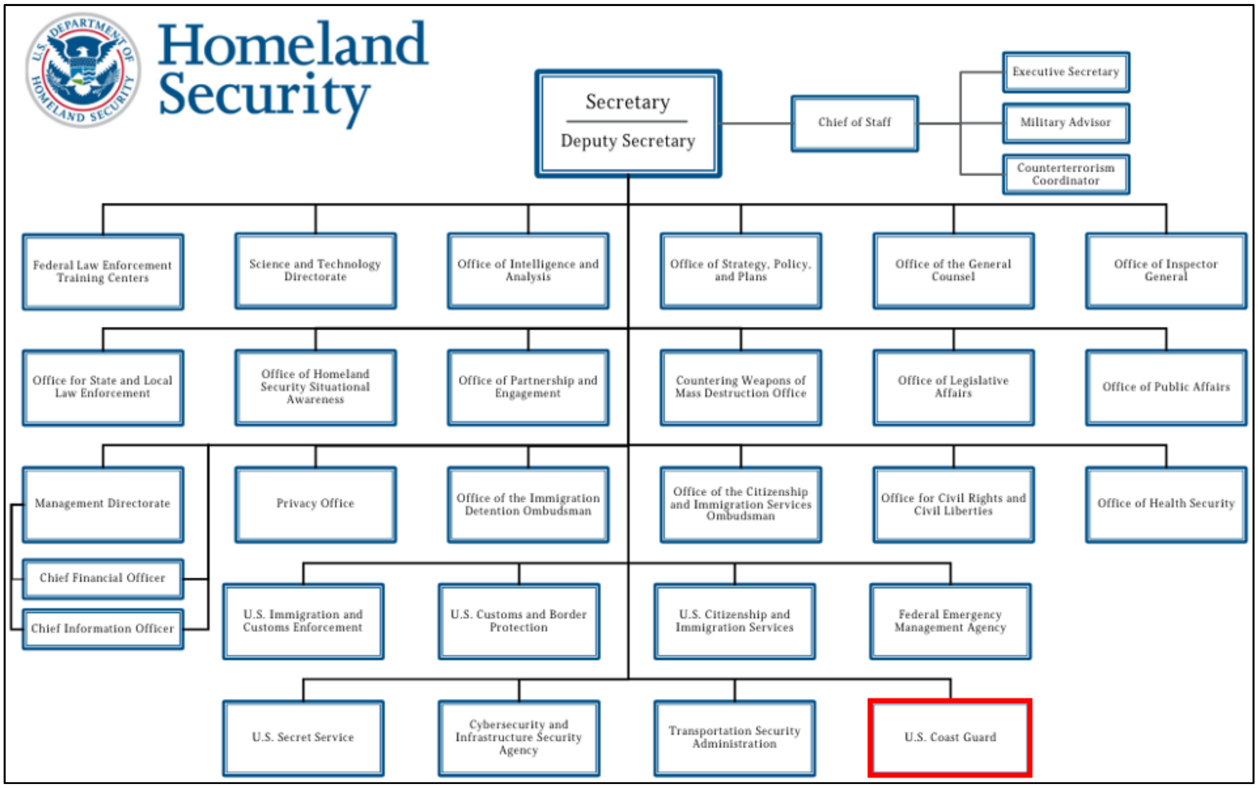



*Figure A.5. DHS Organizational Chart, Coast Guard Highlighted*

### *A.2.1.2. Department of Defense*

The United States Department of Defense (DOD) is a federal executive department, tracing its roots back to pre-Revolutionary times. The DOD's fundamental purpose is to provide the military forces needed to deter war and ensure our nation's security. With more than 3.4 million military service members and civilians, the DOD is the largest agency in the United States government. The Armed Forces of the United States are the Army, Marine Corps, Navy, Air Force, Space Force, and Coast Guard. The Army National Guard and Air National Guard are reserve components of their services. Notably, the Coast Guard is the only Armed Force which resides in the DHS as opposed to DOD.

#### A.2.1.3. United States Coast Guard

The United States Coast Guard (USCG) is a military service and branch of the United States armed forces. A multi-mission, maritime, and military service, the Coast Guard is a branch of the United States Armed Services, a regulatory agency, a law enforcement agency, and a first responder. This unique blend of authorities, broad jurisdiction, and flexible operational capabilities render the Coast Guard unique amongst the armed forces and play a significant role in the culture and ideology of the organization. Figure A.6 depicts the high-level organization of the United States Coast Guard.

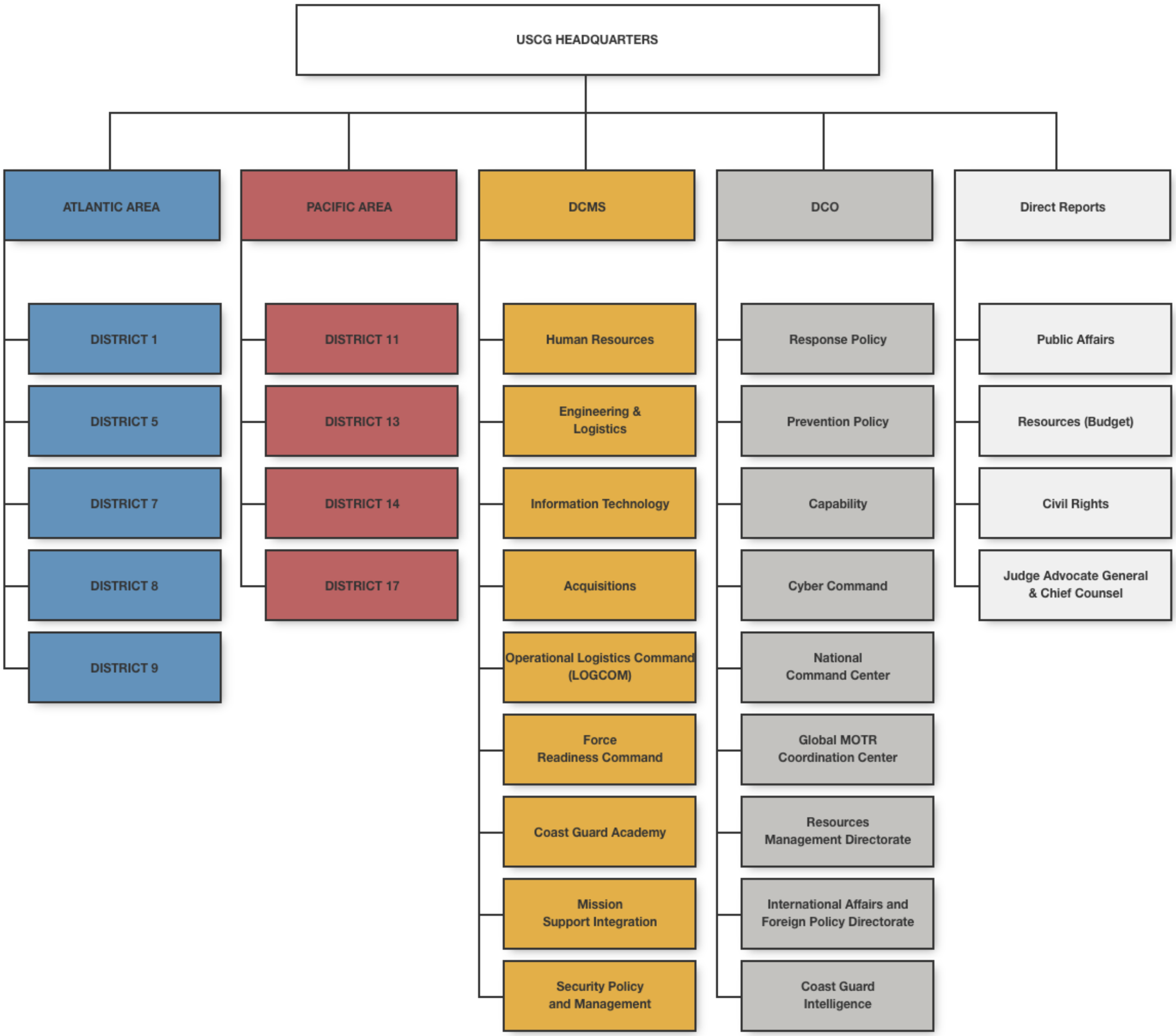



*Figure A.6. Coast Guard Organizational Chart*

### *A.2.1.4. Operational Commanders*

The Coast Guard's operational chain of command is divided geographically into two top line operational commanders, both of whom are three-star Admirals: Atlantic Area (LANT) and Pacific Area (PAC). Figure A.6 depicts LANT in blue, and PAC in red. All Coast Guard operations and operational assets, including cutters, boats, and aircraft, operate within a chain of command that flows up to either LANT or PAC. Each area has very different operational profiles, dictated by the particulars of their respective areas of responsibility. Both operational commanders rely upon mission support products and services, including delivery, staffing, maintenance, and training for the newly constructed vessels that are the focus of this thesis, to execute their missions.

### *A.2.1.5. Deputy Commandants*

The Coast Guard's staff and support services are organized into two top-line Deputy Commandants, both of whom are also three-star Admirals: the Deputy Commandant for Operations (DCO) and the Deputy Commandant for Mission Support (DCMS). DCO is responsible for developing and overseeing the execution of operational policy, planning, resourcing, and international engagement at the strategic level. DCMS enables mission execution through lifecycle support of people, platforms, and systems.

### *A.2.1.6. Coast Guard Acquisitions*

The Coast Guard Acquisition Directorate (CG-9) is responsible for carrying out the service's recapitalization program. The Coast Guard is investing more than $1 billion annually in the acquisition of ships, boats, aircraft, and command and control systems. CG-9's mission is to efficiently and effectively deliver the capabilities needed to execute the full range of Coast Guard missions. Acquisition programs are spread across three domains: air, surface, and command, control, communications, computers, cyber, intelligence, surveillance, and reconnaissance systems (C5ISR).

### *A.2.1.7. Surface Acquisitions*

The portfolio of surface programs addresses the cutter fleet, patrol boats, utility craft, and small boats. The blend of surface programs delivers new and improved platforms to Coast Guard maritime operators, while providing state-of-the-market mission equipment to improve their mission capabilities.

### *A.2.1.8. Offshore Patrol Cutter Program*

The Offshore Patrol Cutter (OPC) Program Manager (PM) is responsible for the overall success of the OPC program, including planning, development, control, and execution of the program to ensure compliance with all applicable directives governing major systems acquisitions. The OPC is one of the Coast Guard's highest investment priorities, replacing 270-foot and 210-foot medium endurance cutter fleets which range from 30 to 60 years old. The Coast Guard plans to spend $12 billion to acquire a fleet of 25 OPCs, highly capable modern vessels 360-feet in length displacing 3,600 long-tons, over the next 15 years. The OPCs will provide the majority of offshore presence for the Coast Guard's cutter fleet, bridging the capabilities of the 418-foot National Security Cutters, which patrol the open ocean, and the 154-foot Fast Response Cutters, which serve closer to shore. The OPCs will conduct missions including law enforcement, drug and migrant interdiction, search and rescue, and other homeland security and defense operations. Each OPC will be capable of deploying independently or as part of task groups and serving as a mobile command and control platform for surge operations such as hurricane response, mass migration incidents, and other events. The cutters will also support Arctic objectives by helping regulate and protect emerging commerce and energy exploration in Alaska.

### *A.2.1.9. Program Resident Office*

For any major shipbuilding effort, the Coast Guard establishes a field unit collocated with the shipbuilder at the shipyard. These units are titled Program Resident Offices (PRO), they serve as the Program Management Office's (PMO) on-site technical, contractual, and business agent. PROs are staffed with a blend of active duty and civilian engineering and mission support personnel and they are responsible for on-site contract administration and project management, working closely with the shipbuilder. Key amongst the PRO's additional responsibilities is bridging the acquisition and sustainment communities.

### A.2.1.10. Pre-Commissioning Crew(s)

Pre-commissioning crews are the Coast Guard personnel who will ultimately operate the ship. The profile of skills and experience is set by operational manning requirements. These personnel are typically assigned in two phases approximately 12 months before a new ship's delivery date. Table A.3 details the current crew composition envisioned for the OPC, including delineation of Phase 1 (13 personnel) and Phase 2 (91 personnel).

*Table A.3. OPC Personnel Allowance List (projected)*

| Rank or Rate | Phase 1 | Phase 2 | Total |
|---|---|---|---|
| O5 | 1 | 0 | 1 |
| O4 | 1 | 0 | 1 |
| O3 | 1 | 1 | 2 |
| O2 | 1 | 2 | 3 |
| O1 | 0 | 4 | 4 |
| CWO | 1 | 3 | 4 |
| E8 | 0 | 1 | 1 |
| E7 | 2 | 7 | 9 |
| E6 | 2 | 16 | 18 |
| E5 | 2 | 19 | 21 |
| E4 | 2 | 25 | 27 |
| E3 | | 13 | 13 |
| Total | 13 | 91 | 104 |

### A.2.1.11. Logistics and Service Centers (SF, C5, PS)

The Coast Guard's Logistics and Service Centers are large scale, geographically distributed field commands responsible for delivering life cycle sustainment support for their respective areas of responsibility. This study identifies three key centers which are stakeholders for the transition of new ships from construction to operations:

- Personnel Service Center (PSC): supports mission execution by recruiting, accessing, assigning, and developing careers, maintaining well-being, compensating, separating and retiring all Coast Guard military personnel.

- Surface Forces Logistics Center (SFLC): provides the surface fleet and other assigned assets with depot level maintenance, engineering, supply, logistics, and information services to support Coast Guard missions.
- Command, Control, Communication, Computer, Cyber, and Intelligence Service Center (C5ISC): provides depot level support for all the Coast Guard's C5I capabilities under a single management structure.

#### *A.2.1.12. FORCECOM*

A DCMS Directorate responsible for training and readiness of the Coast Guard workforce. FORCECOM oversees the training and performance enterprise to deliver operational readiness in the form of human capital resources.

#### *A.2.1.13. Shipbuilding Industry*

The Coast Guard relies on industry for the design and construction of ships. Geopolitical and economic factors play significant roles in shaping this industry, which is heavily dependent upon the U.S. Navy and U.S. Coast Guard. The Coast Guard solicits all major design and build contract opportunities for full, open, and fair competition. As a result, a dynamic variety of commercial enterprises are currently engaged in the design, construction, and delivery of Coast Guard vessels.

#### *A.2.1.14. Congress*

The United States Congress provides funding and oversight for Coast Guard shipbuilding programs. Congress appropriates funding, approves budgets, and scrutinizes Coast Guard's acquisition programs, strategic planning, and budget requests to ensure taxpayer dollars are utilized efficiently and effectively. Congress also influences shipbuilding through legislation that can impact acquisition programs, such as domestic labor or materials requirements and sustainability initiatives.

#### *A.2.1.15. American Taxpayer*

The American taxpayer may be regarded as the end user, or customer, of the United States Coast Guard. Coast Guard assets are developed, acquired, and maintained to enable mission execution. The Coast Guard's statutory missions are drawn from legislation, with the safety, security, and prosperity of the American people in mind.

#### *A.2.1.16. Acquisition Program Sponsor*

The Coast Guard's Assistant Commandant for Capability (CG-7) is typically the sponsor for major surface acquisition programs. The sponsor's representative is the Chief, Office of Cutter Forces (CG-751) works with the Program Manager to ensure all sponsor requirements are met. Sponsor responsibilities include defining operational requirements, ensuring operational and military readiness of the vessel, providing resources

#### *A.2.1.17. OPM and EPM*

Officer Personnel Management (OPM) and Enlisted Personnel Management (EPM) are Divisions within PSC, responsible for a wide range of personnel-related activities, including accessions, evaluations, promotions, assignments, and separations. Collectively they service the Coast Guard's entire active duty workforce of approximately 45,000 personnel.

#### *A.2.1.18. Homeport Stakeholders*

The homeporting of a major cutter constitutes a significant investment in the host region. Political entities (local, state, and federal) have a vested interest in the economic and social benefits that come with homeporting a major cutter, or group of cutters. Local industry and business interests are also significant stakeholders, as the arrival of major vessels, their crews, and the complex logistics tail of support personnel and infrastructure all stimulate growth and boost local economies.

After identifying 18 stakeholders at various levels of abstraction, the list was sharpened to 12 stakeholders including several archetypes which are representative of common needs and requirements. Table A.4 provides the final listing.

*Table A.4. Final Stakeholders*

| Stakeholder | Notes |
|---|---|
| Operational Commanders | One archetype: for the purposes of this study the needs of different operational commanders are common. |
| Coast Guard Acquisition Directorate | Represents surface acquisition portfolio as well as larger USCG and DHS interests in fielding new capable assets. |
| OPC Program | Utilizing the OPC program as a representative proxy for any shipbuilding program. On site contract administration and delivery interests of PRO are represented within OPC Program. |
| Pre-Commissioning Crew | Broader interests of afloat workforce are represented here. |
| LC and SCs | Enterprise lifecycle sustainment represented, includes personnel staffing (PSC) and sustainment (SFLC and C5ISC). |
| FORCECOM | Coast Guard training and certification enterprise is rolled into FORCECOM for this analysis. US Navy testing, evaluation, and certification elements are represented here as well. |
| Shipbuilder | Non-specific shipyard, also represents broader interests of United States shipbuilding industry. |
| United States Government | Includes Executive and Legislative Branches. |
| American Taxpayer | |
| Program Sponsor | Assistant Commandant for Capability and |
| Homeport stakeholders | Represents interests of Coast Guard, DOD, and commercial industry stakeholders in the vicinity of the vessel's intended homeport. |
| United States Navy | Represents joint operations interest as well as DOD training, evaluation, and certification events. |

## A.3. Capture Current Architecture

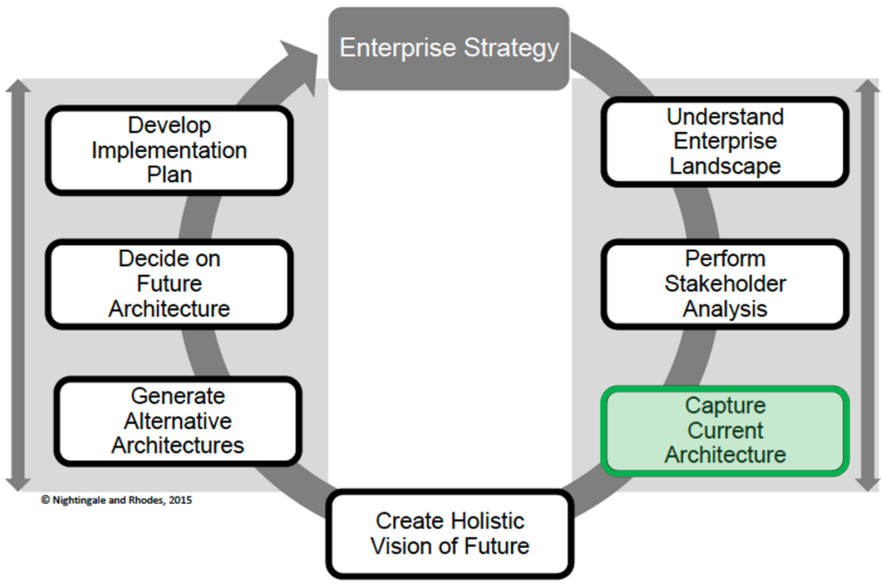



*Figure A.7. ARIES Process Framework: Capture Current Architecture*

The fundamental premise of this thesis is that historically, there has never been a systemic need or justification to develop an enterprise that transitions newly built ships from construction to operations. Thus, there is no current enterprise that integrates mission support products and services to deliver a fully operational cutter and crew; rather, these tasks are matrixed by disparate organizational entities.

Table A.5 presents the results of an as-is analysis representing the current approach, using the eight ARIES view elements. Building on the fundamental assessment that the nature and pace of historical ship delivery efforts have not required, or justified, a dedicated enterprise architecture. This analysis highlighted several key gaps and impacts of the current approach, which informed the recommendations presented by this thesis.

*Table A.5. View Element Current Enterprise Analysis*

| View Element | As-Is Enterprise |
|---|---|
| Strategy | Disparate strategies from various stakeholders, all of which are entangled with inherent uncertainty of shipbuilding process. |
| Information | Critical information related to production schedule risk. Contract structure, multi-layered oversight architectures, and protracted timelines of interdependent processes challenge fidelity of information. |
| Infrastructure | Dedicated infrastructure limited to cutter's eventual homeport, system depends on commercial shipyards and/or non-resident Coast Guard or DOD facilities for all other infrastructure. |
| Products | Ships themselves and all required logistics support products. |
| Services | Mission capabilities of cutter and crew once Ready For Operations designation is made. |
| Process | Existing process is detailed in Chapter 2 of this thesis. |
| Organization | Coast Guard is a hierarchical organization however post-delivery system lacks dedicated oversight and ownership of enterprise tasks. |
| Knowledge | Primary knowledge is accrued and resides within PROs on site at shipyards. Ad hoc approach that utilizes pre-commissioning crews prevents the accumulation of corporate knowledge, best practices, and lessons learned. |

## *A.4. Create Holistic Vision of Future*

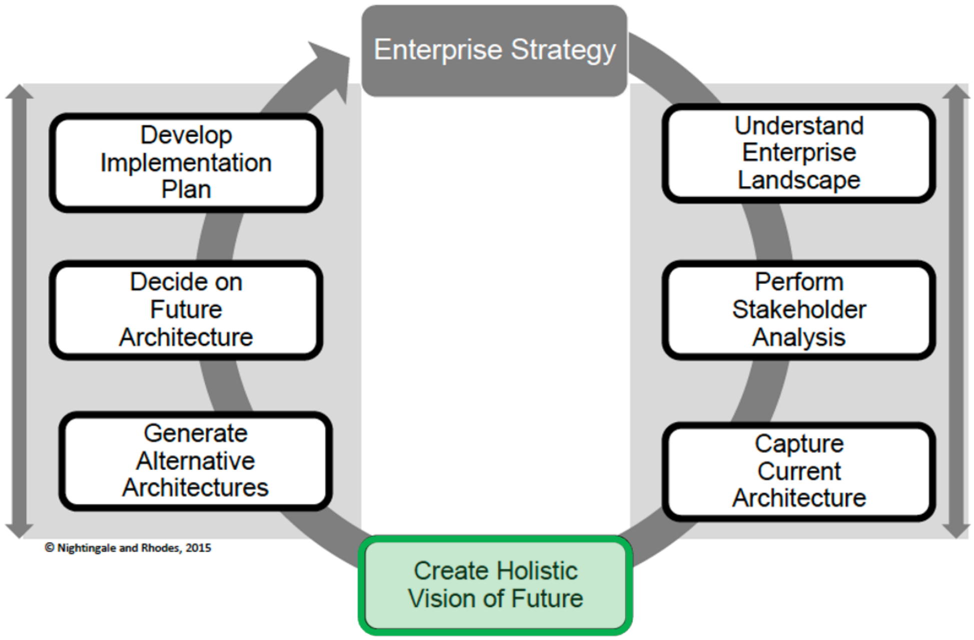



*Figure A.8. ARIES Process Framework: Create Holistic Vision of Future*

Techniques from FED and SDM were utilized to develop executable courses of action for different system architectures. ARIES analyses cemented the stakeholders, needs, and requirements which inform the value delivered by this system.

The holistic vision begins with an organizational acknowledgement that readying a newly built military vessel for operations is a complex sociotechnical task, which necessitates a dedicated system architecture. This flexible system, further developed using FED and SDM, can professionalize the transition from construction to operations and deliver a valuable organizational capability to the Coast Guard.

# Appendix B. Flexible Engineering Design

The underlying principles informing Flexible Engineering Design (FED) are foundational to this thesis, as the study seeks to acknowledge uncertainty and implement a flexible system to effectively deal with highly complex and uncertain external dependencies. FED modeling and Monte Carlo simulation was also used both for analysis and ideation of different flexible system architectures and business processes.

## *B.1. Defining the System*

This analysis is focused on the Coast Guard's OPC Program as a representative and temporally relevant example of the overall shipbuilding portfolio. While first-in-class military vessels are significantly more challenging and uncertain that subsequent hulls, this study proposes an enterprise approach which is probabilistically oriented around the full range of potential outcomes, including but not limited to the outliers.

### B.1.1. System Problem Statement

Amidst a massive shipbuilding effort, the Coast Guard has an opportunity to evolve and improve its ability to transform newly built vessels into fully operational Coast Guard cutters. This study considers how best to breathe life and capability into a newly built vessel, amidst sweeping technological advancements, in order to optimize the path from delivery to RFO. The FED portion of this analysis evaluates crewing strategies for staffing newly constructed Coast Guard cutters to make them ready for operational service in a professional, efficient, and effective manner. A clearly defined problem statement for this treatment is provided below, using the "To-By-Using" construct:

***To*** *minimize Net Present Value cost per hull of readying a newly built cutter for operational service,* ***By*** *investigating flexible crewing strategies,* ***Using*** *Real Options Analysis and Monte-Carlo Simulation.*

### B.1.2. System Boundary

Figure B.1 provides a visual representation of the system boundary for the FED analysis presented in this Appendix, using the system phase framework previously detailed in the body of this thesis. The boundary is indicated by the red dotted line.

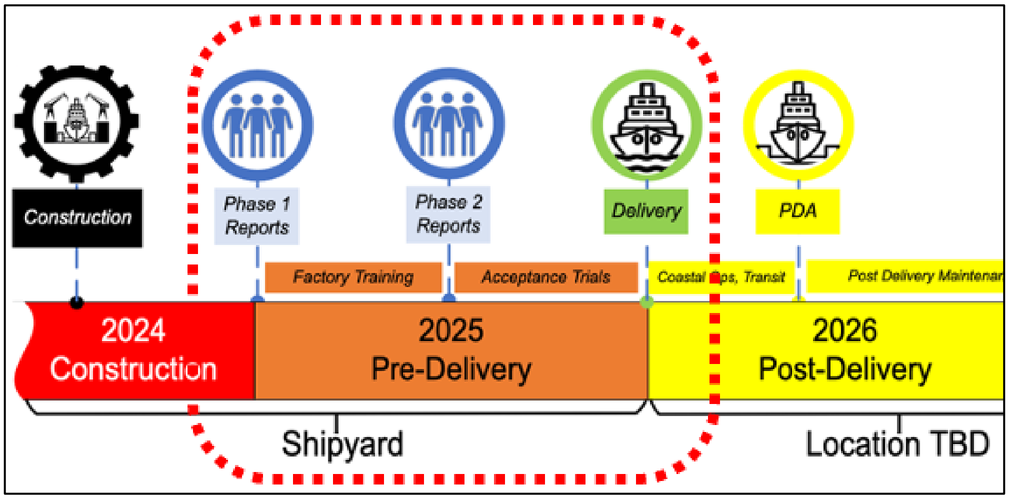



*Figure B.1. Flexible Engineering Design System Boundary*

There are many costs and tradeoffs to consider within this system. This analysis considers personnel costs associated with staffing a fleet of OPCs for a fixed time horizon of 10 years. It does not consider any elements of the complex ship construction process other than the timing of its final output: delivery. Trailing considerations and costs in the post-delivery phase are outside of this boundary as well. Finally, the analysis is tailored to the OPC program however it is scalable, and the underlying principles may be applied to other surface acquisition programs.

### B.1.3. Assumptions

The following key inputs and assumptions are carried throughout the analysis:

- OPC crew size: 104 Coast Guard men and women (U.S. Coast Guard, 2020).
- Annual billet cost (cost of 1 CG service member): $175,000[1] ( (Gates & Robbert, 1998)

[1] The annual cost of one United States military service member varies widely depending on a multitude of factors

- Discount Rate: 2.4% based on OMB guidance and 15-year analysis horizon (OMB, 2023)
- Program scope is delivery of 10 OPCs, initial population at time-0 is 10 OPCs
- Construction is in full rate production and each hull is probabilistically discrete (i.e. performance of one ship build does not impact the performance of subsequent hulls)
- Paradigm staffing of 1 dedicated crew per cutter, versus multiple or flexible crewing options

## *B.2. Uncertainty Evaluation*

Building a new Coast Guard cutter is a challenging and complex multi-year task, highly sensitive to many uncertain and/or unknown factors that may impact cost, schedule, performance, and personnel. Five significant uncertainties were identified for further analysis in this project: production cost, delivery schedule, obsolescence, emergent mission demand, and significant events. Additional uncertainties for future consideration are listed in the *Future Work* section.

### B.2.1. Uncertainty: Estimate Future Possibilities

#### *B.2.1.1. Production Cost*

Defined here as the actual cost of ship construction at delivery. Quantified in $100Ms relative to project estimate. This is a rolled-up total project cost that would incorporate multiple embedded uncertainties, such as supply chain and materials, labor and workforce, poor or unstable contract requirements, re-work, business issues, etc. Historical data indicates that ship construction projects are significantly more costly than anticipated. Notably, management and oversight of

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including rank, location, years of service, benefits, and assumptions regarding accession, training, retirement, and other indirect costs. Incentives and entitlements (such as sea pay) also vary widely. This thesis utilizes the methodology presented by Gates and Robbert, brought to current year dollars with approved Fiscal Year 23 personnel appropriation records (Department of Homeland Security , 2023).

cost uncertainty, while complex and challenging, is well-resourced with clearly defined systems, roles, and responsibilities. It bears acknowledgement here but is not the focus of this thesis.

### *B.2.1.2. Delivery Schedule:*

Defined here as the actual date of delivery. Quantified in months, relative to planned delivery milestone. Schedule delays are commonplace in shipbuilding, and uncertainty is particularly high for government shipbuilding in the United States. Figure B.2 below is a Government Accountability Office (GAO) product detailed average schedule delays in months for the 10 major Navy shipbuilding programs active in the 2010s (Government Accountability Office, 2018). Note

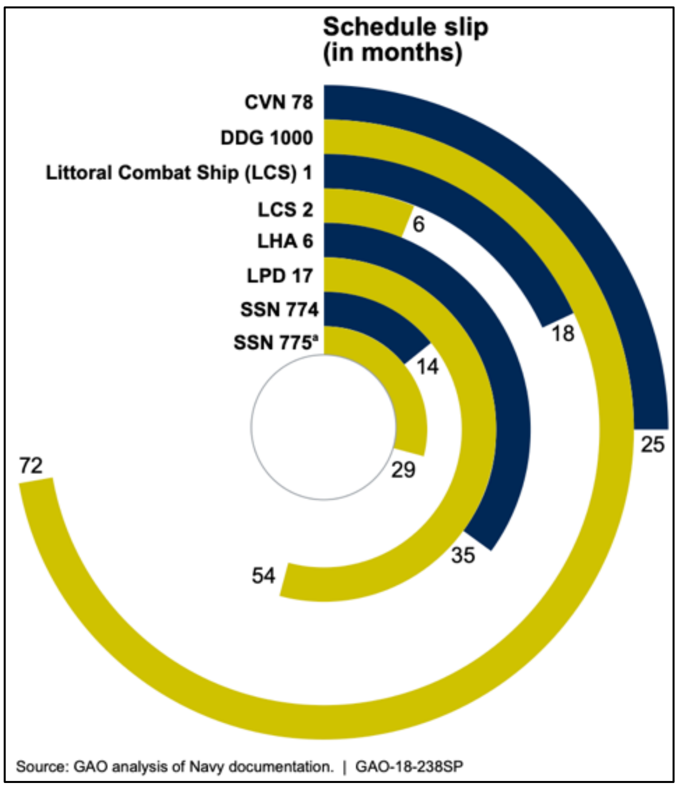


*Figure B.2. U.S. Naval Shipbuilding Schedule Performance*

this data includes all major vessel deliveries, as opposed to only first ship in class deliveries.

#### *B.2.1.3. Obsolescence*

Defined here as the scope of systems and/or components within the delivered configuration baseline, that are already designated for upgrade due to obsolescence. Quantified by the number of obsolescence Time Compliant Technical Orders[2] (TCTO).

- Current rigid contract structures and prolonged duration of ship design and delivery programs (five to twelve years) result in significant systems and equipment obsolescence upon delivery.
- The increasing rate of technological evolution, particularly in electronics and software, is compounding this issue.
- The Coast Guard's relatively small size, unique missions, and contracting strategies (hesitance to invest in IP and common manufacturers) make our platforms particularly susceptible to obsolescence.

#### *B.2.1.4. Emergent Mission Demands*

Defined here as the scope of systems and/or components within delivered ship configuration baseline that are designated for upgrade or install due to emergent mission demand. Quantified by number of mission-related TCTOs upon delivery.

- New missions (capabilities, requirements, etc) often emerge throughout the ship design and delivery lifecycle. Some may be withheld from program scope intentionally due to sensitivity or classification of equipment. These are typically scheduled for installation after delivery and commissioning, but before designating the asset "Ready for Operations."

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[2] TCTO: Coast Guard's term for a discrete equipment upgrade with specified cost, scope, and schedule prescribed in a detailed engineering specification.

- In some cases, these TCTOs remove brand-new systems in favor of preferred versions identified in fleet sustainment but not incorporated into the building program.

### *B.2.1.5. Significant Event (hurricane, fire, pandemic)*

Recent years have shown that events such as these can have significant impacts. Hurricane Michael crippled a major commercial shipyard necessitating re-competition of a multi-$B Offshore Patrol Cutter (OPC) construction contract. A brand new $75M Fast Response Cutter was recently scrapped because of a major fire while in the shipyard. The COVID-19 pandemic breached cost, schedule, and performance requirements across the entire acquisition portfolio.

## B.2.2. Sensitivity Analysis

A sensitivity analysis was conducted to examine and better understand the five identified uncertainties and their potential impact(s) on the performance being modeled. This analysis explored the probabilities and impacts of each uncertainty relative to a common measure of performance: a Net Present Value (NPV) cost per ship. As a cost, the convention is that lower is better. Table B.1 presents summary info for the 5 uncertainties selected.

*Table B.1. Sensitivity Analysis Summary Table*

| Baseline Info | | | Uncertainty | | Sensitivity | | | |
|---|---|---|---|---|---|---|---|---|
| Uncertainty | Unit | Deterministic Base | Min | Max | Translate to NPV (zeroed off of Deterministic Base) | Decrease NPV Cost per Ship | Increase NPV Cost per Ship | Range |
| Obsolescence | tctos (obs.) | 40 | -10 | 40 | Index TCTO value | $ (1,120,000) | $ 4,480,000 | $ 5,600,000 |
| Emergent Mission Demand | tctos (mission) | 10 | -5 | 10 | Index TCTO value | $ (3,125,000) | $ 6,250,000 | $ 9,375,000 |
| Significant Event | $ | $0 | $0 | $75,000,000 | $0 | $0 | $ 75,000,000 | $ 75,000,000 |
| Delivery Schedule | Months | 7/1/24 | -6 | 42 | Un-utilized Crew Costs | $(28,000,000) | $196,000,000 | $224,000,000 |
| Production Cost | $ | $500,000,000 | 10% | 50% | $0 | $(50,000,000) | $250,000,000 | $300,000,000 |

Values and ranges were selected based on the author’s practical experience and further calibrated via market research. Assumptions used in this analysis are summarized below in Table B.2:

*Table B.2. Sensitivity Analysis Assumptions*

| ASSUMPTIONS | # |
|---|---|
| CREW SIZE | 104 |
| SAILOR COST (Annual) | $175,000 |
| TCTO Cost (Obsolescence) | $112,000 |
| TCTO Cost (Mission) | $625,000 |

The primary motivation for conducting a sensitivity analysis in this context is to identify the uncertainties that have the greatest impact on system performance, in order to inform and focus subsequent analyses. The results are presented as a tornado diagram in Figure B.3.

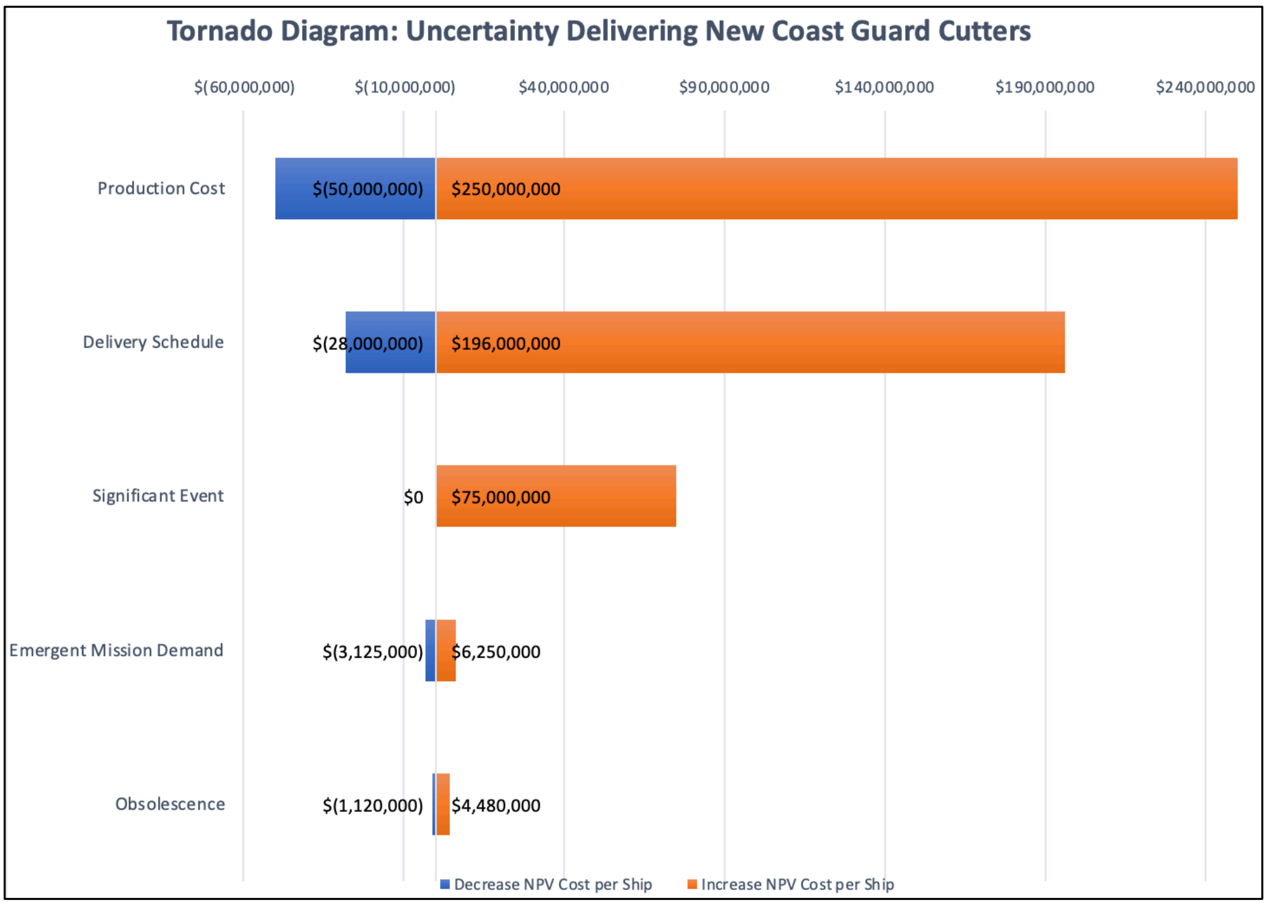



*Figure B.3. Tornado Diagram, Uncertainty Analysis*

Variability in production costs have the greatest impact on NPV costs per ship, however considering the relative degree of influence, the overarching focus of this thesis, and the organizational ability to shape outcomes, delivery schedule was selected as the primary uncertainty for further modeling and analysis. A visual representation of this uncertainty is provided in Figure B.4.

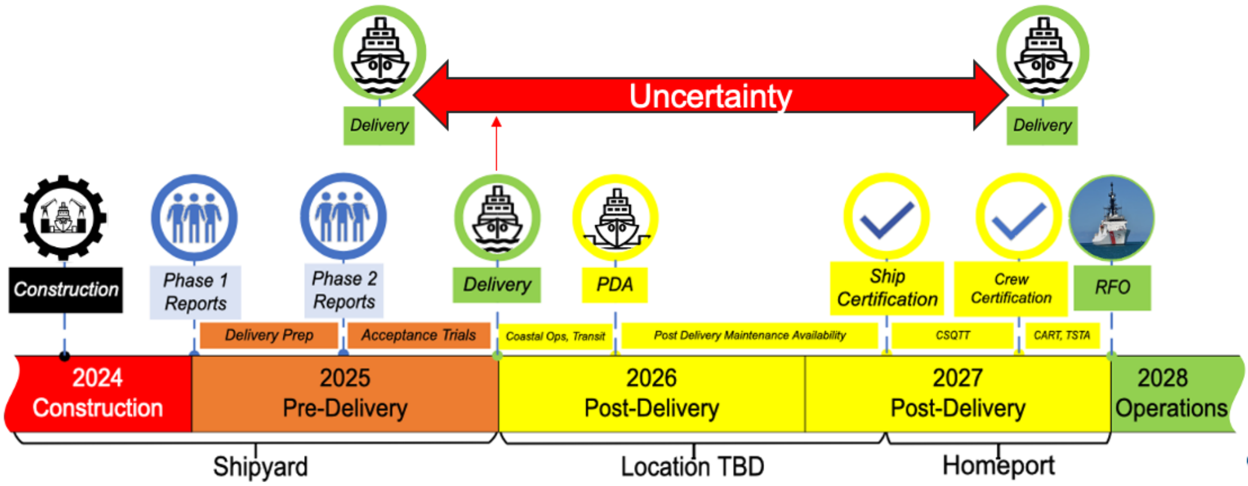



*Figure B.4. Delivery Schedule Uncertainty*

Historical US Navy and Coast Guard major ship delivery records were utilized to build a probability distribution function to model the selected uncertainty of vessel delivery schedule. The unit of measure is years relative to the scheduled baseline. Table B.3 organizes the resulting probabilities across a five-year schedule profile. Each ship delivery is treated as probabilistically discrete, as detailed in the assumptions section. The model is constructed such that probabilities are an input and can be adjusted based upon user needs, input field are highlighted in yellow in Table B.3.

*Table B.3. Uncertainty Probability Estimation Results*

| Delivery Schedule Index | | |
|---|---|---|
| Outcome (years relative to baseline) | Probability Assigned | Cumulative Prob |
| -1 (1 year early) | 1% | 1% |
| 0 (on time) | 22% | 23% |
| 1 (1 year late) | 55% | 78% |
| 2 (2 yrs late) | 15% | 93% |
| 3 (4 yrs late) | 7% | 100% |

Figure B.5 provides a visual representation of the selected probability distribution function.

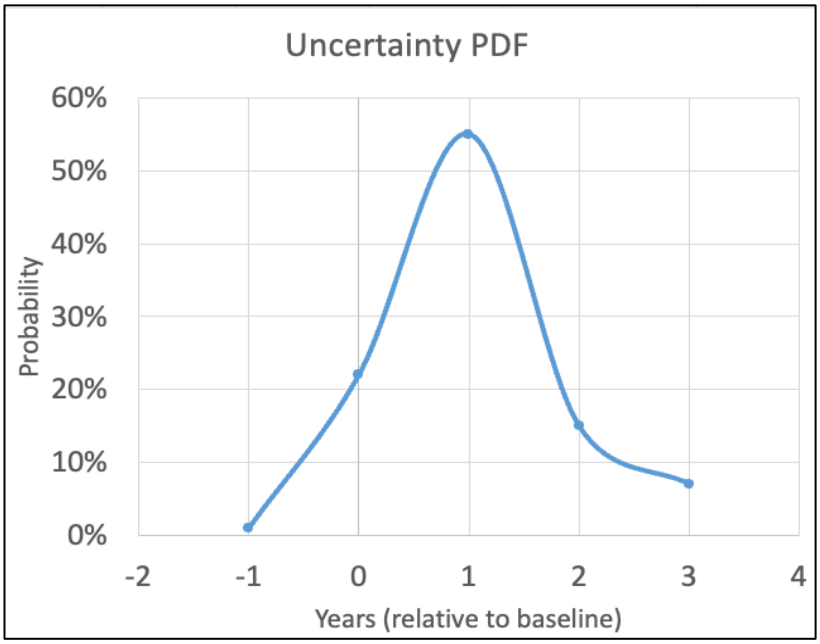



*Figure B.5. Uncertainty Probability Distribution Function*

## *B.3. Flexibility*

This study is focused on the timing of pre-commissioning crew assignments relative to ship construction and delivery timelines. Amidst significant schedule variability, the current staffing approach for pre-commissioning crews is inflexible and conservative. This project incorporates flexible design principles to acknowledge the inherent uncertainties associated with building new Coast Guard cutters, assigning their commissioning crews, and bringing them to a fully operational status. This section aims to provide an understanding of various flexible staffing strategies under consideration, and their performance under uncertain conditions.

The spreadsheet model developed for this project enabled the efficient exploration of many design alternatives. An iterative process of refining the model and examining various crewing strategies ultimately produced three different flexible design scenarios for comparison to the existing approach: *Delivery-Based Staffing, Ship Delivery Team,* and *Ship Buffer.* This section presents each scenario in detail, decision rules used to model the implementation of these strategies are summarized in Section B.4.5.

### B.3.1. Base Case

The base case, or existing approach, takes a deterministic approach to commissioning crews. Personnel staffing timelines are established based on a formal program baseline and initiated as far as 24 months out, independent of the corresponding ship's production status. Targets are established based on long-term projections and often treated as fixed milestones after that. Pre-commissioning crews are broken into 2 phases:

1. Phase One Crew: 13 crew members report 12 months before planned delivery. Includes command cadre, key engineering and logistics personnel.
2. Phase Two Crew: 91 crew members (remainder of the full crew) report six months before delivery.

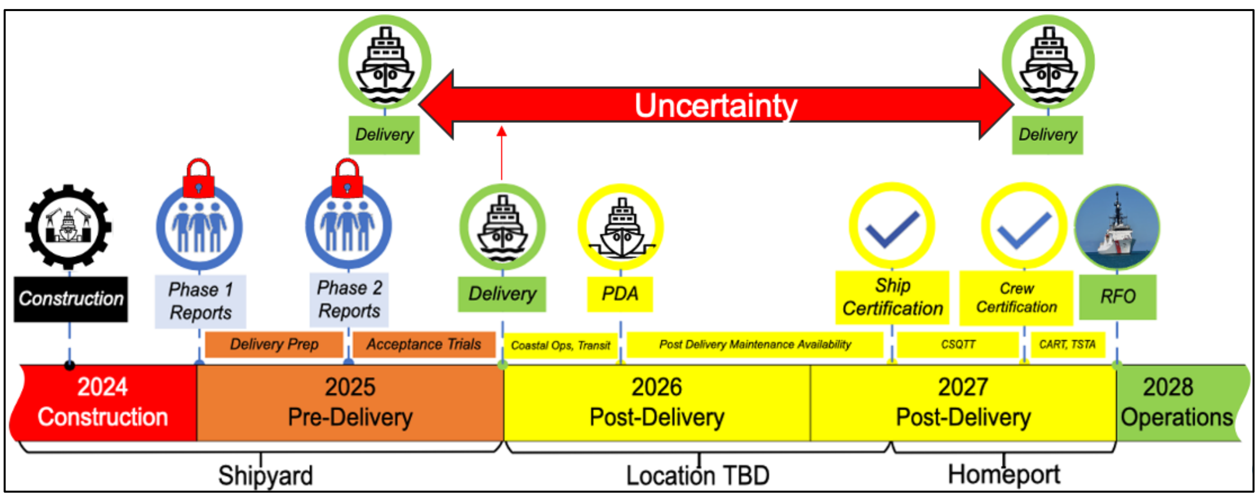



*Figure B.6. Base Case*

Note in Figure B.6 that while uncertainty spreads the profile of probable actual delivery dates over a wide multi-year range, the crew reporting events indicated by blue icons are effectively fixed.

### B.3.2. Delivery-Based Staffing

Delivery-Based Staffing shifts the approach for commissioning crews from deterministic and fixed, to probabilistic and flexible, tailoring the reporting timelines based on actual production status and schedule assessments. This study assumes billets can be activated and filled within six months of a decision to allow Phase-One personnel to report 12 months before delivery. Similar to the base case, flexible staffing assumes that for the duration of a shipbuilding program given ***X*** ships, we will have a limit of (and begin with) ***X+1*** crews. Initiating the model with ***X*** ships and ***X+1*** crews address the initiating pre-delivery queue.

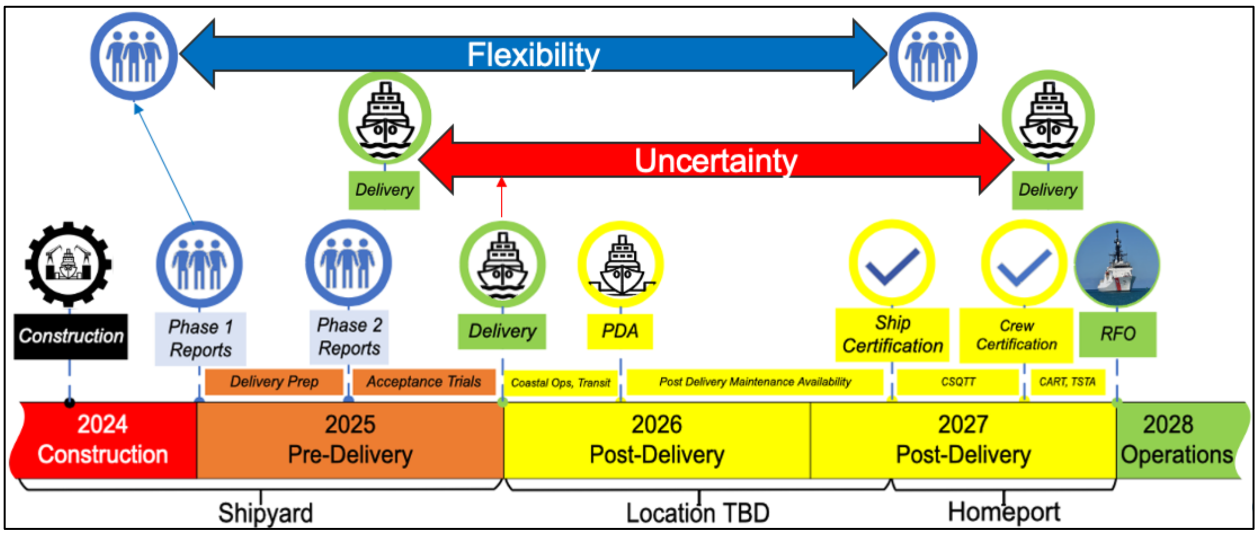



*Figure B.7. Delivery-Based Staffing*

Note in Figure B.7 the crew reporting events indicated by blue icons are not functionally "unlocked" and flexible, to appropriately counteract the uncertainty in schedule milestones.

### B.3.3. Ship Delivery Team

Ship Delivery Team invests in the commissioning of dedicated shore-based personnel up front and attaches them to the shipyard, as opposed to the ship, for the duration of the shipbuilding program. This crew is responsible for the majority of the pre-delivery requirements, allowing an additional year of flexibility and savings for the commissioning of operational crews. Upon delivery of the penultimate hull, the super crew may fleet over to the final delivered ship upon delivery and sail away.

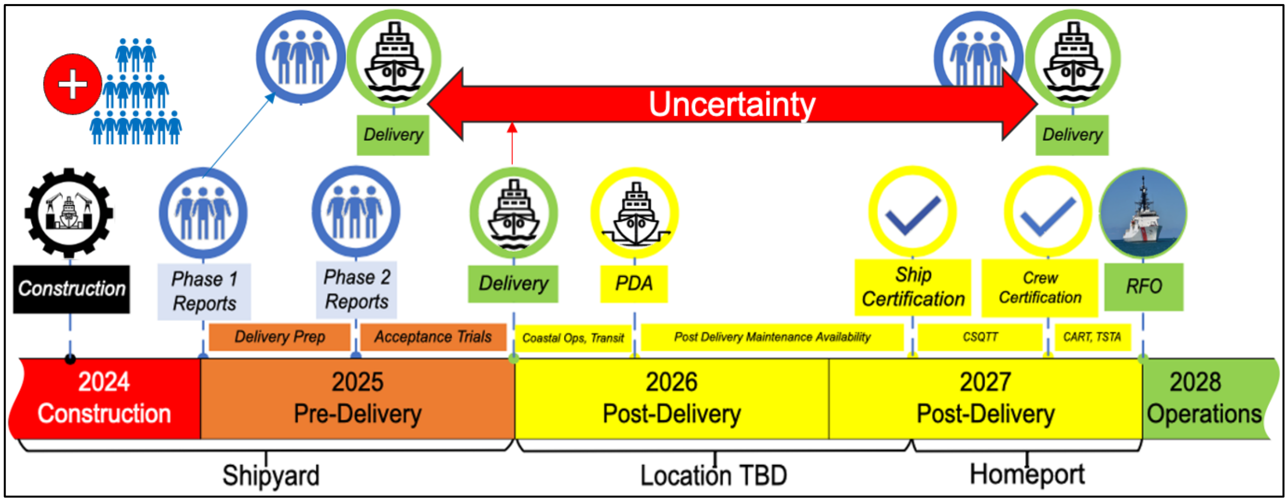



*Figure B.8. Ship Delivery Team*

Note the addition of 1 super crew allows the commissioning of cutter crews to not only be flexible, but tether directly to actual deliveries within a one-year time horizon. It is likely that learning curves may allow the Coast Guard to reduce this super crew from a full complement approximately one quarter of a full crew. This approach consistently condenses the training cycle time when the new crew does report.

## B.3.4. Ship Buffer

Ship buffer tethers the commissioning of crews directly to ship delivery, eliminating the year of pre-delivery activities entirely. The current approach of integrating efforts between the ship's crew and the shipbuilder over the final year of construction is abandoned, providing the bare minimum personnel necessary for the builder to meet contractual requirements. This would serve as a bridge to re-orienting contracts to require a clean delivery. The crew is commissioning in line with the vessel delivery Commission crew when the ship is actually delivered- this amounts to a full one-year delay overall, and will have significant impacts on downstream events (Post

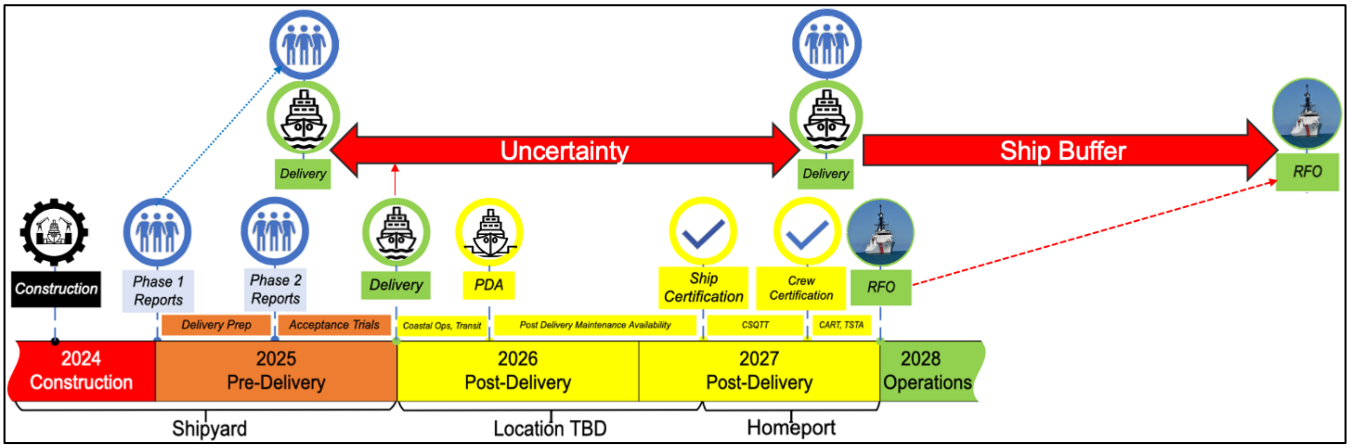



*Figure B.9. Ship Buffer Flex*

Figure B.9 indicates how ship buffer allows crew reporting activities to tether directly to actual deliver. However, significant delays are anticipated for RFO designation.

## *B.4. Model*

This project utilizes a tailored version of the "garage case" excel spreadsheet model template provided in Richard de Neufville's EM.422 course. The uncertainties and flexibilities detailed above form the foundation of the model. This section details model architecture, measures of performance, discount rate, inputs, and decision rules.

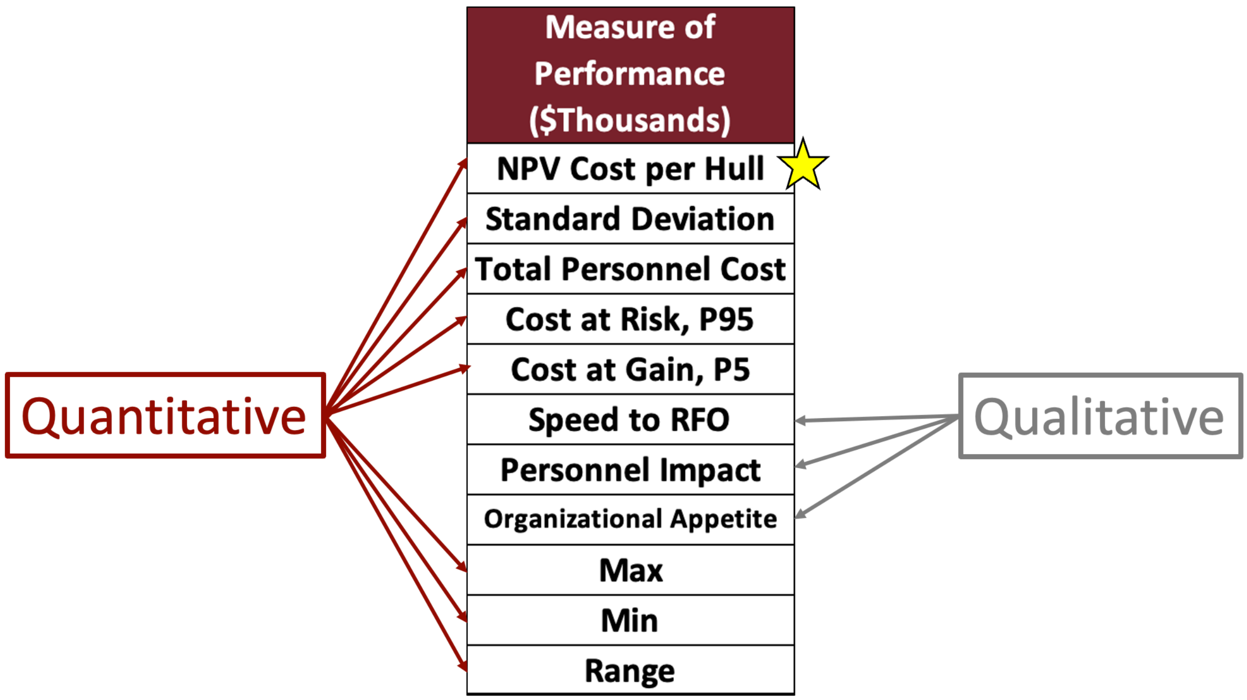
### B.4.1. Model Architecture

The spreadsheet enables efficient probabilistic analyses by modeling uncertainty, flexibility, system behavior, and measures of performance. Given all these inputs, Excel's monte carlo simulation is used to execute a high volume of iterations and evaluations are made based on those outcomes. This project utilized 2,000 simulations for every case considered. The combination of uncertainty, flexibility, and high-volume computation allows us to truly assess a system probabilistically, considering a full range of possible outcomes, instead of deterministically. The differences in results and conclusions are striking. Uncertainty is modeled combing excel's random number generator with the probability distribution function detailed in Section B.2.2. Flexibility is modeled utilizing a series of decision rules, which are presented later in this section. A discount rate is applied to account for the time value of money across the project duration, in making cost-to-benefit analysis. This exercise is repeated for each flexible option presented.

### B.4.2. Measures of Performance

The primary measure of performance for this analysis is a Net Present Value (NPV) cost-per-hull, represented in units of $1,000. The analysis applies a simple lens to a complex problem, just as there are numerous uncertainties, there are numerous dimensions of performance and tradeoffs that may be considered. Key equities include Coast Guard mission readiness and nuanced personnel impacts, and other costs beyond the personnel costs modeled here. There is no single governing measure of performance, however as this project demonstrates, there are significant cost savings potentially available via the implementation of flexible staffing strategies. As a *cost*, the convention is the lower the NPV cost per hull, the better. Table B.4 presents a summary view of the qualitative and quantitative measures of performance.

*Table B.4. Model Measures of Performance*




## B.4.3. Discount Rate

The US Office of Management and Budget (OMB) promulgates recommended discount rates for use in government cost-to-benefit analyses annually. In accordance with 2023 Circular A-94, a discount rate of 2.4% was used for this analysis (OMB, 2023). The model is structured to allow the user to input a discount rate.

## B.4.4. Inputs

The model was constructed to receive inputs on key variables based on user discretion and needs. Table B.5illustrates the input section of the model. The figures indicated in yellow are consistent with the inputs utilized for the analyses presented in this report. Cutter crew size and the financial cost per crew member were addressed in the assumptions section of this report. The discount rate and the probability distribution of the uncertainty in the delivery schedule are addressed in the model section of this report.

*Table B.5. Model Inputs*

| Yellow Indicates Model Inputs | |
|---|---|
| Cutter Crew Size | 104 |
| Cost per person (in $1,000) | 175 |
| Discount Rate | 2.4% |
| | |
| **Delivery Schedule Index** | |
| Outcome (yrs relative to planned yr) | Prob |
| -1 (1 year early) | 1% |
| 0 (on time) | 22% |
| 1 (1 year late) | 55% |
| 2 (2 yrs late) | 15% |
| 3 (4 yrs late) | 7% |
| | |
| Max Ships | 20 |

## B.4.5. Decision Rules

This section describes the decision rules used to model each design scenario within Excel, and presents a representative view of the model itself. For the discussion below, ***X*** *= number of ships,* ***C*** *= number of crews, and* ***T =*** *time*.

## B.4.6. *Base Case with Uncertainty*

The existing approach is deterministic, there is no decision rule to model flexibility. The base case model architecture is presented in Figure B.10.

Uncertainty

| Year | 25 | 26 | 27 | 28 |
|---|---|---|---|---|
| Ships Planned | 10 | 11 | 12 | 13 |
| Planned Deliveries | 1 | 1 | 1 | 1 |
| Ships Actual | 10 | 10 | 11 | 13 |
| Random | 0.298 | 0.298 | 0.100 | 0.737 |
| Yrs Late | 1 | 1 | 0 | 1 |
| Delivery within year | 0 | 0 | 1 | 0 |
| Residual Pick-up (Minus 1) | | 1 | 1 | 0 |
| Residual Pick-up (Minus 2) | | | 0 | 0 |
| Residual Pick-up (Minus 3) | | | | 0 |
| Actual Delivery | 0 | 1 | 2 | 0 |
| Crews Planned | 11 | 12 | 13 | 14 |
| Crew Commissions Planned | 1 | 1 | 1 | 1 |
| Personnel Cost (Total) | $ 687,500 | $ 750,000 | $ 812,500 | $ 875,000 |
| Pers Cost Per Hull Theoretic | $ 68,750 | $ 68,182 | $ 67,708 | $ 67,308 |
| Pers Cost per Hull Actual | $ 68,750 | $ 75,000 | $ 73,864 | $ 67,308 |
| DCF | $ 68,750 | $ 73,746 | $ 71,415 | $ 63,988 |
| Cost: Total Program | $ 14,687,500 | | | |
| Cost: Per Hull | $ 953,816 | | | |
| NPV Cost: Per Hull | **$ 859,468** | | | |

*Figure B.10. Base Case Model Excerpt*

## B.4.7. Delivery-Based Staffing

*If **X** ships are queued for delivery at **T**, then commission **X** crews, if not, commission **0** crews.* This rule is applied annually, always bound by the maximum number of ships on contract. A 4-tiered time-phased construct models the uncertainty of schedule delivery, then translates projections for each ship to the current year (T) and the decision rule is applied to each year of the 5 year profile. Figure B.11 illustrates the flexible staffing model with uncertainty:

| | | 25 | 26 | 27 | 28 |
|---|---|---|---|---|---|
| | Year | 25 | 26 | 27 | 28 |
| | Ships Planned | 10 | 11 | 12 | 13 |
| | Planned Deliveries | 1 | 1 | 1 | 1 |
| Uncertainty | Ships Actual | 10 | 10 | 11 | 12 |
| Uncertainty | Random | 0.245 | 0.641 | 0.234 | 0.513 |
| Uncertainty | Yrs Late | 1 | 1 | 1 | 1 |
| Uncertainty | Delivery within year | 0 | 0 | 0 | 0 |
| Uncertainty | Residual Pick-up (Minus 1) | | 1 | 1 | 1 |
| Uncertainty | Residual Pick-up (Minus 2) | | | 0 | 0 |
| Uncertainty | Residual Pick-up (Minus 3) | | | | 0 |
| Uncertainty | Actual Delivery | 0 | 1 | 1 | 1 |
| Uncertainty | Crews Planned | 11 | 12 | 13 | 14 |
| Flexibility | Crews Actual | 11 | 11 | 12 | 13 |
| Flexibility | Crew Commissions Planned | 1 | 1 | 1 | 1 |
| Flexibility | commission within year | delay | delay | delay | delay |
| Flexibility | Residual Pick-up (Minus 1) | | 1 | 1 | 1 |
| Flexibility | Residual Pick-up (Minus 2) | | | 0 | 0 |
| Flexibility | Residual Pick-up (Minus 3) | | | | 0 |
| Flexibility | Crew Commissions Actual | 0 | 1 | 1 | 1 |
| | Personnel Cost (Total) | $ 687,500 | $ 687,500 | $ 750,000 | $ 812,500 |
| | DCF | $ 68,750 | $ 67,601 | $ 65,921 | $ 64,369 |
| | Pers Cost Per Hull Theoretic | $ 68,750 | $ 68,182 | $ 67,708 | $ 67,308 |
| | Pers Cost per Hull Actual | $ 68,750 | $ 68,750 | $ 68,182 | $ 67,708 |
| | Cost: Total Program | $ 14,000,000 | | | |
| | Cost: Per Hull | $ 923,442 | | | |
| | **NPV Cost: Per Hull** | **$ 831,375** | | | |

*Figure B.11. Delivery-Based Staffing Model Excerpt*

## B.4.8. Ship Delivery Team

*If* $X_{T+1} > C_T$*, then commission* ***(X-C)*** *crews that year (****T****), if not, commission* ***0*** *crews.* Note that while it is a general rule that a decision rule in the model cannot be based on a future time, the uncertainty in this model is oriented towards a queue of **T+1**. The model construct is common with flexible staffing, the decision rule and time structure are updated, and the additional personnel are manually entered into the baseline calculations. Note the model presented here includes a conservative implementation with one full crew compliment manning the Ship Delivery Team for the duration of the program.

### B.4.9. Ship Buffer

*If $X_T > C_T$, then commission **(X-C)** crews that year (**T**), if not, commission **0** crews.* Again the model construct is common with flexible staffing, the decision rule and time phase are updated to tether crew commissioning's directly to ship deliveries.

## *B.5. Results of Flexible Engineering Design*

This section presents the results of FED Analysis. Table B.6 presents a multi-dimensional performance evaluation of the 4 cases analyzed. The color gradient intuitively organizes the relative performance within each measure. The Methods section above presented details regarding each approach, analysis results are presented here.

*Table B.6. Multi-Dimensional Evaluation*

| Measure of Performance ($Thousands) | Base Case | Delivery-Based Staffing | Ship Delivery Team | Ship Buffer Flex |
|---|---|---|---|---|
| NPV Cost per Hull | $245,664 | $233,284 | $228,169 | $209,090 |
| Std Deviation | $4,596 | $5,297 | $5,404 | $4,684 |
| Total Pers Cost | $4,277,000 | $4,167,800 | $3,894,800 | $3,785,600 |
| Cost at Risk, P95 | $254,183 | $235,339 | $231,594 | $209,789 |
| Cost at Gain, P5 | $239,408 | $231,964 | $226,126 | $208,794 |
| Speed to RFO | 1 | 1 | 2 | 4 |
| Personnel Impact | 4 | 2 | 2 | 1 |
| Organizational Appetite | 1 | 2 | 3 | 10 |
| Max | $266,315 | $236,399 | $234,959 | $210,875 |
| Min | $234,195 | $231,675 | $224,654 | $208,658 |
| Range | $32,121 | $4,725 | $10,305 | $2,216 |

The primary measure of performance is NPV cost per hull, note that the convention is that lower is better and units are thousands of dollars.

Figure B.12 overlays the modeled cumulative distribution functions for each of the 4 options considered. The deterministic forecast (red) is what the CG plans to invest in staffing a given population of new Offshore Patrol Cutters currently being built. The light blue plot models outcomes for the same existing approach, factoring in uncertainty. The area between the light blue curve and the red curve represents modeled liabilities the Coast Guard is currently incurring but not accounting for as a result of a deterministic approach. All of the remaining analyses include the same uncertainty: orange models Delivery-Based Staffing, dark blue is Ship Delivery Teams, and black is Ship Buffer.

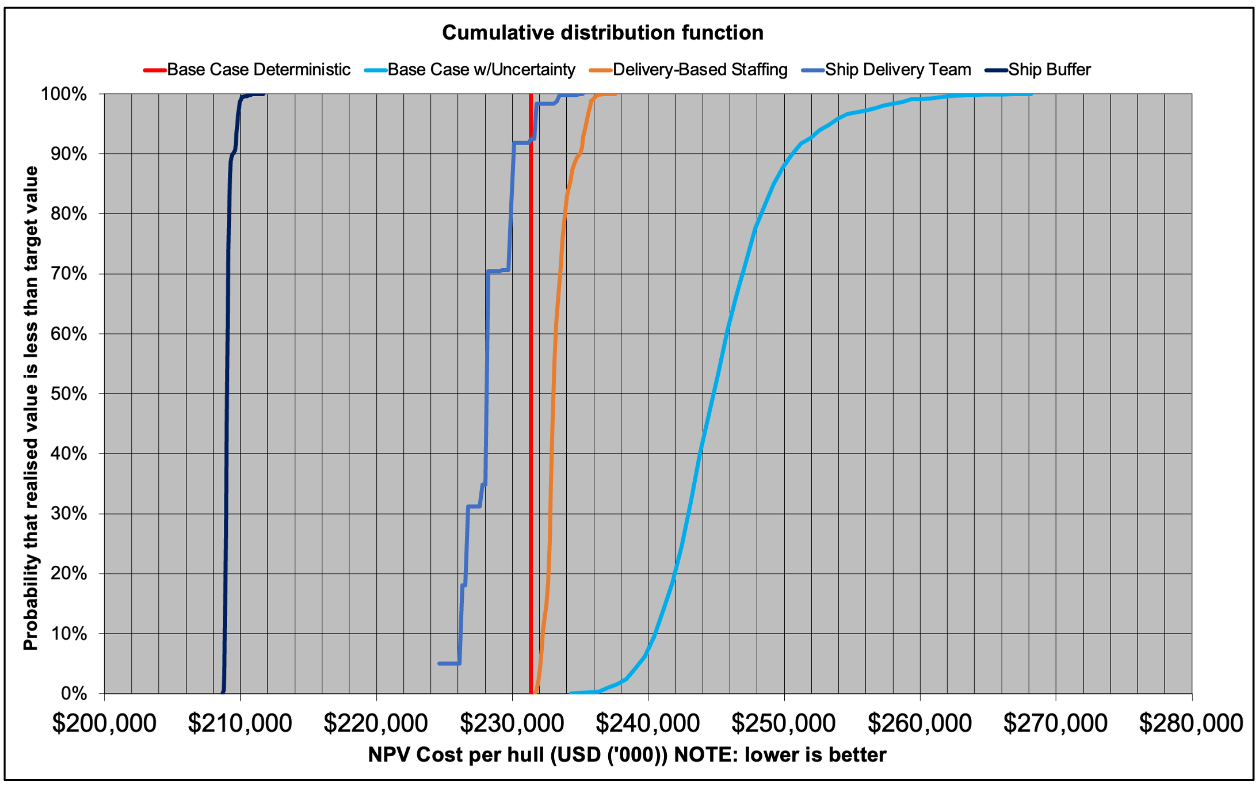



*Figure B.12. Integrated NPV Cost Per Hull, CDFs*

The remainder of the results section will present each scenario that was modeled with a summary table (expanded version of Table B.6), a graph of the primary measure of performance (NPV Cost per hull), and a cumulative distribution function (CDF) of the range of possible NPC cost per hull outcomes modeled.

### B.5.1. Base Case

A deterministic analysis is inherently unrealistic as it fails to consider uncertainty, particularly in an application like shipbuilding where schedule variability is known to be high. Having acknowledged this, the current approach is constructed within a deterministic paradigm. Therefore, a comprehensive comparative analysis requires a baseline to assess against. The deterministic base case with no uncertainty is modeled to achieve an NPV cost per hull of approximately $231 million; this is indicated above in Figure B.12 by the straight red line. Simply adding uncertainty in the schedule delivery while keeping the base case approach inflexible, the modeled NPV cost per hull increases by more than $14 million to **$245 million** with a standard deviation of $4.6 million. The cumulative distribution function of the NPV cost per hull in this scenario is indicated above by the light blue line Figure B.12., summary results of all performance measures assessed are presented below in Table B.7. The difference between these two calculations exceeds **$350 million** over the life of the 25-hull OPC program, and scales to other major ship projects as well. This delta is foundational to this project: it empowers us to look skeptically at the existing approach. To interrogate the deterministic approach and measure it probabilistically against the flexible strategies proposed in this report.

The Base Case is modeled to achieve a **NPV cost per hull of $245 million**, summary results are presented in Table B.7. The Base Case results are highlighted within a bold red perimeter, with the color gradient from Table B.6 is applied to the overall table to maintain context of strengths and weaknesses relative to the other approaches modeled.

*Table B.7. Base Case Performance Evaluation*

| Measure of Performance ($Thousands) | Base Case | Delivery-Based Staffing | Ship Delivery Team | Ship Buffer Flex |
|---|---|---|---|---|
| NPV Cost per Hull | $245,664 | $233,284 | $228,169 | $209,090 |
| Std Deviation | $4,596 | $5,297 | $5,404 | $4,684 |
| Total Pers Cost | $4,277,000 | $4,167,800 | $3,894,800 | $3,785,600 |
| Cost at Risk, P95 | $254,183 | $235,339 | $231,594 | $209,789 |
| Cost at Gain, P5 | $239,408 | $231,964 | $226,126 | $208,794 |
| Speed to RFO | 1 | 1 | 2 | 4 |
| Personnel Impact | 4 | 2 | 2 | 1 |
| Organizational Appetite | 1 | 2 | 3 | 10 |
| Max | $266,315 | $236,399 | $234,959 | $210,875 |
| Min | $234,195 | $231,675 | $224,654 | $208,658 |
| Range | $32,121 | $4,725 | $10,305 | $2,216 |

In Figure B.13 base case performance improvements can be observed in the fit of the blue line relative to the black theoretical limit. The area between blue (base case) and black (theoretical deterministic) represents the costs of uncertainty hidden by thinking deterministically: more than ***$14 million per hull***, or $350+ million over the life of the OPC program.

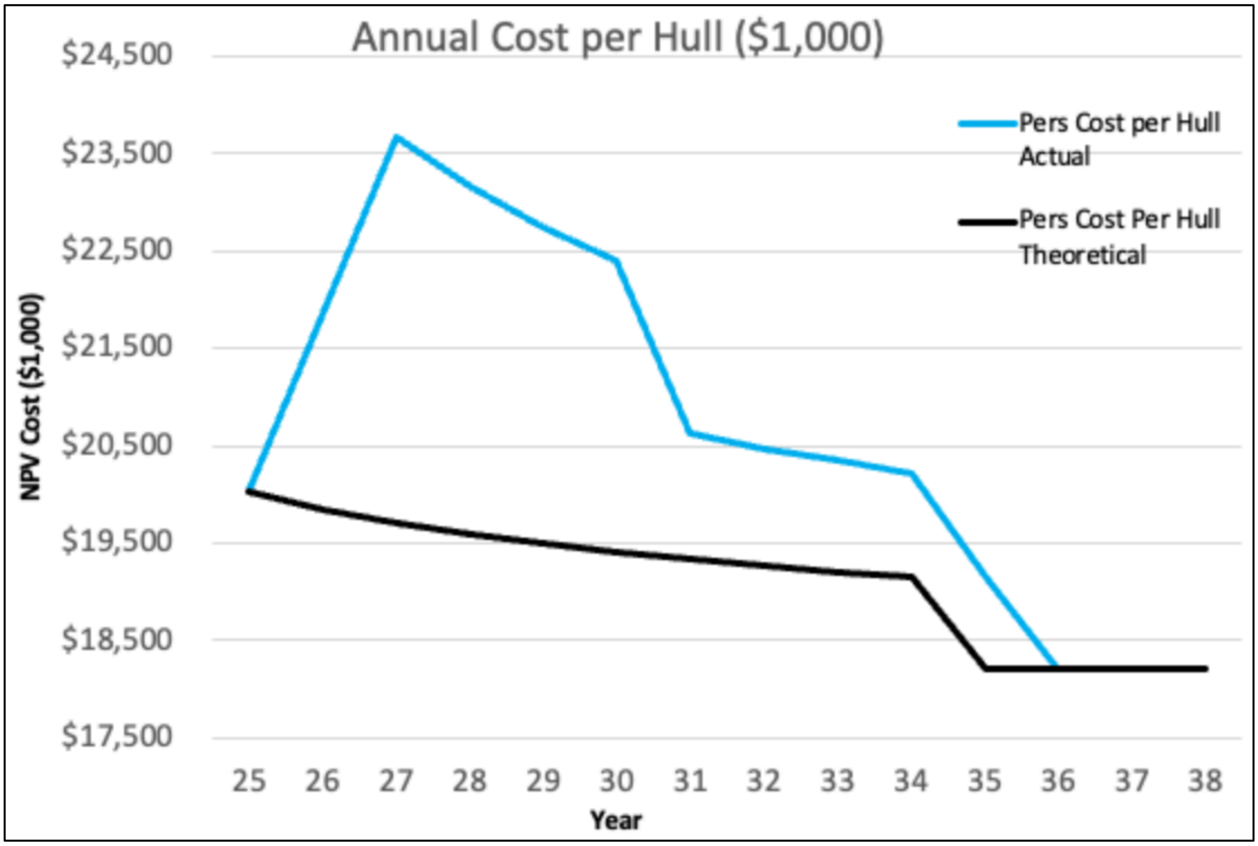



*Figure B.13. Base Case Annual Cost Per Hull*

The analysis presented earlier in this section translates the profile produced by 2,000 iterations of probabilistic performance analysis into a digestible and meaningful single value: Net Present Value of personnel cost per hull. The light blue CDF displayed below in Figure B.14 maps the full range and shape of probable performance outcomes for the base case, against the deterministic projection of $231 million (indicated by the red plot). Modeling a realistic representation of uncertainty produces higher costs across the entire range. However, when we include the top and bottom sides of the probability distribution function, significant risks (at the high end) and opportunities (at the low end) emerge. Figure B.14 displays these critical results, bracketing an overall range of more than $33 million.

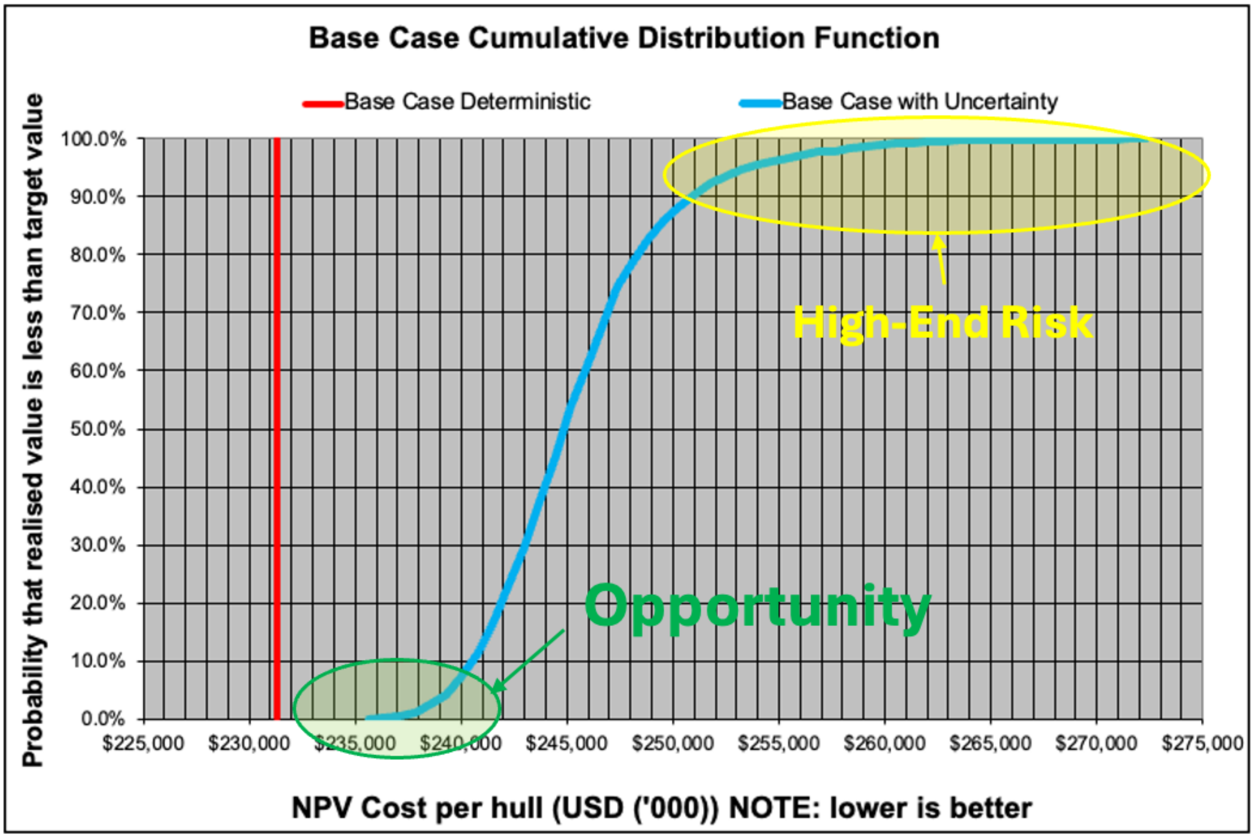



*Figure B.14. Base Case Cumulative Distribution Function*

### B.5.2. Delivery-Based Staffing

Knowledge and insights gained from the modeling of uncertainty informed ideation of potential flexible approaches to improve outcomes amidst uncertainty. Delivery-based staffing (DBS) is the first staffing strategy that was developed using this model, specifically to implement tailored organizational flexibility. Factoring in uncertainty, DBS is modeled to achieve an NPV cost per hull of approximately *$233 million* with a standard deviation of $5.3 million. This is an improvement of $12 million per hull relative to the Base Case, representing more than **$300 million** in savings over the life of the 25-hull OPC program. Summary results are presented in Table B.8, DBS results are highlighted within a bold red perimeter. The color gradient from Table B.6 is applied to the overall table to maintain context of strengths and weaknesses relative to the other approaches modeled.

*Table B.8. Integrated Performance Evaluation: Delivery-Based Staffing*

| Measure of Performance ($Thousands) | Base Case | Delivery-Based Staffing | Ship Delivery Team | Ship Buffer Flex |
|---|---|---|---|---|
| NPV Cost per Hull | $245,664 | $233,284 | $228,169 | $209,090 |
| Std Deviation | $4,596 | $5,297 | $5,404 | $4,684 |
| Total Pers Cost | $4,277,000 | $4,167,800 | $3,894,800 | $3,785,600 |
| Cost at Risk, P95 | $254,183 | $235,339 | $231,594 | $209,789 |
| Cost at Gain, P5 | $239,408 | $231,964 | $226,126 | $208,794 |
| Speed to RFO | 1 | 1 | 2 | 4 |
| Personnel Impact | 4 | 2 | 2 | 1 |
| Organizational Appetite | 1 | 2 | 3 | 10 |
| Max | $266,315 | $236,399 | $234,959 | $210,875 |
| Min | $234,195 | $231,675 | $224,654 | $208,658 |
| Range | $32,121 | $4,725 | $10,305 | $2,216 |

In Figure B.15 DBS performance improvements can be observed in the fit of the orange line (delivery-based staffing) relative to the light blue (base case) and black (theoretical limit) profiles. The area between orange (delivery-based staffing) and blue (base case) represents the value of flexibility in this case: more than $12 million per hull, or $300 million+ over the life of the OPC program.

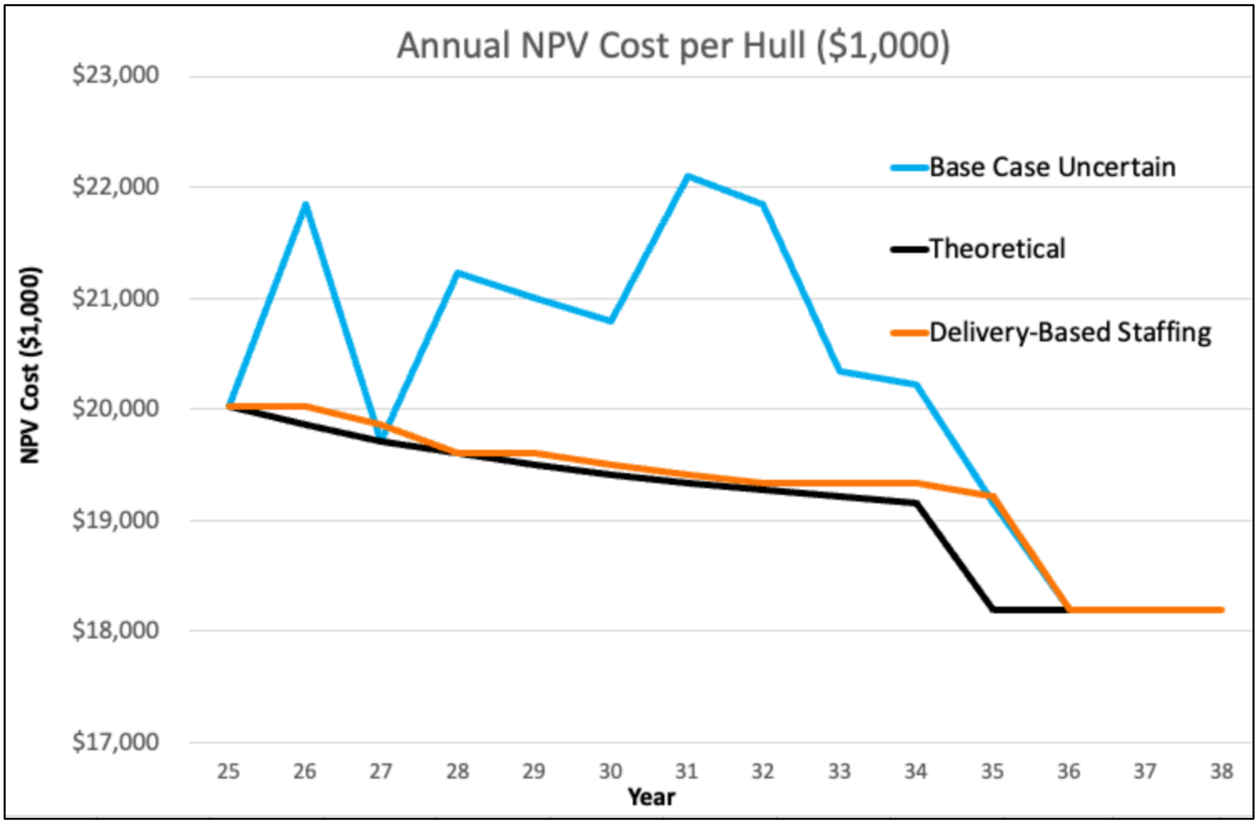



*Figure B.15. Delivery-Based Staffing Annual Cost Per Hull*

Figure B.16 overlays CDF results for all scenarios considered so far, with highlights calling attention to the differentiating characteristics with respect to the low probability / high-impact extremes. The flexible approach of DBS significantly reduces exposure to these extreme outcomes within the delivery schedule uncertainty profile, as indicated in the reduced size of the risk (yellow) and opportunity (green) highlights in Figure B.16. The DBS results span a range of $4.7 million, a significant reduction in risk and uncertainty relative to the base case range of $32 million with the majority of the change residing in the mitigation of high-end risks associated with protracted delivery schedule delays.

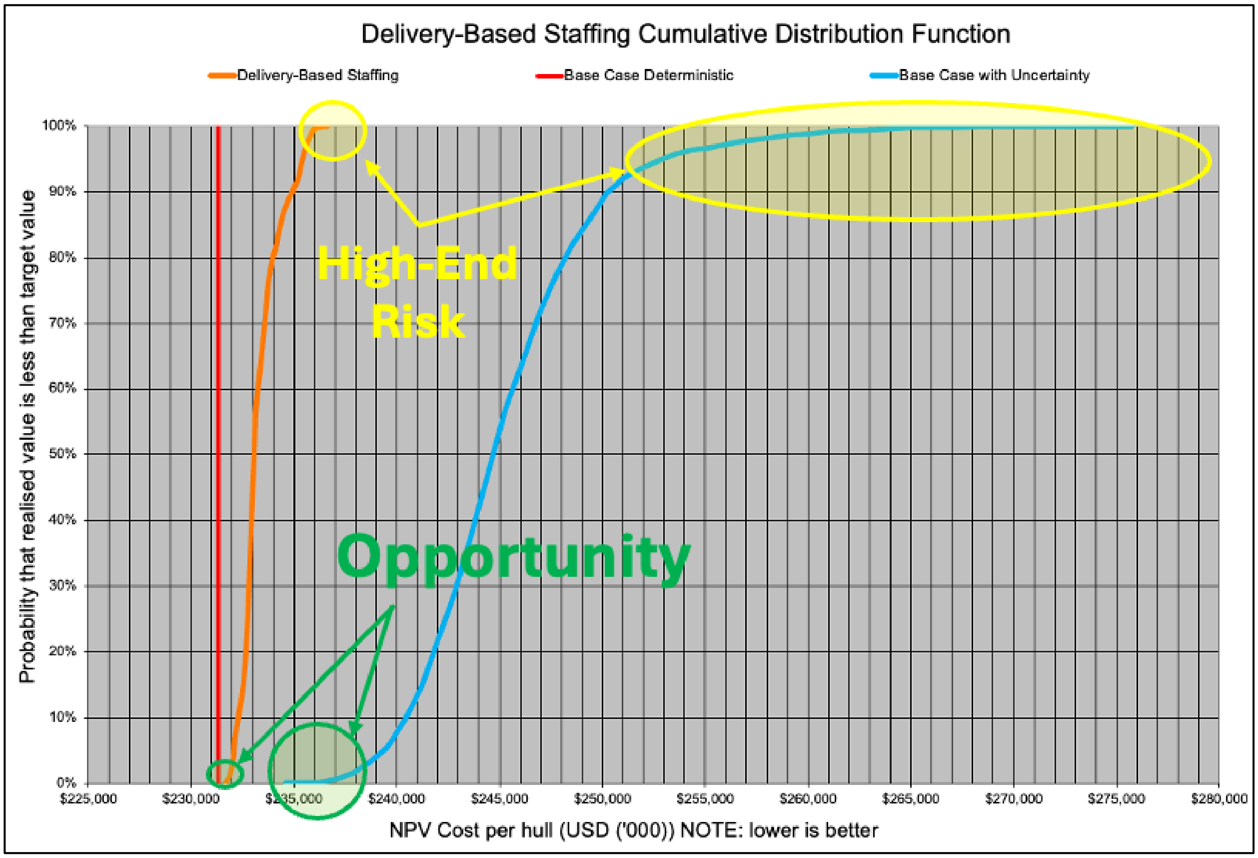



*Figure B.16. Delivery-Based Staffing Cumulative Distribution Function*

Figure B.17 displays a zoomed in version of the Delivery-Based Staffing CDF to make the topography of the distribution visible.

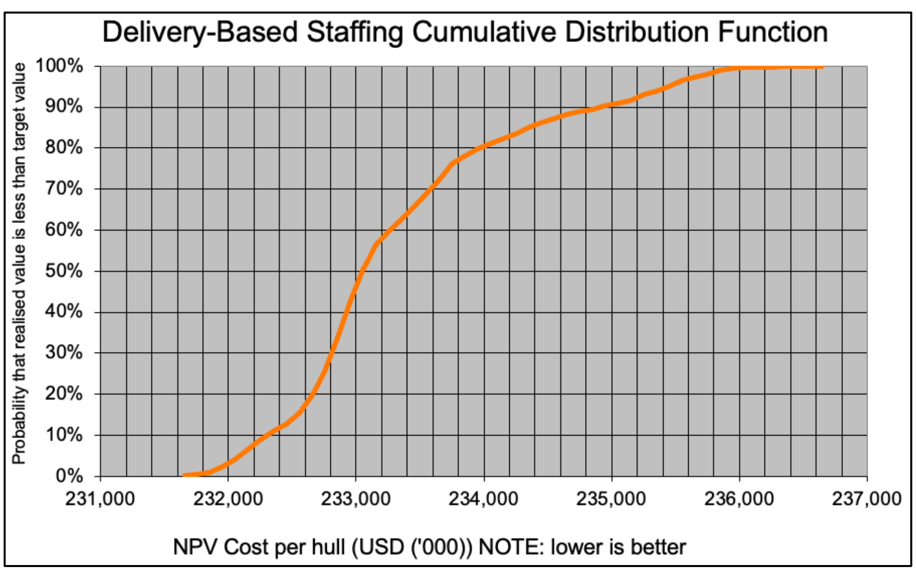



*Figure B.17. Delivery-Based Staffing: CDF Zoom*

## B.5.3. Ship Delivery Team

The Ship Delivery Team (SDT) strategy requires an upfront investment equivalent to one full crew for the duration of the program, however FED analysis demonstrates that even with this upfront investment the expected value is net positive. Factoring in uncertainty, SDT is modeled to achieve an NPV cost per hull of approximately *$228 million* with a standard deviation of $5.4 million. This is an improvement of $5 million per hull relative to Delivery-Based Staffing, and $17+ million per hull relative to the Base Case, representing more than **$425 million** in savings over the life of the 25-hull OPC program. Summary results are presented in Table B.9, SDT results are highlighted within a bold red perimeter. The color gradient from Table B.6 is applied to the overall table to maintain context of strengths and weaknesses relative to the other approaches modeled.

*Table B.9. Integrated Performance Evaluation: Ship Delivery Team*

| Measure of Performance ($Thousands) | Base Case | Delivery-Based Staffing | Ship Delivery Team | Ship Buffer Flex |
|---|---|---|---|---|
| NPV Cost per Hull | $245,664 | $233,284 | $228,169 | $209,090 |
| Std Deviation | $4,596 | $5,297 | $5,404 | $4,684 |
| Total Pers Cost | $4,277,000 | $4,167,800 | $3,894,800 | $3,785,600 |
| Cost at Risk, P95 | $254,183 | $235,339 | $231,594 | $209,789 |
| Cost at Gain, P5 | $239,408 | $231,964 | $226,126 | $208,794 |
| Speed to RFO | 1 | 1 | 2 | 4 |
| Personnel Impact | 4 | 2 | 2 | 1 |
| Organizational Appetite | 1 | 2 | 3 | 10 |
| Max | $266,315 | $236,399 | $234,959 | $210,875 |
| Min | $234,195 | $231,675 | $224,654 | $208,658 |
| Range | $32,121 | $4,725 | $10,305 | $2,216 |

Figure B.18 presents annual NPV cost per hull over the time period modeled, for the three approaches analyzed thus far as well as the theoretical deterministic limit. Ship Delivery Team's performance improvements can be observed in the area between dark blue (SDT) and other lines representing the value of flexibility: further improvement of  $5 million per hull, or $125 million over the life of the program, relative to delivery-based staffing. This approach requires added upfront costs to resource one additional permanent crew for the duration of the program, however as indicated, this investment is more than offset by the savings offered from increased staffing precision.

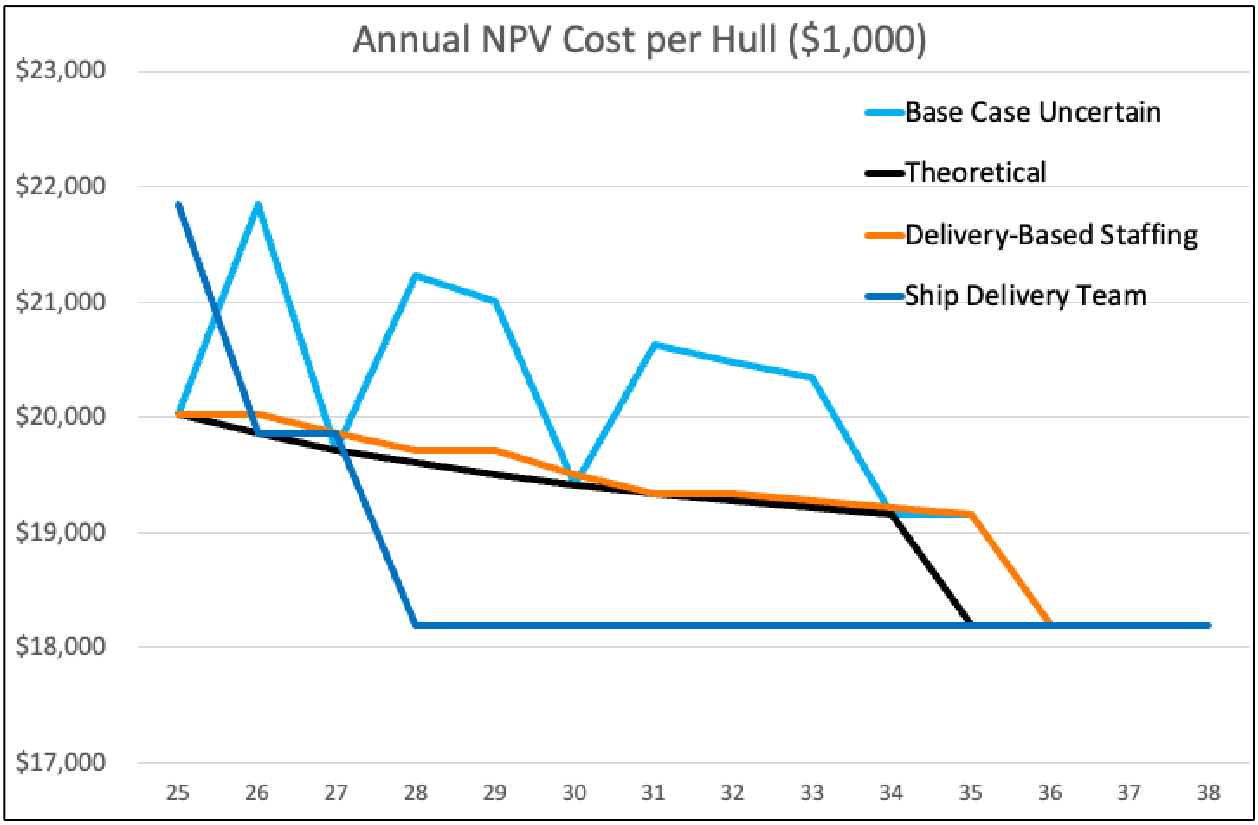



*Figure B.18. Ship Delivery Team Annual NPV Cost Per Hull*

Figure B.19 overlays CDF results for all scenarios considered so far. The organizational flexibility gained with the investment in a crew of shore-based personnel significantly improves overall performance while reducing exposure to extreme outcomes within the delivery schedule's uncertainty profile.

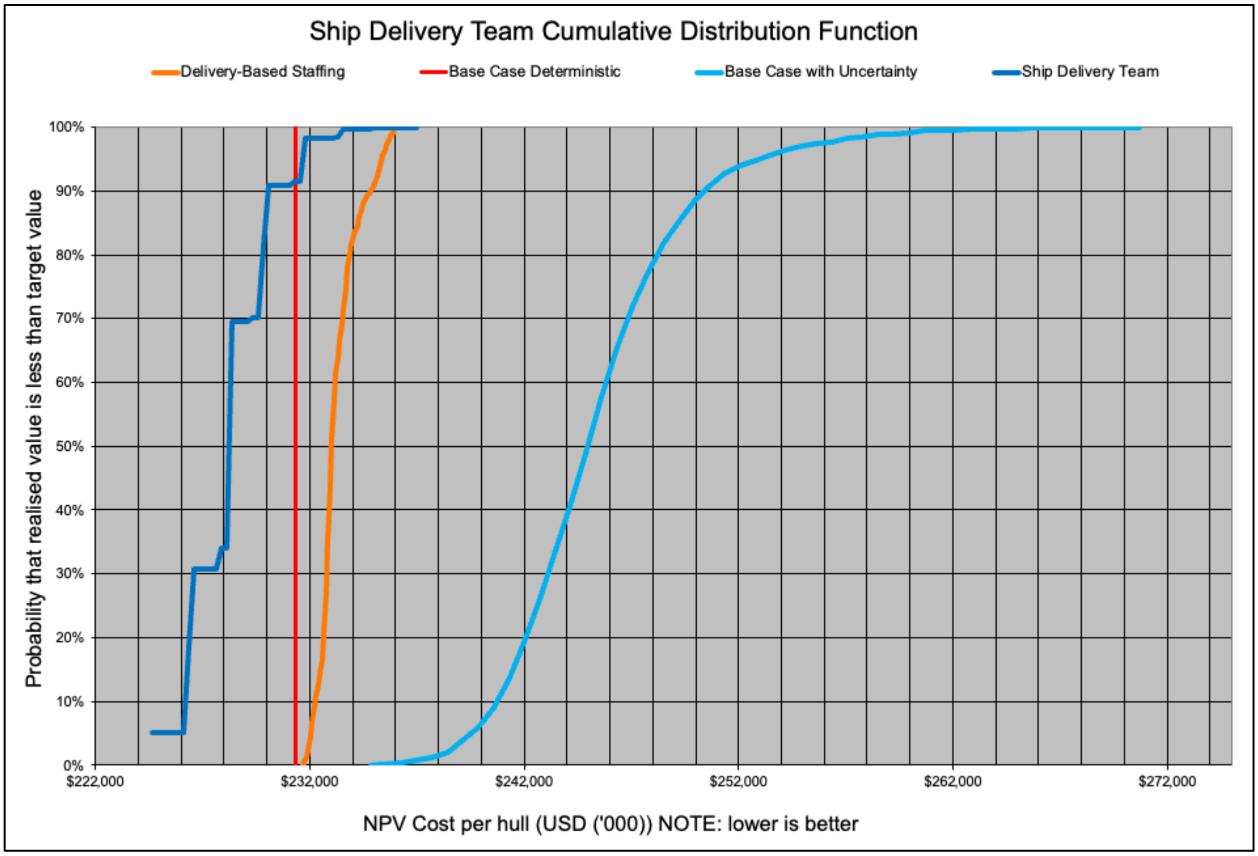



*Figure B.19. Ship Delivery Team Cumulative Distribution Function*

Figure B.20 displays a zoomed in version of the Ship Delivery Team CDF to make the topography of the distribution visible.

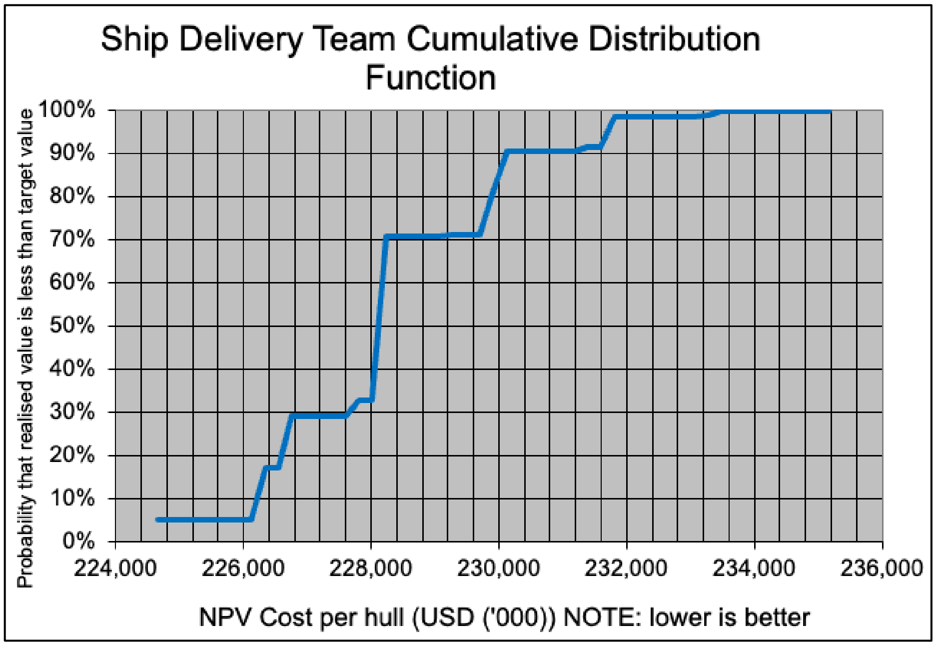



*Figure B.20. Ship Delivery Team: CDF Zoom*

## B.5.4. Ship Buffer

The Ship Buffer strategy performs exceptionally well however it comes at a significant organizational cost in the form of delaying RFO. Ship Buffer is modeled to achieve an NPV cost per hull of approximately *$209 million* with a standard deviation of $4.6 million. This is an improvement of $19 million per hull relative to Ship Delivery Teams, and $36+ million per hull relative to the Base Case, representing more than **$900 million** in savings over the life of the 25-hull OPC program. Summary results are presented in Table B.10, Ship Buffer results are highlighted within a bold red perimeter. The color gradient from Table B.6 is applied to the overall table to maintain context of strengths and weaknesses relative to the other approaches modeled.

*Table B.10. Integrated Performance Evaluation: Ship Buffer*

| Measure of Performance ($Thousands) | Base Case | Delivery-Based Staffing | Ship Delivery Team | Ship Buffer Flex |
|---|---|---|---|---|
| NPV Cost per Hull | $245,664 | $233,284 | $228,169 | $209,090 |
| Std Deviation | $4,596 | $5,297 | $5,404 | $4,684 |
| Total Pers Cost | $4,277,000 | $4,167,800 | $3,894,800 | $3,785,600 |
| Cost at Risk, P95 | $254,183 | $235,339 | $231,594 | $209,789 |
| Cost at Gain, P5 | $239,408 | $231,964 | $226,126 | $208,794 |
| Speed to RFO | 1 | 1 | 2 | 4 |
| Personnel Impact | 4 | 2 | 2 | 1 |
| Organizational Appetite | 1 | 2 | 3 | 10 |
| Max | $266,315 | $236,399 | $234,959 | $210,875 |
| Min | $234,195 | $231,675 | $224,654 | $208,658 |
| Range | $32,121 | $4,725 | $10,305 | $2,216 |

Figure B.21 presents annual NPV cost per hull over the time period modeled, for all four approaches analyzed as well as the theoretical deterministic limit. Ship Buffer's performance improvements can be observed in the area between red (Ship Buffer) and other lines representing the relative value of flexibility: further improvement of $19 million per hull, or $475 million over the life of the program, relative to Ship Delivery Teams. This approach performs exceptionally well on the Measures of Performance modeled, however this comes at a significant operational cost that may prove untenable to the Coast Guard as indicated in the qualitative "Speed to RFO" and "Organizational Appetite" scores.

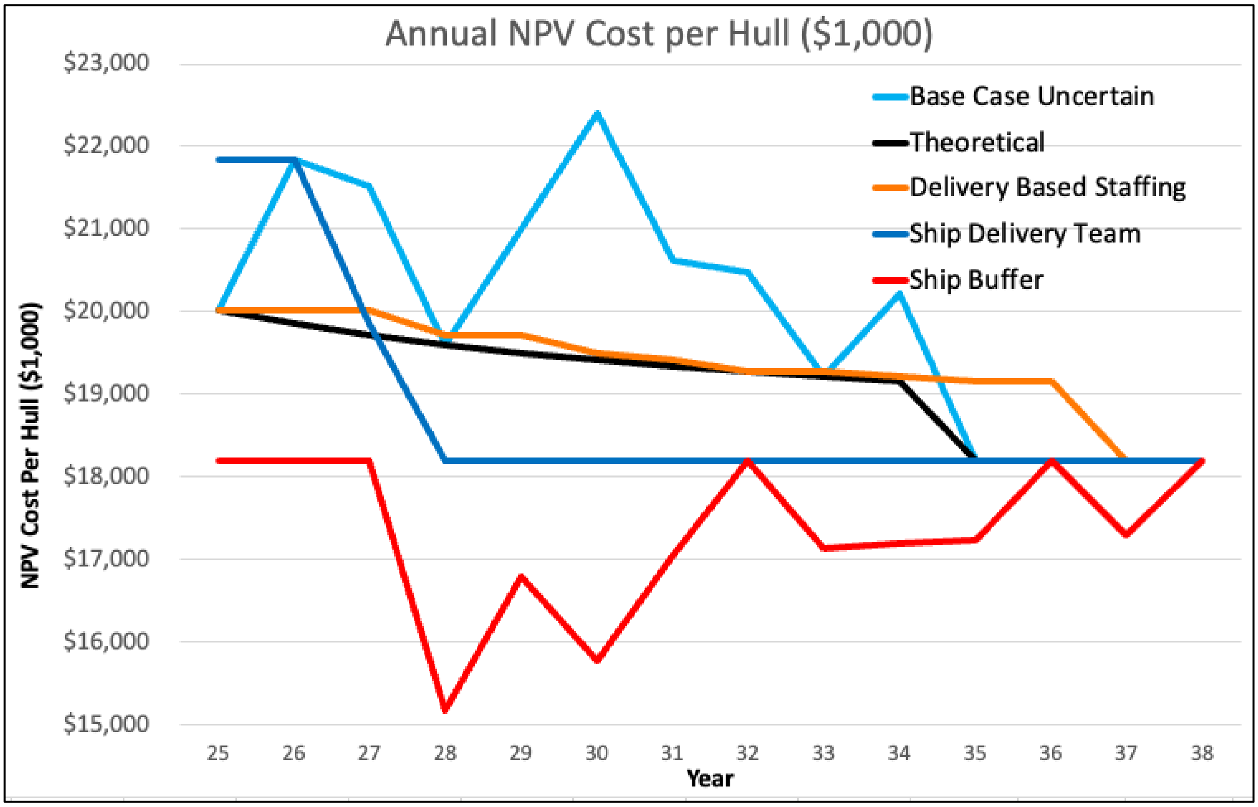



*Figure B.21. Ship Buffer Team Annual NPV Cost Per Hull*

Figure B.22 overlays CDF results for all scenarios considered so far. The organizational flexibility gained by waiting for actual delivery before initiating staffing and Post Delivery activities is significant within the assumptions of this model, however implementation is likely untenable.

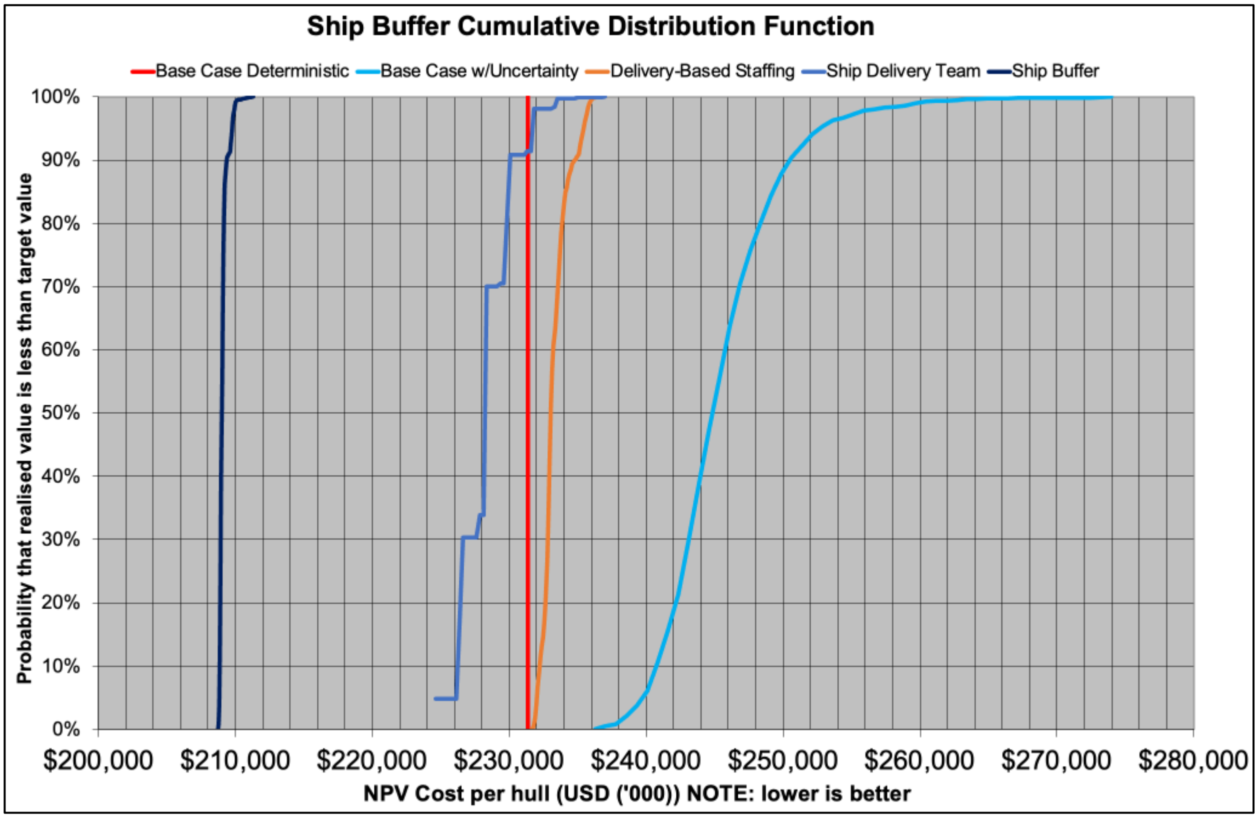



*Figure B.22. Ship Buffer Cumulative Distribution Function*

Figure B.23 displays a zoomed in version of the Ship Buffer CDF to make the topography of the distribution visible.

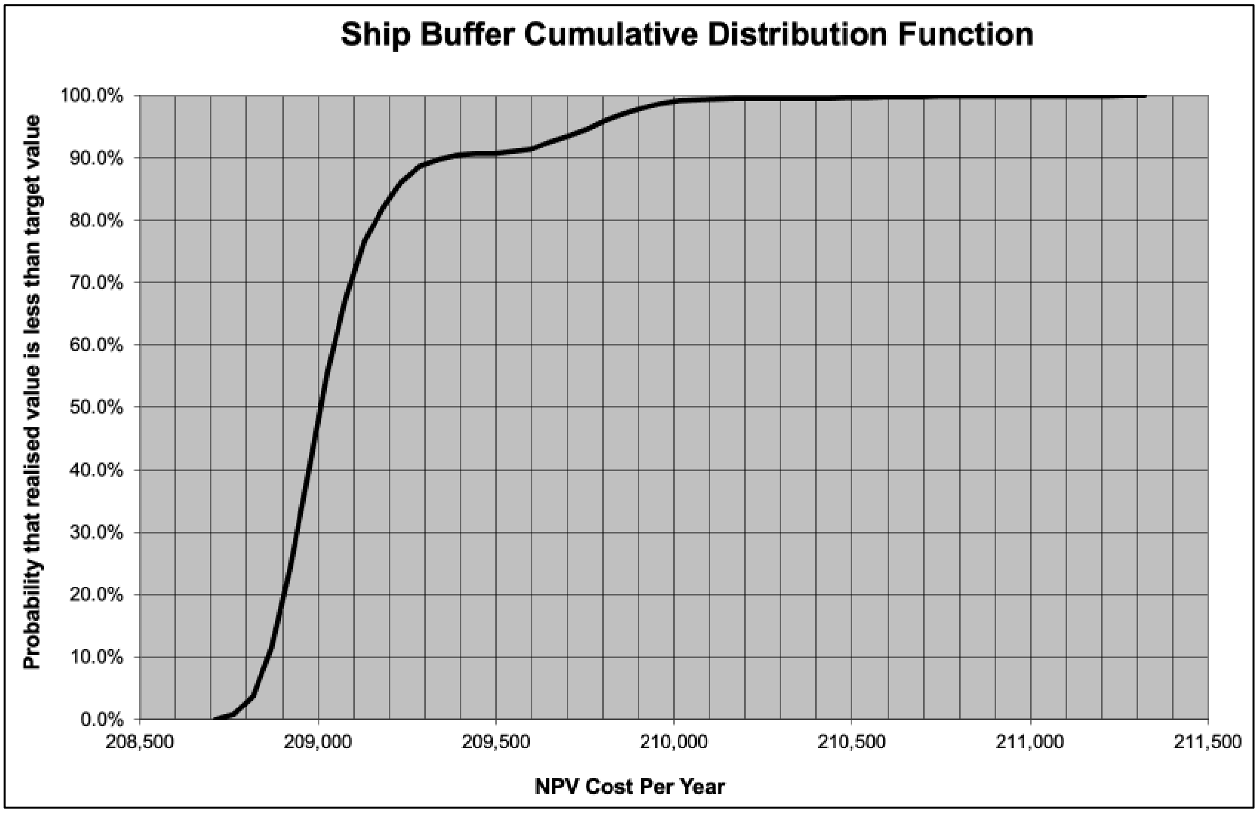



*Figure B.23. Ship Buffer: CDF Zoom*

## B.6. Conclusion and Recommendations

Figure B.24 below presents the potential savings in NPV cost per hull offered by the three flexible approaches modeled, relative to the base case. All three flexible options offer significant cost savings relative to the base, and Ship Buffer outperforms the other options by a factor of 2 or more. Based on a qualitative analysis of the model results Ship Buffer Flex would the clear recommendation, however, this is a complex system and the NPV cost per hull is one of several dimensions of analysis.

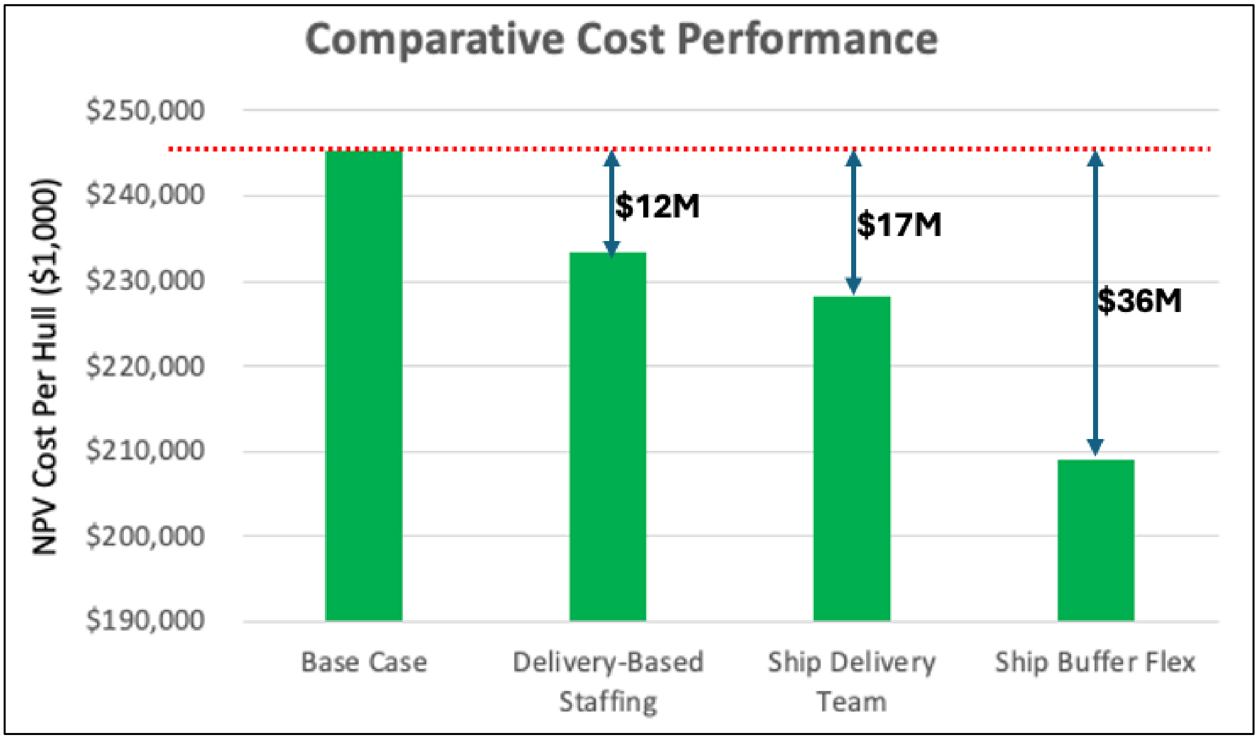



*Figure B.24. NPV Cost Per Hull Summary Findings*

Table B.11 adds three qualitative evaluation factors to the multi-dimensional analysis of options: speed to RFO, personnel impact, and organizational appetite. Within the assumptions and bounds of this analysis, both Delivery-Based Staffing and Ship Delivery Teams have significant merit and are recommended for implementation. These strategies represent the first two phases of a three-phased recommendation for the Coast Guard to improve the transition of newly built ships from construction to operations. it is my recommendation that the Coast Guard further develop the flexible "***Super Crew"*** approach to staffing newly built Coast Guard vessels. This approach returns a discount adjusted $61.9 million per hull, or $619 million across this project's time horizon, relative to the base case. It achieves these savings with little to no negative impact on the speed to RFO and moderate, and potentially net-positive, impact on personnel. Notably it outperforms Ship Buffer Flex on Organizational Appetite, which is an index for the feasibility of implementation.

*Table B.11. Multi-Dimensional Performance Evaluation and Recommendations*

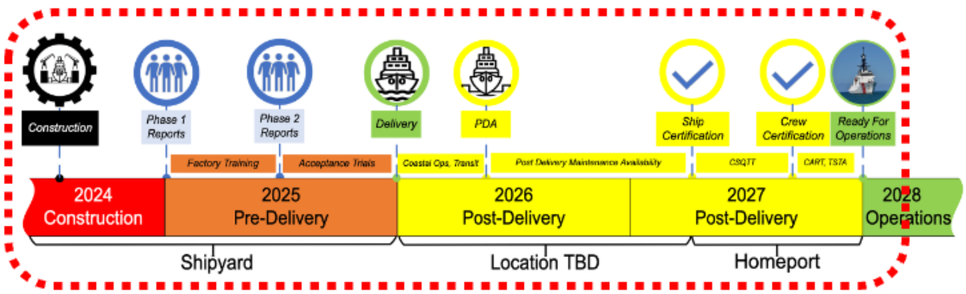
| Measure of Performance ($Thousands) | Base Case | Delivery-Based Staffing | Ship Delivery Team | Ship Buffer Flex |
|---|---|---|---|---|
| NPV Cost per Hull | $245,664 | $233,284 | $228,169 | $209,090 |
| Std Deviation | $4,596 | $5,297 | $5,404 | $4,684 |
| Total Pers Cost | $4,277,000 | $4,167,800 | $3,894,800 | $3,785,600 |
| Cost at Risk, P95 | $254,183 | $235,339 | $231,594 | $209,789 |
| Cost at Gain, P5 | $239,408 | $231,964 | $226,126 | $208,794 |
| Speed to RFO | 1 | 1 | 2 | 4 |
| Personnel Impact | 4 | 2 | 2 | 1 |
| Organizational Appetite | 1 | 2 | 3 | 10 |
| Max | $266,315 | $236,399 | $234,959 | $210,875 |
| Min | $234,195 | $231,675 | $224,654 | $208,658 |
| Range | $32,121 | $4,725 | $10,305 | $2,216 |

Implementation considerations are represented in the "Organizational Appetite" measure of performance, which is a qualitative blended index of known implementation considerations.

Economies of scale may be available. The Gulf Coast is currently the geographic hub of Coast Guard shipbuilding contracts, with the vast majority of construction occurring within a 150-mile radius encompassing Pascagoula, MS and Lockport, LA.

Crew members reporting too early has many negative impacts, including inefficient use of resources, under-utilization of skilled personnel, and negative impacts on workforce morale. Reporting too late also has negative impacts, including delaying post-delivery commissioning activities. These factors are represented in the “Speed to RFO” and “Personnel Impact” measures of performance.

This project applied a very simple lens to a complex problem. Significant opportunities for future work exist. Pictured below is a revised system boundary for a potential expanded problem statement:




This expanded scope could focus on speed and efficiency to achieve Ready For Operations, including evaluation of the final phases of construction as well at the entire post-delivery construct through RFO. Scope could also be expanded vertically to identify fundamental approaches that can be scaled and applied to the other 6 surface acquisition programs. The current model considers only the fielding of new cutters and considers the de-commissioning of old cutters as outside the scope of this analysis. Future study may also examine utility of multi-crew (i.e. 4 crews operating 5 cutters) concepts.

# Appendix C. System Design and Management Integrated Analysis

This thesis examines the complex process of making a newly constructed CG cutter and crew fully operational. In treating the set of time and tasks defined here as "Post Delivery" (PD) as a socio-technical system, we can exercise the SDM suite of tools to develop a ground-up system concept that is in alignment with the stakeholder needs and requirements.

## *C.1. System Problem Statement*

Amidst a massive shipbuilding effort, the Coast Guard has an opportunity to evolve and improve its ability to transform newly constructed vessels into fully operational Coast Guard cutters. A new and growing fleet, evolutionary technology trends driving complexity up and technology refresh cycles down, and significant workforce challenges are pressuring the already difficult Post Delivery period.

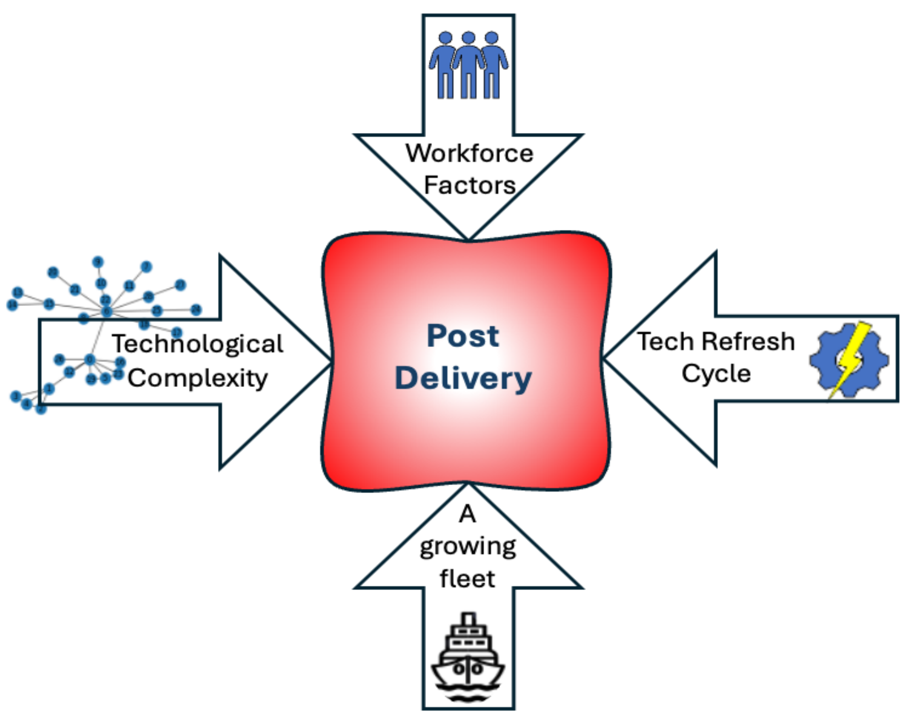



*Figure C.1. Driving Forces*

The System Problem Statement (SPS) evolution over the course of this study is presented below, using the "To-By-Using" construct described in Section 3.5.1.

- Preliminary: To minimize Net Present Value cost per hull of readying a newly built cutter for operational service, By investigating flexible crewing strategies, Using Real Options Analysis and Monte-Carlo Simulation.
- Interim-1: To optimize the delivery of newly constructed Coast Guard cutters, By treating the Post Delivery period between contract delivery and unrestricted operations as a complex sociotechnical system, Using academic tools from MiT.
- Interim-2: To enhance organizational outcomes in fielding newly constructed Coast Guard cutters, managing the Post-Delivery phase of shipbuilding efforts, By treating the Post-Delivery phase as a complex system, Using flexible engineering design and system design management tools.
- Interim-3: To design a (scalable) system to make newly constructed Coast Guard cutters ready for unrestricted operations, By treating the period and tasks between contract delivery and unrestricted operations as a complex sociotechnical system, Using Flexible Engineering Design, Systems Design and Management principles.
- Final: To improve organizational outcomes fielding newly constructed vessels, By treating the post delivery time and tasks as a complex and enduring sociotechnical system, Using Using SDM, FED, and ARIES principles.

## C.2. System Boundary

A novel aspect of this thesis is its lack of a physical technological product. Instead, the period of time and complex array of interdependent tasks and resources after construction and before operations are treated as a system. The dotted red line overlaid on Figure C.2 below denotes the System Boundary for this thesis.

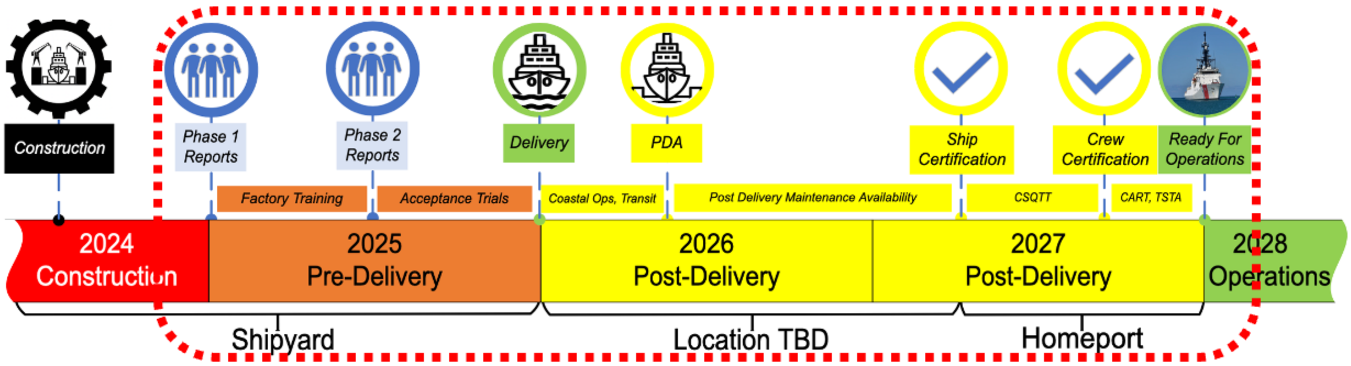



*Figure C.2. Reference Architecture and System Boundary*

## C.3. Performance Metrics

Four performance measures were selected for the system to assess its overall success.

1. Time to RFO: the amount of time between contract delivery and designation of cutter and crew as RFO. *Less time (lower score) is better.*
2. Cost to RFO: the organizational investment specific to each hull from delivery to RFO. Includes personnel costs, operational costs (transit, fuel, husbanding), logistics and maintenance costs. *Lower costs (lower score) is better.*
3. Quality at RFO: blended maintenance indicator of condition of ship at RFO from configuration (currency of configuration at system and sub-system level) and maintenance (queue of depot maintenance events i.e. years before first drydock). *Higher is better.*

4. People Impacts: qualitative assessment of operational crew utilization, job satisfaction, PERSTEMPO, and DAFHP. *Higher is better.*

The Flexible Engineering Design portion of this thesis generated probabilistic cost estimates associated with flexible crewing and maintenance strategies, the tradespace analysis employed a 1 through 10 scale to differentiate tensions and tradeoffs for potential alternative system architectures.

## *C.4. Architectural Decisions*

Chapter 3 laid the groundwork for architectural decisions (ADs) by defining and discussing them in a general context; this section will address their practical application and outcomes. The set of tasks, resources, and activities required to make a newly constructed Coast Guard cutter ready for operations is dynamic and complex. This key Systems Architecture methodology was selected because it excels in deconstructing and organizing a solution space that is vast and complex into a meaningful, coherent array of design choices that may be examined and analyzed (both quantitatively and qualitatively) from multiple perspectives.

The highly iterative process of crafting and honing a meaningful suite of ADs was informed by a variety of inputs. These included the process map itself, system needs, requirements, and performance metrics, stakeholder input, and ideation fueled by external insights and the author's personal experience. Special attention was given during ideation to generate innovative and novel options markedly distinct from the Coast Guard's current and historical approaches. Table C.1 (de Neufville & Scholtes, 2011)below presents the preliminary ADs and their associated options, comprising a total of 5,184 unique system configurations.  The table below summarizes the architectural decisions and associated design options that form the foundation of our modeling and analyses. These decisions were carefully constructed to enable a comprehensive representation of the feasible design space, collectively they represent 16,384 unique system architectures.

*Table C.1. Preliminary Architectural Decisions*

| Seq | Architectural Decision | Option A | Option B | Option C | Option D |
|---|---|---|---|---|---|
| 1 | Staffing Strategy | Fixed | Flexible | | |
| 2 | Crew Structure | 1-phase | 2-phase | 3-phase | |
| 3 | Staffing Timing | Pre-delivery | Delivery | Post-PDA | Homeport |
| 4 | PDA Strategy | Fixed | Flexible | | |
| 5 | PDA Location | Shipbuilder | Homeport | East / West COEs | CG Yard |
| 6 | PDA Scope | Program | Hull | Modular | |
| 7 | PDA Growth | No growth | Growth | High | |
| 8 | Crew Training | Concentrated | Distributed | | |
| 9 | PDS Labor | Organic | Commercial | Hybrid | |

Significant investment in constructing, de-constructing, and refining the framework of architectural decisions ensured that downstream modeling and tradespace analyses would represent a meaningful expression of feasible-but-meaningful system configurations, enabling decision-makers to balance innovation with execution. Sensitivity analysis gauged their impact on performance metrics, while connectivity analysis assessed the degree of coupling with other architectural decisions. Other interdependent elements of this thesis, particularly flexibility and uncertainty modeling and stakeholder analysis, provided information and insights that sharpened the decisions and their options.

Ultimately 3 decisions were eliminated entirely, either because they were meaningfully represented within other decision options or because the level of connectivity and/or sensitivity simply didn't warrant inclusion. The elements highlighted in red below in **Error! Reference source not found.** were removed, elements highlighted in yellow were significantly revised. The context for these adjustments is included within the table.

*Table C.2. Final Evolution of Architectural Decisions and Options*

| Seq | Architectural Decision | Option A | Option B | Option C | Option D | Notes |
|---|---|---|---|---|---|---|
| 1 | Staffing Strategy | Fixed | Flexible | | | |
| 2 | Crew Structure | 1-phase | 2-phase | 3-phase | | Eliminate 3-phase option. |
| 3 | Staffing Timing | Pre-delivery | Delivery | Post-PDA | Homeport | |
| 4 | PDA Strategy | Fixed | Flexible | | | Flexibility meaningfully reflected within PD location. |
| 5 | PDA Location | Shipbuilder | Homeport | East / West COEs | CG Yard | Make homeport the fixed AD, other 3 are inherently flexible. |
| 6 | PDA Scope | Program | Hull | Modular | | Options aren't mutually exclusive. |
| 7 | Crew Training | Concentrated | Distributed | *Flexible* | | Add a flexible option. |
| 8 | PDA Growth | No | Yes | | | Revised to orient as growth. |
| 9 | PDA Labor | Organic | Commercial | Hybrid | | Industrial labor meaningfully represented in PD location. |

The final set of Architectural Decisions and their corresponding options are presented below inTable C.3. This architectural construct is the product of many iterations, described below, and collectively represents 384 unique system concepts.

*Table C.3. Final Architectural Decisions*

| Architectural Decision | Option A | Option B | Option C | Option D |
|---|---|---|---|---|
| Staffing Strategy | Fixed | Flexible | | |
| Crew Structure | 1-phase | 2-phase | | |
| Staffing Timing | Pre-delivery | Delivery | Post-PDA | Homeport |
| PDA Location | Shipbuilder | Homeport | East / West COEs | CG Yard |
| Crew Training | Concentrated | Distributed | Flexible | |
| PDA Growth | No | Yes | | |

## C.4.1. Narrative Explanation of Final Architectural Decisions

### *C.4.1.1. Staffing Strategy*

Assigning a crew to a newly constructed cutter is an anomalous personnel activity in several ways: the timing is highly sensitive to external factors (shipbuilding), there are no incumbent crew members, and the geographic location members will report to is uncertain. This architectural decision examines the fundamental paradigm in approaching this complex task.

A. *Fixed*: a deterministic approach. Crews are commissioned and assigned on fixed timelines prescribed by programmatic baselines.

B. *Flexible*: a probabilistic approach. Crew commissioning events are flexible, tailored to the actual program status.

### C.4.1.2. Crew Structure

A crew may be comprised of as many as 150 Coast Guard members. A pre-commissioning crew for a newly constructed cutter may be assigned concurrently as one large activity, or de-constructed into smaller groups which are assigned at different points in time based on the nature of their roles and responsibilities. Either approach is sensitive to shipbuilding progress and commissioning requirements.

A. *1-Phase*: All crew members are assigned concurrently as one large activity.

B. *2-Phase*: crew is broken into two phases each of which is assigned at different times. The earlier phases is comprised of key leadership positions and technical positions with key roles early in the pre-commissioning process.

### C.4.1.3. Staffing Timing

This decision may sound similar to the “Staffing Strategy” decision however it is fundamentally distinct. Staffing Timing determines where, or at what stage in the PD process, is targeted for commissioning the crew. We can think of Staffing Strategy as the *means,* and Staffing Timing as the *end* or goal. Notably, multiple key system elements are embedded within this decision. The options are so tightly coupled that they have been consolidated into one AD, but these options govern the *timing*, the *geographic location*, and the *functional role* and responsibilities of the crew.

A. *Pre-Delivery*: cutter crew reports to the shipyard concurrent to the late stages of construction and contract delivery. Crew is responsible for some targeted pre-delivery activities.
B. *Delivery*: cutter crew reports to the shipyard upon completion of all shipbuilding contract requirements. Crew is not responsible for any pre-delivery activities.
C. *Post-PDA*: cutter crew is not commissioned until delivery and post-delivery activities are completed. This scenario is geographically uncoupled from the shipbuilder and the homeport.
D. *Homeport*: cutter crew reports to the ships eventual homeport where they receive a post-PDA ship and commence outfitting, grooming, training, and certification events. Notably there is a broad and diverse range of geographic homeports.

### *C.4.1.4. Post Delivery Availability (PDA) Location*

Multiple key system elements are embedded within this decision as well, and again the options are so tightly coupled that they have been consolidated into one AD. This decision represents the Coast Guard's PD maintenance strategy by selection a geographic location to complete PD activities. Notably, multiple key system elements are embedded within this decision. These options influence the scope of responsibilities between the shipbuilder and the Coast Guard, the maintenance strategy for PD maintenance (speaks to the Coast Guard's approach to managing technological complexity and obsolescence), the capabilities the Coast Guard desires or needs for this period, and the cutter's geographic location, for a significant period of time following construction.

A. *Shipbuilder*: the shipyard responsible for building and delivering the ship is also utilized for the tasks currently defined as industrial PD tasks. This option implies the primary industrial labor for this period is commercial.

B. *Homeport*: a commercial contract, or series of commercial contracts, are utilized to complete PD tasks in the vicinity of the cutter's homeport. Notably there is a broad and diverse range of geographic homeports. This option implies the primary industrial labor for this period is commercial.

C. *East and West Coast Centers of Excellence (CoE)*: a clustered approach balancing geographic diversity with institutional learning and economies of scale. Two centers of excellence are identified and developed to execute standardized PD availabilities: one on each coast. This option is compatible with both commercial and organic industrial labor approaches.

D. *Coast Guard Yard*: centralize PD industrial activities at the Coast Guard Yard. This option implies the primary industrial labor for this period is organic.

#### C.4.1.5. Crew Training

This option describes the Coast Guard's approach to completing the various training and certification events necessary during the PD-period, culminating in designation as Ready for Operations.

*A. Concentrated:* all training and certification events are programmed into one large and integrated event. This option implies a relatively fixed structured approach to this tasks across all ships within an acquisition program.

B. *Distributed*: training and certification events are programmed into a distributed suite of events. This option includes some flexibility but implies an underlying fixed structure of commonality across all ships within an acquisition program.

C. *Flexible*: training and certification requirements are established, maintained, and refined across all ships within an acquisition program, but the execution is tailored to suit each individual ship and crew's needs.

### *C.4.1.6. Post Delivery Availability (PDA) Growth*

This option distills a complex suite of maintenance and configuration-related equities into two simple decisions. Growth in this context speaks to the flexibility of the PD industrial activities scope of work.

A. *Yes*: the underlying structure is designed to accommodate significant growth in scope. This option implies a high degree of flexibility with tradeoffs in economies of scale and institutional learning.

B. *No*: the PD scope is approached via a long-term contract maintenance vehicle and project concept, which is not designed to optimize the evolution of scope via growth. This option implies low flexibility, but higher investment in economies of scale and institutional learning.

## *C.5. Flexibility and Uncertainty in Systems Architectural Decisions*

This thesis blends Flexible Engineering Design with Systems Design and Management strategies of Systems Architecture, Systems Engineering, and Project Management. The architectural decisions themselves are tremendously important to the overall analysis, as well as the synthesis of these different tools. Options were thoughtfully constructed to enable modeling and analysis insights with respect to value, costs, and tradeoffs associated with flexible options within the system. Table C.4 overlays flexibility markers onto the final architectural framework for this thesis.

*Table C.4. Flexibility Embedded in Architectural Decisions*

| Architectural Decision | Option A | Option B | Option C | Option D |
|---|---|---|---|---|
| Staffing Strategy | Fixed | Flexible | | |
| Crew Structure | 1-phase | 2-phase | | |
| Staffing Timing | Pre-delivery | Delivery | Post-PDA | Homeport |
| PDA Location | Shipbuilder | Homeport | East / West COEs | CG Yard |
| Crew Training | Concentrated | Distributed | Flexible | |
| PDA Growth | No | Yes | | |

*Implicit flexibility* in this application may be considered residual flexibility inherent to a decision that is not fundamentally intended to achieve flexibility. There are little to no costs associated with implicit flexibility. *Explicit flexibility* is deliberate, where flexibility itself is fundamental to the decision. Thoughtfully constructed flexibility typically offers significant cost savings and value generation. However, there is typically an investment required to achieve the flexibility.

## C.6. *Mapping Architectural Decisions to Outcomes*

Sensitivity to performance outcomes was one of the key factors assessed to develop and refine the architectural decisions. A forward pass (mapping architectural decisions to performance metrics) ensured each decision had a substantive impact on the system's key outcomes. A backwards pass (mapping performance metrics to architectural decisions) ensured that enough architectural decisions were represented to ensure all key outcomes were meaningfully represented within the tradespace. Figure C.3 provides a visual representation of the final results of this highly iterative process.

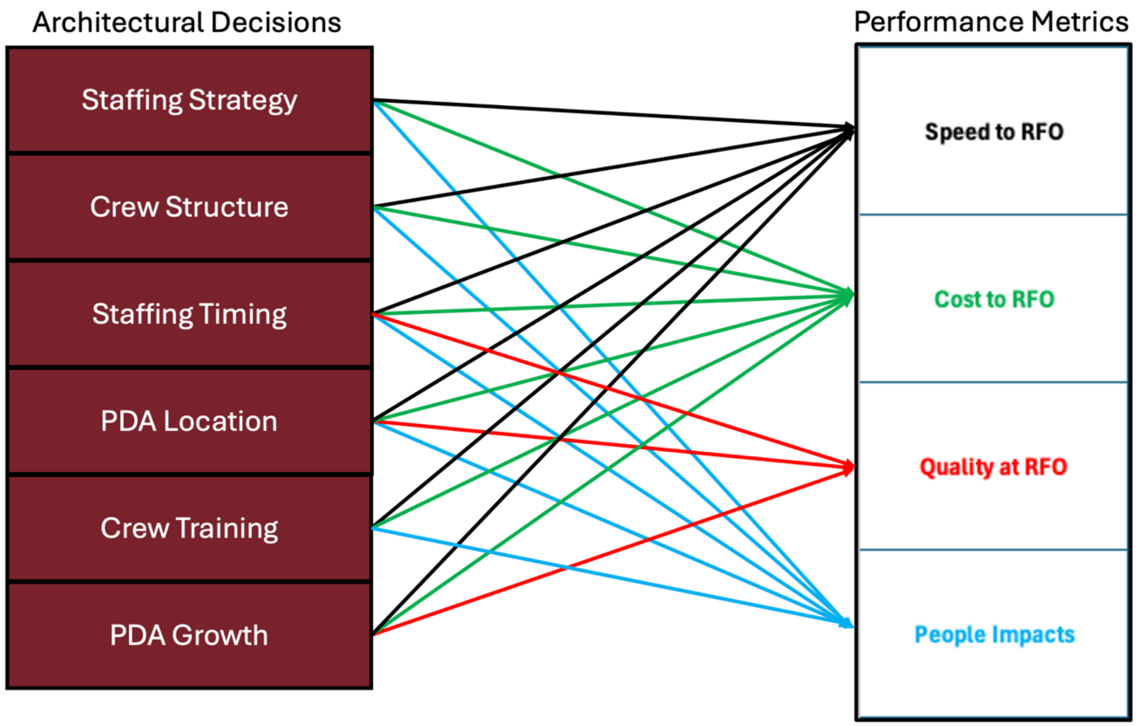



*Figure C.3. Mapping of Final Architectural Decisions to Performance Metrics*

## *C.7. Tradespace Model*

Armed with key performance metrics and a high-fidelity framework of architectural decisions and options, a model was generated to analyze performance tradeoffs of different system configurations. Preliminary model iterations attempted a bottom-up modeling approach to forecast actual days and dollars, however the complexity of the defined system, lack of reference data for the more innovative decision options, and scope of heterogeneous system attributes and performance elements drove the method to a utility-based approach. Appendix A presents the framework utilized to collect input from stakeholders and subject matter experts. Multi Attribute Tradespace.

Figure C.4 presents a tradespace plot with various system configurations delineated by color. Not the concentration of more flexible system architectures along the pareto front.

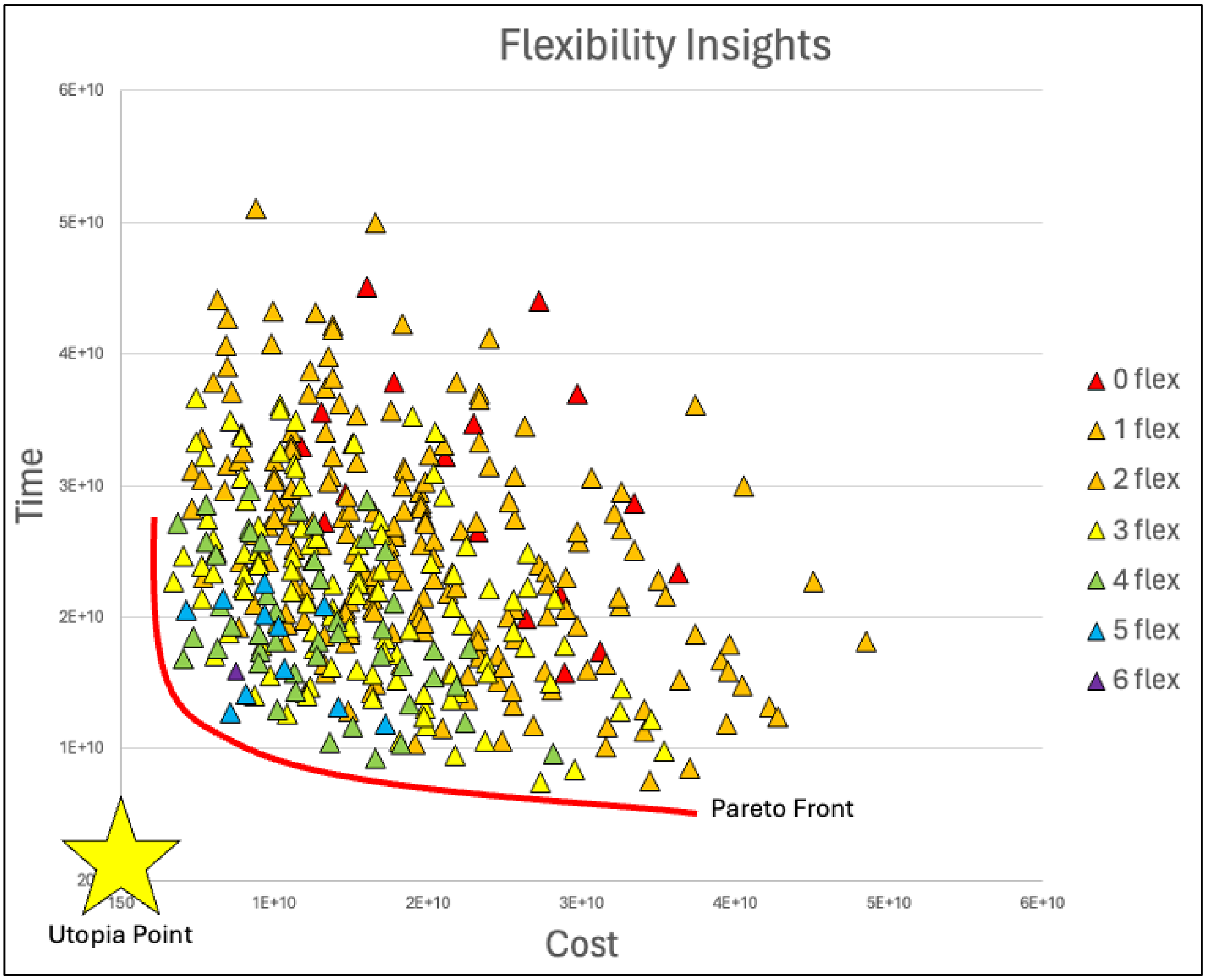



*Figure C.4. Flexibility Insights Tradespace and Pareto Front*

Figure C.5 maps the recommended system architecture, as defined by the set of architectural decisions employed, alongside the existing system architecture.

| Decision | Option A | Option B | Option C | Option D |
| --- | --- | --- | --- | --- |
| Staffing Approach | Fixed | Flexible | | |
| Crewing Target | Delivery | Post-PDA | Receive at HP | |
| Crew Structure | 2-phase | 3-phase | 1-phase | |
| PDA Location | Builder | Homeport | East / West COEs | Baltimore |
| PDA Scope (ships) | Program | Hull | Chunks | |
| PDA Fidelity (how much do you go after | Low | Medium | High | |
| PDA Award | Builder | Open / Homeport | Long Term Commercial | CG Yard |

Status Quo    Recommended

*Figure C.5. Recommended System Architecture*

# Appendix D. Stakeholder MATE Packet

Thesis Primer

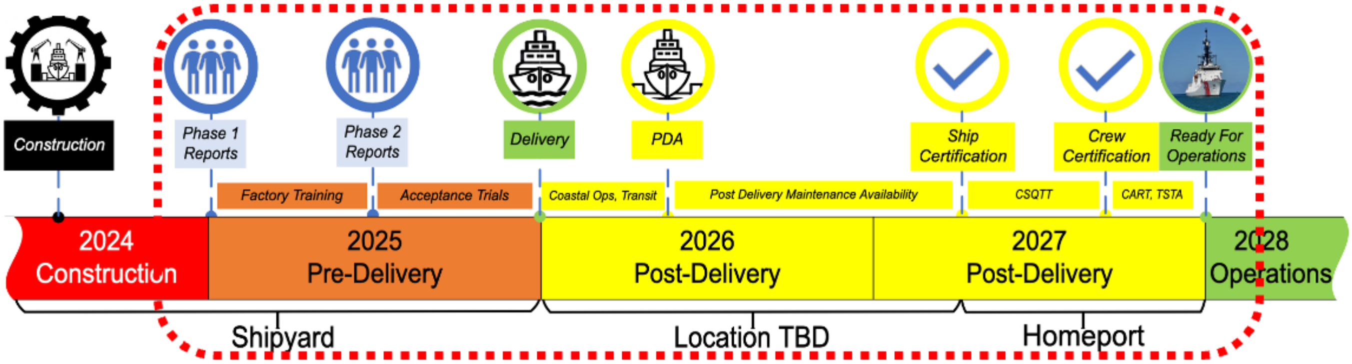
Jay Kime, U.S. Coast Guard Fellow, MIT-sdm

**Purpose:** this thesis is an academic exercise to apply and integrate knowledge from engineering, business, and systems coursework to address challenges of substantial complexity and significance. Ideal topics encompass issues where both technical expertise and management strategies are important and interdependent. My topic selection process was guided by the aspiration to orient my thesis work to create some knowledge, value, or application for the CG. Additional MIT System Design & Management (SDM) program info is here.

**Topic / Research Questions:** these questions will evolve over the course of this project:

1. How can the Coast Guard improve the transition of new cutters from construction to operations?
2. Are there fundamentally different architectures that could meet CG needs while improving outcomes?
3. Are there executable strategies and processes that are resource-neutral or provide resource savings?

**Scope:** the time and tasks between shipbuilder's delivery and unrestricted operations can be treated as a complex sociotechnical system, rich with complexity, diverse stakeholders with dynamic relationships and interdependent tasks, technology change management at the system, sub-system, and component levels, and heavy industrial activities. The red box below provides a simplified visual of this scope, this period often exceeds two years.




Success requires effective integration of multiple DCMS elements as well as operational commanders and crews.

**Methods:**

1. Flexible Eng Design
2. Uncertainty Analysis
3. SDM (Sys Architecture / Engineering, Proj Mgmt)
4. ARIES (S.A. Enterprises)

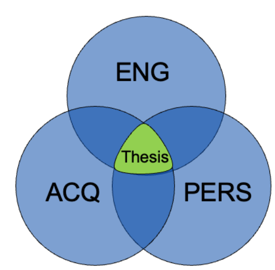
**Metrics:**

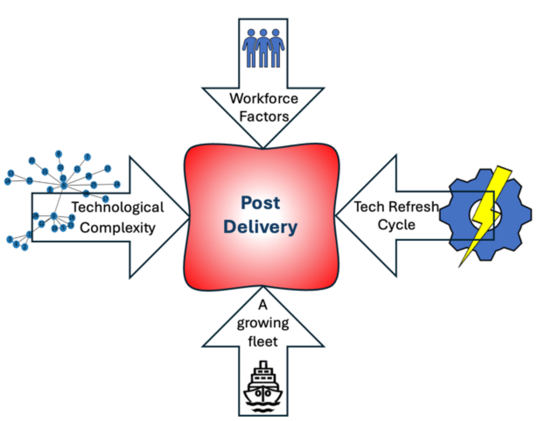
1. Cost
2. Speed to RFO
3. Quality at RFO
4. Personnel Satisfaction

**Focus Areas:**

1. Uncertainty and Flexibility
2. Personnel: timing and strategy of crew assignments
3. Engineering: tension between technology lifecycles & design re-cap/contract timeline

**Motivation:** my personal experience organizes into three buckets: engineering, acquisitions, and personnel management. This topic uniquely sits at the intersection of these three specialties. The confluence of four contemporary trends underscores the fundamental premise, *and value proposition,* of this thesis:




- Growing Fleet: CG is building many new ships
- People: significant CG workforce challenges, afloat of particular interest
- Technological complexity: product evolution, interdependence, & complexity all increasing exponentially
- Technology life/refresh cycles are getting shorter, and commercial product owners are more de-centralized. No master integrator.

Views expressed in this thesis are those of the author and do not reflect the official policy or position of the United States Coast Guard, the Department of Homeland Security, or the United States Government.

Stakeholder Input Scorecard
Designing Post Delivery for New Coast Guard Cutters

| Architectural Decision | Decision Narrative | Options | Option Narrative |
|---|---|---|---|
| Staffing Strategy | Assigning a crew to a newly constructed cutter is an anomalous personnel activity in several ways: the timing is highly sensitive to external factors (shipbuilding), there are no incumbent crew members, and the geographic location members will report to is uncertain. This architectural decision examines the fundamental paradigm in approaching this complex task. | Fixed | Deterministic approach. Crews are commissioned and assigned on fixed timelines prescribed by programmatic baselines. |
| | | Flexible | Probabilistic approach. Crew commissioning events are flexible, and tailored to the actual program status. |
| Crew Structure | A crew may be comprised of as many as 150 Coast Guard members. A pre-commissioning crew for a new cutter may be assigned concurrently as one large activity, or de-constructed into smaller groups assigned at different times based on the nature of their roles and responsibilities. | 1-phase | All crew members are assigned concurrently. One large activity. |
| | | 2-phase | crew is broken into two phases each of which is assigned at different times. The earlier phases is comprised of key leadership positions and technical positions with key roles early in the pre-commissioning process. |
| Staffing Timing | What stage in the Post Delivery process is targeted for crew commissioning. Notably, multiple key system elements are embedded within this decision: timing, geographic location, and the functional roles and responsibilities of the crew are meaningfully represented within these decision options. *Note this decision may sound famliar to the "Staffing Strategy" decision however it is fundamentally distinct. We can think of Stagging Strategy as the *means*, and Staffing Timing as the *end* or goal. | Pre-delivery | Crew reports to the shipyard concurrent to the late stages of construction and contract delivery. Crew is responsible for some targeted pre-delivery activities. |
| | | Delivery | Crew reports to shipyard upon contract delivery. Crew is not responsible for any pre-delivery activities. |
| | | Post-PDA | Crew reports after delivery and post-delivery activities are completed. This scenario is geographically uncoupled from the shipbuilder and the homeport. |
| | | Homeport | Crew reports to the ships eventual homeport where they receive a post-PDA ship and commence outfitting, grooming, training, and certification events. |
| PDA Location | This decision represents the Coast Guard's Post Delivery maintenance strategy by selection a geographic location to complete PD activities. Notably, multiple key system elements are embedded within this decision: the scope of responsibilities between the shipbuilder and CG, the PD maintenance strategy (speaks to the Coast Guard's approach to managing technological complexity and obsolescence), the capabilities the Coast Guard desires or needs for this period, and the cutter's geographic location, for a significant period of time following construction. | Shipbuilder | Shipyard responsible for building the ship is also utilized for tasks currently defined as industrial PD tasks. This option implies primary industrial labor for PD is commercial. |
| | | Homeport | Commercial contract(s) are utilized to complete PD tasks in vicinity of the cutter's homeport. Notably there is a broad and diverse range of geographic homeports. This option implies the primary industrial labor for this period is commercial. |
| | | East / West COEs | Clustered approach balancing geographic diversity with institutional learning and economies of scale. Two centers of excellence are identified and developed to execute standardized PD availabilities: one on each coast. This option is compatible with both commercial and organic industrial labor approaches. |
| | | CG Yard | Centralize PD industrial activities at the CG Yard. This option implies the primary industrial labor for this period is organic. |
| Crew Training | This option describes the Coast Guard's approach to completing the various training and certification events necessary during the PD-period, culminating in designation as Ready for Operations. | Concentrated | Training and certification events are programmed into one large integrated event. This option implies a relatively fixed structured approach to this tasks across all ships within an acquisition program. |
| | | Distributed | Training and certification events are programmed into a distributed suite of events. This option includes some flexibility but implies an underlying fixed structure of commonality across all ships within an acquisition program. |
| | | Flexible | Training and certification requirements are established, maintained, and refined across all ships within an acquisition program, but the execution is tailored to suit each individual ship and crew's needs. |
| PDA Growth | This option distills a complex suite of maintenance and configuration-related equities into two simple decisions. Growth in this context speaks to the flexibility of the PD industrial activities scope of work. | No | PD scope is approached via long term contract maintenance vehicle and project concept, which offers minimal flexibility. This option implies low flexibility, but higher investment in economies of scale and institutional learning. |
| | | Yes | Underlying structure is designed to accommodate significant growth in scope. This option implies a high degree of flexibility with tradeoffs in economies of scale and institutional learning. |

**Scoring:** assess each architectural decision option for its performance with respect to four key performance metrics. A scale of 1 through 10 will be used. Note the absolute scores are less important than the relative differentiation. Performance metric definitions and scoring conventions are provided.

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Stakeholder Input Scorecard

Designing Post Delivery for New Coast Guard Cutters

- Time to RFO: the amount of time between contract delivery and designation of cutter and crew as RFO. *Less time (lower score) is better.*
- Cost to RFO: the organizational investment specific to each hull from delivery to RFO. Includes personnel costs, operational costs (transit, fuel, husbanding), logistics and maintenance costs. *Lower costs (lower score) is better.*
- Quality at RFO: blended maintenance indicator of condition of ship at RFO from configuration (currency of configuration at system and sub-system level) and maintenance (queue of depot maintenance events i.e. years before first drydock). *Higher is better.*
- People Impacts: qualitative assessment of operational crew utilization, job satisfaction, PERSTEMPO, and DAFHP. *Higher is better.*

| Architectural Decision | Options | Time to RFO | Cost to RFO | Quality at RFO | People Impacts | Notes & Insights |
|---|---|---|---|---|---|---|
| | | 1 Lower is Better 10 | | 1 Higher is Better 10 | | |
| Staffing Strategy | Fixed | | | | | |
| | Flexible | | | | | |
| Crew Structure | 1-phase | | | | | |
| | 2-phase | | | | | |
| Staffing Timing | Pre-delivery | | | | | |
| | Delivery | | | | | |
| | Post-PDA | | | | | |
| | Homeport | | | | | |
| PDA Location | Shipbuilder | | | | | |
| | Homeport | | | | | |
| | East / West COEs | | | | | |
| | CG Yard | | | | | |
| Crew Training | Concentrated | | | | | |
| | Distributed | | | | | |
| | Flexible | | | | | |
| PDA Growth | No | | | | | |
| | Yes | | | | | |

Views expressed in this thesis are those of the author and do not reflect the official policy or position of the United States Coast Guard, the Department of Homeland Security, or the United States Government.