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A QUALITATIVE STUDY OF AFFORDABILITY: VIRGINIA AND SAN ANTONIO CLASS PROGRAMS

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June 2014

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13. ABSTRACT (maximum 200 words)

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This study compares the Virginia-class submarine and San Antonio-class ship across platforms and across time in order to find those factors that appear to affect cost. This study isolates those key metrics and relationships that demonstrate an apparently significant impact on affordability. The purpose of this study is to find the programmatic decisions, environmental circumstances or managerial tools that benefit or jeopardize affordability in a consistent manner, and recommend further study in those areas most likely to promote the development of better practices for affordability throughout a program's life cycle.

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LIST OF ACRONYMS AND ABBREVIATIONS

3D	three-dimensional
ADM	acquisition decision memorandum
AEC	average end cost
ACWP	actual cost of work performed
ALRE	aircraft launch and recovery equipment
AOA	analysis of alternatives
APB	acquisition program baseline
APUC	average procurement unit cost
ASN(RDA)	Assistant Secretary of the Navy for Research, Development, and Acquisition
ASPA	armed service procurement act
BA	budget authority
BAH	Booz Allen Hamilton
BCWP	budgeted cost for work performed
BCWS	budgeted cost for work scheduled
BY	base year
C4I	command, control, communication, computers, and intelligence
CAC	civilian access card
CAD	computer-aided design
CAE	component acquisition executive
CAIG	cost analysis improvement group
CAPE	cost assessment and program evaluation
CARD	cost analysis requirements description
CBO	congressional budget office
CCB	change control board
CE	current estimate
CG	guided missile cruiser
CJCS	Chairman of the Joint Chiefs of Staff
CLIN	contract line item number
CNO	Chief of Naval Operations

COC	chain of command
COTS	commercial off-the-shelf
CPARS	contractor performance assessment reporting system
CPI	consumer price index
CPI	cost performance index
CPIF	cost-plus-incentive fee
CPT	cross-product team
CREI	cost reduction effectiveness improvement
CRS	congressional research service
CY	current year
DAES	defense acquisition executive summary
DAG	*Defense Acquisition Guidebook*
DAMIR	defense acquisition management information retrieval
DAR	Defense Acquisition Regulation
DARPA	Defense Advanced Research Projects Agency
DAS	defense acquisition system
DAWIA	Defense Acquisition Workforce Improvement Act
DCAPE	Director of the CAPE
DDG	guided missile destroyer
DECKPLATE	decision knowledge programming for logistics analysis and technical evaluation
DIB	defense industrial base
DOD	Department of Defense
DPA	Defense Production Act
EB	Electric Boat
EMD	engineering and manufacturing development
FOC	full operation capability
EVMS	earned value management system
FAR	Federal Acquisition Regulations
FOUO	for official use only
FPIF	fixed price incentive fee
FY	fiscal year

GAO	Government Accountability Office
GDEB	General Dynamics–Electric Boat
GDP	gross domestic product
GE	General Electric
GFE	government-furnished equipment
GPM	gallons per minute
HM&E	hull, mechanical and electrical
ICD	initial capabilities document
IDA	Institute for Defense Analyses
IDAM	Introduction to Defense Acquisition Management
IMS	integrated master schedule
INSURV	Board of Inspection and Survey
IPDE	integrated product data environment
IPPD	integrated product and process development
IPT	integrated product team
ISET	integrated ships electronic team
JCIDS	joint capabilities integration and development system
JIC	joint inflation calculator
JROC	Joint Requirements Oversight Council
KO	contracting officer
KPP	key performance parameter
KSA	key system attributes
LPD	Amphibious (L) Transport (P) Dock (D)
LPD-17	San Antonio-Class (Ship)
LRIP	low rate initial production
MAT	major area team
MDA	milestone decision authority
MDAP	Major Defense Acquisition Program
MILCON	Military Construction
MILPERS	Military Personnel
MILSPECS	Military Specifications and Standards
MIRWS	master integrated work schedule

MTBF	mean time between failures
NAS	new attack submarine
NAVSEA	Naval Sea Systems Command
NDA	National Defense Act
NDI	non-developmental item
NGSS	Northrop Grumman Ship Systems
NNSB	Newport News Shipbuilding
NPV	net present value
NSLC	Navy Sea Logistics Command
NSS	National Security Strategy
O&M	operations and maintenance
O&S	operations and support (O&M plus MILPERS)
OSD	Office of the Secretary of Defense
OUSD	Office of the Under Secretary of Defense
PAUC	program acquisition unit cost
PD	production and deployment
PEO	Program Executive Officer
PM	Program Manager
PMBOK	*Program Management Book of Knowledge*
PMO	program memorandum objective
PMS 317	Program Management Ships: San Antonio-Class (LPD-17)
PMS 450	Program Management Submarines: Virginia-Class (SSN-774)
PMT	program management team
PPBE	planning, programming, budgeting, and execution
R&M	reliability and maintainability
RDT&E	research, development, test, and evaluation
RTOC	reduced total ownership cost
SAR	Selected Acquisition Report
SDV	swimmer delivery vehicle
SECNAV	Secretary of the Navy
SOF	special operations force
SOS	system of systems

SPI	schedule performance index
SSBN	ballistic missiles submarines
SSGN	cruise missile and special operations forces insertion submarines
SSN	submarine (SS) nuclear power (N)
SSN-774	Virginia-Class (Submarine)
SUPSHIP	Supervisor of Shipbuilding, Conversion, & Repair
T-AKE	Auxiliary Cargo (K) and Ammunition (E) Ship
TD	technology development
TOC	total ownership cost
TY	then-year
UCR	unit cost report
U.S.C.	united states code
USG	united states government
USD(AT&L)	Under Secretary of Defense for Acquisition, Technology, and Logistics
VAMOSC	Visibility and Management of Operating and Support Costs
WSARA	Weapon Systems Acquisition Reform Act

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I. INTRODUCTION

The Virginia-class submarine program and the San Antonio-class amphibious transport dock ship program both began within a year of each other, and both were considered pilot programs for various Department of Defense (DOD) acquisition reform initiatives. Both vessels were conceived and designed in a post–Cold War environment that has faced increasing degrees of fiscal constraint. The U.S. Navy's nuclear-powered Virginia-class submarine displaces 7,900 tons of water, about one-third the displacement of the non-nuclear San Antonio-class ship (25,000 tons). Though differing in many key factors, such as displacement, mission set, capabilities, modularity, and more, these two vessels share surprisingly similar narratives.

The Virginia-class and San Antonio-class efforts to reduce total ownership costs (RTOC) have become models for future programs. This study explores the effort in depth to answer several questions, including the following:

- Can Virginia-class submarines be validly compared with San Antonio-class ships?
- What does affordability mean for the Virginia-class submarine and the San Antonio-class ship programs?
- How should factors affecting affordability be categorized for these programs?
- What common and/or disparate mix of enablers and decisions drives affordability?
- How is affordability measured?
- How much more or less affordable does a program need to be to merit future study?

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II. BACKGROUND AND LITERATURE REVIEW

As the DOD has acquired and operated increasingly more technologically advanced and complex ships and submarines, costs for new vessels have tended to grow. During the past few decades, the DOD has established and implemented numerous acquisition reform initiatives intended to increase affordability in the acquisition and the sustainment of DOD weapon systems. Notably, the current costs for Virginia-class submarines are less than costs for their predecessor vessels (Los Angeles-class and Seawolf-class), and the current sustainment costs for San Antonio-class amphibious transports appear to be equivalent to their predecessor vessels (Austin-class). The unique mix of enabling circumstances and methodologies encountered and employed by the Virginia-class and San Antonio-class programs contributed to the programmatic decisions that ultimately led to the resultant costs of these two major defense acquisition programs (MDAPs). A review of the narratives of the Virginia-class and San Antonio-class programs in conjunction with a basic understanding of the U.S. DOD acquisition system facilitates the investigation of interactions between programmatic enablers and decisions, and their resultant costs.

A. U.S. DEFENSE ACQUISITION FAMILIARIZATION

This section familiarizes the reader with a basic knowledge of DOD acquisition, with the many stakeholders, processes, and concepts that affect the MDAPs examined in this study. These descriptions are neither exhaustive nor absolute in their depiction of the DOD acquisition environment. They provide an introductory vocabulary and framework, which enables the reader to more thoroughly perceive the functional and conceptual relationships within the U.S. defense acquisition domain.

1. Purpose

U.S. defense acquisition provides the equipment and services necessary to establish and sustain DOD missions (Rendon & Snider, 2008).

2. Origins: A Gradual Evolutionary History

Neither academia nor organizational leaders within the DOD have pinpointed a formal or specific date of inception for U.S. defense acquisition. Although the United States has requisitioned various goods and services since the formation of the First Continental Congress (Schwartz, 2010a), the modern and complex system through which the DOD acquires its various weapons systems arose from a number of influential events spanning more than a century.

The most noteworthy turning point for U.S. defense acquisition occurred during World War II, when more than one third of U.S. gross domestic product (GDP) was dedicated to the war (Levit, 2010; Office of Management and Budget, 2011). To empower American soldiers and sailors to compete on the battlefield, a new degree of weapons systems and acquisition complexity was required. This was especially true in the growing fields of aviation, submarine, and nuclear warfare. During this period in America, the military was required to significantly increase the level of sophistication of its planning, design, purchase, and control of defense acquisitions. WWII demonstrated to all major U.S. stakeholders that advantages on the battlefield depended on more advanced weapons and more advanced acquisition systems (Hooke, 2005).

In the years between WWII and the Korean War, leaders within U.S. business and industry, as well as leaders within the U.S. government (USG), recognized the need for a significant transformation in how the United States developed and acquired new weapons systems (Brown, 2005). Those organizations whose production drove the American war effort during WWII positioned themselves, over the following decades, to ensure that both they and the U.S. warfighter would retain the advantages they established during WWII (Converse, 2005).

The first and most significant of these changes were the Armed Services Procurement Regulations, called the ASPR, and the National Defense Act (NDA), which consolidated diverse service-specific rules and regulations that had governed military procurement since the Civil War (Converse, 2005). One year later, in 1948, the Defense Production Act (DPA) was created, which continues to define key aspects of the Defense

Industrial Base (DIB). As these laws were codified within Title 10 and Title 50 of the United States Code (U.S.C.), the regulations governing U.S. defense acquisition continue to expand. In 1978, after decades of growth and adaptation, the ASPA evolved into the Defense Acquisition Regulation (DAR), and less than a decade later it was transformed again.

Almost 40 years after WWII, in 1984, Congress formalized and published the version of acquisition regulation currently in use, the Federal Acquisition Regulation (FAR). These rules for managing the purchase of DOD weapons systems comprise Title 48 of the United States Code (U.S.C.) of Federal Regulations. They are an extension of Title 41, which outlines the laws governing contracts between the USG and the public. It is ultimately these statutory laws that govern the scope and nature of the ever-evolving DOD acquisition environment.

Even in recent years, this evolutionary legislation continues to alter the DOD acquisition process in significant ways. From the Defense Acquisition Workforce Improvement Act (DAWIA) of 1990 to the Weapon Systems Acquisition Reform Act (WSARA) of 2009, these incremental changes continue to transform, and often complicate, weapon systems acquisitions.

Modern U.S. defense acquisition differs significantly from prior decades. The U.S. defense acquisition system slowly evolves via a process of punctuated equilibrium states, undergoing continuous cycles of innovation and reform, much of it driven from within the DOD, but sometimes helped along by Congress, as evidenced in the preceding paragraphs.

3. Functional Roles

In general, the traditional functions of a commercial business can also be found within DOD acquisition organizations. Unlike traditional separations of an organization into departments, which support specific business functions or divisions, the DOD acquisition environment relies on organizational structures and authority chains often separated by both division and function. Additionally, because authority and responsibility are divided among the various organizations in a manner that separates power and compels the sharing of information and oversight, a significant degree of complexity and bureaucracy can impact DOD acquisition.

A simple example of organizational complexity in DOD acquisition can be seen in the way manpower is sourced. The billet, called a *manpower requirement*, of the program manager (PM) for an MDAP can derive from an organization separate from and unrelated to the organization overseeing the MDAP. The PM is paid for and professionally evaluated by one organization and administratively used by another. In cases of potential conflict, leaders depend on formal policy to provide resolutions. Thus, the many DOD acquisition policies, as well as the various influencers (e.g., process and technical information experts) and decision-makers, can significantly affect activities.

4. "Big A" Acquisition

The various organizations and the integrated workforce of the DOD acquisition environment, though structurally separated, are interconnected through flexible relationships in order to operate as a single entity. The many experts each serve in numerous capacities and subtly complex roles across this macro-domain, often called the "Big A" acquisition process. Within this system-of-systems (SOS) level of interactions (Schwartz, 2010a), these experts must continually navigate potentially conflicting interests with regard to the formal and informal authority and reporting hierarchies (refer to Figure 1).

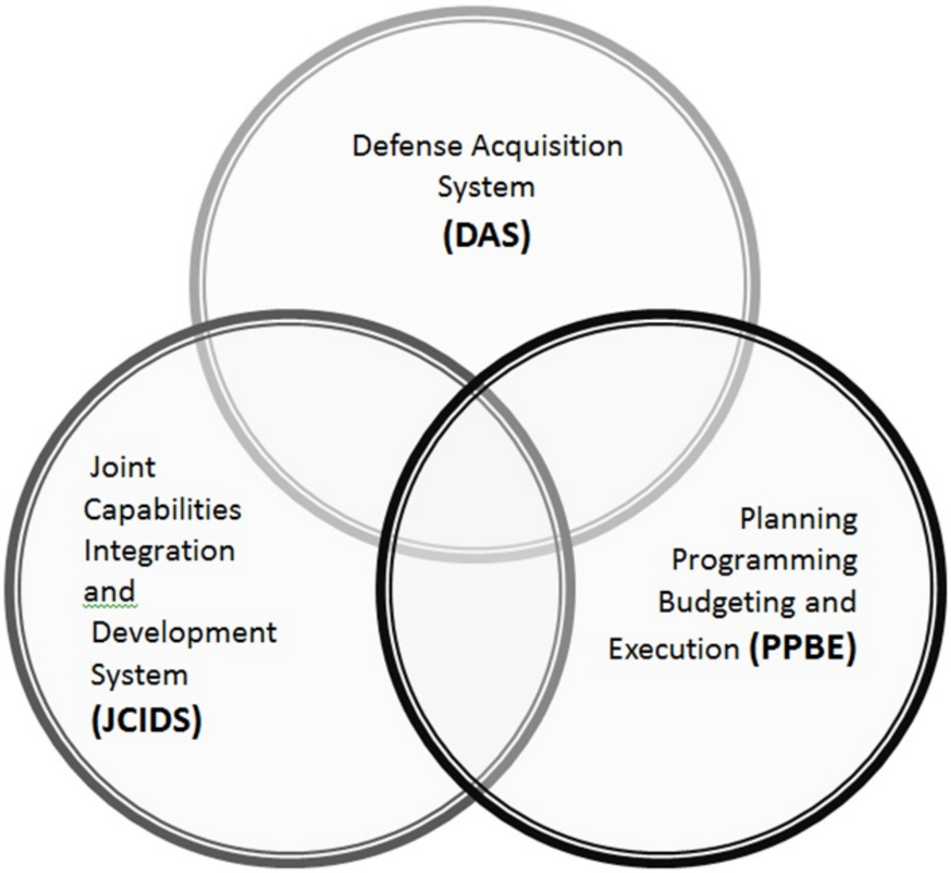


Figure 1. DOD Acquisition Environment Functional Areas

Personnel within the Defense Acquisition System (DAS) generally provide the project management services for each acquisition program. Their efforts include planning, research, design, development, inter-organizational synchronization, budget control, historical and forecast reporting, innovation, and production. The DAS operates continuously, while in a segmented manner, with personnel serving multiple needs as required. It is a very fluid environment, under a vigorous bureaucracy. Acquisition programs, managed from within the DAS, are event-driven but depend on funding, which is calendar-driven (Jones & McCaffery, 2005).

The outputs of the Joint Capabilities Integration and Development System (JCIDS) process provide information and advice to the Chairman of the Joint Chiefs of Staff (CJCS) and the Joint Requirements Oversight Council (JROC), as well as facilitate the evolution of doctrine, organization, training, materiel, leadership and education, personnel, facilities, and policy (DOTMLPF-P; CJCS, 2012). In a significant sense, this process bridges the gap between the U.S. National Security Strategy (NSS) and the procedural and physical advancement of warfighter capabilities, which are necessary to accomplish the objectives of the NSS. The JCIDS process operates on an as-needed or where-needed basis, identifying, validating, and prioritizing required capabilities. Once approval is given for the development of a program, the capability requirements are rarely revisited during the development cycle unless there is a significant program breach (that is, a major increase in cost or schedule) or a major revision to warfighting strategy.

The planning, programming, budgeting, and execution (PPBE) process acts as a means of managing programs and budgets in a continuous manner across the current year and future years, and as designated within the various and separate funding lines. These funding lines are often called *colors-of-money* and have specific legally defined boundaries. The year-by-year legalities of DOD acquisition funding and the dual scrutiny this process receives from the executive and legislative branches of the USG constrain and complicate it, especially when compared with analogous processes within the commercial sector. The calendar drives the PPBE process and sets the pace for the reporting process and the numerous information exchanges (Jones & McCaffery, 2005).

5. Managerial Stakeholders

When seeking to comprehend a large and/or complex system, it can help to recognize its key influencers. Since 2003, four groups of experts directly influence the ongoing management and development of DOD acquisitions (see Figure 2). These experts derive from three primary sources: the JROC, the DOD acquisition workforce (to include senior Office of Secretary of Defense [OSD] and military service branch leadership and subject matter experts), and U.S. business and industry. Although the White House, Congress, and other agencies have significant influence, they rarely become involved in the day-to-day management and development of weapons systems. Even the JROC depends primarily on the pre-acquisition phase and milestone decision meetings in order to exert its full authority.

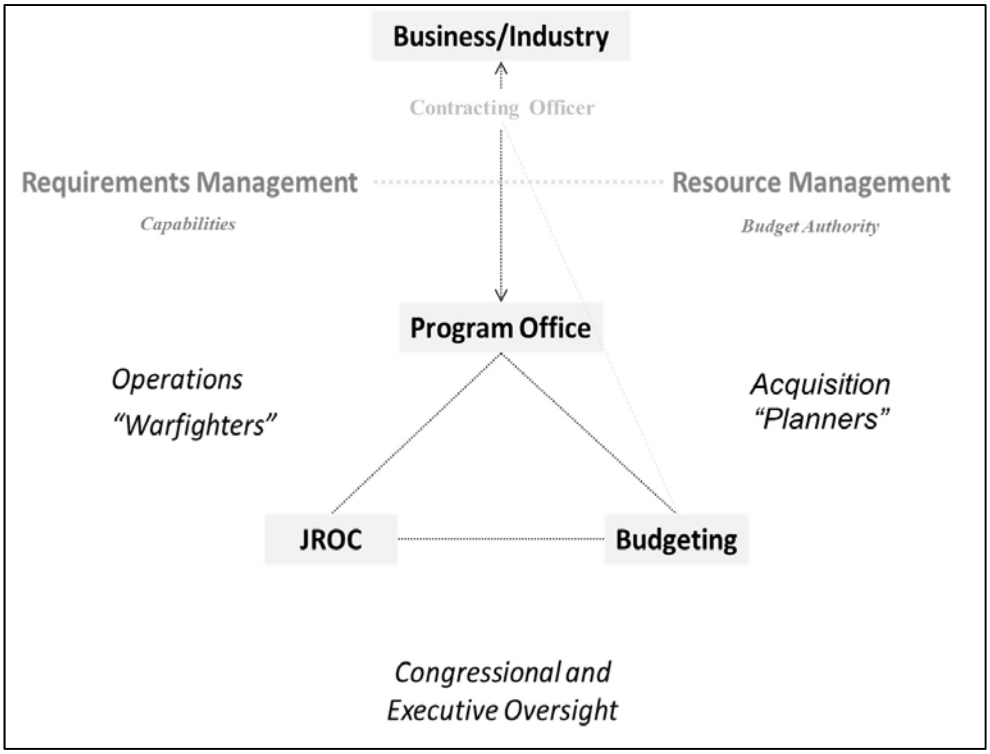


Figure 2. Acquisition Program Basic Stakeholders

The JROC is composed of the vice chairman of the Joint Chiefs of Staff (JCS) and the vice chiefs of staff from the military branches, and is supported by the JCS staff. These senior leaders consider current military assets and operations and compare those capabilities and missions to the ever-changing required capabilities, which collectively define the NSS. The JROC and its supporting staff organizations collectively facilitate and approve those capabilities that will empower U.S. warfighters to accomplish the NSS (CJCS, 2012).

The JROC not only grants the authorization to develop materiel solutions (concepts), which leads to the creation of an acquisition program, but they establish the metrics of performance for weapon systems and their approval of the initial capabilities documents (ICDs). Jointly, these JROC approvals and disapprovals of the various ICDs they receive from sponsors (a specific operational command-group within a military branch; see Figure 3) determine how all DOD capabilities are spread and integrated across a broad range of weapons systems. After the approval of the ICD, the JROC depends on the service's sponsor (or user representative) and the PM to ensure the programs are developed and executed appropriately. The ongoing oversight provided by the sponsor and milestone decision authority (MDA) and the Stakeholder Requirements Definition documents generally serve the JROC's interests where capabilities are concerned, bridging the gap between the DAS and JCIDS environments (DOD, 2013).

Each program office contains civilian and military acquisition professionals drawn together for the MDAP from a broad resource pool. The team is selected based on factors such as experience, education and training, and availability. Each individual chosen for a designated role within the program office team is typically matched to his or her specialty area (e.g., engineering, financial management, logistics). In a loose way, these processes are analogous to the commercial sector's processes for project management as described in the *Project Management Body of Knowledge* (*PMBOK*) (DAU Press, 2008; PMI, 2000).

Program managers in the Navy generally report to the assistant secretary of their branch of service through a program executive office (PEO) whose personnel oversee multiple weapons systems of similar category (see Figure 3). Large, expensive programs are often overseen by the Under Secretary of Defense for Acquisition, Logistics, and Technology (USD[AT&L]), who in this role is called the defense acquisition executive (DAE). The program manager is the most vital position for synchronizing information and decision-making for its designated weapons system.

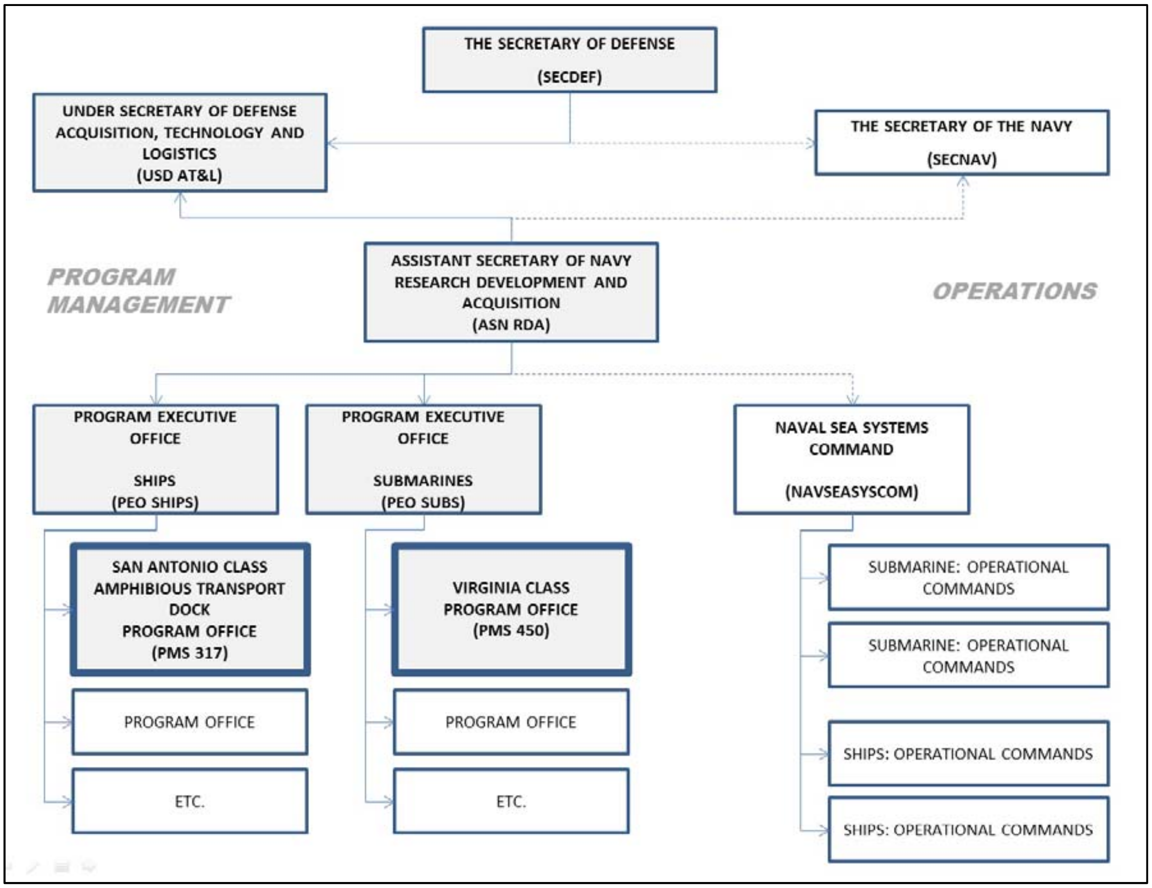


Figure 3. Program Office Command Hierarchy

Contractors, both in the early competitive process and after they are selected, have a significant direct and indirect influence on the DOD acquisition environment and on the specific weapons systems they develop, produce, and sustain. Once the contractor has been selected, the USG and the contractor become highly dependent on each other. The cost of midstream change is substantial.

The formal and informal relationships and interactions can be both complex and nuanced. For example, although only the warranted procuring contracting officer (PCO) is legally capable of authorizing outlays to the contractor, the other leaders and experts within the program office can positively and negatively affect the contractor in areas as simple as determinations of compliance. Furthermore, the specialized, long-term, and often highly competitive nature of DOD acquisition ensures higher degrees of collaboration than would be strictly anticipated based on the legal definitions of USG and contractor relationships. The degree of and timing of contractor integration into the DOD acquisition value chain affects effectiveness and efficiency of planning and design for every MDAP. In this respect, the contractor must work closely with the USG program management offices.

Congress alone holds the power of the purse. The Senate Armed Services Committee and the House Armed Services Committee authorize funds, set limits, and provide legislative oversight for DOD acquisition programs. The Senate and House Appropriations Committees provide additional oversight and specifically appropriate funds for DOD acquisition programs (DAU Press, 2008). The yearly budget authority (BA) authorized by Congress ensures that DOD weapons systems can be acquired and sustained. Updated changes to cost across the various colors-of-money appear in the program objective memorandum (POM), for which the program office submits input to their service headquarters for established funding periods.

Although congressional programming and budgeting affects every aspect of defense acquisitions, this study focuses on program management–level decisions and policies. Much of the budgetary system is addressed only briefly. Only the most critical interactions between Congress and these programs are addressed.

6. The Program Life Cycle

During the past three decades, a number of segmentations and terms for each phase of an MDAP life cycle have been used in the DOD acquisition environment. Figure 4, found at the end of this section, provides the detailed life cycle typically used by DOD acquisition professionals. For simplicity, when depicting the critical events of the DOD acquisition life cycle, this study generalizes the elements provided in the textbook by Rene G. Rendon and Keith F. Snider's *Management of Defense Acquisition Projects* (2008; see Figure 5).

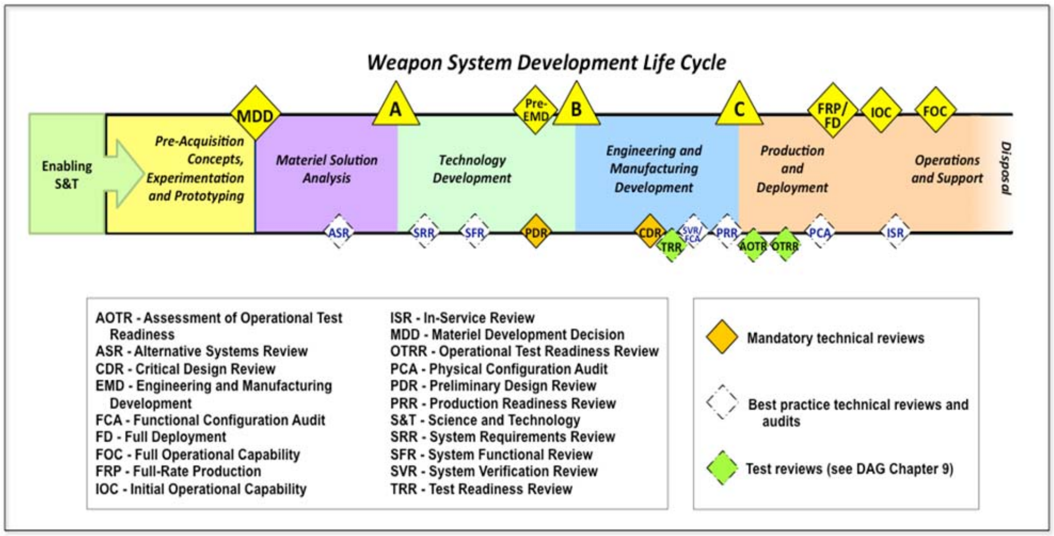


Figure 4. Formal Program Life Cycle (from DOD, 2013)

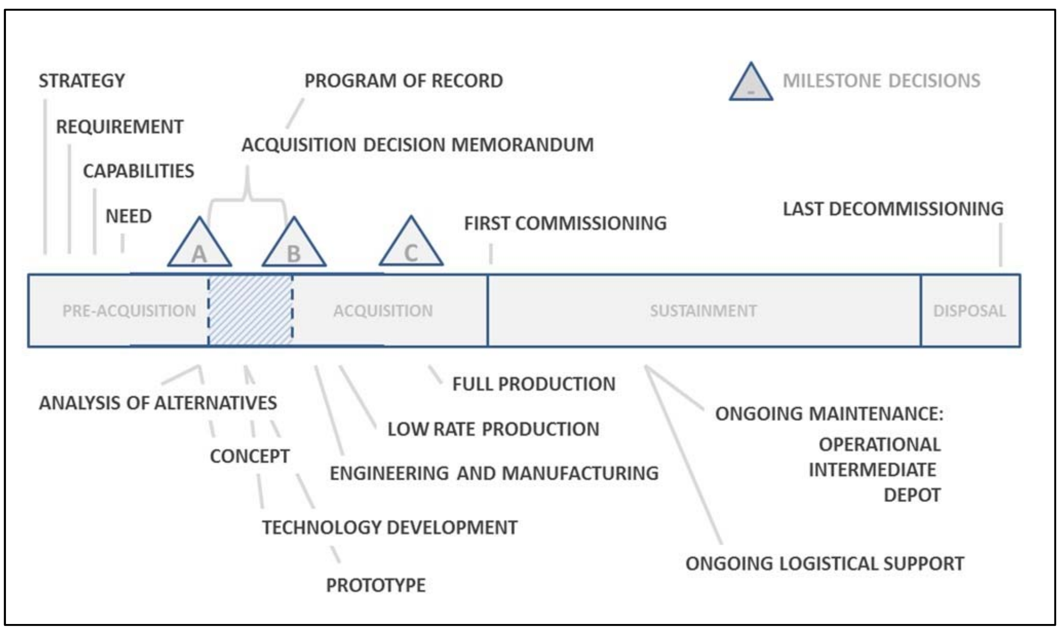


Figure 5. Elementary Conceptual Program Life Cycle

a. Pre-Acquisition Phases

The JROC notes strategic requirements as extracted from the National Military Strategy documents and oversees the task by which they are transformed into specific *mission capabilities.* The emerging mission portfolios (capabilities), such as the development of a naval vessel, which can operate in the littoral space and major river-ways, are then developed into exact *capability metrics* (e.g., operate in shallow 10-fathom waters, operate safely in sea states of 20-foot swells, and operate 60 days without resupply). This capabilities list then becomes a declared *need*.

This need goes through an analysis of alternatives (AOA) process, which examines the value of each *concept*, similar in the commercial sector to selecting which commercial projects should be initiated based on calculations of net present value (NPV). Sometimes the need can be met by procedural or policy changes, but other times the need should be met by a materiel concept. When the JROC validates the need, it starts the process that leads to the establishment of a DOD acquisition program.

The formal approval of the materiel concept begins with the Materiel Development Decision initiating the Materiel Solution Analysis (MSA) Phase. During MSA, an AOA is conducted, resulting in approval of a *materiel solution* at Milestone A. At this point, the life cycle crosses into the technology development (TD) phase, which is composed of the early developmental work to mature technologies needed for the weapons system and to agree on the preliminary design of the weapon system. As a program moves through its life cycle, these early stages tend to impact it in increasingly substantial and often unanticipated ways. Planning and design, even in the earliest segments of the pre-acquisition period, are the foundation on which every DOD acquisition program is established. Any weaknesses in planning or design are likely to result in higher costs over the life cycle of the weapon system.

The initial TD phase is often synonymous with the research, development, test, and evaluation (RDT&E) phase. Regardless of the terminology, this period in an emerging program's life cycle is centered on designs, prototypes, and testing. This phase solidifies concepts into physical systems (i.e. prototypes) that perform to exact capability metrics, called key performance parameters (KPPs; "Key Performance," 2013) and key system attributes (KSAs; "Key System," 2013).

All throughout the TD phase, competing contractors demonstrate what their materiel solution does; specifically, they prove whether their proposed weapons system will likely meet the target KPPs and KSAs in a more efficient and/or effective manner. When the best prototype design and corresponding contractor are determined, the milestone decision authority (MDA) decides whether the emerging development will move forward. Milestone B is generally the latest point at which a materiel solution is declared a program of record (see Figures 4 and 5). In the development of a ship, the decision as to whether a program enters the acquisition phase earlier than Milestone B depends on numerous design and planning factors. The document that formalizes this decision is the Acquisition Decision Memorandum (ADM). The TD phase can take several years depending on the weapon systems and incorporated technologies.

b. Acquisition Phases

The engineering and manufacturing development (EMD) phase begins when a weapons system passes Milestone B ("Milestone B," 2012). After the JROC agents and MDA have approved the weapons system as a program of record, the program office and the selected contractor begin to engineer the systems and processes required to build and maintain the weapons system. The physical prototype and its engineering, manufacturing, maintenance, and logistics systems all undergo significant developmental processes in order to ensure that both production and sustainment can be dependably accomplished within projected timelines and costs levels.

The EMD phase completes at Milestone C as the production and deployment (PD) phase begins ("Milestone C," 2012). The PD phase has a dual focus of thoroughly improving weapons system production and implementing support (logistics) systems for the sustainment period, also called the operations and support (O&S) period.

For ships and submarines, these three phases of the acquisition period overlap and blend significantly due to the long-term nature of ship construction schedules. This blending is further complicated by the fact that the lead ship and lead submarine are considered "Block 1" vessels, which will be deployed operationally without the prototyping process typical of many other weapon systems. Only after a final evaluation, called the initial operational capability (IOC) review, will the first Block 1 ship or submarine be commissioned and then operationally deployed.

Once these initial vessels are deployed into the operational environment, new blocks with incrementally improved designs, systems, and processes will cycle through the program life cycle. Although this spiraling or cyclic loop for incremental development improves both the usefulness and the efficiency of the weapons system, it also adds to the complexity of sustainment. In significant respects, especially with ships and submarines, each major weapons system is unique.

c. Sustainment Period

Although planning and decisions that affect the sustainment stage can occur as early as the materiel systems analysis phase and TD phase, sustainment does not begin until the first weapons system is delivered to an operational command. In a significant sense, the first commissioning ceremony formally initiates the sustainment stage of a ship or submarine.

As authority over each weapons system is transferred from the program office to the appropriate operational command hierarchy, a number of significant changes occur. For instance, the pre-staged logistics (e.g., pre-purchased initial spares, component consumables, initial shelf stock, etc.) and maintenance and logistics information channels are activated. Also, critical contractor technical representatives (tech reps) are stationed to provide supplemental training and troubleshooting. During each vessel's first year in operation, the operational commands depend heavily on the program management team and the contractor tech reps to ensure that operational performance reflects the benchmarks established within the acquisition period.

The complexity of such beginnings, as well as the least-developed nature of the Block 1 (i.e., first in its class) ships and submarines, may cause these vessels to experience higher than average O&S costs, when compared to other vessels in the class. The reassignment of the weapons system from what is a laboratory developmental/test environment into its intended operational environment can disrupt both the performance and the cost assumptions. The necessity of making complex and expensive weapons systems work ensures that some portion of uncertainty is mitigated by ingenuity.

Ultimately, the inherent correlation between theoretical and practical application attained during this period sets the stage for this platform's (weapons system) future.

Although the operational information channels filter data back to the program office, as of 1984 there are central and permanent repositories for costs and usage incurred during the O&S (sustainment) period. For the U.S. Navy, the primary data repository is the Visibility and Management of Operating and Support Costs (VAMOSC) database. Even though this wealth of information is both centralized and accessible, the availability of this data does not automatically lead to conclusive analysis or immediate program updates.

Most ship and submarine platforms are expected to serve in the fleet for only about 30 years. This means that more than one third of the Block 1 vessel's life will be complete before 10 annual data points have been recorded for a trend analysis. Furthermore, during these 10 years, as many as 20 additional vessels may have been commissioned. Each of these vessels, though grouped, do not necessarily fit the initial vessel's averages, due in part to operations schedules and major repair schedules, which span across multiyear periods and are difficult to directly compare. If each vessel is unique prior to commissioning, this condition increases as each vessel progresses through its life cycle.

Decisions as well as results within the sustainment period depend on highly variable conditions. No absolute synchronicity is imposed between the assumptions of the acquisition period and the O&S phase. Just as the forecasting of costs for significantly different operating conditions around the world (in an ever-changing world) is perhaps one of the most uncertain aspects of the life-cycle cost estimates, ensuring that actual costs and operational tempos resemble original assumptions is the most uncertain aspect of sustainment costs. Operators must respond to a highly variable operational environment.

d. Disposal

Although this stage of a vessel's life cycle is affected by a number of interesting factors, many of which relate to cost and performance (e.g., resale, spare parts cannibalization, and social and contingency considerations), this study does not focus significantly on this period. Although costly, especially when nuclear systems are involved, the disposal period is the least costly of the life-cycle phases. Typically, ship disposal occurs incrementally as individual weapons systems are decommissioned. As the disposal stage begins, overlapping with the sustainment stage, average sustainment costs are reduced due to reduced usage.

7. Triple Constraint

DOD acquisition programs are constrained by the same three tradeoff metrics as commercial sector projects: cost, schedule and performance (Rendon & Snider, 2008). In the USG acquisition environment, this is simply referred to as the *triple constraint*, and PMs are required to adhere to their budget, time, and specification thresholds.

DOD acquisition PMs must understand where the flexibility exists within these three constraints, and who owns which primary and secondary factors. Understanding who has the authority to readjust component KPPs and KSAs gives the PM an understanding of the limits of possible reapportionment within the triple constraint *trade space*.

Dennis K. Van Gemert and Martin Wartenberg (2007), in an article of the *Defense Acquisition Review Journal*, "Lessons Learned in Acquisition," discussed the triple constraint trade space as follows:

> During initial scope planning, prioritize the triple constraint variables. For example, quality tends to be an inflexible variable, whereas availability, maintainability, and reliability are components of quality. Determining relative sensitivities among triple constraint variables will facilitate system requirements trades performed during critical points in the program. (p. 387)

Similarly, in the *2013 Defense Acquisition Guidebook* (*DAG*), the writers elaborate on the triple constraint trade space as follows:

> Cost, schedule, and performance may be traded within the "trade space" between the objective and the threshold without obtaining Milestone Decision Authority (MDA) approval. Making trade-offs outside the trade space (i.e., decisions that result in acquisition program parameter changes)

require approval of both the MDA and the capability needs approval authority. Validated Key Performance Parameters may not be traded-off without approval by the validation authority. The PM and the user should work together on all trade-off decisions. (DOD, 2013, p. 805)

These quotes demonstrate the unique language through which DOD acquisition professionals communicate. More simply restated, many metrics that are otherwise untouchable can be affected and managed by their component variables. The power to adjust these smaller pieces of the triple constraint trade space gives PMs a means of locally managing uncertainty and any emerging conditions that could negatively affect the cost, schedule, or performance of their MDAP. See Figure 6 for a conceptual depiction of the Triple Constraint.

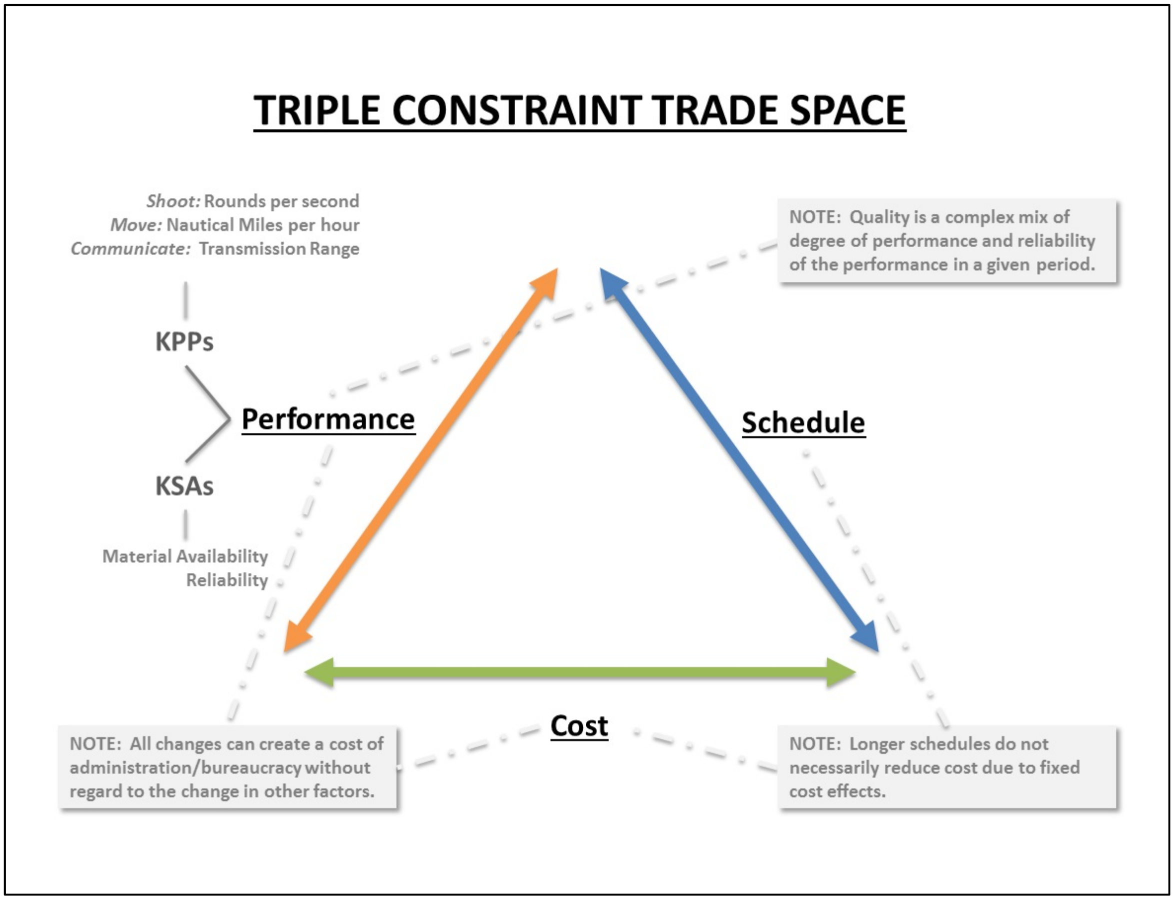


Figure 6. Triple Constraint Trade Space Diagram

PMs excel by expertly mitigating the risks of such uncertainty and by adapting the trade space within the triple constraint to responsively pursue their initial targets. In essence, all of the various decisions that alter or adapt an MDAP can be simplified to simply reflect their effect on these three factors. All changes to a program affect either one or more of these three primary factors: performance, cost, and schedule.

8. Basic Acquisition Cost Terminology

When analyzing the management of a DOD acquisition program, readers must understand some key terms and practices as to how the DOD sums and groups costs. The outcome of grouping costs is dependent on conditions such as different organizations with differing missions, differing points in the MDAP's life cycle, and differing practices regarding the inclusion or exclusion of manpower costs. These differences can make a detailed analysis difficult. For example, a keen understanding of the interactions between elemental properties of some costs (e.g., variable, incremental fixed, fixed) is muddied when mixing dissimilar cost types. The following cost terms provide an introductory acquaintance with cost groupings utilized within the DOD acquisition environment (see Figure 7).

Before addressing the different ways of summarizing acquisition program costs, it is important to understand that acquisition costs are expressed in base-year (BY) dollars, often called then-year (TY) dollars (e.g., nominal dollars), and in current-year (CY) dollars (e.g., constant dollars). The BY dollars represent the purchase power of a dollar as normalized to the acquisition program's first year. The difference between these dollar types is inflation. The DOD acquisition environment has established an approved joint inflation calculator (JIC) by which the TY dollars and CY dollars are normalized for proper comparison. When reading and expressing dollars within the DOD acquisition environment, the dollar type provides the correct context for equivalent discussions and appraisals.

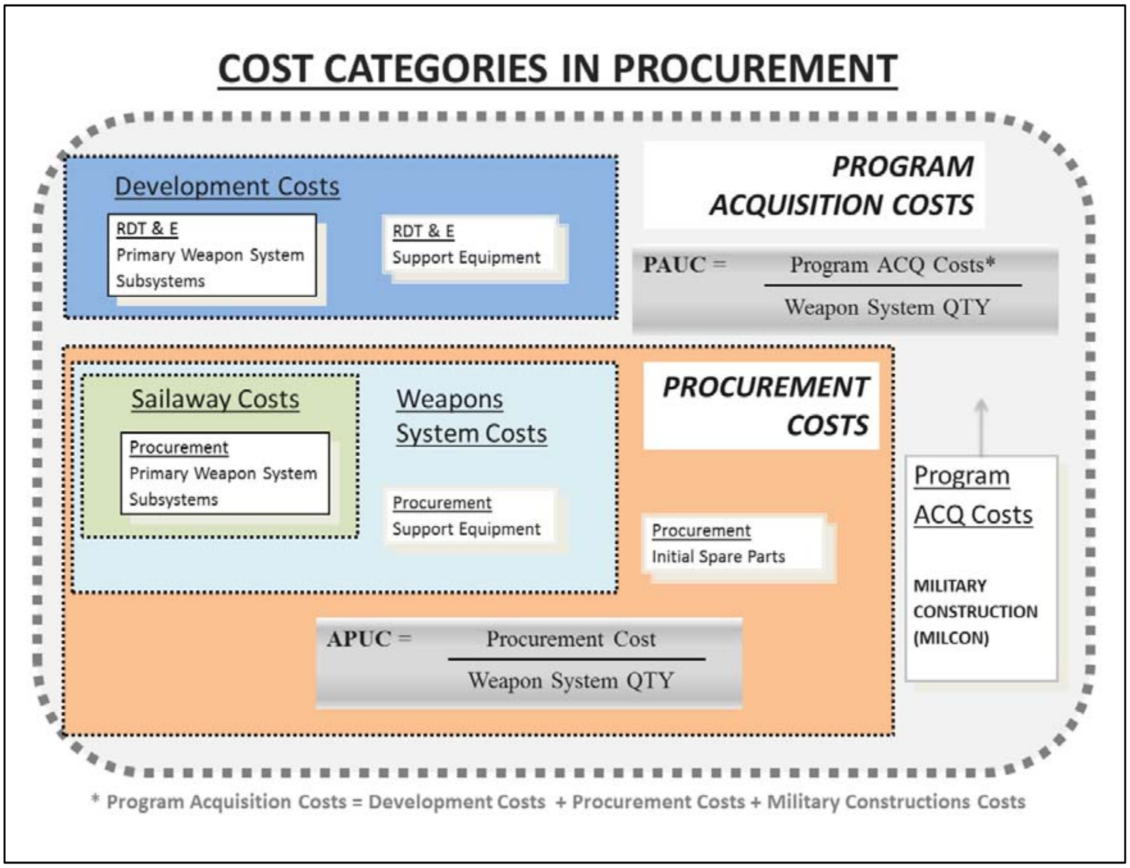


Figure 7. Cost Categories in Acquisition

a. Average Procurement Unit Cost

The average procurement unit cost (APUC) factors in all the procurement costs, excluding the RDT&E and MILCON costs, as shown in Figure 7. Reports show the APUC as a smaller cost than the program acquisition unit cost (PAUC). The APUC includes the weapons system, the support equipment and tools, the hardware and software, the training and technical document and electronic files, and the initial spare parts required to stand-up the operational command and support for about a year when it deploys (see Figure 7).

Average Procurement Unit Cost (APUC) = Total Procurement Dollars (in program BY$) / Total procurement quantity. (1)

b. Program Acquisition Unit Cost

The PAUC factors in all the acquisition costs including all of the RDT&E, Procurement and MILCON costs. Reports show PAUC as a larger cost than APUC. Conceptually, the PAUC reflects every cost required to produce the weapons system, including the technology and capital expenditure costs necessary to bring the program into an operational status (e.g., producible, reproducible, reliable, etc.).

Program Acquisition Unit Cost (PAUC) = Total Acquisition Dollars (in program BY$) / Total procurement quantity. (2)

c. Total Ownership Cost

The total ownership cost (TOC) factors in all the acquisition costs (research, design, development, and production) and all the sustainment costs (O&S). The TOC includes the cost of personnel required to operate the weapons system, as well as infrastructure and administration costs (cost of doing business), which can be attributed to the weapons system. Although the TOC and the life-cycle cost are often used interchangeably in the DOD acquisition environment, the TOC does not typically include the disposal costs. Life-cycle cost typically does not include the service-level overhead slice (such as recruiting, retaining, and otherwise supporting military and civilian personnel) that is chargeable to the weapon system. Affordability, as discussed in this study, refers to reductions in TOC (DOD, 1992).

d. Sailaway Costs

The sailaway cost refers to the individual contract cost to produce one specific weapon system (i.e., ship or submarine). These costs reflect the efficiency of production, especially schedule conditions like labor. These costs, more than any other, should demonstrate gains from the benefits of the *learning*. As the competing contractors produce each additional hull, the costs should decrease geometrically (i.e., learning curve). Although the degree of learning expressed in the curve can be debated, without a logical and consistent decrease in these costs, the contractor cannot credibly assert they have performed well.

9. Earned Value Management

The earned value management system (EVMS) process offers a common means of tracking and evaluating progress and change of cost, schedule, and work performance within an MDAP, expressed in terms of dollars (DOD, 1992). PMs and other stakeholders monitor and discuss the status of cost and schedule via the language of the EVMS process (Defense Contract Management Agency, 2006). This section familiarizes the reader with the most succinct ratio for appraising how well the MDAP has executed costs and schedules relative to the approved targets: cost and schedule efficiency indexes. Although cost and schedule variances also reflect whether an MDAP has outperformed or underperformed relative to the target budget and schedule (as established from the acquisition program baseline [APB]), the cost and schedule efficiency ratios simplify appraisals. Cost and schedule efficiency can simply be stated as favorable or unfavorable (see Figure 8).

Notably, the EMVS also tracks performances in an indirect sense, through the credible assumption that signatories cannot or will not sign off any portion of the scheduled work effort unless it is substantially complete and is therefore in compliance with quality tolerances. The EVMS process does not provide an absolute depiction of the degrees of quality and the quantity of incorporated rework due to its indirect manner of addressing performance. The amount to which the EMVS process depicts performance fulfillment depends significantly on the experts embedded within the DAS who evaluate the contractor.

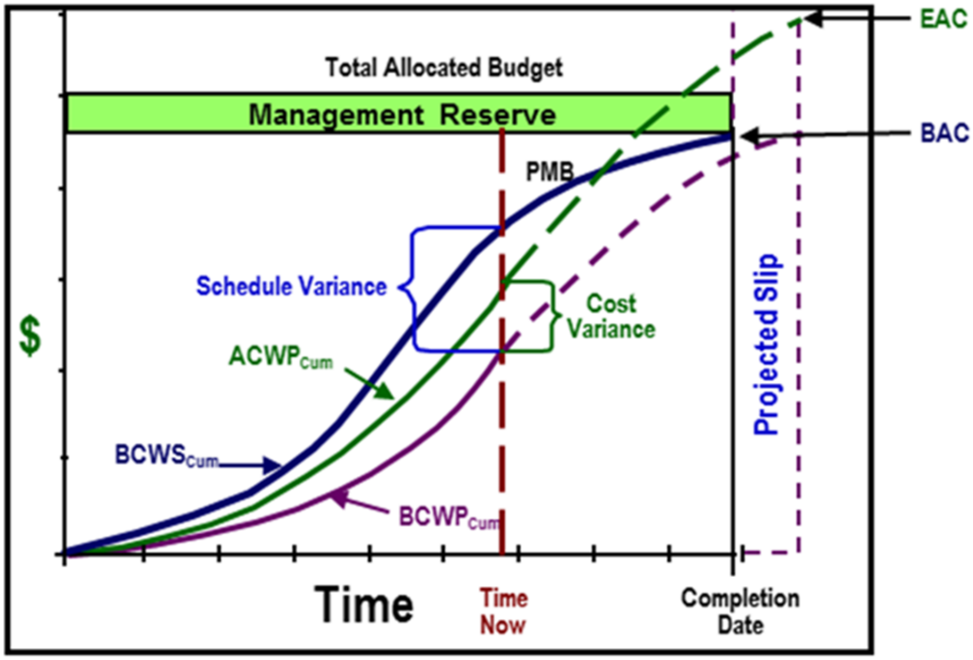


Figure 8. EVMS Measuring Performance, Gold Card (from DOD, 2013)

a. Cost Efficiency

DOD acquisition professionals calculate cost efficiency from the Cost Performance Index (CPI) ratio of budgeted cost for work performed (BCWP) to date and actual cost of work performed (ACWP) to date. That is,

CPI = Budgeted Cost for Work Performed / Actual Cost of Work Performed. (3)

This ratio can provide a comparison between the costs a contractor has reported as incurred in order to construct a submarine (or ship) to a specific percentage complete versus the costs from the original plan to be complete to that percentage. A CPI score above 1.00 reflects a favorable position for the program. A CPI score below 1.00 reflects an unfavorable position for the program. A CPI score of 1.00 shows the program to be on target, often stated as "on course" or "on glide-slope." Notably, the CPI score does not necessarily indicate the source or causes of the underperformance, only the status of the program relative to its original plan.

b. Schedule Efficiency

DOD acquisition professionals calculate schedule efficiency from the Schedule Performance Index (SPI) ratio of BCWP to date and budgeted cost for work scheduled (BCWS) for the current date. That is,

SPI = Budgeted Cost for Work Performed / Budgeted Cost of Work Scheduled. (4)

This ratio can provide a comparison between the costs a contractor has reported as incurred in order to construct a submarine (or ship) to a specific percentage complete versus the costs from the original plan to be complete as of the current date. As with the CPI, an SPI score below 1.00 reflects an unfavorable position for the program, whereas a score above 1.00 reflects favorable. An SPI score of 1.00 shows the program to be on target. Again, the SPI score does not necessarily indicate the source or causes of the underperformance, only the status of the program relative to its original plan.

10. Basics of Acquisition Reporting

Various critical reviews for MDAPs, as noted on the life-cycle chart (see Figure 5), to include milestone decision meetings, require the preparation and dissemination of specific reports. These reports depict the ongoing changes to the triple constraint trade space. A high degree of familiarity with the DOD acquisition environment and program development leads to a nuanced understanding of this trade space and the depictions in these reports. As with the commercial sector, some important answers reside between the lines.

This section provides the reader with the most basic familiarity with the types of reports and their intended purposes. The story for each MDAP emerges from these reports. Finding this story requires the utilization of the previously mentioned terminology and a general understanding of the fundamental relationships and practices of project management, accounting, and business management. The story is always there, buried beneath the words. However, in some cases reports and information remain unavailable and therefore cannot be analyzed.

The *DAG* (DOD, 2013) discusses some of the following reporting documents:

- analysis of alternatives (AOAs);
- life-cycle cost estimates;
- independent cost estimates (ICEs);
- acquisition program baseline (APB) reports;
- current estimates (CEs);
- selected acquisition reports (SARs);
- defense acquisition executive summary (DAES) reports;
- significant cost growth notices;
- unit cost reports (UCRs);
- critical cost breach notices;
- initial operational capability objective breach notices.

Although all of these reporting documents provide important information, this study draws primarily from SARs, DAES reports, and information regarding critical cost breach notices. These reports corroborated data and assisted in the substantiation of findings from key qualitative references (e.g., RAND, the Congressional Research Service [CRS], and the Government Accountability Office [GAO]).

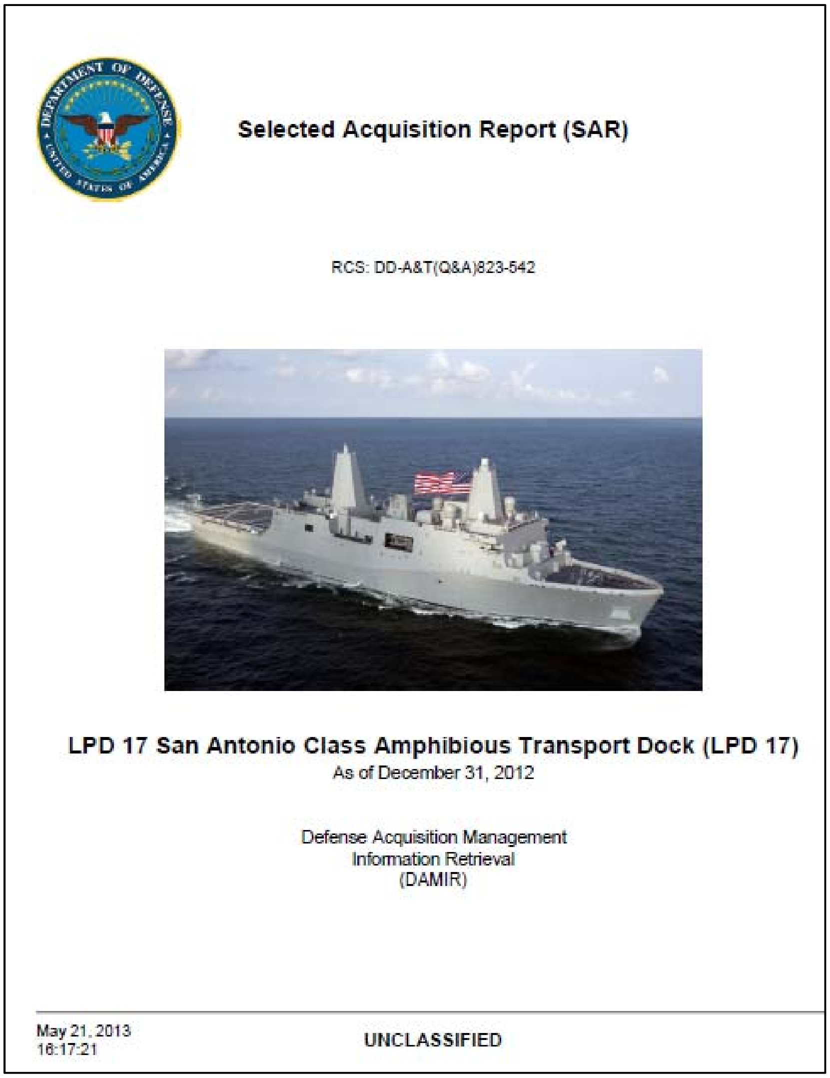
Notably, the reporting for the sustainment period, often called the O&S period, flows through less readily accessible channels. Solutions for many issues in an operational environment come from a diverse and dispersed group of experts. Although the cost databases and the maintenance databases collect a wealth of information, this data does not necessarily depict or flag every event in a manner that will explain a resolution and permit the extraction of best practices. Eventually, numerous sustainment period reports for cost and maintenance provide information bundled into central repositories, such as Defense Acquisition Management Information Retrieval (DAMIR), Visibility and Management of Operations and Support Costs (VAMOSC), and Decision Knowledge Programming for Logistics Analysis and Technical Evaluation

(DECKPLATE). Access to such repositories is closely managed by the DOD through their applicable web entry-points and access to this data is restricted.

a. Selected Acquisition Report

The SAR provides reviewers with a synopsis of past, present, and likely future cost and schedule execution. Additionally, it offers generalized explanations as to why progress differs from targets. An example SAR coversheet is provided in Figure 9. Each SAR includes the PAUC and APUC, which can be compared against targets and previous costs. The Office of the Secretary of Defense (OSD) in its 1996 executive summary on acquisition program reporting (DODD 5000.1, 5000.2-R) summarized the SAR as follows:

> The SAR provides the status of total program cost, schedule, and performance, as well as program unit cost and unit cost breach information; and, in the case of joint programs, the SAR shall include such information for all joint participants. Each SAR shall also include a full life-cycle cost analysis for the reporting program and its antecedent program.
>
> The SAR for the quarter ending December 31 is called the annual SAR. Each annual (December) SAR, shall be submitted 60 days after the date on which the President transmits the budget to Congress for the following fiscal year. Annual SARs are mandatory for all programs that meet the reporting criteria. (section 6.2.4.1, p. 3)



Selected Acquisition Report (SAR)

RCS: DD-A&T(Q&A)823-542

LPD 17 San Antonio Class Amphibious Transport Dock (LPD 17)
As of December 31, 2012

Defense Acquisition Management
Information Retrieval
(DAMIR)

May 21, 2013
16:17:21

UNCLASSIFIED

Figure 9. Selected Acquisition Report Cover Page Example (from DAMIR, 2012b)

b. Defense Acquisition Executive Summary

The DAES reports potential and actual program risks, primarily in text-based descriptions summarizing events and conditions. DAES reports are typically submitted quarterly with changes in cost reported and forecasts made based on a month-to-month basis. The OSD (1996) summarized the DAES report as follows:

> At a minimum, the DAES is the vehicle for reporting program assessments, unit cost (10 USC § 24331), current estimates of the APB parameters (10 USC § 24352), status reporting of exit criteria, and vulnerability assessments (e.g. APB deviation) (FMFIA3). (part 6, p. 2)

The DAES reports include different types of information and degrees of detail depending on where the program is in its life cycle and the cost, schedule, and performance statuses. As noted in the *DAG* (DOD, 2013), at any given time, the assessment categories shown in Figure 10 could be addressed by a key stakeholder.

ASSESSMENT INDICATOR CATEGORIES
COST
SCHEDULE
PERFORMANCE
FUNDING
TESTING
SUSTAINMENT (O&S)
MANAGEMENT
CONTRACTS
INTEROPERABILITY
PRODUCTION
INTERNATIONAL

Figure 10. Assessment Categories Defense Acquisition Executive Summary (from DOD, 2013)

c. Critical Cost Breach Notice

Notices of critical cost breaches are typically called notifications of a Nunn–McCurdy breach. Such a notice refers to costs increasing or decreasing beyond thresholds established in the Nunn–McCurdy Act of 1982. To understand the manner in which and the specificity with which DOD acquisition professionals explain these notices, consider the following excerpt from the *DAG*:

> Per section 2433a of title 10 United States Code, the Program Manager shall notify the Department of Defense Component Acquisition Executive (CAE) immediately, whenever there is a reasonable cause to believe that the current estimate of either the Program Acquisition Unit Cost (PAUC) or Average Procurement Unit Cost (APUC) objective of a Major Defense Acquisition Program (MDAP), or designated subprogram (in base-year dollars) has increased by at least *25 percent over the PAUC or APUC objective of the currently approved Acquisition Program Baseline (APB) estimate*, or at least *50 percent over the PAUC or APUC objective of the original/revised original APB* [emphasis added]. (DOD, 2013, p. 819)

Without a prior knowledge of BY dollars, the PAUC, the APUC, and the APB, someone unacquainted with the DOD acquisition environment and its terms would be hard-pressed to discern this excerpt. In simple terms, the PM must inform key stakeholders (like the CAE, as noted above) of a critical cost breach when the program costs of either type (APUC or PAUC) exceed 25% of the most current approved budget. Additionally, if the MDAP exceeds 50% of the original baseline budget, for either cost type, the MDAP has breached Nunn–McCurdy cost thresholds and must notify the CAE of this breach. Since 2009, a 50% cost breach will prevent the MDAP from receiving any additional funding (essentially killing the program) if the secretary of defense does not specially certify the program for continuation. More details on this and other forms of cost control legislation follow in the next section.

11. Affordability in Legislation

Whether due to Cold War exigencies or capabilities-centric management, for decades the DOD acquisition environment focused so fiercely on the performance of a weapon system that cost considerations were often marginalized. Legislation has continued to grow in an effort to institutionalize and reinforce cost-wise practices and requirements. Two of the most noteworthy and well recognized of such congressional acts are the DOD Authorization Act of 1983 (Public Law 97–252), which included the Nunn–McCurdy Act (10 U.S.C. 2433), and the Weapon Systems Acquisition Reform Act (WSARA) of 2009 (Public Law 111–23). In conjunction with other legislative mandates and institutionalized policies aimed at controlling costs, these acts legally require activities that compel DOD acquisition professionals (such as PMs) to regularly consider costs when appraising their programs and when making cost critical decisions. The Nunn–McCurdy Act evolved and the WSARA was established while the submarines and ship MDAPs of this study were in development or production. Although the precise effects on these MDAPs would be difficult to ascertain, the influence of these acts was present as noted by comments in numerous studies.

a. Nunn–McCurdy Act

The Nunn–McCurdy Act focuses on the costs of acquisition. Although the Nunn–McCurdy Act continues to be amended (updated), its purpose has generally remained the same. It mandates the consideration and communication of specific negative cost events. Most notably, it requires that the PM notify key stakeholders of a critical cost breach, in particular the CAE, when either APUC or PAUC increase beyond 25% of the current baseline budget or 50% of the original baseline (target) budget. In the most general sense, the Nunn–McCurdy Act simply enforces cost tracking and reporting. The introduction of the WSARA in 2009 further expanded the influence of the Nunn–McCurdy Act, giving it "real teeth."

b. Weapon System Acquisition Reform Act

Like the Nunn–McCurdy Act, the WSARA primarily addresses the costs of the acquisition (RDT&E and procurement). In a significant sense, the WSARA was created to both increase the impact of the Nunn–McCurdy Act requirements and expand on its aim of improved cost control and general affordability in DOD acquisition. The specific languages of the WSARA forces cost consideration across all of the DOD acquisition functional areas (DAS, JCIDS, and PPBE). Additionally, it indirectly informed the contractors of the legislative seriousness of the breaching cost thresholds. These are examples of WSARA mandates that significantly altered the manner in which the DOD acquisition environment addresses costs:

- The Office of Cost Assessment and Program Evaluation (CAPE) was created to analyze and address the costs of new programs. This mandate creates a central authority that enforces better cost management (affordability).

- The director of the CAPE (DCAPE) must ensure that each alternative materiel solution presented to the JROC fully considers possible trade-offs among cost, schedule, and performance objectives (Husband & Kaspersen, 2012). This mandate forces the sponsor (military service seeking the weapon system) to more fully address affordability from the outset.

- The DCAPE must assess whether or not "the joint military requirement can be met in a manner that is consistent with the cost and schedule objectives recommended by the Joint Requirements Oversight Council"

(U.S. Congress [1997], part 1, ch. 7, p. 1) This mandate requires the DCAPE to ensure the JROC is considering affordability when approving ICDs (10 U.S.C. §181 [1977]).

- The WSARA directs that continued funding (budget authority) must cease for any program that has a critical Nunn–McCurdy breach, unless the secretary of defense certifies the program shall continue to be funded. Both the immediate threat of program cancelation and the additional oversight imposed by the WSARA for such breaches make them increasingly menacing to both PMs and contractors.

- The WSARA obligates DOD acquisition professionals, specifically cost estimators, to pursue 80% confidence levels when producing cost estimates.

- The WSARA establishes a Configuration Requirements Board, which addresses ongoing trade-off decisions within the triple constraint trade space. This board gives PMs a place where they can make unilateral affordability recommendations, including whether or not they believe the program will likely meet cost, schedule, or performance objectives.

III. VIRGINIA-CLASS SUBMARINE STUDY

This section seeks to inform about the U.S. Navy's Virginia-class submarine and submarines in general, to provide enough understanding of the circumstances surrounding the industry to comprehend this case study's focus of controlling the costs of acquisitions. This chapter relies heavily on the previous work of Ronald O'Rourke (2013), Congressional Research Service (CRS) specialist in naval affairs in his *Navy Virginia (SSN-774) Class Attack Submarine Procurement: Background and Issues for Congress.* Readers seeking the full report are encouraged to source it through the CRS.

A. INTRODUCTION TO VIRGINIA CLASS

The Virginia-class submarine is the first American submarine acquisition following the end of the Cold War, with initial planning commencing in 1992 and the first submarine achieving initial operating capability in September 2008. A goal of Virginia-class was to provide a lower cost platform comparison to Seawolf-class in both procurement and sustainment with a broad mix of capabilities to enable it to perform a variety of missions. Virginia-class is the product of design efforts by Electric Boat with input from the material developer, the U.S. Navy. This differs from early nuclear-powered submarines that were designed solely by the Navy (Schank et al., 2007).

1. Existing Submarines

The U.S. Navy operates four nuclear-powered submarine classes, in chronological order: Ohio-class, Los Angeles-class, Seawolf-class, and Virginia-class. These four classes of submarines perform three missions:

1. ballistic missile submarines (SSBN);
2. cruise missile and special operations forces insertion (SSGN); and
3. attack submarines: submarine nuclear power (SSN; O'Rourke, 2013).

a. Ballistic Missile Submarines

As referenced from the U.S. Navy's fact file, fleet ballistic missile submarines have one mission: to provide the United States with the most enduring nuclear strike capability. The U.S. fleet of ballistic missile submarines is composed of 14 Ohio-class submarines, each capable of carrying 24 submarine-launched Trident II D5 ballistic missiles. The warheads of the Trident II D5 are capable of being independently targeted. Ballistic missile submarines are deployed solely for strategic-deterrence missions (Naval Sea Systems Command, 2014b).

b. Cruise Missile and Special Operations Insertion

Cruise missile employment is an act of launching an offensive land-attack missile from submerged depths. U.S. Navy attack submarines and guided-missile surface combatants (CG and DDG) employ the Tomahawk Land Attack Missile, capable of striking targets on land greater than 800 or 1000 miles, depending on the variant used. The Tomahawk carries a 1000-pound warhead or several smaller warheads capable of being designated to strike different targets (Naval Sea Systems Command, 2014c).

Special operations forces (SOF) insertion is the capability to employ SOF, typically U.S. Navy Seals, from a deployed submarine. The SOF is deployed either from one of the missile tubes on an attack submarine, or via a miniature submarine known as a swimmer delivery vehicle (SDV) on a converted ballistic missile submarine, recently redesigned as an SSGN. Insertion of SOF via submarines decreases the chances of being detected on covert missions in comparison to surface ships or airborne delivery, in many cases.

c. Attack Submarines

The Navy Fact File describes attack submarines as "designed to seek and destroy enemy submarines and surface ships; project power ashore with Tomahawk cruise missiles and Special Operation forces; carry out Intelligence, Surveillance, and Reconnaissance (ISR) missions; support battle group operations; engage in mine warfare" (Naval Sea Systems Command, 2014a. The U.S. Navy currently has three different classes of attack submarines in its inventory: the Los Angeles-class, Seawolf-class, and Virginia-class.

The Virginia-class will eventually replace the Los Angeles-class and must perform all five of the following strategic mission types: national-level surveillance, SOF insertion and recovery (on a smaller scale than SSGNs), Tomahawk Cruise Missile strikes (on a smaller scale than SSGNs), covert offensive and defensive mine warfare, and anti-surface ship and anti-submarine warfare (O'Rourke, 2013).

2. Seawolf-Class History

The Seawolf-class was designed at the height of the Cold War when the United States sought a new vessel to provide the unprecedented performance capabilities required to counter the Soviet Union. The 1997 Seawolf-class SAR described the Seawolf-class as follows:

> The SEA WOLF submarine is a multi-mission vessel that introduces unprecedented performance capabilities. It is the quietest, most heavily armed attack submarine the Navy has ever built. The design of the SEA WOLF is based on an extensive research and development program and incorporates technological advancements to provide: order of magnitude improvement in ship quieting; improved acoustic sensors; more capable combat systems; greater weapon capacity and capability; quieter launch; weapon launch at high ship speed; advanced reactor; improved performance machinery program; an advanced propulsor; increased operating depth; improved ship control; and enhanced survivability. (DAMIR, 1997a, p. 4)

The post–Cold War–U.S. Navy inventory no longer required a significant number of Seawolf-class submarines. Originally, the class was to consist of 30 submarines but was later reduced to 12; however, construction was stopped after three, due to the high cost of acquisition, sustainment, and need to produce more submarines. The submarines replaced the aging fleet of attack submarines approaching planned disposal. The APUC adjusted for 2010 dollars is $4.255 billion (2010 dollars) for Seawolf-class in comparison to $1.926 billion (2010 dollars) for Virginia-class, based on a reduced number of units in the Seawolf-class (DAMIR, 1997a, 2012a).

3. Alternatives to Virginia Class

In 1994, the Senate discussed whether to continue building Seawolf-class as planned to avoid the high startup costs of any new ship class, or to consider building Virginia-class. Continuing Seawolf-class construction, as the Senate committee debated, would cost $21.05 billion (2010 dollars) and would yield five submarines over 10 years from 1994 to 2004. Virginia-class was selected over Seawolf-class, and the cost incurred through 2004 was $24.955 billion (2010 dollars). Two new submarines were completed and three were under construction (DAMIR, 1997a, 2012a).

Continuing the Seawolf-class line would have provided additional quantity, lethality, and reduced costs in the near term (through 2004). Because the primary goal of Virginia-class was affordability followed by flexibility then lethality, this brings into question the strategic validity of choosing Virginia-class in the near term.

Considering only the difference in acquisition costs, the current APUC of $2.757 billion (adjusted to 2010 dollars) per submarine represents a savings of $1.35 billion per submarine over the Seawolf-class's $4.212 billion (2010 dollars). The savings per submarine and the reduction of APUC over time make Virginia-class a fiscally responsible decision when judged solely by affordability in acquisition. The operations and maintenance (O&M) aspect of the Virginia-class is evaluated in the following sections (DAMIR, 1999a, 2012a).

4. An Ocean Devoid of the USSR

At the earliest point in the pre-acquisition phase, acquisition leaders and the Congress planned for the Virginia-class to cost less and have greater mission flexibility than the Seawolf-class and Los Angeles-class. The demand for Seawolf-class was established during the Cold War, when the United States determined strategic capability requirements based on a defined, well-known threat—in this case, the Soviet Navy. At that time, the emphasis in acquisition was not on affordability, at least not to the degree that PMs experience today. Seawolf-class was cancelled after only three submarines were constructed. The primary drivers behind this decision were the escalating construction costs and evolving requirements (Johnson, Drakeley, & Smith, n.d.).

5. Emphasis on the Littorals

Although the Virginia-class of submarine would need to factor in the continued Russian threat, it would also be asked to do much more in terms of the variety of its missions. Most notably, it would operate in the areas nearer the shore, known as littoral operating areas, or commonly as the *littorals*. This increase in capability of the Virginia-class increased the complexity of the design. In contrast to previous classes of U.S. submarines, the Virginia-class was required to have the capability to operate in the littorals. Although many other nations had been routinely focusing their operations in these areas for several years, this capability of the Virginia-class was new to the U.S. Navy (Schank et al., 2011).

B. VIRGINIA-CLASS ACQUISITION STRATEGY

The following subsections provide background to the acquisition and construction of the initial submarines in the Virginia-class.

1. The 21st-Century Submarine

It was anticipated that the Virginia-class submarine would be optimized from initial build to meet the operational demands of the 21st century while seeking a more disciplined acquisition strategy that considered affordability. The procurement team faced three distinct challenges that its predecessors did not:

1. The platform must be able to perform all traditional submarine missions, operate in the littorals, plus be able to perform multiple new missions, some of which have not yet been developed.
2. It must be affordable to build.
3. It must be affordable to sustain.

The Navy sought to meet the variety of capability requirements while controlling the costs. The Virginia-class team sought to retain the quieting and maintain the elementary combat system of Seawolf-class, but also sought to shift to open-architecture design for the various proven technologies. Open architecture allows components to be removed or replaced based on mission necessity and future technologies not yet required or available. Virginia-class looked for reductions, resulting in cost savings in the following areas:

- reduction in maximum flank speed,
- reduction in weapons payload and weapons delivery rate,
- reduction in maximum depth, and
- minimizing crew complement (Schank et al., 2011).

2. Mission Requirements

The Virginia-class is designed to accomplish seven core missions:

- covert strike,
- anti-submarine warfare,
- battle group support,
- covert intelligence,
- covert mine laying, and
- special operations (Schank et al., 2011; U.S. Senate, 1992).

3. Planning

In planning, the Navy sought to accomplish savings through preventing common mistakes from previous acquisition projects. Lessons learned from previous programs reflected that high common costs in submarine acquisition were incurred once deviations from initial requirements occurred (Schank et al., 2011).

a. Introduction of Integrated Product Teams

The most expensive labor cost in ship construction is rework. Virginia-class planners sought to mitigate rework to the extent that Electric Boat completely restructured its management control system and implemented a divisional structure to address the problem of costly rework during ship construction. The divisionization, known as major area teams (MATs), functionally operated as integrated product teams

(IPTs), consisting of designers, engineers, vendors, environmental and logistics technicians, computer-assisted design (CAD) operators, a space manager, and Navy PM representative. Newport News Shipyard, following successful implementation by Electric Boat, used IPTs, and construction utilized 15 MATs that were supervised by two major area integration teams (Schank et al., 2007, 2011).

The Navy engaged the union leadership from the beginning of the design process with Virginia-class. This engagement brought the customer (Navy) together with the contractor, Electric Boat (EB), to work toward their individual and common goals. The Navy sought to keep costs down, while EB had compensation goals. Together, they sought to build Virginia-class and keep EB open. Although the Virginia-class program was not free of labor issues, the early engagement with union leadership is viewed as a positive contributor to the program (Schank et al., 2011).

The MATs realized efficiencies in collaboration among the teams on the integration of the major areas that divided the ship. An example of this is the collaboration between a space manager of an auxiliary machinery room, which shares bulkheads with the habitability, command and control systems module, and weapons space. Under the MAT structure, the teams could collaborate as necessary to remove any uncertainty in how their teams would integrate. Examples include piping, electric, ventilation, and hydraulic systems, many of which travel through multiple compartments throughout the ship. The ease of communication and interaction facilitated by existing relationships and contacts fostered strong working relationships in the program (Schank et al., 2011).

IPTs were used extensively throughout the acquisition phase of Virginia-class: design, construction, and delivery. Virginia-class was the first submarine class designed using IPTs. Use of the IPT was successful in controlling costs of acquisition by fostering communication with stakeholders in the construction process. Positive feedback from the program indicated that collaboration was improved by compelling the USG representative, either a PM or direct representative, to be involved in the cooperative acquisition process with the contractors and suppliers. This organization of the IPTs contributed toward reaching a cooperative goal of cost reduction without quality degradation (Schank et al., 2007, 2011).

b. Two Shipyards

The first four submarines were built with significant components from two shipyards and this process has continued throughout the Virginia-class program. EB was the single design agent for the contract and the construction prime contractor; however, several components have been subcontracted to Newport News to follow the build contracts. Additionally, several submarines have been, and will continue to be constructed in Newport News, VA, with components prefabricated at EB in Connecticut (Schank et al., 2011).

c. Multiyear Procurement Contract

While the projected cost acquisition savings did not materialize in SSN 774 or SSN 775, innovations eventually resulted in stopping, and in some cases reversing, the cost growth of major components of the program. The initial procurement proposal from the Navy requested the procurement of four Virginia-class submarines under a multiyear procurement agreement. This proposal was considered a deviation from the norm in the acquisition community for a program of this magnitude and complexity that had yet to produce even one unit in the class. "In contrast, to the Arleigh Burke-class destroyer (DDG 51) program, the last shipbuilding program to enter into a multiyear procurement contract was well into its acquisition cycle when multiyear procurement authority was approved" (GAO, 2003, p. 2).

Multi-year procurement became a significant component of the cost savings. Multiyear procurement had a positive effect on controlling cost growth in procurement, resulting in $200 million in cost savings. When procuring submarine raw materials and components, defense contractors were able to reduce costs by purchasing materials in bulk for the construction of several different submarines of the class. The savings achieved by the multiyear procurement contract is referred to as *economic order quantity* (Goff, McNamara, Bradley, Trost, & Jabaley, 2012; Johnson et al., n.d.).

d. Lean Six Sigma

The Virginia-class team utilized Lean Six Sigma throughout the procurement process to control cost growth and build efficiencies through continuous process improvement, eliminating waste and duplication efforts (Johnson et al., n.d., p. 5). By utilizing Lean Six Sigma the Virginia-class program was able to reduce rework, improving on the costly mistakes that caused rework on Seawolf-class. In *Engineering the Solution*, Johnson et al. (n.d.) stated that the implementation of Lean Six Sigma resulted in noticeable cost savings in rework, risk, and delays over the initial several ships, specifically in non-propulsion electric systems.

e. Software Design

Virginia-class was solely designed using CAD software through all four current design blocks. The employment of the software allowed several design modifications in the planning phase without the requirement of costly models or drawings after each change (Schank et al., 2011).

The use of CAD contributed to a reduction of rework throughout the design process and assisted in making required changes when moving from one block to the next. The use of CAD in comparison to previous methods resulted in a much more rapid development of drawings that were far superior in quality through their accuracy. Three years into construction, 99% of the Virginia-class' drawings had been issued in comparison to 65% on Seawolf-class, and the number of errors identifying changes required was 12,000 for Virginia-class in comparison to 70,000 for Seawolf-class, an 80% reduction (Schank et al., 2011). The overall reduction in rework translates into lower design and labor cost reductions, ultimately controlling cost growth in the program.

The combination of the evolution in software design and the management of the program utilizing MATs drastically increased efficiency in the build process over Seawolf-class. These tools place Virginia-class 2.5 years ahead of Seawolf-class at the time of construction start when measured by the number of drawings issued (Schank et al., 2011).

f. Only Mature Technology

An additional area where containment of cost growth was targeted were those costs attributable to non-mature technology. From the outset, the program prohibited new technologies that either were not previously approved as a part of production on previous submarines, or were not fully tested on a Los Angeles-class submarine prior to inclusion in the Virginia-class program. Table 1 represents the understood risks of technologies at different stages of maturity. The paradigm of payoff versus risk, when inserting non-proven technology into production, was considered and discussed on the U.S. Senate floor on July 21, 1992.

Levels of Technology Maturity

Maturity Category	**Risk**	**Technology Base**
Proven	N/A	Los Angeles-class
Demonstrated	N/A	Seawolf-class
Demonstrated or will be demonstrated	Low	Post-Seawolf-class/ Near term
Requires significant development with ship design	High	Developmental—Defense Advanced Research Projects Agency (DARPA) structural initiatives

Table 1. Virginia-Class Levels of Technology Maturity (after U.S. Senate, 1992)

4. Special Congressional Oversight

Congress decided that after the Seawolf-class they would provide additional oversight for the next attack submarine. The previous cost overruns in the acquisition of the Seawolf-class had shaken congressional confidence in the Navy's ability to manage submarine acquisition. In response to the previous cost overruns, Congress decided that the Virginia-class would receive special oversight to control cost growth.

a. Loss of Confidence

Congress and the Navy sought to make the new attack submarine (referred to as NAS in congressional proceedings) affordable long before construction began. The Virginia-class would have a focus on affordability early in the acquisition phase and throughout the life cycle. In Senate proceedings on September 13, 1991, during the hearing on the forthcoming Centurion-class (which became the Virginia-class), the main focus of testimony centered on how the NAS would be more affordable than the new Seawolf-class with less concern for capability improvements. Navy testimony stated that *affordable* would “be anything that costs less than Seawolf-class” (U.S. Senate, 1994). In contrast, Congress had a more exact definition of how Centurion-class would be affordable. They defined *affordable* as “a submarine that will fit in the shipbuilding and conversion budgets of the future” (Naval Sea Systems Command, 2014a; U.S. Senate, 1994).

Congress established that future funding would first depend on the quarterly reports from William Perry, the secretary of defense. The increased reporting was aimed at controlling costs of the new submarine to prevent a repeat of the unpopular cost growth incurred during the acquisition of the Seawolf-class. The increased congressional oversight was unsuccessful in averting cost growth in the initial submarines of the Virginia-class (U.S. Senate, 1994).

The original PAUC target at Senate hearings was $1.765 billion (2010 dollars). That number grew to an estimate of $2.014 (2010 dollars) at the start of production and has since been adjusted through rebaselining in 2005 to a new target of $2.185 billion per boat. Despite the increased congressional oversight, the Virginia-class program incurred a cost overrun of $420 million, or 20% over the original PAUC estimates proposed at Senate hearings, and $171 million or 8% over original APUC (DAMIR, 2012a; U.S. Senate, 1994).

b. *Meeting Cost Goals*

The cost goals for Virginia-class were not met initially. As the learning curve in production was improved, costs came down and significant savings were accomplished later in the program. The recent submarine completions and those under construction (SSN 781, SSN 782, SSN 783, SSN 784, SSN 785, SSN 786, and SSN 787) have attained the adjusted cost goals. Table 2 represents these submarines and their estimated cost at completion, as compared to the current 2010 APB. This data does not represent the costs incurred on SSN 774, SSN 775, SSN 776, SSN 777, SSN 778, SSN 779, and SSN 780 due to classification levels of the data that are inconsistent with this report. Data from Table 2 reflect improved efficiencies in the acquisition of Virginia-class as experience is gained through SSN 787. Reduced cost growth in acquisition is projected on these submarines; they represent the eighth through 14th submarines of the class.

Sources of cost savings include the following:

- schedule variance through effective schedule maintenance;
- efficient completion of a milestone (completion of the pressure hull) resulting in cost variance;
- contract optimizing efforts of labor, effective man-hour use;
- favorable cost variance due to favorable performance in final assembly and testing before final delivery;
- reduced labor costs due to schedule variance created by efficient integration and testing facilities;
- modular fabrication; and
- reduction in rework on SSN 783 as compared with previous submarines (DAMIR, 2011a, 2012a).

An "unfavorable variance" is where the actual cost or outcome is greater than the expected or estimated outcome. In the case of Virginia-class, the sources of unfavorable variances are as follows:

- authorized contract change orders (scope creep),
- overtime labor costs to avoid a schedule variance,

- inaccurate estimates of man-hours required to perform required tasks (modular integration), and

- schedule variance caused by labor hour degradation in structural component fabrication and assembly (DAMIR, 2012a).

Hull #	PAUC 2010 APB, 1995 Dollars	EST PAUC, 1995 Dollars	Cost Var 1995 Dollars	PAUC (2010 APB, 2010 Dollars)	Est. Price at completion	Cost Variance (2010 Dollars)
SSN 781	$2.145	$1.50	(.31)	$3.069	$2.139	(.31)
SSN 782	$2.145	$1.516	(.30)	$3.069	$2.165	(.30)
SSN 783	$2.145	$1.596	(.26)	$3.069	$2.156	(.30)
SSN 784	$2.145	$1.873	(.13)	$3.069	$2.673	(.13)
SSN 785	$2.145	$1.820	(.16)	$3.069	$2.540	(.08)
SSN 786	$2.145	$1.716	(.20)	$3.069	$2.519	(.08)
SSN 787	$2.145	$1.778	(.18)	$3.069	$2.544	(.08)

Table 2. Cost Variance in Billions (USD), Converted to 2010 Dollars (after DAMIR, 2010a, 2011a, 2012a)

Note. Due to classification levels of cost data on hulls 774–780 that are not compatible with this report, only a portion of cost data is displayed in Table 2.

C. FIRST VIRGINIA-CLASS CONSTRUCTION

Initial construction commenced in September 1998 with the construction of USS *Virginia* (SSN 774), which entered service in 2004. The new class had evolved from data collected and experience on the Los Angeles-class of attack submarines (Goff et al., 2012).

SSN 774 cost $3.182 billion (PAUC), 2010 dollars; this includes startup costs associated with initial construction. The APUC target was originally $2.013 billion (2010 dollars), and the PAUC estimate was $2.014 billion. Current APUC is $2.616 billion

(2010 dollars), and the PAUC is $2.887 (2010 dollars). U.S. Senate (1994) testimony on September 13, 1995, sought a PAUC of $1.76 billion (2010 dollars) on hulls (unspecified) following SSN 774 versus the estimate of $2.2 billion (2010 dollars) per hull. Table 3 depicts this cost information in table form.

Cost Measure (per unit)	Navy Est. 1994 (In Senate Testimony)	1995 Baseline	2010 Baseline	Current Estimate 2012 SAR
PAUC	N/A	2.176	3.069	2.887
APUC	2.2	2.014	2.810	2.616

Table 3. Virginia-Class Controlled Cost Growth and Acquired New Submarines Below the Baseline Values Only After the Baseline was Adjusted (after DAMIR, 2012a)

The cost growth in comparison to established baselines is +29.91 for APUC and +32.66 for PAUC, resulting in a Nunn–McCurdy Breach. Since rebaselining, the PAUC has -5.93% cost growth and APUC -6.92. Table 4 depicts the change in cost variance in the 1995 and 2005 baselines.

Category	1995 Baseline	2005 Baseline
PAUC	+32.66*	(5.93)
APUC	+29.91	(6.92)

Table 4. Cost Growth by Variance

Note. * Indicates Nunn–McCurdy Breach

D. VIRGINIA-CLASS CONTRACT

Virginia-class was originally contracted under a cost-plus-fixed-fee (CPFF) contract for the electric plant and later added cost-plus-award fee for the construction of the ship (Schank et al., 2011). Electric Boat designed the Virginia-class submarine. The contract was established as a sole-source design and build for the first ship of the class.

The Navy originally planned to procure Virginia-class from a sole-source shipyard on the lead ship of the class, the USS *Virginia*, whereby the contract to design and build would be awarded on a sole source basis. This measure was recommended following the Seawolf-class program as a way to reduce costs. The measure, however, was not implemented. Instead, a consortium of two shipyards was planned for the building of the first four ships of the class. EB was the sole design agent and prime contractor for the program, while Newport News was a major subcontractor, executing approximately 50% of the work on every other submarine constructed (Schank et al., 2011).

The USS *Virginia* was designed and built at Electric Boat; the decision to award a design and build contract to a single company was made following the lessons learned from the Seawolf-class. This recommendation is studied in depth in the RAND Corporation's *Learning From Experience* (Schank et al., 2011), in which the Seawolf-class and Ohio-class are compared with Virginia-class. Although Virginia-class did sustain cost growth on the initial build at both shipyards, the cost growth was less than incurred on the first submarine of both Ohio-class and Seawolf-class. As described by the RAND Corporation, this practice of single-source designs and builds for the first submarine of the class "sets the tone" for the program (Schank et al., 2011).

SSN 781 through SSN 787 were contracted under fixed-price incentive fee (FPIF) awarded on a competitive contract to General Dynamics and Electric Boat Corporation (GDEB). The RDT&E contract, awarded under a lead yard services contract, was most recently awarded to GDEB under a CPFF structure. The initial decision to utilize two shipyards for SSN 774, SSN 775, SSN 776, and SSN 777 has been extended through the current build and will likely continue through Block IV in January 2014. The Virginia-class builds to date, as organized in block build, are reflected in Table 5 (DAMIR, 2011a, 2012a).

Block	Hull Numbers
1	SSN 774–777
2	SSN 778–783
3	SSN 784–791
4	SSN 792-TBD

Table 5. Virginia-Class Block Build Schedule (after U.S. Navy, Commander Submarine Forces Atlantic, 2013)

1. Utilizing Two Shipyards

The two shipyards selected to build Virginia-class were Electric Boat, Inc., of Groton, CT, and Newport News Naval Shipyard in Virginia, which also builds and refuels Nimitz-class and Ford-class aircraft carriers. The construction of two submarines per year was beneficial because it provided enough work to employ the workers of two shipyards simultaneously, it alleviated a single point of vulnerability in the event of a wartime attack on shipbuilding, and it provided replacement submarines for the existing submarines as they were decommissioned. The constant production of two submarines allows the Navy to meet national security requirements (DAMIR, 2012a; Johnson et al., n.d.; Schank et al., 2011). The initial four submarines were built jointly between the two shipyards. Subsequent contracts are planned as a sole-source contract while keeping existing business practices in place.

The major component division of labor is described in *The VIRGINIA Class Submarine Program: A Case Study*, by General Dynamics–Electric Boat (2010, p. 33):

> EB is the lead design contractor and lead construction contractor while NNS is a co-construction contractor. EB and NNS will final-assemble alternate ships, EB delivering the SSN774 and SSN776, and NNS delivering SSN775 and SSN777. The construction work is evenly split between EB and NNS. Modules and hull cylinders are fabricated at EB Quonset Point, RI, and shipped by barge to the two final assemblers – EB Groton, CT, and NNS. NNS fabricates modules and installs them in hull cylinders for final assembly in their shipyard or ships them by barge to EB Groton for final assembly. Each shipbuilder manufactures the same section for every ship with one exception that is always manufactured by the final assembly/delivery yard.

The use of two shipyards in the construction of the Virginia-class has been successful in meeting goal of employing two shipyards while still producing a high-quality product. The collaboration between the Navy and contractors, in all phases of production and through the co-location of teams with each team being present in the other shipyard, is the key to these two builders consistently producing Virginia-class submarines that pass the Navy’s acceptance trials (General Dynamics–Electric Boat, 2010).

2. Military Industrial Complex

One of the primary drivers behind the early decommissioning of several Los Angeles-class submarines at mid-life refueling was an effort to protect the military-industrial complex by providing a steady supply of new contracts for submarine construction. As of 2013, 20 of the 62 Los Angeles-class submarines have been decommissioned (Schank et al., 2011).

The initial Virginia-class acquisition strategy was to design and build at a single shipyard, Electric Boat, for the entire Virginia-class (Schank et al., 2011). The decision was later reversed because a modified build plan required that SSN 775 and beyond would be constructed in a collaborative effort from two shipyards. This decision—described in *The VIRGINIA Class Submarine Program: A Case Study* (General Dynamics–Electric Boat, 2010) and the RAND Corporations' *Learning From Experience: Volume II* (Schank et al., 2011)—was made by the U.S. Congress in the interest of protecting national security. Lawmakers believed that concentrating skills and abilities for the construction of nuclear-propulsion submarines in one shipyard left them vulnerable and did not provide Congress with sufficient industrial scalability in the event of rapid escalation of submarine construction (Schank et al., 2011).

E. INITIAL ACQUISITION SOURCES OF COST GROWTH

1. Seawolf-Class

Rework costs on Seawolf-class were the most significant driver of cost increases in the program. Incomplete drawings were often issued to start production on immature designs that had not yet been proven in testing, resulting in rework when modification or replacement was required (Schank et al., 2011).

To express the cost growth in terms of budgeted dollars, the sources of cost growth for the acquisition grew by the following amounts (expressed in percentage and based on data supplied that compares all data in base year for the Seawolf-class): 1990: RDT&E +320.7.

Specific contributors of cost growth were as follows:

- schedule +18.1
- engineering +141.0
- estimating +108.0
- support +52.3.

The procurement budget category was negative because procurement was halted at three submarines; however, cost growth within the estimating budget subcategory grew by +952.9% (DAMIR, 1999a).

2. Virginia-Class Cost Overage Sources

There were numerous sources of cost overages for the Virginia-class submarine. The acquisition and industry experts never stopped combatting the unfavorable cost variances. The concerted efforts by these acquisition professionals were successful over time.

a. Research, Development, Test, and Evaluation

The largest source of cost growth in the RDT&E category on the original baseline of the Virginia-class program was in the engineering subcategory with a $556 million (1995 dollars) growth above the 1995 estimate. The RDT&E category, estimating that the subcategory had a favorable cost variance of ($111.2) million (1995 dollars), the total RDT&E variance was $445 million (1995 dollars; DAMIR, 2012a). Table 6 reflects the cost variances of the program.

Changes in estimating have since resulted in an additional $184 million (1995 dollars) favorable variance. Specific drivers of this cost reduction are a reduction in the following, expressed in 1995 dollars:

- RTOC estimating $91.3 million;
- reduction to Virginia-Class Payload Module program estimating $15.9 million;

- estimating process improvements for hull, mechanical, and electrical (HM&E) and combat systems improvements $73.9 million; and

- estimating $2.9 million.

The current RDT&E summary is $261 million (1995 dollars) unfavorable over the initial estimate (DAMIR, 2012a).

	RDT&E	Procurement	Total
SAR Baseline (prod est.)	6351.2	86856.1	93207.3
Previous Changes			
Economic	+6.9	+3575.1	+3582.0
Schedule		392.7	392.7
Engineering	798.0		798.0
Estimating	(162.6)	(4307.8)	(4470.4)
Support		(233.4)	(233.4)
Subtotal	642.3	(573.4)	68.9
Current Changes			
Economic	36	1758.8	1794.8
Quantity	0	0	0
Schedule	0	(1845.3)	(1845.3)
Estimating	(264.3)	(1126.4)	(1428.8)
Total Changes	414	(1773.9)	(1359.9)

Table 6. Virginia-Class Cost Variances, 1995 Dollars (after DAMIR, 2012a)

3. Virginia-Class Procurement

The largest source of cost growth was schedule overruns with $129.7 million (1995 dollars) when comparing the initial schedule with cost incurred. Support had a favorable cost variance of $158.7 million (1995 dollars) and estimating was favorable ($2613.6 million in 1995 dollars; DAMIR, 2012a).

Changes in procurement have resulted in a favorable variance of $877.2 million (1995 dollars) and $599.1 million (1995 dollars) in estimating. The only unfavorable cost in procurement is support at $13.2 million (1995 dollars). The acceleration of procurement by moving a 2020 ship to 2014 and gaining favorable economic terms resulted in savings of $877.2 million (1995 dollars), estimate revision resulted in a savings of $638.5 million (1995 dollars), adjustment for prior escalation estimates $291.5 million (1995 dollars), reduction to estimates of the technology insertion program estimates $52.5 million (1995 dollars), revised estimate for spares $3.4 million (1995 dollars), a revised estimate for shipbuilding and conversion $4.8 million (1995 dollars), and an adjustment for current and prior support escalation $1.3 million (1995 dollars). Sources of cost growth are as follows: advance procurement funding for 2018 class extension estimating $314.6 million (1995 dollars), revised estimates due to refinement of requirements caused by estimates $73.6 million (1995 dollars), and modified estimate for initial spares $17.9 million (1995 dollars; DAMIR, 2012a).

Significant favorable cost variances continue to be realized in part through labor and fixed shipyard overhead reduction costs. A major contributor to these savings is the refined modular design build process, which contributed to the USS *Mississippi* (SSN 782) delivery 12 months early. Although improvements in labor costs do not occur in every submarine, a relationship between cost and schedule variance exists.

USS *Virginia* (SSN 774) was delivered to the Navy in 2004 with a total schedule variance of four months. This overrun reflects a significant improvement over the performance of previous programs of Ohio-class and Seawolf-class. The first Ohio-class was delivered 19 months late, and the first Seawolf-class was 25 months late (Schank et al., 2011).

4. Material Costs

Contributors to unfavorable material cost variances are mixed but represent 43% of cost growth. Specific sources are increases in supplier costs of material in excess of 40% beyond estimates and fewer suppliers of highly specialized material. Despite focused efforts to curb excess costs incurred in Seawolf-class and Ohio-Class, cost growth was incurred due to a lack of design maturity in specialized electronic components (DAMIR, 2012a; Schank et al., 2011).

5. Inaccurate Estimates

Labor costs on the Virginia-class were underestimated by 40%. The contributors to this growth were as follows:

- increases in wages at Newport News Shipyard,
- new product introduction at Newport News Shipyard, and
- new workforce at Newport News Shipyard.

These increases were caused by a combination of their lack of recent experience in building submarines, familiarity with the Virginia-class, retooling processes, and a shift in the local knowledge of the workforce who were more experienced in working on Nimitz-class aircraft carriers. Additionally, supply chain management failures resulted in work delays. A number of key parts were not available when scheduled in the build process (Schank et al., 2011).

Even though these inaccurate estimates for the Virginia-class were closer to actual cost estimates in comparison to previous nuclear-powered submarines, it should be recognized that the first units of nearly all expensive acquisition programs (ACAT 1 C/D) exceed cost estimates. Nuclear-powered submarines and related facilities have consistently exceeded cost estimates by a significant margin on initial units (Birkler et al., 1994).

The Navy's method for estimating the number of ships and submarines that it will need to build has a fundamental flaw: The Navy has been unable to accurately project the likelihood of cost growth. As referenced in the February 2005 GAO report, *Improved Management Practices Could Help Minimize Cost Growth in Navy Shipbuilding Programs*, the Navy does not account for the probability of cost growth when estimating costs. This most recently occurred in the early builds of the Virginia-class, prior to rebaselining. This failure to account for cost growth, historically speaking, results in program cost overruns.

6. Changing Requirements

Another source of cost growth for the Virginia-class program was a change in bubble pulse regulations. This regulation change affected how the ship was designed and created cost growth through redesign work. Changes to acoustic requirements resulted in redesign work from original specifications. These examples of scope creep increased costs in procurement.

7. Personnel

The costs to reconstitute a workforce and suppliers capable of designing and building a new submarine that has been allowed to atrophy during periods of inactivity is high in comparison to other ACAT 1 programs. In the study *The U.S. Submarine Production Base* (Birkler et al., 1994), the following excerpt was provided:

> Personnel-related reconstitution costs dominate. This is true across all cases and all restart years. The costs of rebuilding a workforce account for two-thirds to 90 percent of all shipyard reconstitution costs in submarine construction. The reasons for this are given in the factors listed in the description of the workforce model: Not only is it necessary to account for hiring and training, but also for the inefficiency of newly hired workers and the need to allocate fixed shipyard overhead to the few boats that a slowly growing workforce can simultaneously build. (p. 40)

Virginia-class was not immune to these findings. Further analysis and relationship recognition is covered in following sections.

F. COST REDUCTION

Cost overruns on the Seawolf-class drove the Navy to focus on controlling cost growth on the Virginia-class. Seawolf-class was not designed and built at the same location, thus contributing to cost and schedule overruns. Designing and building Virginia-class at the same location was a must. A major source of cost-growth reduction was to eradicate the cost growth experienced on Seawolf-class as a result of concurrent development and ship construction (Schank et al., 2011).

1. Understanding and Implementing Lessons Learned

Not repeating the mistakes made on Seawolf-class was a priority to the Navy and was seen as a great enabler to controlling cost growth and reducing risk. The most common factor in cost growth is the current estimating system that does not factor in sensitivity analysis for risk. The reduction of risk was soon a key to making Virginia-class affordable and surviving as an acquisition. Not replicating the mistakes made in the Seawolf-class was accomplished through reviews of lessons learned in the acquisition of the program.

The following were key tenants of the Seawolf-class lessons learned:

- insertion of only mature technology;
- strengthening the specification development and approval process;
- logistics and identifying critical components who will supply them early in the program;
- reducing the combat system development risk;
- economies of scale through building two boats at once; and
- economies of scale through utilizing the resources, including labor pool at two shipyards (Schank et al., 2011).

2. Initial Incentive Systems

The Earned Value Management System (EVMS) was employed by the PM through cost performance indices (CPIs) and schedule performance indices (SPIs) to monitor construction progress (Schank et al., 2011). Examples of specific employment of EVMS in construction were comparisons of drawing type versus schedule, production plan versus schedule, and special instruction packages versus schedule (Schank et al., 2011).

Despite the close relationship that EVMS created between the budget and construction schedule, it did not stop the decisions which resulted in cost growth of USS *Virginia*. A 32.66% PAUC, which resulted in a Nunn–McCurdy breach, and a 29.91% APUC were incurred in the original baseline (DAMIR, 2012a).

Part of the cost growth on the initial block is attributable to requirements scope creep as experienced through "bubble pulse" regulations. This change had a cascading effect through design and acoustic signatures, requiring redesign work (Schank et al., 2011).

3. Mandated Competition through Duopoly

Sourcing submarines through two shipyards for national security considerations was one of the drivers behind the decision to source it from two locations. Because neither shipyard had a monopoly on the construction to force competitive prices, cost growth was controlled. Following congressional approval that would assign approximately 50% of the work on each submarine to both shipyards, GDEB and Northrop Grumman–Newport News established an agreement that profits would be split down the middle between the two builders after each submarine was delivered to the Navy (GAO, 2003).

Contracts on new construction of the Block IV submarines, starting in 2014, will be a sole-source contract to GDEB with 50% of the work being contracted to Northrop Grumman–Newport News. The profits of the contract will continue to be split 50/50, as in previous builds.

Most large defense acquisitions in the Navy last for several years; dividing production into build batches is referred to as *blocks*. Improvements or changes in the program are typically made when a new block build is started. In the case of the Virginia-class submarine, Block IV will have 10 submarines and will be in place from 2014 to 2018 until Block V supersedes it. Block IV is consistent with a five-year contract for 10 submarines, five to each contractor. Changes in Block IV are modeled to achieve savings in the O&S phase of the Virginia-class' life cycle (DAMIR, 2012a).

4. Communication with Vendors

Virginia-class brought the major vendors that supplied components for construction closer and made them a part of the process. This brought the supplier closer to the buyer and removed the spatial and perceived distance that commonly exists in production. Although the Navy's position of the design *authority* had not changed, the vendors were now included and had the ability to provide meaningful input into the process of reducing costs of the program without compromising performance (Schank et al., 2011).

5. Construction Efficiencies

Construction efficiencies were gained by improving on a previous modular design used in the construction of the Ohio-class. The initial build had 10 modules that were later reduced to four super modules. This change resulted in decreased construction time and fixed overhead costs.

The reduction of construction time was a major focus in lowering the per-unit cost of the program. Each day that a submarine is in production, the costs of labor and fixed overhead costs contribute to the overall cost of construction. Shortening production time results in lower costs of production and contributes to controlling cost growth. The source of the decision to move to four super modules was the Virginia-class PM reducing construction time from 88 to 60 months (R. Sykes, personal communication, January 18, 2014).

6. Threat of Cancellation

In 2005, the Navy and the Virginia-class program office were given a goal and ultimatum by Admiral Mike Mullen: Reduce the cost of each Virginia-class submarine or face program cancellation. This sobering reality can be viewed as the catalyst that turned the program around through controlling, and in some cases, reversing cost growth (Johnson et al., n.d., p. 4).

Following Admiral Mullen's ultimatum, GDEB submitted a proposal to the Virginia-class program office on a course of action to reduce costs to a level at or below Admiral Mullen's established $2 billion level. The proposal consisted of the following elements:

- determine the cost drivers from construction costs to date;
- develop cost targets and specify reductions from cost area;

- develop a cost framework to guide decisions about cost reduction efforts; and
- establish a comprehensive program plan to integrate and implement the effort (Johnson et al., n.d.).

The impact of this ultimatum cannot be overstated; when the program faced cancellation, the trend toward cost growth was reversed. Although a qualitative consideration, this appears to be more effective in spurring beneficial evolutionary improvements than the traditional incremental approach to process improvement.

The Virginia-class' cost growth was ultimately brought under control, but it is unknown whether the various teams would have been as effective if they had not been motivated by this unavoidable mandate. The chief of naval operations' (CNO's) "if-then" execution orders led to a clear, defined goal of controlling cost, and ultimately to the program office's successful reduction in costs. This unwavering cost threshold led to the contractor hiring Booz Allen Hamilton (BAH) and the implementation of a broad-ranging and innovative cost reduction effort.

G. LESSONS LEARNED

1. Virginia-Class

The most significant lesson learned in designing and building the Virginia-class was not to repeat the mistakes of previous submarine acquisition programs, but to make corrections and/or improvements before construction work commenced. In qualitative terms, the relative success that the Navy is enjoying in the procurement of Virginia-class submarines can be attributed to a culmination of management efforts. Management efforts, made prior to construction, focused on not repeating the mistakes of previous acquisition programs and on inserting innovative practices into the program. Certainly, there was cost growth incurred in the program, some due to inaccuracy in estimate assumptions and some due to design changes. Some cost growth was due to factors that could not have been accurately projected in the design phase, such as healthcare and employee wage inflation, which far outpaced the consumer price index (CPI). Ultimately, the various RTOC enablers, such as IPTs, use of the IPT framework, and the policy of standardization and commonality in design contributed to meet the goal of achieving affordability.

2. Focus

The primary focus of the program was to control costs while developing a versatile submarine. The necessity of this aim was punctuated when the CNO's ultimatum to procure two submarines for $4 billion (in CY 2005 dollars) in 2012 was issued. This mandated required a reduction in sailaway costs or else lose the Virginia-class along with losing major business infrastructures within the military-industrial base due to closures driven by contract cancelations. Meeting this ultimatum required that $400 million in costs per submarine be cut. The increase in urgency that followed resulted in decisions, innovations, and enablers, leading to not only the halting of cost growth but also actual procurement savings and projected savings for the future operations and sustainment phase of the program (O'Rourke, 2013).

The Virginia-class was built to compete with the most advanced submarines in the world, but the majority of the technology incorporated was mature and available, and unlike similar programs, was not the primary driver of the program. For Virginia-class, the focus on cost savings has allowed the program to control cost growth more effectively in comparison to other ACAT 1D acquisitions (DAMIR, 2012a).

3. Integrated Master Schedule

The integrated master schedule (IMS) provided cohesiveness between major contributors in the design and construction of Virginia-class. The IMS resulted in the completion of 99% of Virginia-class drawings after three years, a great improvement in comparison to Seawolf-class' 65% at the three-year mark (DAMIR, 2012a).

4. Iterative Process

The Virginia-class process continues to achieve procurement savings as they begin the Block IV build of the program. One of the major success stories in the process is the cost savings that came as a result of improvements to the modular build approach.

The submarine originally consisted of 10 modules that were later pieced together to form super modules.

Reducing the number of modules, starting with USS *New Hampshire* (SSN 778), resulted in significant cost savings, as only four super modules were required in the submarine. The reduction in the number of modules to four positively contributed to the reduction in build time from 84 to 60 months per submarine, directly reducing the PAUC as well (Johnson et al., n.d.).

5. Tradeoff

Virginia-class represents a possible shift in future acquisitions in which precious DOD procurement dollars will be in greater demand. The fall of the Soviet Union resulted in Congress and the Navy procuring a submarine on cost through a compromise in capability (e.g., quietness, firepower, targeted capability) to accept enough quantity to meet force structure requirements.

6. Capital Expenditures

In support of the Virginia-class program, the Navy made a relatively small investment in capital expenditures initially. An initial investment of $9.4 million was made at the Electric Boat Quonset Point Facility that is projected to save $71 million in manufacturing costs over the life of the 30 shipbuilding programs. Total capital investments of $63 million are expected to yield $422 million in savings through the fiscal year (FY) 2020 submarine. The program’s capital investments are considered successful when they directly contribute to decreasing the build time per hull (Johnson et al., n.d.).

IV. SAN ANTONIO-CLASS SHIP STUDY

This chapter informs readers of the specifics of the U.S. Navy's San Antonio-class amphibious ships, giving the reader an understanding of the industry in order to comprehend the acquisition of this vessel. The term LPD derives from the Navy coding system for vessel types; amphibious (L), transport (P), and dock (D) ships are knows as LPDs. This chapter relies heavily on the previous work of Ronald O'Rourke (2011), specialist in Naval Affairs, in his *Navy LPD-17 Amphibious Ship Procurement: Background, Issues, and Options for Congress*. The full report is available through the Congressional Research Service (CRS).

A. INTRODUCTION TO THE SAN ANTONIO CLASS

The San Antonio-class program began in the 1990s to replace four different amphibious class ships that were either already retired or, in the case of the Austin-class ship, preparing to retire. With the lead ship, the USS *San Antonio* (LPD-17), construction began in August 2000 and was delivered to the Navy in July 2005. The mission of the amphibious class ship is to transport marines and their equipment in support of military operations on shore. Amphibious ships have been used increasingly in non-combat situations, such as humanitarian assistance and disaster response missions, since they are ideally suited to perform this role.

1. Amphibious Force Structure

To support the marines in their ability to conduct operations, the Navy has requested a 33-ship amphibious force. The Navy's amphibious forces are made up of six classes of ships (amphibious inventory as of November 2013):

- (8) Wasp-class (LHD-1)
- (1) Tarawa-class (LHA-1)
- (8) San Antonio-class (LPD-17)
- (3) Austin-class (LPD-4)

- (8) Whidbey Island-class (LSD-41)
- (4) Harpers Ferry-class (LSD-49) (U.S. Navy, 2013)

The San Antonio-class will have a total of 11 ships. Currently, eight LPDs have been built, the latest commissioning April 6, 2013. There are two LPDs under construction and a final LPD authorized for construction. These three ships will replace the remaining LPD-4 class ships when they are decommissioned. The Senate Appropriations Bill for 2013 has provided funding for the initial acquisition of a 12th LPD-17 (Inouye, 2012).

2. LPD-17 Acquisition Background

After a competed bidding process, Avondale Industries was awarded a $641 million cost-plus-award-fee contract in 1996 for engineering and manufacturing development. The San Antonio-class was built to support the Marine Corps warfighting concept "Operational Maneuver from the Sea," as well as to replace outdated amphibious ships (Office of the Inspector General, 1998). The capabilities requirements for the San Antonio-class are as follows:

- conducting over-the-horizon landing operations;
- carrying assault vehicles and landing craft;
- allowing the AV-8 to land and take off from the flight deck;
- reducing radar cross section; and
- carrying compartments configured for amphibious craft logistics support, aviation maintenance and medical treatment (Office of the Inspector General, 1998).

The concern for controlling cost was an ever-present aspect of the San Antonio-class program. One of the tenets of the program was to target program cost drivers. The understanding that paying more during the early stages to reduce costs over the 40-year life cycle was an important concept shaping the San Antonio-class program. After the Cold War, there was no single, large superpower like the USSR to contend with. Military leaders realized that future warships would need to be highly flexible to counter unknown threats. Designing ships to be flexible can be problematic if these capabilities interfere with other desired mission activities. One example of this type of design problem that occurred during the San Antonio-class program design process was the requirement for reduced radar cross-section that, in order to comply with this design requirement, created issues with traditional methods for using ship's boats (Fireman, Nutting, Rivers, Carlile, & King, 1998).

B. SAN ANTONIO-CLASS ACQUISITION STRATEGY

Developing an acquisition strategy is important in providing direction and guidance for the program personnel. The Navy designed the acquisition strategy for the San Antonio-class program to accomplish three objectives:

- operate with ease in performing mission requirements to support the warfighter;
- expedite ship deliveries with no degradation of quality; and
- install applications and products that reduce life cycle cost growth (Office of the Inspector General, 1998).

To support these goals, the Navy solicited input from the warfighters and developed the "LPD-17 War Room." This is where the warfighters, engineers, and trainers could collaborate on problems and issues to develop solutions early in the development process. The San Antonio-class program incorporated numerous management tools designed to reduce cost. The San Antonio-class program used IPTs consisting of subject matter experts in various fields that have developed and logistically supported similar systems. The focus of these efforts was to make meaningful changes early in the program where it would cost less than if those changes were made later. An important cost-saving process that was first used and developed during the San Antonio-class program was the integrated product and process development (IPPD).

1. Integrated Product and Process Development

In 1995, the undersecretary of defense directed a significant change in the way that the DOD acquires weapon systems in that the concepts of IPPD and IPT were applied in the acquisition process. The DOD defines IPPD as

> a management technique that simultaneously integrates all essential acquisition activities through the use of multidisciplinary teams to optimize the design, manufacturing and supportability processes. (Office of the Under Secretary of Defense [OUSD], 1998, p. 1)

There are five main principles for implementing the IPPD process:

- customer focus,
- concurrent development of products and processes,
- easy and continuous life-cycle planning,
- proactive identification and management of risk, and
- maximum flexibility for optimization and use of contractor approaches (OUSD, 1998).

The details of the IPPD process are tailored to the specific program that is using it. Not all programs go through the various phases or decision points that any other program goes through. The IPPD process is flexible in its ability to integrate various activities based on the requirements of each program.

2. LPD-17 Integrated Product and Process Development

The IPPD process was used by the program office in making decisions that would reduce costs. In the report *LPD 17 on the Shipbuilding Frontier: Integrated Product & Process Development*, Fireman et al. (1998) discussed the fundamentals of this tool and how it applied to the San Antonio-class program. For the LPD-17, the fundamental pillars for the IPPD were goals, people, process, and tools. These pillars, as they apply to the San Antonio-class program, are defined here.

a. Goals

(1) Satisfy Customer Requirements. Identifying the customer can be difficult for a government program and not as straightforward as one would surmise. The customers for a government program can vary from the program office to the end user and ultimately the taxpayer—the people buying this system (Fireman et al., 1998).

(2) Reduce Total Ownership Costs. When the San Antonio-class program reached milestone II in June 1996 (using current terminology, this would be Milestone B—entry into Engineering and Manufacturing Development), the program performed an analysis of the TOC drivers. The main O&S cost drivers were identified as manpower and maintenance. By focusing on reducing costs in these areas, the IPPD determined that it would be able to reduce TOC (Fireman et al., 1998).

(3) Reduce Cycle Time . Reducing the time taken on any step during the acquisition stages can reduce cost. The San Antonio-class program focused its cycle time reductions on the contract change, ship production, total ship testing, logistics, shipboard maintenance, and the government decision-making processes. The less time spent on each of these processes, the more the program could reduce costs. This type of schedule change must be carefully managed because if essential activity is omitted at a critical stage, it could have cost and time implications if they affect the developmental or manufacturing process (Fireman et al., 1998).

(4) Reduce Program Rework. As with any production process, the goal of reducing rework can lead to significant cost savings. The IPPD's goal focused on eliminating possible problems in the product development phase, early in the program, to reduce the amount of rework in later phases. Such a goal must be carefully balanced against reduction in cycle time because the two may pull in opposite directions (Fireman et al., 1998).

(5) Total Ship System Integration. The integration of new ship systems had to be integrated into the ship's command, control, communication, computers, and intelligence (C4I) infrastructure. This concept was new for a ship in which previously installed systems were integrated into only the mission area that it was going to support. With the new concept of total ship system integration, these new systems had to be integrated not only to their mission areas, but also into the entire ship's system (Fireman et al., 1998).

(6) Long-Term Relationship. The San Antonio-class program is expected to be around for 40 years. This will require a working relationship with the contractors over this entire period (Fireman et al., 1998).

b. People

The people involved in the IPPD system are the most important aspect to the success of the program. Clearly defined goals and tasks help to clarify the direction the IPPD will take and aid in its effectiveness. The people making up the IPTs must have the skills and experience in all stages of a ship's life, and they must also be composed of people from both sides of the government–contractor relationship. For the San Antonio-class, the IPTs were co-located at an agreed-upon contractor site. Being co-located meant that this team shared the same room on the same floor in a building. Interaction and communication is important for the IPTs to function properly, and placing these people in the same room aided in that. At the head of the IPPD structure was the program management team (PMT). The PMT was co-led by the PMs from both the government and the contractor. Below the PMT were seven IPTs. These different IPTs focused on different systems, products, or components for the life of the ship (Fireman et al., 1998). The focuses of these IPTs were as follows:

- integrated ship electronics team (ISET),
- distributive systems team,
- accommodations team,
- hull team,
- topside team,
- mission team, and
- machinery team.

Many of the issues that these teams were solving may have affected other teams. To ensure the IPTs were not developing problems for other teams, the IPT structure had four cross-product teams (CPTs). Each IPT had representation in the CPTs allowing for coordination and performance monitoring of their efforts to achieve reductions in total life-cycle costs. The four CPTs consisted of the following:

- ownership team,
- total ship engineering team,

- integrated product data environment team (IPDE), and
- combined test team (Fireman et al., 1998).

(1) Training. The use of IPTs was a new approach, having been launched across DOD acquisition systems in 1995 and requiring extensive training of personnel in how these teams would work to achieve their goals. These teams were made up of people from different organizations with different specialties and different cultures. Training helped to ensure that these differences did not hinder the communication process or the ability to solve ship integration issues. The training consisted of three phases over the course of 10 weeks: (1) the focus highlighting the goals of the program, key processes, and rules of behavior; (2) various schedule and integration plans; and (3) a self-assessment process (Fireman et al., 1998).

c. Processes

The IPPD process is a combination of multiple series of processes that come together to form an effective management tool. These processes are product development, risk management, design for ownership, RTOC, life-cycle support, design integration, and management tools (Fireman et al., 1998).

(1) Product Development Process. The acquisition process must take into consideration three areas of concern (cost, schedule, and risk) that can drive costs. The production development process is divided into six phases. The first phase, defining product requirements, reviews multiple areas for detail design requirement, the most important being allocation of RTOC goals. The goal of one of the activities that occurs in the second phase, define ship systems, is to perform engineering analysis in multiple areas, one of which is TOC (Fireman et al., 1998).

(2) Risk Management Process. Risk was identified and assessed at each step of the process. Identifying risk early allowed the program to make decisions to mitigate this risk early in the design process when the cost to change was lower. A risk mitigation program was developed and assessed quarterly by the program management team (Fireman et al., 1998).

(3) Design for Ownership Process. One of the key focuses of the San Antonio-class program was designing the product for the user. By identifying the customers and the users early, the program was able to focus on designing a product best suited for them. In order for the San Antonio-class program to do this, it included operators, maintainers, and trainers in the design process early to ensure that its requirements were included in the final product. The San Antonio-class program management team realized it could reduce the amount of rework that might be required if the customers were involved in the design process early. Finding ways to reduce rework can reduce the acquisition cost of a program. The enablers that were used in order to bring all of these players together were a series of workshops that focused on specific areas of concern (Fireman et al., 1998). Some of the workshops that the San Antonio-class program used were as follows:

- expeditionary warfare,
- missions and capability,
- manning requirements,
- C4I requirements,
- habitability requirements,
- maintenance requirements,
- training requirements,
- combat cargo requirements,
- pre-commissioning requirements,
- mixed-gender crew and troop requirements, and
- aviation requirements.

The design for the ownership process used virtual mockups to obtain useful end-user feedback. If this feedback required a change, the program manager could still make these changes early in development while the cost to do that was low (Fireman et al., 1998).

(4) Reduced Total Ownership Cost Process . As mentioned earlier, RTOC was an important focus for the San Antonio-class program. The program team focused on all known cost drivers and developed tools or policies that led to better ways to reduce cost. The program team identified high-level design activities in the master integrated work schedule (MIRWS), and when each of these activities began, a meeting was held, composed of members from the various CPTs. During these meetings, a collection of lessons learned and opportunities to reduce TOC were discussed and, if found, forwarded to Program Management Ships: San Antonio-Class (PMS 317) change control board (CCB; Fireman et al., 1998).

(5) Life-Cycle Support Process. An important area in reducing TOC is to focus on the cost over the entire life cycle of the system. Both the contractor and the government must develop plans that consider the cost associated with running a program throughout its life. The San Antonio-class program included, in the Avondale contract, a line item option for life-cycle support planning. This contract line item number (CLIN 009) was exercised in October 1998 (DAMIR, 1999b; Fireman et al., 1998).

(6) Design Integration Testing. Ensuring the systems were compliant with the total ship integration concept required significant testing throughout the design process. The goal of incorporating design integration testing early in the development of these systems was meant to reduce the amount of possible rework that may be required once these systems were in production or just before the delivery of the ship (Fireman et al., 1998).

(7) Management Processes. In order to effectively manage the various aspects of the San Antonio-class program, the PMT developed the following processes: government representatives at Avondale, the MIRWS process, the change process, and the IPDE process. The government detachment was composed of representatives with sufficient technical, legal, contract, and financial authority to effectively resolve issues early at the shipbuilding site. As mentioned in subsection 4 above, the MIRWS process was the tool that the program used to manage activities. This process linked and connected various schedules, resources, and events together to create and manage the program timeline. This system identified key milestones and their associated exit criteria.

The goal of this system was to reduce the amount of rework associated with items that were started early in the timeline (Fireman et al., 1998).

The IPPD process was started early in the San Antonio-class program and required flexibility to change and evolve as the program progressed. Bringing customers and team members together early in the acquisition process can help reduce cost (Fireman et al., 1998).

C. FIRST SAN ANTONIO-CLASS CONSTRUCTION

The San Antonio-class was the first Navy shipbuilding program aimed at minimizing military specifications and standards (MILSPECS). By foregoing the traditional requirements for MILSPECS during construction, the contractor could capitalize on cost savings by using commercial off-the-shelf (COTS) technologies (Office of the Inspector General, 1996). Initial construction commenced with the USS *San Antonio* (LPD-17) in August 2000, and the ship was commissioned in 2005.

1. Initial Estimates

The San Antonio-class program had an initial PAUC of $751.55 million. This included startup costs associated with initial construction. Table 7 shows the difference in the PAUC and the APUC from 1996 to 2012 in millions of U.S. dollars

Cost Measure (per unit)	May 1997 APB	Current Estimate 2012 SAR	Over Initial Cost
PAUC	751.55	1292.782	72%
APUC	743.825	1282.227	72%

Table 7. A Per Unit Cost Comparison in the Acquisition of the San Antonio-Class (after DAMIR, 1997b, 2012b)

2. Acquisition Timeline

The PAUC and APUC changed throughout the life of the San Antonio-class program. An intial baseline was established in May 1997. Table 8 shows the initial cost per unit estimate and the May 1997 baseline.

Cost Measure (per unit)	May 1997 APB	Current Estimate Dec 1997 SAR	Cost Per Unit Dec 1997 SAR
PAUC	9018.6	8729.9	729.158
APUC	8925.9	8649.8	720.817

Table 8. A Total Program Comparison of Cost Estimates in the Acquisition of the San Antonio-Class (after DAMIR, 1997b)

The change from the baseline to the December 1997 estimate was mainly in the procurement funds in adjusting for current and prior inflation and revising the estimate for combat systems capability. The contract awarded to Avondale in December 1996 had a target price of $641 million with a PM-estimated price at completion of $646.7 million (DAMIR, 1997b). Table 9 shows these changes against the May 1997 baseline.

Cost Measure (per unit)	May 1997 APB	Current Estimate Dec 1998 SAR	Cost Per Unit
PAUC	9018.6	8732.4	727.7
APUC	8925.9	8633.9	719.492

Table 9. A Comparison of Cost Estimates in the Acquisition of the San Antonio-Class from 1997 to 1998 (after DAMIR, 1998)

The PM estimated the price at completion to be $666.6 million with negative cost and schedule variances. The negative cost variance was attributed to an increase in the training required for the new IPPD teams and the requirement for the IPDE systems to function earlier than orginally planned (DAMIR, 1998). Table 10 shows the cost variance against the 1997 baseline.

Cost Measure (per unit)	May 1997 APB	Current Estimate Dec 1999 SAR	Cost Per Unit
PAUC	9018.6	9693.6	807.8
APUC	8925.9	9596.0	799.667

Table 10. A Comparison of Cost Estimates in the Acquisition of the San Antonio-Class between 1997 and 1999 (after DAMIR, 1999b)

The greater-than-anticipated start-up cost for the IPPD and the IPDE continued in 1999 as costs continued to grow. In addition to the earlier problems, there was also a lack of government-/vendor-funished information, insufficient resources, and less than anticipated performance resulting in a lack of progress in the program. At the request of the assistant secretary of the Navy for research, development, and acquisition (ASN[RD&A]), there was a yard-wide review of Navy programs at Avondale. One of the results of this review was for Avondale to propose a 10-month delay in the delivery of the USS *San Antonio* and a delay of less than six months for the USS *New Orleans* (LPD-18). The delivery date was extended to September 2003, a slip of 10 months that resulted in a breach in the APB. The PM estimated the price at completion to be $871.8 million (DAMIR, 1999c).

a. Continuing Delays

Construction of the lead ship began in August 2000, and after cost and schedule performance was analyzed, it was realized that a further schedule modification would be required. An independent schedule assessment was conducted, and as a result, an additional 14 months was required to complete the lead ship. The schedule delay was found to be the result of the limited ability of the prime contractor to deal with increasing design complexity and integration. On November 14, 2001, the secretary of the Navy notified Congress that the PAUC and APUC exceeded the APB by more than 25% and was a Nunn–McCurdy breach (DAMIR, 2001). Table 11 shows these cost increases in the current estimate against the 1997 baseline.

Cost Measure (per unit)	May 1997 APB	Current Estimate Dec 2001 SAR	Cost Per Unit
PAUC	9018.6	12939.5	1078.292
APUC	8925.9	12842.4	1070.200

Table 11. A Comparison of Cost Estimates in the Acquisition of the San Antonio-Class between 1997 and 2001 (after DAMIR, 2001)

The two-year schedule delay and profile adjustments resulted in an increase of $1.3 billion in program costs and was the primary reason for the FY2001 and FY2002 hiatus in San Antonio-class procurement (O'Rourke, 2011). Unit APUC increased significantly when the program costs were spread over eight ships instead of 12 when those later ships would have lower costs (DAMIR, 2001). Actions taken to control costs included the following:

- changed contract to cost-plus incentive fee/award fee (CPIF/AF),
- used contractor performance assessment reporting system (CPARS) as a measure of past performance,
- incorporated FAR provision 52.248–1 to target cost reduction/cost avoidance (DAMIR, 2001).

Table 12 shows the 2002 rebaseline with the current estimate as compared to the 1997 baseline.

Cost Measure (per unit)	May 1997 APB	Jun 2002 APB	Current Estimate Dec 2002 SAR	Cost Per Unit
PAUC	9018.6	12939.5	13399.6	1116.633
APUC	8925.9	12842.4	13299.2	1108.267

Table 12. A Comparison of Cost Estimates in the Acquisition of the San Antonio-Class between 1997 and 2002 (after DAMIR, 2002)

A major decision made in 2002 to reduce cost was to sign a workload swap agreement between Navy, Bath Iron Works, and Northrop Grumman Ship Systems (NGSS), consolidating construction within the NGSS Gulf Coast facilities (DAMIR, 2002). Table 13 shows the 2003 estimate against the 1996 baseline.

Cost Measure (per unit)	May 1997 APB	Jun 2002 APB	Current Estimate Dec 2003 SAR	Cost Per Unit
PAUC	9018.6	12939.5	10304.9	1144.989
APUC	8925.9	12842.4	10192.1	1132.456

Table 13. A Comparison of Cost Estimates in the Acquisition of the San Antonio-Class between 1997 and 2003 (after DAMIR, 2003)

b. Reduction in Build Quantity

The FY2006 president's budget reduced the total quantity of requested ships from 12 to nine. This caused a reduction in the PAUC and APUC from the December 2002 numbers, but on a per-unit basis the cost still increased (DAMIR, 2005). The hulls that were being built at this time were experiencing cost growth at the contractor's facility. The causes of this are covered in the following section on cost growth.

3. Initial Ship Delivery

The USS *San Antonio* was delivered to the Navy following the Navy's Board of Inspections and Survey recommendation on July 20, 2005. The following month, Hurricane Katrina hit the Gulf Coast area. One major impact of this event was to the workforce dedicated for the San Antonio-class ship construction, which negativly affected program costs and schedules. In accordance with the FY2006 National Defense Authorization Act, the baseline was updated to the current UCR baseline because the unit costs exceeded 50% (DAMIR, 2005). Table 14 shows the 2005 estimate against the 1996 baseline.

Cost Measure (per unit)	May 1997 APB	Oct 2005 APB	Current Estimate Dec 2005 SAR	Cost Per Unit
PAUC	9018.6	12955.2	10411.6	1156.844
APUC	8925.9	12842.4	10299.9	1144.433

Table 14. A Comparison of Cost Estimates in the Acquisition of the San Antonio-Class between 1997 and 2005 (after DAMIR, 2005)

This makes the October 2005 UCR baseline for the PAUC and APUC both at the 12-unit quantity while the current estimate was at nine ships. The current estimate in total was less than the October 2005 rebaseline; however, on a per-unit basis, the current estimate was greater than the baseline (DAMIR, 2005). Table 15 shows the 2006 estimate against the 1996 baseline.

Cost Measure (per unit)	May 1997 APB	Oct 2005 APB	Current Estimate Dec 2006 SAR	Cost Per Unit
PAUC	9018.6	12955.2	11103.4	1233.711
APUC	8925.9	12842.4	10992.1	1221.344

Table 15. A Comparison of Cost Estimates in the Acquisition of the San Antonio-Class between 1997, 2005 and 2006 (after DAMIR, 2006)

In 2006, the San Antonio-class program utilzed supplemental funding provided to programs that were affected by Hurricane Katrina. The program was 14% above the PAUC and APUC baseline. Of this 14% increase over the baseline, 4% was attributed to the reduction of three ships and 8% attributed to the affects of Hurricane Katrina (DAMIR, 2006). Table 16 shows the 2010 estimate against the 1996 baseline.

Cost Measure (per unit)	May 1997 APB	Dec 2010 APB	Current Estimate Dec 2007 SAR	Cost Per Unit
PAUC	9018.6	14458.4	14379.2	1307.2
APUC	8925.9	14347.1	14263.1	1296.645

Table 16. A Comparison of Cost Estimates in the Acquisition of the San Antonio-Class between 1997, 2007 and 2010 (after DAMIR, 2010)

By the end of 2010, five of the currently planned 11 ships had been delivered. The first three ships were delivered with significant deficiencies. These deficiencies have been reduced as additional hulls have been delivered. The turning point for the San Antonio-class program was the USS *San Diego* (LPD-22), which saw no starred deficiencies at delivery; however, it still had over 3,300 deficiencies that the contractor was resposible for. A starred deficiency is a Part I deficiency that the inspectors from INSURV (the Navy's Board of Inspection and Survey) label as most severe which degrade the ship's ability to perform a primary or secondary operational capability or impede the crew's ability to safely operate and maintain the ship or its systems. Accepting ships with deficiencies is not unique to the San Antonio-class program. The Navy's goal in accepting ships with deficiencies is that they will be corrected within the first four months. Some of these deficiencies were not corrected within that time frame, and there have been cases in which operations and maintenance funds were used to correct the problems, increasing hull costs in the sustainment period (GAO, 2013). Redesign was required when engine reliability issues were discovered to be caused by lube oil cleaniness problems. LPDs 17–21 were affected by this design problem and required rework. The new design will be incorporated into LPD-22 and subsequent hulls, eliminating this cost from these later hulls (DAMIR, 2010b). Table 17 shows the cost growth in the PAUC and APUC by year and the change of that cost from the previous year.

	In Millions of 1996 Dollars			Change From Previous Year		Change From Base Line	
	PAUC	APUC	QTY	PAUC	APUC	PAUC	APUC
May-97	$751.55	$743.83	12				
Dec-97	$729.16	$720.82	12	$(22.39)	$(23.01)	-3%	-3%
Dec-98	$727.70	$719.49	12	$(1.46)	$(1.33)	-3%	-3%
Dec-99	$807.80	$799.67	12	$80.10	$80.18	7%	8%
May-00	$751.55	$743.83	12	$(56.25)	$(55.84)		
Dec-00	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Dec-01	$1,078.29	$1,070.20	12	$326.74	$326.38	43%	44%
Jun-02	$1,078.29	$1,070.20	12	$-	$-		
Dec-02	$1,116.63	$1,108.27	12	$38.34	$38.07	4%	4%
Dec-03	$1,098.68	$1,090.23	12	$(17.95)	$(18.03)	2%	2%
Dec-04	$1,144.99	$1,132.46	9	$46.31	$42.22	6%	6%
Oct-05	$1,079.60	$1,070.20	12	$(65.39)	$(62.26)		
Dec-05	$1,156.84	$1,144.43	9	$77.24	$74.23	7%	7%
Dec-06	$1,233.71	$1,221.34	9	$76.87	$76.91	14%	14%
Dec-07	$1,278.67	$1,265.77	9	$44.96	$44.42	18%	18%
Dec-08	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Dec-09	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Dec-10	$1,314.40	$1,304.28	11	$35.73	$38.51		
Dec-10	$1,307.20	$1,296.65	11	$(7.20)	$(7.64)	-1%	-1%
Dec-11	$1,297.21	$1,286.66	11	$(9.99)	$(9.99)	-1%	-1%
Dec-12	$1,292.78	$1,282.23	11	$(4.43)	$(4.43)	-2%	-2%

Table 17. Cost Changes through the Acquisition of the San Antonio-Class (after DAMIR, 1997b, 1998, 1999b, 1999c, 2001, 2004, 2005, 2006, 2007, 2010b, 2011b, 2012b)

Note. Gray box indicates a baseline.

D. SAN ANTONIO-CLASS CONTRACT

In December 1996, the USS *San Antonio* was contracted under a cost-plus-award-fee contract for detail design, integration, and construction of the USS *San Antonio* to Avondale Industries. Included in this contract was the option for the construction of the USS *New Orleans* and USS *Mesa Verde* (LPD-19). Other major contractors that worked with Avondale were General Dynamics/Bath Iron Works, Hughes Aircraft Company, and Intergraph Corportation. The initial contract was for $641 million with various options that, if exercised, would bring the entire value of the contract to $1.526 million (DOD, 1996). In 2001, as costs continued to increase, the contract was converted to a CPIF/AF to tie profit to control of costs (DAMIR, 2001). Avondale's corporate structure has changed from the initial contract date through various shipbuilding company aquistions and consolidations. San Antonio-class is currently being constructed by Huntington Ingalls Industries, which absorbed Avondale (Shipbuilding History, 2014).

E. ACQUISITION SOURCES OF COST GROWTH

The San Antonio-class program saw considerable cost growth in the first two ships with the follow-on ships having significantly less cost growth. This is not surprising of a major acquisition program because the learning and design issues are resolved in early hulls. Many of the early hulls had cost growth in the same areas. The GAO (2005) discussed the issues of cost growth for the early ships in the San Antonio-class program in its report *Defense Acquisitions: Improved Management Practices Could Help Minimize Cost Growth in Navy Shipbuilding.* The report broke down the cost of building a ship into four components: labor, material, overhead, and Navy-furnished equipment. The main drivers for the cost growth on the USS *San Antonio* and USS *New Orleans* were increases in the labor hours and material costs, approximately 76% of the total cost growth combined; the remaining cost growth was due to increases in overhead and labor rates and, to a small extent, Navy furnished equipment (GAO, 2005). A summary of the cost growth by amount and percentage of total cost growth is provided in Table 18.

Cost Growth in LPD-17 and LPD-18		
	In Millions	In Millions
	LPD-17	LPD-18
Increased Material Costs	$400	$93.00
Percent of total growth	47%	24%
Increased Labor Costs	$284	$184
Percent of total growth	33%	48%
Increased Overhead/Labor rates	$175	$110
Percent of total growth	20%	28%

Table 18. Cost Grown in USS *San Antonio* and USS *New Orleans* (after GAO, 2005)

1. Material Costs Increases

The USS *San Antonio* saw a $400 million material cost growth while the USS *New Orleans* saw a $93 milllion growth. One of the major material cost growth drivers was engineering costs. During the design phase of the San Antonio-class program, a new three-dimensional (3D) product model tool was used in the design process. The 3D product model tool was not fully developled while it was being used on the San Antonio-class program and led to problems that affected the entire design. The San Antonio-class program realized a $215 million growth in engineering cost in order to correct these design problems (GAO, 2005).

2. Labor Hours

Total cost growth due to increased labor hours was $284 million for the USS *San Antonio* and $184 million for the USS *New Orleans*. Problems with the design process and engineering personnel churn resulted in an unstable desgin. The unstable design led to work being delayed from the building cycle to the integration of the hull. Shifting the work from the building cycle to the integration cycle led to higher costs than were originally planned. This delay caused 1.3 million labor hours to be moved from the building phase to the integration phase (GAO, 2005).

3. Overhead and Labor Rates

Overhead and labor rates increased causing a cost growth of $175 million for the USS *San Antonio* and $110 million for the USS *New Orleans*. The growth in overhead for the shipbuilder was due to changing factory workload and economic impacts. The shipbuilder distributes its overhead to all the planned projects that would be completed when the San Antonio-class ships were being constructed. The loss of an auxiliary cargo (K) and ammunition (E) ship (T-AKE), a commercial ship, and a delay in the signing of the contact for the next generation destroyer caused the overhead that would have been applied to these programs to be applied to the remaining. Other factors that impacted the overhead rate were the rise in pension funds and medical care costs. Labor rates increased due to the two-year delay in the program and increased wage rates and inflation (GAO, 2005).

The hulls constructed after USS *New Orleans* saw cost growth but in a smaller amount than the first two hulls. Some of the common causes of cost growth that affected the hulls after USS *San Antonio* and USS *New Orleans* were as follows:

- loss of skilled labor;
- increased overhead cause by the Pension Protection Act and increased property insurance premiums following Hurricane Katrina; and
- increased direct labor rates due to the 2007 collective bargaining agreement (GAO, 2005).

F. COST REDUCTION

Although the San Antonio-class experienced significant cost growth early in the program's life, it can now build ships at a firm price with little cost growth. As the needs of the amphibious force changes, building ships with an already established production line can prevent unexpected cost growth. In the budget deal to fund the DOD, Congress included funding for an additional San Antonio-class ship that the Navy did not request (GAO, 2005).

1. Senate Concerns

Senate Report 112–196 highlighted the Committee on Appropriations' concerns and the reasons behind their decision to add funds for pre-construction on another San Antonio-class vessel:

- The planned 33 amphibious fleet could not meet the 38 amphibious fleet requirements. By 2015, the total amphibious fleet will total 28 ships based on the construction and retirement plans. As the DOD aligns to refocus to the Asia-Pacific region, the Committee on Appropriations views the risk of not having these assets available as being too high.

- There will be a five-year gap in amphibious shipbuilding when the San Antonio-class planned 11-ship line is completed. If there is a funding gap, it will negatively impact the industrial base leading to additional cost growth in multiple shipbuilding programs.

The Committee on Appropriations added an additional $263.255 million only for advance procurement of another San Antonio-class vessel (Inouye, 2012).

2. Dock Landing Ship (Experimental)

The next ship in the amphibious fleet that would need to be replaced is the Whidbey Island-class (LSD-41). Hunting Ingalls (currently building the USS *Portland* [LPD-27]) is suggesting using the San Antonio-class design (LPD-17 Flight II). There are benefits to using the San Antonio-class design as the basis for the experimental version of the next dock landing ship (LSD):

- The design cost is reduced by not having to create an all new design.

- Construction costs are reduced by capitalizing on the learning curves of the San Antonio-class.

- Funding for the 12th San Antonio-class has already been appropriated, and building the 12th ship and keeping the line open until the LSD(X) begins reducing the production gap between the two programs improves the learning curve for the LSD(X).

It may be too early to know whether the San Antonio-class design would be a good basis for the LSD(X) because the requirements are not fully determined. Some skeptics noted that the Navy may lose some new technology by using a San Antonio-class design because a completely new design could more fully incorporate the technological advances from the years since the San Antonio-class was designed, to include technology focused on crew size reduction that would reduce the total life-cycle cost of the new design (O'Rourke, 2011).

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V. OPERATIONS AND SUPPORT VIRGINIA CLASS

This chapter highlights the savings that the Navy seeks in the Virginia-class. It provides a qualitative analysis of tools used in the O&S phase of the Virginia-class submarine program. At the time of this project, the Virginia-class had not yet completed low rate initial production (LRIP), which will be comprised of SSN 774 through SSN 787; this represents 47% of the total inventory, a typical variation for ships from the acquisition standard of 10%. Even though the Virginia-class has incurred only a fraction of the planned O&S costs, this does not preclude analysis of the projected or simulated O&S costs with the limited historical data available.

A. SIGNIFICANT COST SAVINGS IS PARAMOUNT

The Navy continues to seek significantly lower TOC for Virginia-class by the program RTOC. RTOC aims to significantly reduce the costs during the O&S phase of the system's life cycle throughout major DOD acquisition programs. A major cost driver of TOC are shipyard maintenance availability periods, which are costly both in terms of maintenance dollars, as well as the removal of a submarine from service.

1. Reduced Total Ownership Costs

RTOC efforts in the DOD date prior to 1997. These studies that launched the RTOC initiatives highlighted the increasing cost of programs, notably during the O&S phase of the acquisition life cycle. RTOC categorized cost solutions into three elements:

- increasing the visibility and priority of the problem,
- changing the behavior of organizations and individuals, and
- institutionalizing the RTOC process (Mandelbaum & Pallas, 2001).

Reducing cost growth has become a major priority in the Navy. An example of the seriousness of the problem of increasing costs over time is evident in the age of ship disposal: In 1999, ships were disposed after 22 years of service, and at present, this occurs after 30 to 37 years. As ships remain in service longer, the cost of sustainment in comparison to acquisition costs increases, and overall program cost increases as well (Mandelbaum & Pallas, 2001).

The Navy implemented RTOC through the Navy Cost Reduction Effectiveness Improvement (CREI) program. CREI sought to improve vertical communication when considering ways to reduce costs and improve effectiveness. In *Reducing Total Ownership Costs in the DOD*, Mandelbaum and Pallas (2001) said the following when describing the CREI process:

> The Navy CREI process was formulated to ensure ideas that reduce costs, reduce workload, improve quality of life, and improve readiness are appropriately vetted, funded, and implemented. These ideas are compared and balanced against other priorities during the Navy budgeting process. (p. 79)

2. Increasing Total Ownership Cost Effectiveness

A key indicator of RTOC success is an increase in TOC effectiveness. Reducing the number of costly dry-dock maintenance periods the submarine is scheduled to undergo in the targeted 33 years of service increases TOC effectiveness. The demand for dry-dock periods is driven by required maintenance actions to the submarine at subsystem or component levels. RTOC does not seek to reduce the dry-dock periods by making a unilateral change; rather, it takes a holistic approach. Subsystems and components are engineered to require fewer actions by depot-level technicians, and fewer maintenance actions require the submarine to be dry docked (Goff et al., 2012).

3. Thirty-three Years, 15 Deployments, 3 Dry-Dock Periods, 1 Depot-Maintenance Period

RTOC considered the following: a submarine life of 33 years, 15 deployments, three dry-dock periods, and one depot-maintenance period for Block IV submarines, starting with SSN 792. Blocks I through III will likely complete 13 or 14 deployments. The service life of 33 years is nearly the same as previous classes but is directly tied to the Navy’s requirement for attack submarine end strength. A submarine’s failure to meet its required service life results in a reduction of available assets prior to the acquisition of a replacement submarine. The deployment number is intrinsically related to the number of hulls available for tasking, in service and not in dry dock. The dry-dock period is a product of deployments based on modeling. All three of these metrics or requirements must be considered simultaneously at some point if even one is analyzed for possible cost savings in RTOC (DAMIR, 2012a; Goff et al., 2012).

4. Use of Simulation to Determine Costs

Nearly all of the projected life-cycle costs of the Virginia-class program rely on simulation to achieve targeted and perceived savings. Because the submarine is still very new when viewed in O&S terms, the program office has yet to evaluate the full impact of a reduction in dry-dock periods on the submarine's performance; simulation was and continues to be used.

5. Similar Systems Used in Estimation and Simulation

The O&S estimates used for the Virginia-class submarines are comprised of several contributing costs relating to the sustainment period of a submarine's life cycle. The estimate includes costs for unit-level manpower, unit operations, maintenance, sustaining support, continuing system improvements, and indirect support (DAMIR, 2012a).

B. SOURCES OF DATA FOR ESTIMATION

The source data used to develop estimates through modeling were attained from several sources. In the interest of efficiency, the following sections rely on the previous work of the DAMIR in its 2012(a) Virginia-class SAR (see p. 43). In order to fully understand this excerpt from the 2012 SAR, the following definition is provided: The classified cost analysis requirements description (CARD) describes in detail an acquisition program and the system or platform itself.

The following is an excerpt from the 2012 SAR (DAMIR, 2012a):

> Manpower
>
> Manpower was estimated based on the crew description contained in the Manning Estimate Report (MER) (15 officers, 120 enlisted), and the direct personnel costs using Virginia-class rates factored for Virginia-class crew size.

Unit Operations

Unit Operations was based on historical Los Angeles-class data and factored by power, weight, and crew size.

Maintenance

Maintenance was estimated based on historical Los Angeles-class maintenance costs factored for the Virginia-class based on weight. Public and private shipyard data was used, as well as the maintenance schedule provided in the CARD to appropriately phase maintenance costs over the service life of the submarines.

Sustaining Support

Sustaining Support was estimated based on historical Los Angeles-class data factored by weight or crew size, depending on the individual element.

Continuing System Improvements

Continuous system improvements were estimated based on historical Los Angeles-class data factored by weight.

Software Maintenance

Software maintenance was based on the analysis of Arleigh Burke-class with costs estimated per line of code and factored by the total Source Lines of Code count contained in the CARD.

Indirect Support

Indirect Support was based on historical infrastructure costs from U.S. Naval Submarine Bases, as well as historical personnel costs from Los Angeles-class, which were factored for the Virginia-class crew size. (p. 43)

C. OPERATION AND SUPPORT COST COMPARISON

This section provides a comparison between the Virginia-class, Los Angeles-class, and Seawolf-class O&S costs. Typically, comparisons are made between Virginia-class simulated cost data and Los Angeles-class data, which are comprised mostly of estimates based on previous costs incurred in the class. Typically, cost comparisons are limited to these two platforms because they are similar in many ways, and much of the Virginia-class O&S cost estimation modeling is based on the Los Angeles-class. This comparison includes the Seawolf-class because it provides an example of cost savings and cost growth, which may provide tools for future programs.

1. Seawolf-Class Operation and Support Costs

Seawolf-class was originally planned to be a class of 30 submarines; the number was later reduced to 12, and eventually procurement was halted after the third submarine, the USS *Jimmy Carter* (SSN 23), which was commissioned in February 2005. Despite the reduced number of submarines procured, the value of a comparison should not be overlooked.

Each submarine in the Seawolf-class is projected to have a 30-year service life, displace 9,150 tons, consist of a 134-person crew, and require an estimated two overhauls and six SRAs throughout each hull's service life. The scheduled time between availabilities is projected to be 42 months (DAMIR, 1997a, 1999a).

The projected annual O&S cost for each Seawolf-class submarine is $48.97 (expressed in millions, 1995 dollars). ICEs are as follows (expressed in millions, 1995 dollars):

- mission pay and allowance, $6.5
- unit-level consumption, $4.1
- intermediate maintenance, $3.6
- depot maintenance, $13.41
- contractor support, $1.4
- sustaining support, $14.9
- indirect, $5.8 (DAMIR, 1999a)

Seawolf-class sustainment costs on average were comparatively low in the early years of the program, from 1998 to 2003. As the years of operation progressed, from 2004 to 2012, costs continued to grow. Although this data may not represent future costs, the Seawolf-class sustainment costs, on average, appear to be unsupportable in a fiscally constrained environment. Figure 11 itemizes Seawolf-class's actual O&S costs.

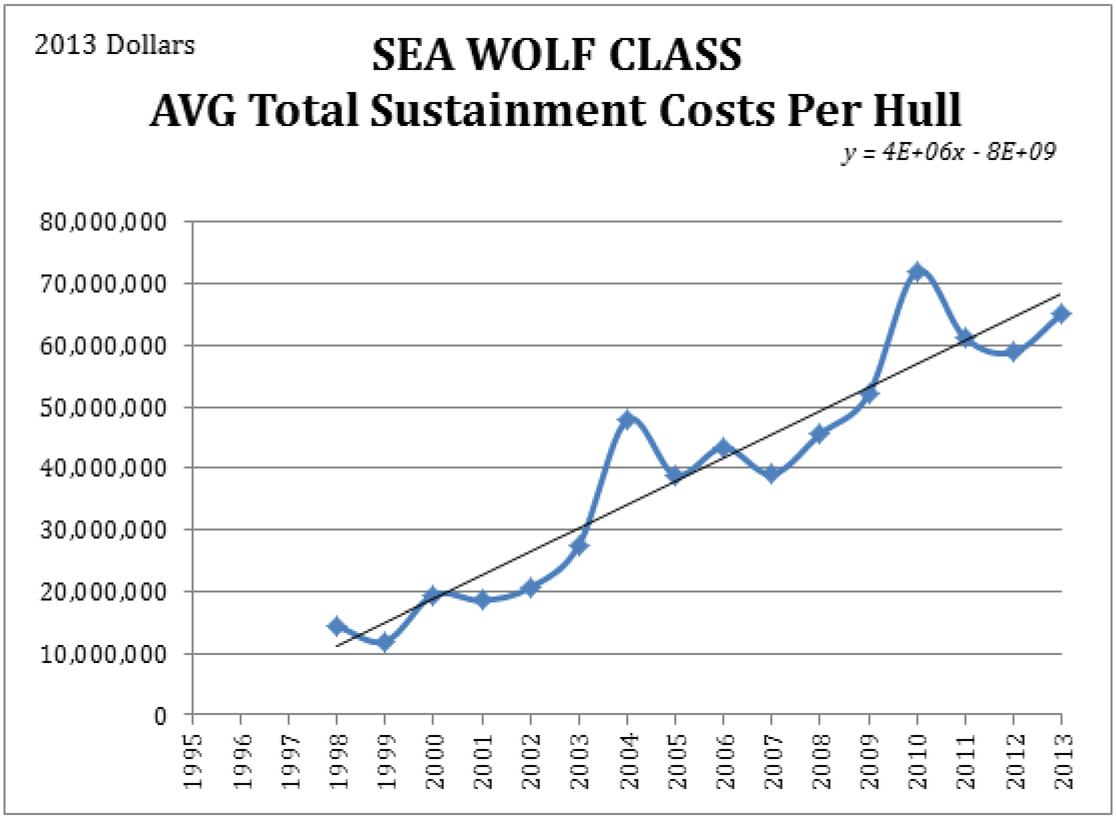

Figure 11. Seawolf-Class Historical Sustainment Costs (after VAMOSC, 2013)

2. Los Angeles-Class Operation and Support Costs

The USS *Los Angeles* was commissioned in 1976; later model builds are expected to remain in service until 2029. The Navy built 62 vessels in this class but later decommissioned 21 instead of performing mid-life nuclear refueling (DAMIR, 2012a). Each submarine in the Los Angeles-class that completed required mid-life nuclear refueling displaces 6,082 tons surfaced, has a crew of 132, and is projected to have a 30-year service life, during which the submarine would undergo four dry-dock periods; one depot-maintenance period; and one engineering overhaul, which includes a nuclear refueling. Recently, the class extended the life cycle by three years, resulting in a total of 33 years of service life for several of the submarines (Office of the Chief of Naval Operations, 2010).

The most current projected O&S costs for each Los Angeles-class submarine were referenced in the 2012 SAR (DAMIR, 2012a) and total $30.52 million (1995 dollars). Individual elements are as follows (expressed in millions, 1995 dollars):

- unit-level manpower, $5.45
- unit operations, $.74
- maintenance, $.70
- sustaining support, $.99
- continuing systems improvements, $4.24
- indirect support, $4.11
- and other, $0

Despite the long history of Los Angeles-class submarines in service, the availability of historic life-cycle O&S cost data is not robust due to the early decommissioning of 21 submarines.

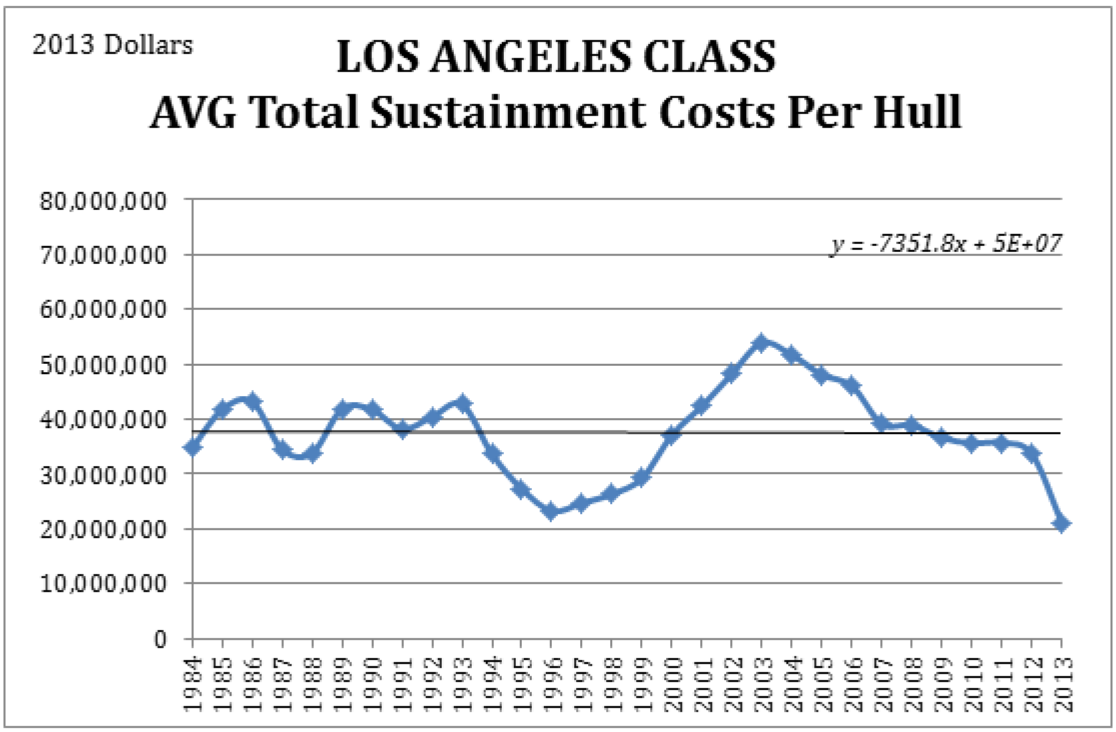

Figure 12. Los Angeles-Class Historical Sustainment Costs (after VAMOSC, 2013)

More than 10 years of sustainment cost data for the Los Angeles-class remains unavailable due to the fact that VAMOSC data collection began in 1984. Los Angeles-class sustainment costs on average were consistent throughout the time period represented in Figure 12. This period represents the final two thirds of the service life of the class. Notably, 21 of 62 hulls were decommissioned at the refueling point of their nuclear reactor; since 2006, a slight decrease in sustainment costs has occurred as older Los Angeles-class submarines were decommissioned. The large number of submarines in this class, the comparatively larger percentage of useful life expended, and its operational effectiveness make this class a credible baseline to compare future affordability.

3. Virginia-Class Operation and Support Costs

The Navy plans to build 30 submarines with a service life of 33 years per hull, with a displacement of 7,800 tons. To date, eight submarines have been delivered to the Navy. The Virginia-class has a crew size of 134 and is projected to have three dry-dock periods and one depot-maintenance period in its 33-year life cycle. These seemingly disconnected facts all contribute to the O&S costs and their comparability to the O&S costs of other submarine classes.

Virtually all of the O&S cost estimates that are provided for Virginia-class are estimates derived from modeling and simulation. Estimates were based on actual VAMSOC data from Los Angeles-class and Virginia-class and used to construct O&S cost estimates. On cases in which Virginia-class and Los Angeles-class differed (e.g., those maintenance actions that are sensitive to displacement differences), the Los Angeles-class historical data was used and adjusted to compensate for the differing weight between the two classes to achieve an estimate for Virginia-class. Similar computations were repeated to adjust for the differences between the two classes (DAMIR, 2012a).

The projected O&S costs for each Virginia-class submarine are $35.4 million (1995 dollars). Individual elements are as follows (expressed in millions, 1995 dollars):

- unit-level manpower, $8.98
- unit operations, $0.74

- maintenance, $13.98
- sustaining support, $.96
- continuing systems improvements,$6.37
- indirect support,$4.37
- other, $0.

Notably, the estimated O&S costs of Virginia-class exceed those of Los Angeles-class. The higher manpower cost on Virginia-class is surprising, considering the smaller crew size. Additionally, the personnel costs in the Navy have outpaced inflation in the decades since Los Angeles-class was commissioned, resulting in a much higher cost estimate for Virginia-class. Visual depiction of O&S cost can be seen in Figured 13.

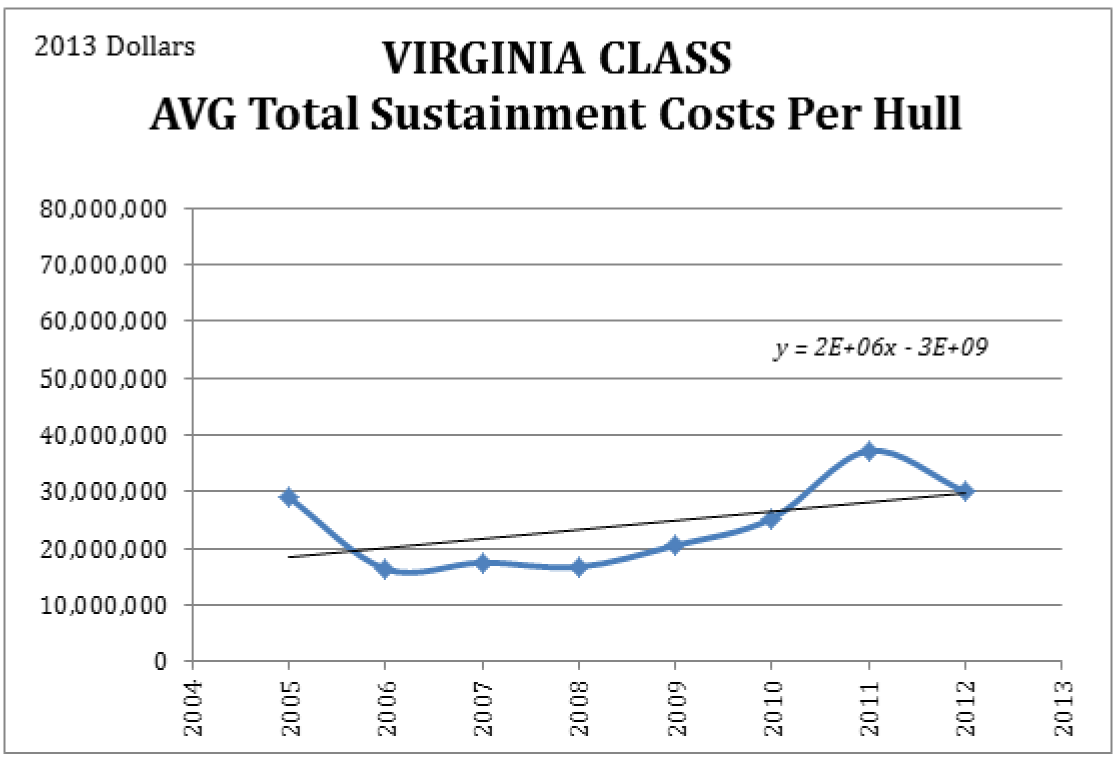

Figure 13. Virginia-Class Historical Sustainment Costs (after VAMOSC, 2012)

Virginia-class sustainment costs on average have not increased to the degree of the Seawolf-class and have remained lower than both Los Angeles-class and Seawolf-class. Although this data may not represent future costs, the Virginia-class sustainment costs, on average, appear to be more affordable in a fiscally constrained environment. Considering the emphasis that the Virginia-class placed on affordability for the sustainment period, even if the average cost per year to sustain a Virginia-class submarine increased by an additional $2 million per hull, the Virginia-class submarine will remain 20% more affordable than the Los Angeles-class and 50% more affordable than the Seawolf-class. Within the limits of the data available, the Virginia-class program appears to have successful in achieving greater affordability within the sustainment period of its life cycle. Table 19 itemizes actual O&S costs of Virginia-class.

Cost Element	VIRGINIA	LOS ANGELES	Cost Element	SEAWOLF
Unit-Level Manpower	$8.98	$5.45	Mission Pay & Allowances	$6.5
Unit Operations	$.74	$.70	Unit-Level Consumption	$4.1
Maintenance	$13.98	$15.03	Intermediate Maintenance	$3.6
Sustaining Support	$.96	$.99	Depot Maintenance	$13.41
Continuing System Improvements	$6.37	$4.24	Contractor Support	$1.4
Indirect Support	$4.37	$4.11	Sustaining Support	$14.9
----------------------			Indirect	$5.8
Other	0	0	Other	0
Total	$35.40	$30.52	Total	$48.97

Table 19. Annual Submarine Operations and Sustainment Cost Comparison (after DAMIR, 2012a)

Note. Expressed in millions, 1995 dollars.

D. EARLY PLANNING FOR COST SAVINGS

The Navy sought to control or cut costs in the sustainment phase on Virginia-class as well as the acquisition phase, which is covered in Section IIIB. The O&S costs typically account for 80% of a program’s cost. This section relies heavily on the previous work of the RAND Corporation and the National Defense Research Institute, in its report titled *Learning From Experience: Volume II: Lessons From the U.S. Navy's Ohio, Seawolf, and Virginia Submarine Programs* (Schank et al., 2011).

1. Life Cycle

Life-cycle costs of the Virginia-class were considered from the early planning stages. Planners met with stakeholders to find ways to reduce life-cycle costs through planning and analyzing the cost drivers of submarines through their 30+ years of service. Planners analyzed and studied the interaction between operators and maintainers in virtual mock-ups to validate human interfaces (Schank et al., 2011, p. 89). This collaboration validated concepts and procedural changes that the teams were considering. Electric Boat was contracted to provide advanced planning and design in support of overhauls and repair availabilities.

Key relationships between design for manufacturing and design for repair must be considered when evaluating the life-cycle cost of a component or system. Additionally, the reliability of installed systems, expressed in mean time between failures (MTBF), and the life-years of all systems, must be considered when estimating life-cycle costs. The life-cycle planning process for the Virginia-class evaluated how knowledge of the preceding information could be used to change what a submarine would cost the Navy over a 30-year period. For example, if a system that normally required overhaul every 48 months could be extended to 72 months through modification or redesign, what interdependent costs are associated with this change? What periodic maintenance costs are involved? These efforts are examples of focusing on the goal of controlling costs; designing for affordability furthered that goal beyond the acquisition phase and into the sustainment phase.

2. Integrated Product Process Development

Integrated product process development (IPPD) was a key contributor in designing the Virginia-class with the goal of reducing life-cycle costs. From early in the design process, traditional modes of interaction were replaced by a relationship in which the contractor stood on nearly equal terms with the customer and worked to reduce costs from the beginning the relationships were reset from traditional roles whereby the contractor who now stood on nearly equal terms with the customer worked to reduce costs from the beginning. Reducing costs was, as previously described in Chapter VI, a requirement for survival of the program, not merely a slogan (Schank et al., 2007).

In the Virginia-class' development, the previous lock-step design process used on Los Angeles-class and previous classes was replaced with IPPD. Use of IPPD enabled the Navy and contractors to work toward the goal of reducing life-cycle costs. Cost reductions were sought through improving integrated design and production planning while ensuring that the life cycle of the platform was considered at every stage of development (Schank et al., 2007, p. 15). The use of IPPD allowed several steps to be performed in parallel, an efficiency improvement over the previous process (Schank et al., 2007).

3. Acquisition Savings ≠ Sustainment Savings

Goff et al. (2012) argued, "In some cases, changes to Virginia-class design from Los Angeles-class to save acquisition cost or improve performance caused increases in the cost and duration of planned maintenance" (p. 2). This tradeoff decision to lower acquisition cost in the short term versus lowering O&S cost was likely attributable to Congress's pressure to keep acquisition costs lower.

4. Design for Cost Reduction

The projected savings for the Virginia-class can be attributed to its design for cost reduction. In *Engineering the Solution,* Johnson et al. (n.d.) provided the following:

> The second leg of the integrated cost reduction strategy was the design changes made for cost reduction. The shipbuilder and the Virginia-class Program Office examined every major cost driver area targeting systems, parts, and process involved in building Virginia-class submarines, looking for ways to modify the design in areas that would reduce overall cost and construction time. However, each design change was required to be "capability neutral," meaning that it would take advantage of new technologies to provide equal levels of performance while concurrently reducing cost. (p. 12)

This paragraph highlights the emphasis on savings throughout the life of the program but not at the cost of established capability.

VI. OPERATIONS AND SUPPORT SAN ANTONIO-CLASS

A. OPERATIONS AND SUPPORT

This chapter focuses on the O&S costs of the San Antonio-class. It provides a qualitative analysis on tools used and decisions made that will have projected impacts in the O&S phase of the San Antonio-class program. At the time of this project, the contractor had delivered eight of the 11 planned ships. (This does not include advance funding for a 12th ship because construction has not yet started.) There is limited actual O&S data due to the short time that the ships have been operational as compared to their 40-year expected life spans. Most of the data in this report come from the early hulls because they reflect the most usage; however, these ships may not be an accurate representation of the costs for the entire program. As problems are discovered in the initial deliveries, they are redesigned in the follow-on hulls, reducing O&S costs.

1. Integrated Product and Process Development Decisions

One aspect of the IPPD tool was to focus on reducing total ownership costs early in the design process when incorporating these decisions required little redesign or rework. Some items that the IPPD processes identified as areas that can reduce RTOCs were as follows:

- reduce manning;
- change ship service diesel generator transient load requirement (increase mean time between overhauls);
- change radar to SPS 73 versus 67/64 (less expensive to maintain and helps to reduce manning);
- use titanium piping in sea water systems, which reduces corrosion and extends system life;
- apply longer-lasting paint and corrosion inhibitors, which reduces maintenance man-hours;
- employ self-cleaning filters on diesel engines, which reduces maintenance man-hours;

- use a 10 gallon per minute (GPM) oily water separator versus 50GPM to save space and weight, and reduce operating cost; and

- use self-cleaning strainers in the machinery's fresh water-cooling system, which reduces maintenance man-hours (Fireman et al., 1998).

These decisions were made for the San Antonio-class program and may not be applicable to other programs due to the differing requirements; however, the tool that was used to develop these decisions (the IPPD process) can be applied to other programs and can lead to decisions that reduce TOC.

2. Reduced Total Ownership Cost Pilot Program

The IPPD process was not the only pilot program that the Navy used on the San Antonio-class. Although the IPPD process was used as a way to reduce acquisition and O&S costs, there were other programs that the San Antonio-class used to further this goal. The Navy identified the San Antonio-class as an RTOC pilot program for testing RTOC approaches. At the end of the pilot program, the Navy shared the results with the DOD acquisition community. The purpose of RTOC is to reduce O&S costs while maintaining or improving current readiness (Reed, 2003). The following are the general approaches that these pilot programs focused on and the specific initiatives that the San Antonio-class used for each area.

Reliability and maintainability (R&M) improvements:

- design O&S cost target,

- design producibility and reduced O&S cost targets,

- identify and replace high-cost and low-MTBF components,

- develop metrics as an assessment tool, and

- use COTS and non-developmental item (NDI) commercial buying practices.

Reduction of supply chain response time and reduction of logistics footprint:

- utilize built-in diagnostics,

- reduce depot-maintenance workload, and
- develop integrated data environment.

Competitive product support:

- develop life-cycle support study/depot source of repair analysis and
- use performance-based logistics.

The sharing of lessons learned from other programs has also helped the LPD-17 incorporate these cost reduction strategies into its program, such as the Advanced Food Service and Integrated Bridge System initiatives (Reed, 2003).

The lessons learned from the San Antonio-class that can be applied to other programs that are focusing on an RTOC-conscious design are as follows:

- identify cost drivers,
- identify a realistic stretch goal,
- create a TOC-conscious environment,
- create a TOC avoidance plan and process,
- balance O&S cost avoidance/savings and design production cost incentives,
- create a government–industry team, and
- validate design changes with warfighter (Reed, 2003).

a. Goals of Reduced Total Ownership Cost

It was important that both the program management team and the contractor were focused on RTOC during the design process. The San Antonio-class program identified four objectives in ensuring that both teams were aligned with RTOC:

- implement a RTOC process,
- identify the TOC drivers,

- set cost objectives and targets that are both realistic and aggressive, and
- focus on the end user (Litton Avondale Alliance, 2000).

The PM has established the RTOC goal for the program to be a 20% reduction of the O&S cost from the program life-cycle cost estimate. It was important to the program to establish a baseline so that decision-makers had a point of reference on which to base their RTOC decisions. This baseline allowed the program to identify TOC drivers and highlight areas that the team could focus on to get the most cost reduction (Litton Avondale Alliance, 2000).

The RTOC pilot program was an enabler that was used to identify design decisions that could lead to RTOC. Some of the decisions that came from the focus on RTOC are listed and may not apply to every program. That, however, does not mean that the enabler cannot be used on other programs.

B. DESIGN FOR REDUCED OPERATION AND SUPPORT

The acquisition thinking that was prevalent in the San Antonio-class program was to design the ship from the start with the focus of reducing O&S costs. The program could realize cost savings if it incorporated technology and strategies to reduce cost early in the design process. The San Antonio-class program office identified 10 items that they could see would provide the largest O&S cost avoidance:

- manning reduction,
- advanced enclosed mast sensor
- total ship training system,
- coatings,
- corrosion control,
- ship’s service diesel generator,
- asynchronous transfer mode switch,
- Stratica deck tiles,

- medium Vs high pressure air system, and
- synthetic decking (Reed, 2003).

Incorporating commercial products and processes could reduce acquisition costs as well as O&S costs. By designing the ship to use these products and processes, the program could reduce the requirement for specially configured pieces of equipment that perform the same function as commercial items. Some examples of the commercial equipment that the San Antonio-class used were as follows:

- food preparation equipment,
- tank level indicator,
- multi-jack fastener,
- remote monitoring TV cameras,
- smart card,
- surge suppressors, and
- Golar 500 incinerator (Reed, 2003).

1. Reducing Deficiencies

Recently, many U.S. shipbuilding programs have been accepting ships with a significant number of deficiencies. The need to maintain the program's schedule timeline or to prevent a delay at key milestones have led the program to accept ships with deficiencies for correction later. These deficiencies can increase costs at the O&S stage of the program. USS *San Antonio* through USS *New York* (LPD-21) saw problems that were transferred to the fleet requiring O&M funds to correct the defects (GAO, 2013).

The Navy's Board of Inspection and Survey (INSURV) teams conduct one of the inspections that a ship must go through before it is accepted into the Navy. During these inspections, the INSURV team identifies and categorizes deficiencies found in the ship.

These deficiencies are quality problems with the ship that are not in compliance with Navy standards or do not meet contract specifications. It can be difficult to determine who is responsible for correcting a deficiency. The program office, supervisor of shipbuilding, conversion, & repair (SUPSHIP) and the contractor determine who has the responsibility for correcting it. There can be many reasons that the government would be responsible for correcting the deficiency, but typically the deficiencies for which the government is responsible are ones that require a change to the ship design, a change in the ship specification, or a change in equipment that the government is responsible for providing. Deficiencies that do not fall into these categories are the responsibility of the contractor to correct and are primarily manufacturing defects (GAO, 2013).

USS *San Antonio* through USS *New York* were delivered with significant deficiencies, the majority of which were the contractor's responsibility. In 2009, the government initiated the Back-to-Basics Quality Improvement Initiative, which helped reduce the number of deficiencies that were found in delivered LPDs. USS *San Diego* saw an approximately 50% reduction in open non-starred deficiencies, as compared to the USS *San Antonio* (GAO, 2013).

C. ESTIMATED OPERATION AND SUPPORT COSTS

In the beginning, the San Antonio-class program determined the anticipated O&S cost by using comparative actual costs and parametric measurements, which the cost analysis improvement group (CAIG) found to be realistic ("Parametric Cost," 2011). Table 20 shows the breakdown of the estimated O&S cost as listed in the 1997 SAR (DAMIR, 1997a). The primary source of the data was the VAMOSC database. The program office used the LSD-41 actual cost data and adjusted those numbers to take into account the differences in the LPD-17 program.

Unitized Cost in Millions, 1996 Dollars	
Cost Element	Cost per Hull
Mission Pay & Allowance	15.7
Unit-Level Consumption	5.5
Intermediate Maintenance	0.3
Depot Maintenance	11.8
Contractor Support	
Sustaining Support	2.9
Indirect	1.5
Other	
Total	37.7

Table 20. Operation and Support Cost Estimate per Hull (after DAMIR, 1997b)

As the program progressed, the O&S estimates were updated to reflect changes and decisions that had occurred that would affect O&S costs. In 2001, the program continued to use Whidbey Island-class VAMOSC data to develop estimates. The Whidbey Island-class data was modified to account for the differences in the two ships, such as crew size and fuel consumption (DAMIR, 2001). Table 21 shows the O&S estimates for San Antonio-class and the updated increased O&S costs as identified in 2001.

Unitized Cost in Millions, 1996 Dollars	
Cost Element	Cost per Hull
Mission Pay & Allowance	24.9
Unit-Level Consumption	9.7
Intermediate Maintenance	0.6
Depot Maintenance	17.2
Contractor Support	0.0
Sustaining Support	0.0
Indirect	0.0
Other	2.0
Total	54.4

Table 21. Operation and Support Cost Estimate per Hull (after DAMIR, 2001)

There was a significant decrease in projected O&S costs from 2001 to 2007. The areas that saw decreases were in mission pay and allowances (now referred to as unit-level manpower and depot maintenance). Table 22 shows a comparison in the O&S cost estimate from 1996 to 2007, as well as the areas that showed the cost decreases. The changes in depot maintenance were made to reflect current maintenance availabilities and man days. The changes in the unit-level manpower was updated based on data from the VAMOSC website (DAMIR, 2007).

Unitized Cost in Millions, 1996 Dollars		
Cost Element	Cost per Hull 1997	Cost per Hull 2007
Unit-Level Manpower	15.7	11.0
Unit Operations	5.5	9.7
Intermediate Maintenance	0.3	.5
Depot Maintenance	11.8	5.2
Contractor Support	0	0
Sustaining Support	2.9	0
Indirect	1.5	0
Other	0	2
Total	37.7	28.4

Table 22. Estimated Operation and Support Costs per Hull (after DAMIR, 1997b; 2007)

2010 showed an increase in the cost per hull totaling $43.5 million. The increases were in manpower costs, maintenance, and other (DAMIR, 2010b). Unitized O&S costs in 2010 can be seen in Table 23.

Unitized Cost in Millions, 1996 Dollars	
Cost Element	Cost per Hull
Unit-Level Manpower	17.7
Unit Operations	9.4
Maintenance	6.9
Sustaining Support	.3
Continuing System Improvements	0.0
Indirect Support	0.0
Other	9.20
Total	43.5

Table 23. Operation and Support Cost Estimate per Hull (after DAMIR, 2010b)

Data from the VAMOSC website showed an increase in maintenance cost starting in 2010 from the hulls that have been in service the longest. Figure 14 shows the maintenance cost of the 17th hull through the 22nd hull from 2006 to 2012.

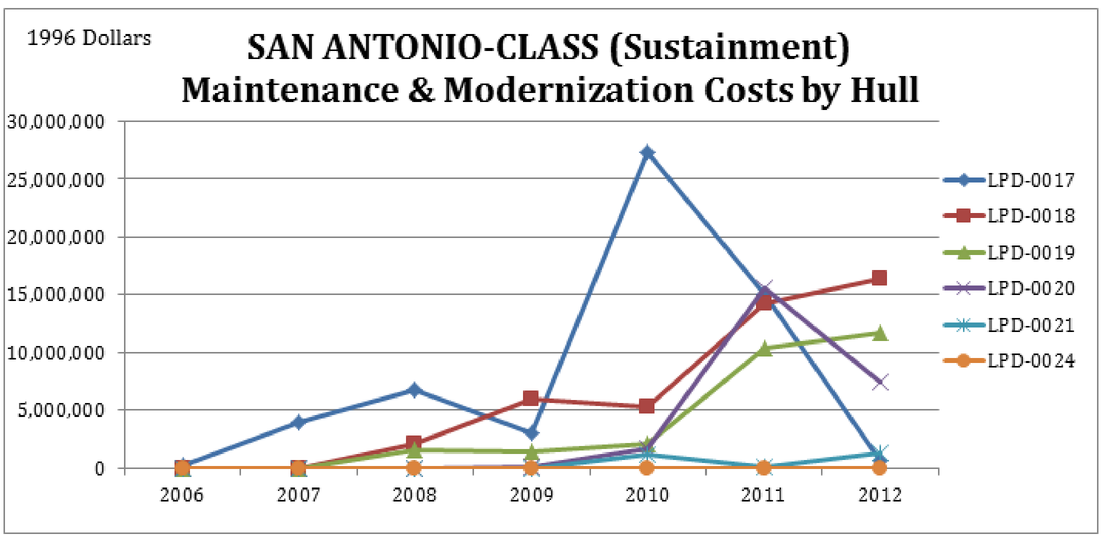

Figure 14. Maintenance Costs per Hull (after VAMOSC, 2013)

In 2012, eight ships had been delivered to the Navy. The O&S estimates were updated using data from the VAMOSC data based on the Austin-class ship, normalized on a 40-year life expectancy and using the expected production quantity of 11 hulls

(DAMIR, 2012b). The program office decided to use the Austin-class as the antecedent program, as opposed to the Whidbey Island-class that they were using before, because Austin-class is the ship class that is most similar in configuration to the San Antonio-class. Table 24 shows the estimated O&S costs per hull that were computed in 2012 (DAMIR, 2012b).

Unitized Cost in Millions, 1996 Dollars	
Cost Element	Cost per Hull
Unit-Level Manpower	16.1
Unit operations	2.5
Maintenance	9.8
Sustaining Support	.8
Continuing System Improvements	1.3
Indirect support	8.1
Total	38.6

Table 24. Estimated Operation and Support Cost per hull (after DAMIR, 2012b)

The total O&S cost per hull for the San Antonio-class was slightly larger than the cost per hull for the Austin-class, which was $36.4 million (DAMIR, 2012b).

D. ACTUAL COST DATA

Using data that was gathered from the VAMOSC website, the actual cost to date can be compared to the program's estimated cost per hull. Because the San Antonio-class is a relatively new program, there is limited actual O&S data available.

Selected Elements number 1 through 4 (direct unit cost, maintenance and modernization–depot, maintenance–intermediate, and other operating and support), captured as much O&S cost as possible. Element number 1 sums the cost of the sub elements of personnel, unit-level consumption, and purchased services. Element number 2 is the sum of the sub elements for labor and material for intermediate maintenance and commercial industrial services. Element number 3, maintenance modernization–depot, is the sum of the following:

- scheduled depot maintenance,
- non-scheduled depot maintenance,
- fleet modernization,
- aircraft launch and recovery equipment (ALRE),
- field change installation,
- equipment rework,
- design services allocation, and
- other depot, which consist of “other depot maintenance costs not covered above, including scheduled and non-scheduled repairs to fleet ballistic missile systems” (IBM, 2013).

Element number 4 is the sum of sub-elements for training, publications, engineering, and technical service and ammunition handling.

To capture all available O&S data years 1984 (earliest year available) to 2013, all hulls that had VAMOSC data, USS *San Antonio* through USS *Arlington* (LPD-24), were selected. The cost values from VAMOSC were in constant 2013 dollars. These values were converted to 1996 dollars to match the base dollars used in the San Antonio-class SARs. The Joint Inflation Calculator, dated February 2013, provided by the Naval Center for Cost Analysis, was used to convert the values from the VAMOSC site to the same year dollars in the SARs. Selecting Operations and Maintenance, Navy (O&MN)(composite), setting the input year to 2013, and setting the target year to 1996 ensured that the most accurate inflation factor was used for normalizing the data. These settings resulted in an inflation factor of .6105, which was then applied to the data from VAMOSC.

The program office estimated in 2012 that the annual average cost per hull would be $38.6 million in BY$1996. The data from VAMOSC shows the average cost per hull from 2006 to 2012 when each new hull was turned over to the Navy (see Figure 15).

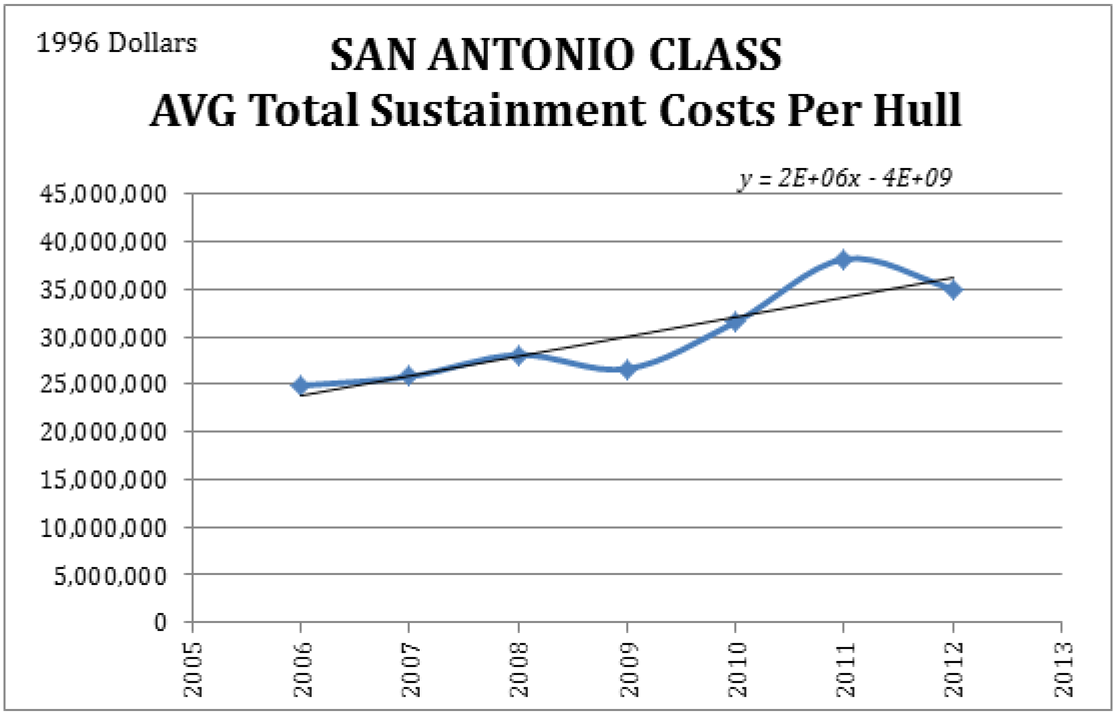

Figure 15. Average Total Sustainment Costs per Hull (after VAMOSC, 2013)

The average total sustainment cost per hull is trending up; however, the data available are on the first hull numbers in the program and may not be an accurate starting point to make estimations on future costs. The average cost per hull has generally stayed below the O&S estimate provided in the program's SAR. Because it is early in the O&S stage, it is difficult to know the future trend of the cost data.

The O&S costs from the San Antonio-class have been less than the costs from the Austin-class. Using O&S cost data from the VAMOSC database and averaging the costs over the number of hulls shows that the current average O&S costs per hull for the San Antonio-class have been less than the O&S costs per hull of the Austin-class. Figure 16 shows the O&S cost of the Austin-class ship and the San Antonio-class. These dollar values are in constant BY1996 $, and the San Antonio-class shows a slightly lower cost than the Austin-class ship. The earliest data available on VAMOSC was from 1984.

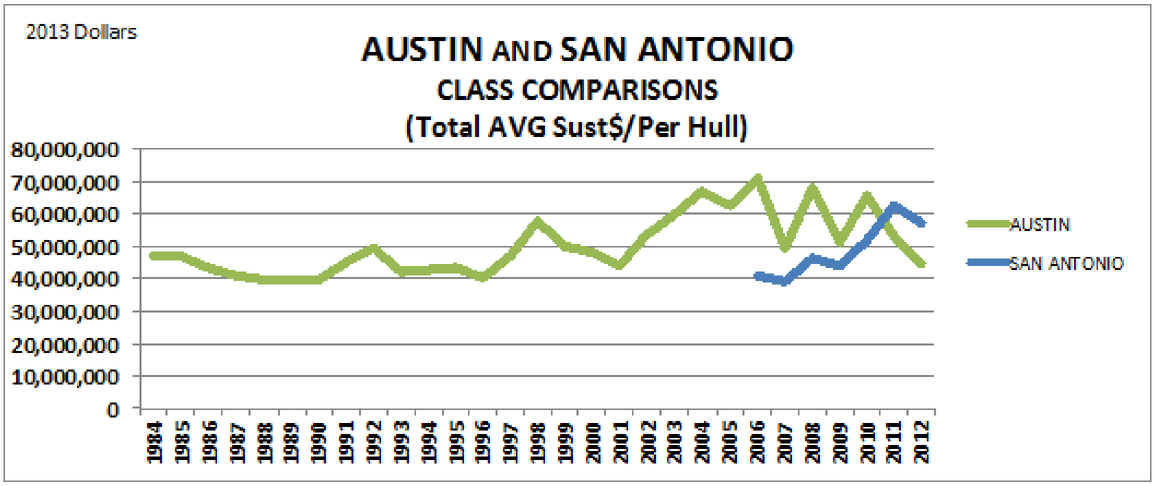

Figure 16. Operation and Support Cost Comparison per Hull between the Austin-Class and San Antonio-Class Ships (after VAMOSC, 2013)

It is too early to make a definite judgment on whether the actual costs in O&S are the same as the estimated costs. If the program office was including O&S cost-saving measures in their estimates, then because the actual costs are below their estimates, it appears they have been saving costs in the O&S period. Table 25 shows the estimated costs of O&S and the comparison to the actual O&S costs that year.

Unitized Cost in Millions, 1996 Dollars		
Year	SAR Estimate	VAMOSC
2006	28.4	24.8
2007	28.4	25.8
2008	N/A	28.8
2009	N/A	26.6
2010	43.5	31.5
2011	35.3	38.1
2012	38.6	35.0

Table 25. SAR Operation and Support Comparison to Actual Operation and Support Data (after DAMIR 2006, 2007, 2010b, 2011b, 2012b)

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VII. METHODOLOGY

Research and analysis of the Virginia-class submarine and San Antonio-class amphibious transport enablers and decisions in conjunction with affordability outcomes was approached under a multiple–case-study design. The goal is to isolate those enabling circumstances and management tools and those programmatic decisions that appear to increase the likelihood of greater or lesser degrees of affordability. Under Ernest Boyer's (1990) model of scholarship (Boyer, 1990), this study expands the body of knowledge for DOD acquisition through the scholarship of integration, by synthesizing information across two topical areas (ship and submarine vessel types) and across time (acquisition and sustainment periods; see Figure 17). The exploratory nature of this study lends itself to a qualitative research and analysis approach.

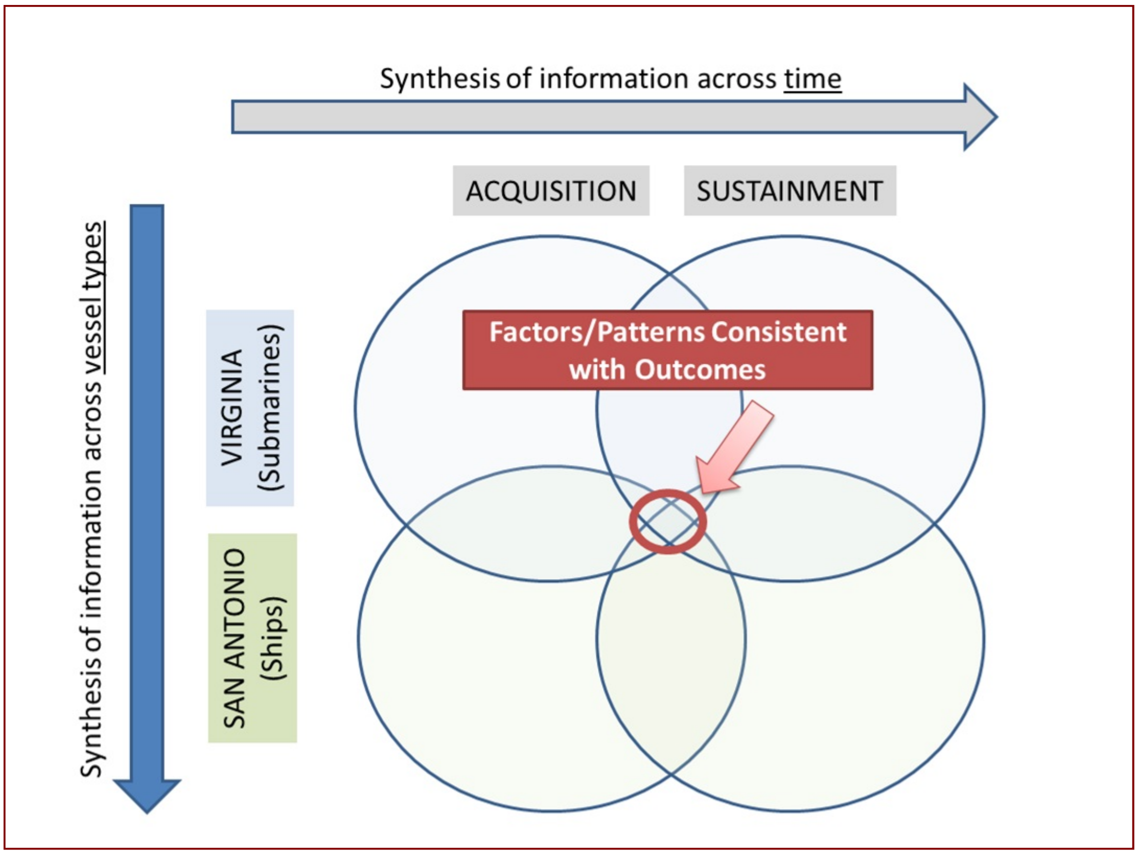

Figure 17. Depiction of this Study's Scholarship of Integration, Conceptual

A. EXPLORATION AND COMPARISON

Rather than testing a specific hypothesis, this study uses the previous literature on qualitative research design to develop a set of findings from a detailed exploration and comparison of the Virginia-class submarine and San Antonio-class amphibious transport programs. These programs are comparatively evaluated with regard to affordability. Although affordability is be addressed consistently across vessel types, across time the definition of affordability differs:

- Affordability in the pre-acquisition period is defined by both the effects on the risk of cost growth as well as resultant cost growth.
- Affordability in the acquisition period is defined by Sailaway, APUC, and PAUC target costs, as these targets are an extension of congressional mandates.
- Affordability in the operations and support period is defined by the costs comparisons with the previous platforms these programs were mandated to replace, as no direct or indirect baseline (target) for sustainment has been legislatively mandated.

By exploring how the enabling circumstances and management tools found in each program and the emerging programmatic decisions led to the resulting levels of affordability achieved in acquisition and sustainment, this study aims to find consistent factors or patterns which appear to markedly affect affordability and would benefit from more detailed studies.

B. QUALITATIVE RESEARCH DESIGN (Z-PATH)

In Joseph Maxwell's (1941) *Qualitative Research Design: An Interactive Approach*, five key elements comprise a qualitative research design: the goals, the conceptual framework, the research questions, the specific methods (for data collection, filtering, and analysis), and the validation. Each of these components of a qualitative research design reflexively informs on and interacts with each other to collectively refine the entire research process (see Figure 18). The design of a qualitative study is well suited to exploratory studies that must adapt in response to changes in circumstances and the nature of the information revealed by the research. As each component evolves, the entire model should adjust to appropriately reflect these refinements across the entire research methodology.

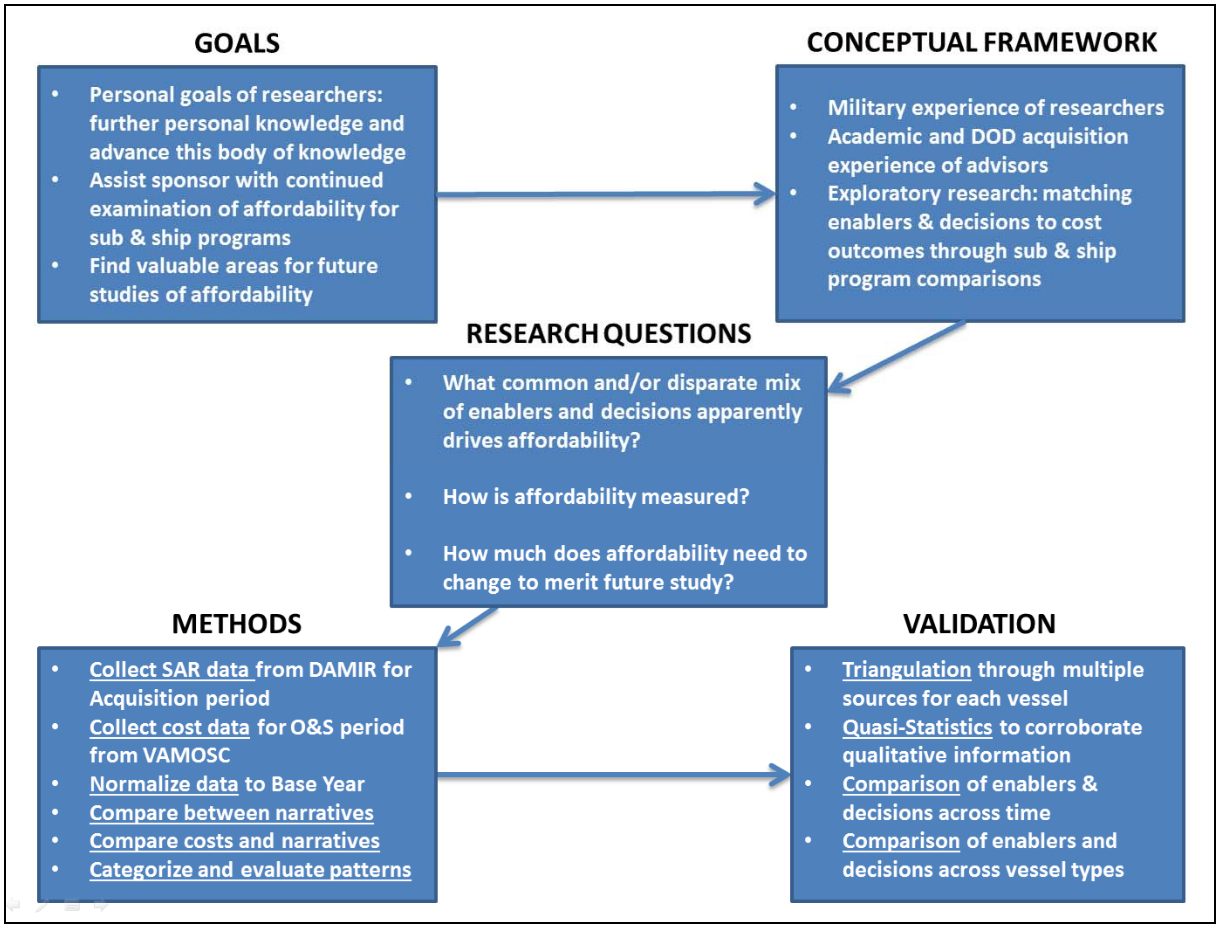

Figure 18. Qualitative Research Design for This Study (from Maxwell, 1941)

1. Goals

Numerous goals converged in the development of this study. The various personal goals of the Naval Postgraduate School (NPS) researchers, the goals of Naval Sea Logistics Command (NSLC) staff as the sponsoring command, the goals of the NPS advising faculty, and the goals of a prior NPS researcher and graduate (Gregory B. Storer) worked in concert to benefit this research effort. The primary goals are the following:

- Confirm whether the decisions and corresponding results, which related to the Virginia-class program, translated to other, similar programs (Storer, 2012).
- Expand personal knowledge while simultaneously expanding the body of knowledge related to DOD acquisition (NPS researchers and advisors).
- Assist U.S. Navy interests in further reducing costs by studying interactions in DOD acquisitions that may affect affordability (NPS researchers and advisors).
- Assist in bridging any possible knowledge gaps between academia and business stakeholders with regard to DOD acquisition to increase the value of this MBA capstone project (NPS researchers and advisors).
- Explore whether any generalizable correlations appear regarding affordability outcomes, when compared to consistent patterns of enablers and decisions for Virginia-class and San Antonio-class programs (NSLC sponsor, NPS researchers, and NPS advisors).

- Find valuable areas for future studies of affordability (NPS researchers).

2. Conceptual Framework

Experience in the military, even with additional studies of DOD acquisition, is no substitute for direct expertise. The expertise of NPS faculty advisors and the inputs from the sponsor assisted in the ongoing refinement of the conceptual framework of this qualitative research design. This framework evolved significantly as the research progressed. Ultimately, two factors emerged as the narratives of the Virginia-class and San Antonio-class programs were repeatedly examined: enablers and decisions.

- *Enablers* were defined as those circumstances (e.g., events, cultural norms, or conditions that are otherwise difficult to control) or managerial tools (e.g., meetings, cross functional teams, reporting processes, or conditions that are otherwise easy to regulate) that influence decisions and are likely to bias the program toward or away from affordability.
- *Decisions* were defined as those choices aimed at influencing the triple constraint (cost, schedule, or performance).

Although some overlap does exist between these two types of influencing factors, the definition of decisions was further constrained by the degree and precision apparent in their intent. If enough of the narrative information gathered could be generalized to these two categories, then the interactions between them and their effects on affordability were examined in sequence for this research. These factors begin to suggest relationships with affordability and should be considered for future study.

3. Research Questions

Research questions emerged naturally from the conceptual framework but required repetitive review for precision and simplification. The original questions began with general inquiries, which evolved and ultimately led to a refinement of the conceptual original framework. The model for qualitative research is a highly iterative process. The evolution of these questions and others, in combination with this study's ongoing research, led to a continuous process of improvements in this methodology.

One such early research question was, "How do (should) we define affordability?" This question led to similar questions such as, "How does DOD acquisition leadership define affordability" and "How is affordability legally defined?" Curiously, our research suggested that none of the answers precisely matched one another, and none of the publications researched expressed the answers in a manner that suggested consistency across the acquisition period and the sustainment period (see Figure 19).

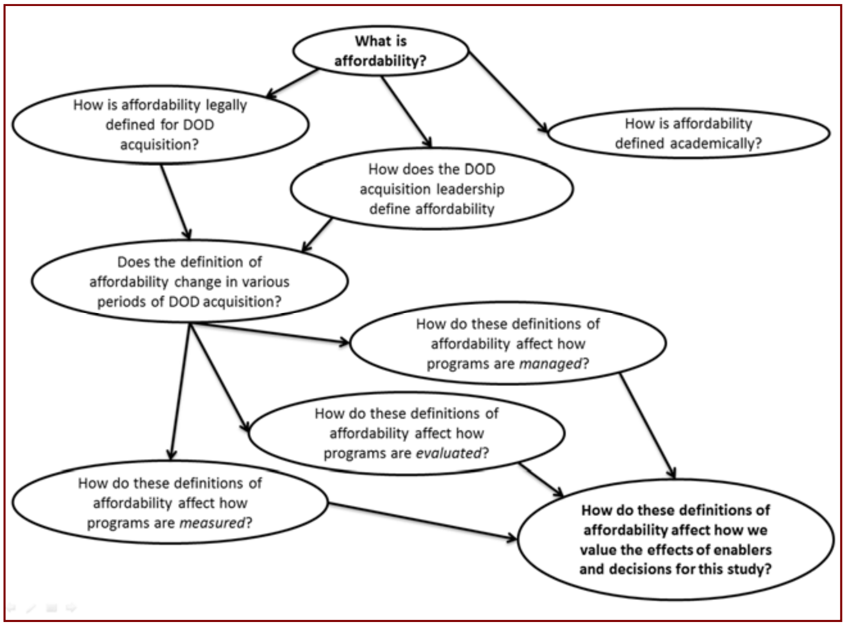

Figure 19. Example Concept Map for Affordability Questions

Without a consistent definition of affordability, there would be no way of validly comparing these programs, either with each other (across vessel type) or within their various periods (across time). The development of the primary research question depended on this subordinate question and on its answers (which are noted in the introduction of the exploration and comparison section). Similar questions, such as "What is an enabler," "What is a decision," and "How do we know when they matter," all manifested from the iterative process of research and inquiry and finally led to the primary research question.

This study seeks to answer the following primary question: What common and/or disparate mix of enablers and decisions apparently drives affordability in the pre-acquisition, acquisition, and sustainment periods and therefore merit further study?

4. Methods

A structured approach was selected to maximize comparability within the data, across vessel types and across time. Additionally, by establishing consistent categories for processes, interactions, and outcomes through which the narratives of the Virginia-class program and San Antonio-class program were interpreted, more stable generalizations were possible. The data was therefore gathered, filtered, and analyzed through the lens of the primary research question and focused on apparent enablers and decisions.

The public nature of MDAPs and the numerous legislative requirements for the data archival of DOD acquisition programs ensured a broad range of source data available in the research of the Virginia-class and San Antonio-class programs. At all levels (congressional, program office, contractor, mass media, etc.), both the successes and the challenges relative to the Virginia-class and San Antonio-class programs were recorded, along with their specific corresponding circumstances, decisions, and costs. The Congressional Research Service (CRS), the GAO, the U.S. Inspector General, the RAND Corporation, and several other independent sources have all published reports on these programs, including details that reflect the sources of cost growth and the effectiveness of various cost-reduction efforts. Additionally, cost data was available from sources of public record designated For Official Use Only (FOUO), including DAMIR and VAMOSC (see Figure 20).

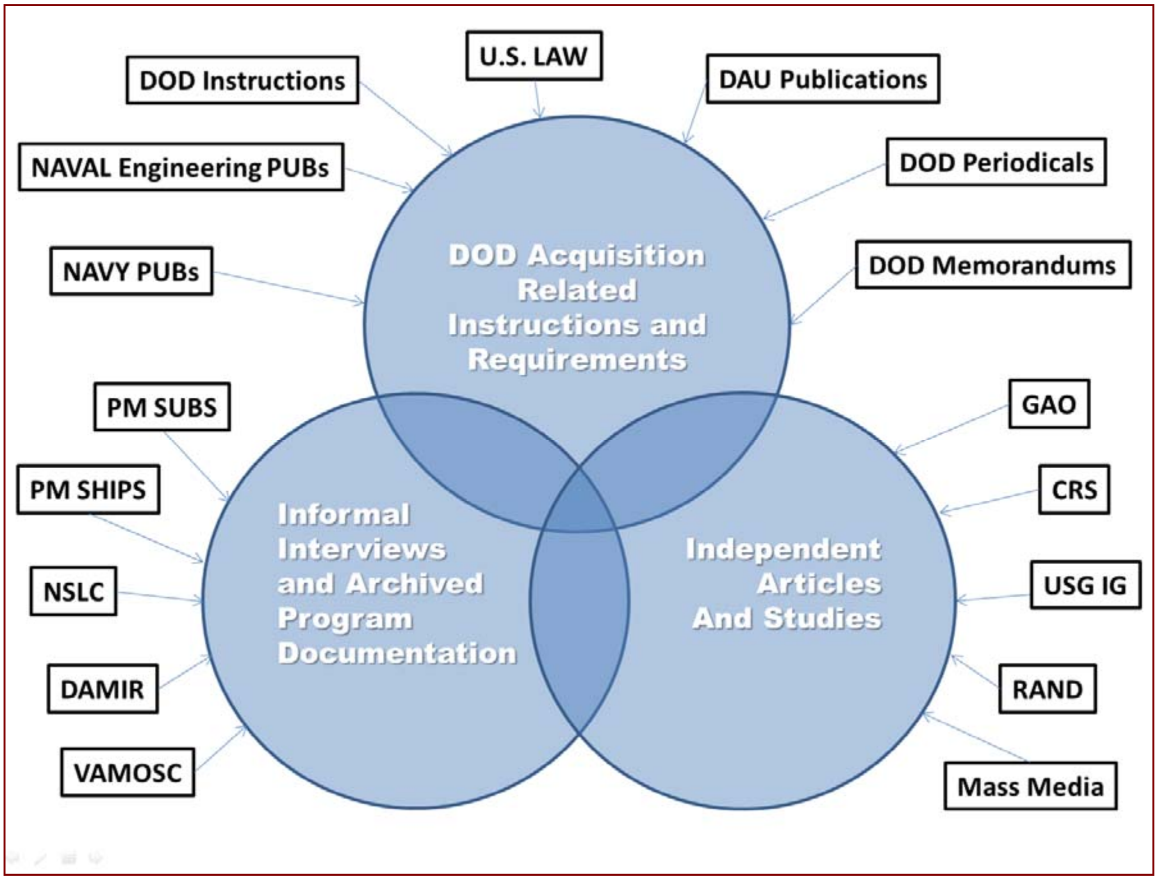

Figure 20. Example Concept Map for Data Sources and Triangulation

- The narrative information for both programs was collected and then evaluated in conjunction with the cost details from DAMIR and VAMOSC to determine credibility and criticality. Once a dependable representation of what happened relative to the pre-acquisition, acquisition, and sustainment periods was established, grouped categories of enablers and decisions were created from the major elements within these periods. These enablers and decisions were then evaluated in relation to their cumulative effects on affordability within the pre-acquisition, acquisition, and sustainment periods.

- Those outcomes on affordability, which were the same across both programs and shared a common set of enablers and decisions, were noteworthy.

- Those outcomes on affordability, which were apparently different across both programs and shared apparently different enablers and decisions, were noteworthy.

Three types of valid findings are depicted in Table 26. This analysis of the data culminated in one summary finding for each period.

Enablers	Decisions	Outcome	Finding	Explanations
Same	Same	Same	Yes	If all the same then outcome should match
Same	Different	Same	No	Differing decision should not result in the same outcome, no apparent finding
Different	Same	Same	No	Differing enablers should not result in the same decision or outcomes, no apparent finding
Different	Different	Same	No	No significance can be drawn/no means of comparison
Same	Different	Different	Yes	Looking for which different decisions lead to different outcomes
Different	Same	Different	Yes	Different enablers that lead to the same decision but different outcome are significant
Same	Same	Different	No	No significance can be drawn/source of difference could not be determined
Different	Different	Different	No	No significance can be drawn/no means of comparison

Table 26. Findings Determination Criteria

5. Validation

- Although the validation process is the tail-end consideration of this model in qualitative research design, it significantly affected the methods portion of this study's design. Each inspection of the validation step reprised and refined numerous aspects of the methods step, in the pursuit of greater and greater degrees of validity. The following traditional strategies in qualitative research design were used (Maxwell, 1941):

- *Triangulation:* to minimize both researcher bias and source bias, to assist through examination, and to promote comprehensive generalizations.

- *Quasi-statistics:* to corroborate narratives via cross-comparisons between textual representations and numerical changes and to measure cost related outcomes (measures of affordability).

- *Comparison between groups:* to maximize an understanding of apparent similarities and differences.

- *Comparison across time:* to maximize an understanding of apparent casual relationships.

VIII. JOINT SUMMARY

By comparing enablers and decisions in the Virginia-class and the San Antonio-class programs, this study seeks consistent cause-and-effect relationships that are likely to improve affordability. In this study, affordability relates to both cost growth prevention and total ownership cost reduction. These findings are not comprehensive with respect to the programs in their entirety; rather, they are comprehensive within the limitations of data available in the public domain. These limitations include information that is not proprietary, information that is not censored due to security, and the incomplete current immaturity of the sustainment costs (i.e., less than one fifth of operational life cycle expended).

Enablers and decisions are categorized by the consistency of their effect on cost. Enablers include events, policies, management tools, current cultural norms, and environmental conditions. Decisions include those choices that appear to have resulted in both favorable and unfavorable cost changes.

A. PRE-ACQUISITION

This section explains the relationships between enablers and decisions and their effects on affordability relative to the pre-acquisition stage of the Virginia-class submarine and San Antonio-class ship. These tables conceptually depict the cause-and-effect relationships using available data extracted from preceding sections. These enablers and their interactions with decisions are addressed from a qualitative perspective. In some cases, as few as two data points were used to establish a relationship between an enabler and decision.

From the outset, the Virginia-class and San Antonio-class had enablers and decisions that affected affordability in a positive and negative manner. For example, decisions that accepted a high level of expected risk might completely counter efforts to control cost. The relationships between these enablers and decisions will eventually affect affordability considerations for both acquisition and sustainment.

PRE-ACQUISITION			
Class of Vessel	**Cumulative Effect on Affordability**	**Example of an Impacting Enabler**	**Example of an Impacting Decision**
VIRGINIA (Submarine)	Greater Risk of Cost Growth	*Insensitivity to Production Break*	Cost-Plus Contracts
SAN ANTONIO (Ship)	Greater Risk of Cost Growth	*Insensitivity to Production Break*	Cost-Plus Contracts
VIRGINIA (Submarine)	Better Cost Control	*Integrated Product Teams (IPT)*	Mature Technology
SAN ANTONIO (Ship)	Better Cost Control	*Integrated Product Teams (IPT)*	Mature Technology

Table 27. Pre-Acquisition Enablers and Decisions

1. Example Enablers

In both the Virginia-class and San Antonio-class programs, leadership had developed an insensitivity to production breaks between platforms. In the case of naval submarine construction, a 14-month gap existed between the USS *Connecticut* (SSN 22) and USS *Jimmy Carter*, more than two years prior to the laying of the keel for the first Virginia-class submarine. Additionally, a six-year lapse occurred between new submarine commissioning in the U.S. In the case of naval amphibious transport construction, a 46-month gap existed between the launch of the USS *Pearl Harbor* (LSD-52; a similar platform) and the laying of the keel for the first San Antonio-class ship. The antecedent platform for the San Antonio-class—the Austin-class—was launched in 1970. This represents a span of 30 years between these two ship classes. Production breaks increased the risk of cost growth in several areas. Refer to Table 27.

In both the Virginia-class and San Antonio-class programs, IPTs were employed early and throughout both programs. IPTs were employed by both the program offices and by the contracted shipyards to minimize rework and control cost. The collaboration that IPTs fostered between stakeholders that were previously competitors (General Dynamics and Newport News), and between the Navy and the shipbuilders, were not present in antecedent classes. The integration of the San Antonio-class program office and the contracted shipyard, through the various integrating and working-level IPTs led to innovations intended to reduce cost. By employing these IPTs, the San Antonio-class program was able to de-conflict design challenges early in the construction phase. Refer to Table 27.

2. Example Decisions

In both the Virginia-class and San Antonio-class programs, cost-plus contracts were awarded. These contracts placed a disproportionate amount of risk on the USG and, ultimately, the taxpayer, in comparison to the prime contractor. This form of contract is common in the early phases of naval construction of a platform. Cost-plus contracts like these are used to protect the contractor's ability to make a reasonable profit, thus preserving vital portions of the Defense Industrial Base (DIB) and ensuring the USG ability to acquire current and future vessels. Refer to Table 27.

In both the Virginia-class and San Antonio-class programs, a herculean effort was made from the outset to maximize the use of mature technology in the design of these vessels. Lessons learned from previous MDAPs led to the DOD acquisition reforms that encouraged these program offices to use mature technology to reduce rework and control cost. In the specific case of the Virginia-class, any potentially immature technology that had not been previously employed but was required to meet program goals was first tested and demonstrated on Los Angeles-class submarines prior to insertion into the Virginia-class program. The program office of the San Antonio-class used the AN/SPS-73, air-search RADAR, to reduce the risk of cost growth and promote lower sustainment costs. The AN/SPS-73 RADAR was chosen over all other air-search RADAR suites because of its lower manpower and maintenance requirements over the life of the employment. Refer to Table 27.

B. ACQUISITION

As the Virginia-class and San Antonio-class programs transitioned from the pre-acquisition to the acquisition period, the cumulative effect of all enablers and decisions from the pre-acquisition period resulted in cost growth. These enablers and decisions carried over a higher risk of further cost growth into the engineering and manufacturing development (EMD) phase. Additional enablers and decisions within the acquisition period were used in response to the cost growth incurred in the pre-acquisition period. Table 28 refers to acquisition enablers and decisions.

ACQUISITION			
Class of Vessel	**Cumulative Effect on Affordability**	**Example of an Impacting Enabler**	**Example of an Impacting Decision**
VIRGINIA (Submarine)	Cost Reductions	*Critical Cost Nunn-McCurdy Breach*	A Shift to a Target Costing Approach
SAN ANTONIO (Ship)	No Favorable Cumulative Change		Rebaseline

Table 28. Acquisition Enablers and Decisions

1. Example Enablers

In both the Virginia-class and San Antonio-class programs, multiple Nunn–McCurdy breaches occurred. Cost and schedule breaches continued to mount in both programs and further cost growth ultimately led to critical cost breaches in these programs. A critical cost breach is a current UCR 50% above original UCR as listed in the APB, or 25% above current UCR. The Nunn–McCurdy breaches typically necessitated a decision to reduce costs, rebaseline the cost or schedule thresholds, or cancel of the program. Refer to Table 28.

2. Example Decisions

As these programs proceeded through production, cost growth continued to mount; the most significant difference between them was the decision of how to respond to the Nunn–McCurdy critical cost breach that each program experienced (Virginia-class in 2005 and San Antonio-class in 2001). Refer to Table 28.

In the Virginia-class following the Nunn–McCurdy critical cost breach (50% above original UCR in APB, or 25% above current UCR), the shift to a target-costing methodology appears to have been the catalyst for the innovations that have overcome cost growth to date since the last breach. The critical cost breach led to the threat of program cancellation. The stakeholders of the Virginia-class program decided to reduce costs rather than permit the program to be cancelled. Of note, not all cost reductions can be attributed to target costing as the workforce maturation process was already making gains with the construction of each additional hull. Refer to Table 28.

The San Antonio-class program responded by broadening and adding to ongoing RTOC initiatives, as well as rebaselining the UCR. The San Antonio-class acquisition costs (Sailaway cost, APUC, PAUC) all continued to increase. Refer to Table 28.

In contrast, the Virginia-class program faced the possibility of cancellation. In response to the mandate by the CNO to reduce acquisition costs, the program office and the contractor acquired assistance from the BAH consulting group in pursuit of additional affordability. The new approach that emerged from this collaboration resembled a target-costing methodology. The Virginia-class acquisition costs were substantially reduced as a result of the implementation of innovations conceived from this paradigm.

C. SUSTAINMENT

As the Virginia-class and San Antonio-class programs transitioned from the acquisition to the sustainment period, the cumulative effect of all enablers and decisions from the prior periods pre-determined the affordability of the O&S component that will play out over the systems operating life. The cumulative results from the enablers and decisions that carried over into the sustainment period, however, the effectiveness of these decisions on the total and final sustainment cost will not be known for several decades. Based on current production quantities and schedules for these programs, the sustainment period of both programs is less than one-third complete. Table 29 refers to sustainment enablers and decisions.

SUSTAINMENT			
Class of Vessel	**Cumulative Effect on Affordability**	**Example of an Impacting Enabler**	**Example of an Impacting Decision**
VIRGINIA (Submarine)	Appears Effective	*RTOC Initiatives*	Reduction of Drydock by 1
SAN ANTONIO (Ship)	Inconclusive		Titanium Piping

Table 29. Sustainment Enablers and Decisions

1. Example Enablers

In both the Virginia-class and San Antonio-class programs, multiple incorporated RTOC initiatives were implemented. These initiatives spanned both the pre-acquisition and acquisition periods with the intent of reducing TOC in the sustainment period. RTOC initiatives were comprised of multiple potential innovations derived as a product of the IPTs. These initiatives included, but were not limited to the following: the use of COTS, replacement of high-failure parts, and reduction of crew maintenance hours. Refer to Table 29.

2. Example Decisions

The different decisions made in the Virginia-class and San Antonio-class across both the pre-acquisition and acquisition periods appear to have disparate results in the two classes studied.

In the Virginia-class, a reduction of scheduled dry-dock periods by one appears to positively contribute to the reduction of cost growth through the sustainment period. This determination is described previously in the Operations and Support section of this report, and visually depicted in Figure 13. However, it must be noted that the determination of whether the program cost reductions were *effective* is based on the realization of less than one fifth of the entire projected sustainment period for the Virginia-class. The initial cost trend is known and supports the determination that the Virginia-class efforts were effective in reducing costs in comparison to the antecedent classes. Refer to Table 29.

In the San Antonio-class, it appears that the decision to use titanium piping in some of the systems will contribute to the reduction of cost growth through the sustainment period. However, the results are inconclusive as to whether the San Antonio-class cost-reduction efforts were effective, on the basis of less than one fifth of the entire projected sustainment period for the San Antonio-class. Since the antecedent program is significantly older than the San Antonio-class and VAMOSC did not have the initial sustainment cost of that program, the findings for the San Antonio-class are inconclusive. See Figure 16.

D. CONCLUSION

In the exploration of the DOD acquisition of amphibious transports and submarines with regard to affordability in acquisition and sustainment, this study has found enough apparent consistency in cause-and-effect relationships to suggest that these programs can be credibly compared to one another. The significant similarities and differences reflected in the previously discussed findings merit further study of more granular data (to track down to subsystem and component levels) over a longer period of sustainment. By improving the understanding of the detailed interactions involved in these cause-and-effect relationships, decision-makers can improve the likelihood of developing more affordable weapon systems.

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IX. FINDINGS AND RECOMMENDATIONS

Ship and submarine programs differ significantly in their construction, technology, and management. Despite these many differences, by grouping enablers and decisions into general categories that relate to chronology and function, potential cause-and-effect relationships become more apparent. The enablers and decisions of these disparate programs can be grouped in numerous ways. This study pursued groupings that captured the greatest degree of commonality between these programs. By creating highly analogous categories, likely relationships and areas for future inquiry were more easily targeted.

A. FINDINGS

The greatest commonality between all DOD acquisition programs is that they are managed using the DOD 5000 series Process Life Cycle Framework. This study categorizes enablers and decisions chronologically. Because earlier periods determine latter outcomes, this study grouped enablers and decisions primarily based on the period they affect. The three categories used in these findings are pre- acquisition, acquisition, and sustainment. This study used Milestone B as a general dividing point, in order to properly differentiate between initial acquisition (e.g., planning, source selection, design), which acts as the foundation upon which the program is built, and the portion of acquisition where cost growth is realized and responded to. These groupings are not absolute; rather, they are used as a means of comparison.

As noted in the methodology section, this study's findings of apparent significance derived from similarities or differences in *outcomes* that were consistent with similarities or differences in *enablers and decisions.* Table 30 shows three types of patterns between enablers, decisions, and outcomes that this study determined to indicate relevant relationships. Such indicated relationships merit further study.

Type	Enablers	Decisions	Outcome	Finding	Explanations
1	Same	Same	Same	Yes	If all the same then outcome should match
2	Same	Different	Different	Yes	Looking for which different decisions lead to different outcomes
3	Different	Same	Different	Yes	Different enablers that lead to the same decision but different outcome are significant

Table 30. Enabler, Decision, Outcome Pattern

1. Pre-acquisition (Finding Type 1)

The following are common enablers for both ships and submarines for the pre-acquisition stage:

- insensitivity to production break,
- culture of affordability,
- learning atrophy,
- source selection constraints,
- PM affordability goals,
- EVMS,
- enhanced schedule management,
- IPPD,
- IPT, and
- enhanced CAD.

The following are common decisions for both ships and submarines for the pre-acquisition stage:

- stop production of platform,
- merged mission requirements of multiple prior platforms,
- at least one inexperienced builder,
- cost-plus contract (risk on USG),
- single-source for design and build,
- use of mature technology,
- optimized manning,
- better drawings, and
- pursued innovation.

The following are the common outcomes for both ships and submarines for the pre-acquisition stage:

- these programs faced significant cost growth, leading to Nunn–McCurdy critical cost breach (>50% original baseline or >25% over current baseline) and
- these programs faced significant schedule delay.

From the inception of these programs, DOD acquisition leaders managed enablers and made decisions in a manner that either accepted the risk of cost growth (i.e., cost-plus contracts) or sought to mitigate the risk of cost growth (i.e., use of mature technology). The enablers and decisions common to both programs, as listed above, even when combined, resulted in cost growth. This study finds no conclusive evidence in these programs that the listed enablers and decisions intended to minimize cost were effective when compared to the enablers and decisions that were inherently accepting of a higher risk of cost growth. The cost growth was so significant in comparison to estimates that it exceeded the identifiable benefits of the enablers and decisions intended to control cost growth.

a. Finding 1

The combination of production break in platform, cost-plus contracts, low experience contractors, and increased complexity due to merged missions resulted in a degree of cost growth which could not be overcome by enablers and decisions intended to reduce costs.

2. Acquisition (Finding Type 2)

The following are common enablers for both ships and submarines for the acquisition stage:

- Nunn–McCurdy critical cost breach,
- schedule delay,
- labor complications,
- PM affordability goals,
- IPT,
- enhanced CAD,
- Lean/Six Sigma,
- implementation of RTOC, and
- culture of affordability,
- The following are the different decisions for both ships and submarines for the acquisition stage:
- CNO ultimatum [SUB],
- contractor target costing shift [SUB],
- program rebaseline [SHIP], and
- additional cost reduction initiatives [SHIP].
- The following are the different outcomes for both ships and submarines for the acquisition stage:
- costs significantly reduced for acquisition [SUB] and

- no conclusive evidence of significantly reduced acquisition cost [SHIP].

As these programs proceeded through production, cost growth continued to mount; the most significant difference between them was the decision of how to respond to the Nunn–McCurdy critical cost breach (Virginia-class in 2005 and San Antonio-class in 2001) that each program experienced. The San Antonio-class program responded by broadening and adding to ongoing RTOC initiatives, as well as rebaselining the UCR. The San Antonio-class acquisition costs (Sailaway cost, APUC, PAUC) all continued to increase. In contrast, the Virginia-class program faced the possibility of cancellation. In response to the mandate by the CNO to reduce acquisition costs, the program office and the contractor acquired assistance from the BAH consulting group in pursuit of additional affordability. The new approach that emerged from this collaboration resembled a target-costing methodology. The Virginia-class acquisition costs were substantially reduced as a result of the implementation of innovations conceived from this paradigm.

a. Finding 2

The most significant decision of the Virginia-class program consistent with the reduced costs realized by the program, as contrasted with the San Antonio-class program, was the use of a methodology by the program office, Electric Boat, and BAH that resembled target costing.

3. Sustainment Initiatives (Finding Type 2)

The following are the common enablers for both ships and submarines relative to the sustainment stage:

- culture of affordability,
- PM affordability goals,
- IPT,
- enhanced CAD,
- Lean/Six Sigma, and
- implementation of RTOC.

The following are the different decisions for ships and submarines relative to the sustainment stage:

- extended period between dry docks [SUB],
- more mature implementation of RTOC process [SUB], and
- pilot program for DOD acquisition reform initiatives (RTOC) [SHIP].

The following are the different outcomes for ships and submarines relative to the sustainment stage:

- VAMOSC reflects reduced sustainment costs in comparison to Los Angeles-class and Seawolf-class submarines [SUB].
- VAMOSC shows no conclusive evidence of significantly reduced sustainment costs in comparison to the Austin-class amphibious transport ship [SHIP].

As previously stated, less than one fifth of the sustainment period has been expended. The sustainment cost-related findings are preliminary. Although this study highlights the apparent success of the Virginia-class program in attaining greater affordability than its predecessors, sustainment costs of the San Antonio-class appear to be equivalent with its most recent predecessor. The two most significant points of difference in the case of the Virginia-class program derived from the decision to extend the period between dry docks and the degree to which reductions in total ownership cost were pursued. The lessons learned in the continuing development of DOD acquisitions reform initiatives within the San Antonio-class program appear to have contributed to the success of the Virginia-class program RTOC sustainment initiatives.

a. Finding 3

The current sustainment cost data (VAMOSC) suggests that the programmatic decisions of the Virginia-class program with regard to RTOC in sustainment were successful.

B. RECOMMENDATIONS

This research extends the NPS thesis, *Virginia Class Cost Reduction: Achieving Savings in Submarine Acquisition*, written by Gregory B. Storer in June 2012 as well as the Virginia-class and San Antonio-class studies published by the CRS, CBO, GAO, and RAND, all noted in the References section. Additionally, these findings establish a basis for further study, which will more completely explain and define the relationships between the programmatic enablers and decisions of DOD acquisition and cost (affordability). As these two MDAPs proceed further through the operations and support period (sustainment), an increasing pool of data will continue to emerge that will provide researchers and leaders a higher degree of confidence in the correlation between programmatic efforts to reduce ownership costs and the relevant cost outcomes within the operational environment. This study reaffirms two recommendations provided by Storer (2012):

- Update this research in the future to provide definitive evidence of cost savings after more actual cost data has been returned from Block III [and IV] ship construction. Use additional analysis techniques, possibly involving multivariate analysis to project costs from a continuation of Block I & II ship construction and compare with the updated data. (p. 56)

- Perform an in-depth case study with more extensive field interviews of the Virginia-class class program as a whole. Develop lessons learned and best practices that can be applied extensively to other programs. This will aid in institutionalizing the aspects of the Virginia-class program that can be most beneficial to major defense acquisition programs beyond just submarine construction or other shipbuilding. (p. 56)

- In addition, this study recommends NPS students and other researchers investigate this body of knowledge further in the following areas:

- Refine and/or revise this research by quantitatively analyzing the interactions and outcomes noted in the pre-acquisition findings of this study. Specifically, use the RAND methodology, "Root Cause Analysis of Nunn-McCurdy Breaches," to quantitatively describe the relationships between the enablers and decisions included in the launch of Virginia-class and San Antonio-class programs and their cost outcomes. (Blickstein, I., 2012)

- Develop a case study outlining the efforts by the Virginia-class program office, Electric Boat, and Booz Allen Hamilton that resulted in significant reductions in the Virginia-class costs. A richer understanding of those decisions which led to the greatest cost reductions will improve DOD acquisition best practices and policies.

- Develop a case study of the Virginia-class sustainment initiatives, which currently reflect a significant improvement in affordability as compared to previous DOD submarine platforms.

- Develop a supplemental extension of the sustainment initiative case study noted above, which quantitatively analyzes the marginal changes between cost, schedule, and performance (KPPs and KSAs), projected and actual (to the degree sustainment costs are available), resulting from the implementation of each programmatic change to the Virginia-class.

C. AFTERWORD

In the exploration of the DOD acquisition of amphibious transports and submarines with regard to affordability in acquisition and sustainment, this study has found enough apparent consistency in cause-and-effect relationships to suggest that these programs can be credibly compared to one another. The significant similarities and differences reflected in these findings merit further study. By improving the understanding of the detailed interactions involved in these cause-and-effect relationships, decision-makers have a greater likelihood of developing more affordable weapon systems.

APPENDIX A. VAMOSC

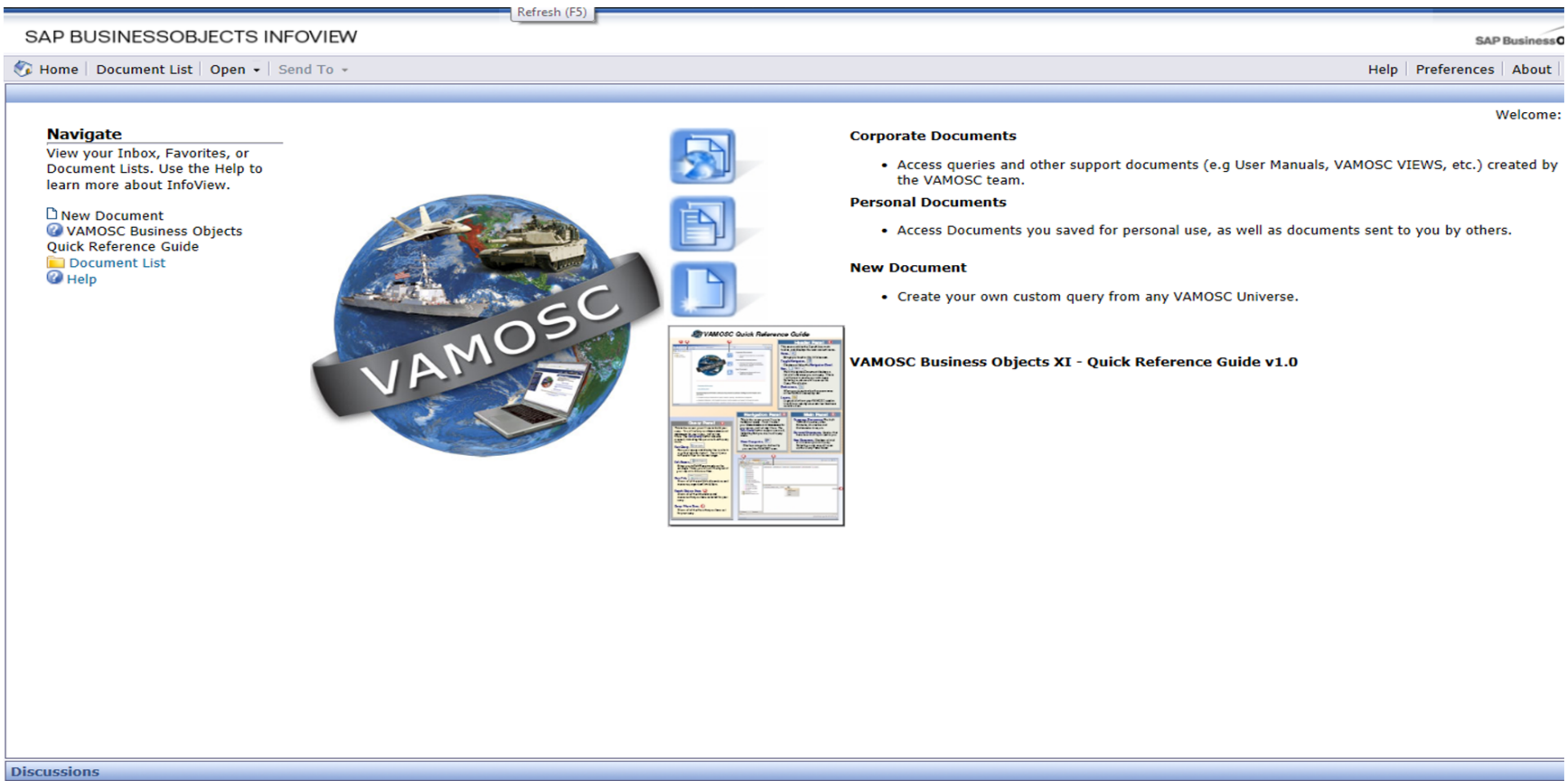


Figure A-1: Front Page of VAMOSC Web-Portal (VAMOSC, n.d.)

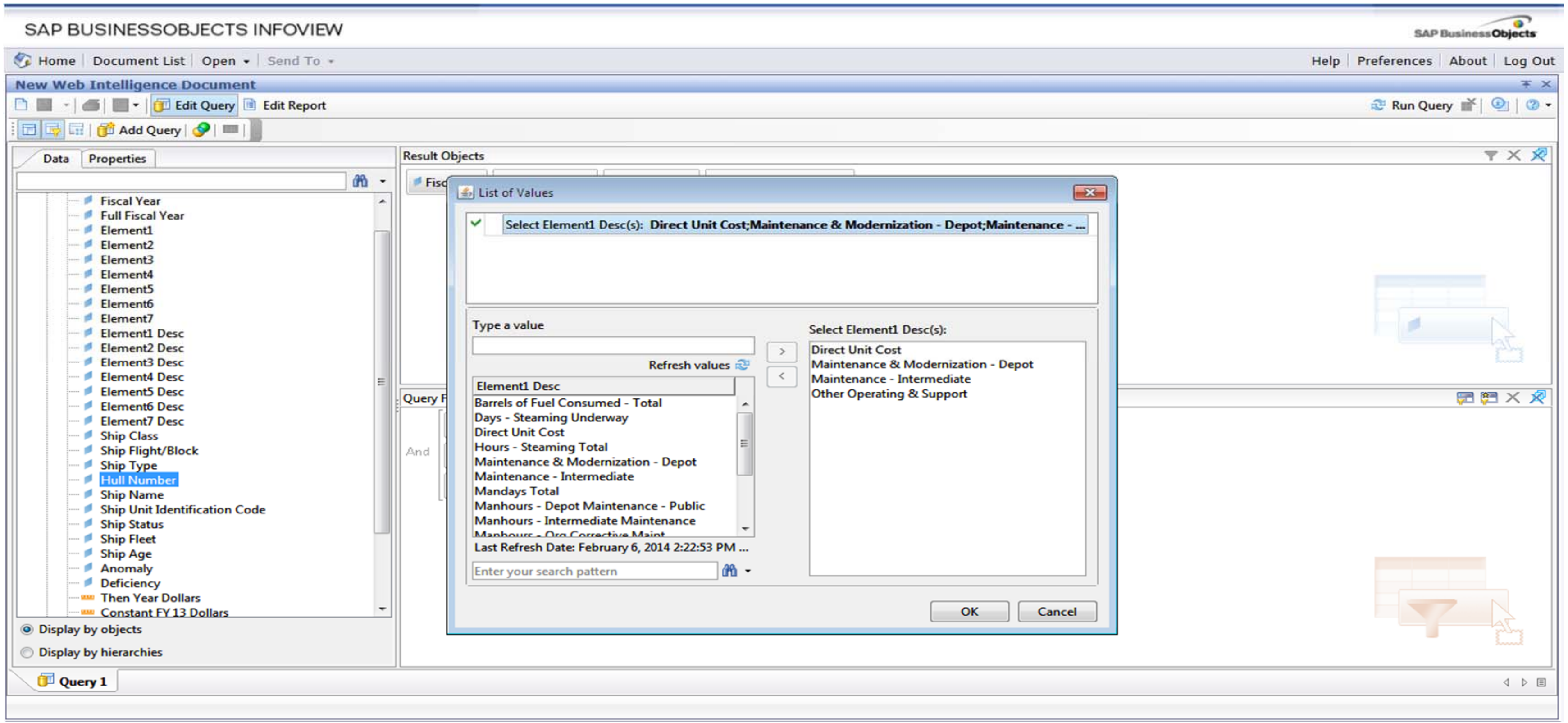
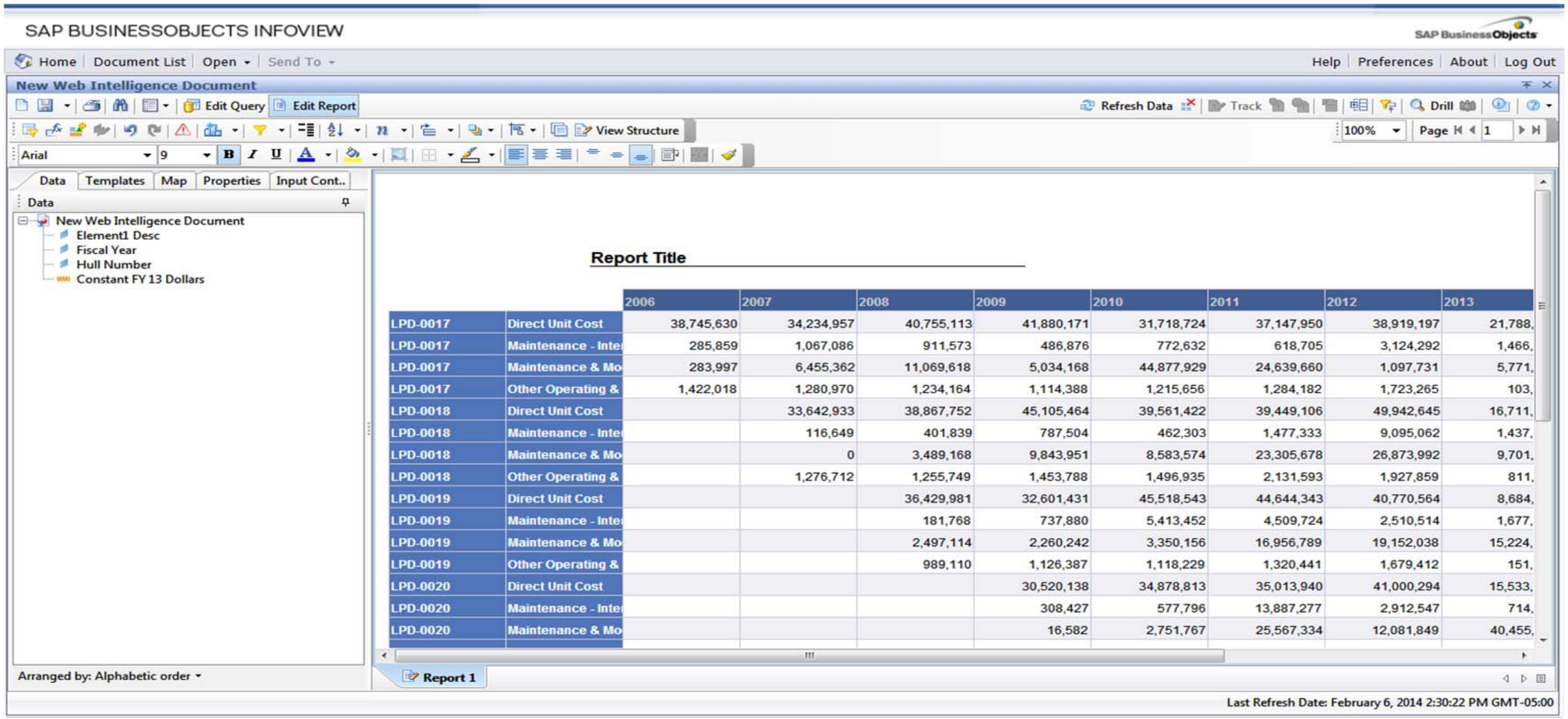


Figure A-2: Query Building Page of VAMOSC Web-Portal (VAMOSC, n.d.)



		2006	2007	2008	2009	2010	2011	2012	2013
LPD-0017	Direct Unit Cost	38,745,630	34,234,957	40,755,113	41,880,171	31,718,724	37,147,950	38,919,197	21,788,
LPD-0017	Maintenance - Inte	285,859	1,067,086	911,573	486,876	772,632	618,705	3,124,292	1,466,
LPD-0017	Maintenance & Mo	283,997	6,455,362	11,069,618	5,034,168	44,877,929	24,639,660	1,097,731	5,771,
LPD-0017	Other Operating &	1,422,018	1,280,970	1,234,164	1,114,388	1,215,656	1,284,182	1,723,265	103,
LPD-0018	Direct Unit Cost		33,642,933	38,867,752	45,105,464	39,561,422	39,449,106	49,942,645	16,711,
LPD-0018	Maintenance - Inte		116,649	401,839	787,504	462,303	1,477,333	9,095,062	1,437,
LPD-0018	Maintenance & Mo		0	3,489,168	9,843,951	8,583,574	23,305,678	26,873,992	9,701,
LPD-0018	Other Operating &		1,276,712	1,255,749	1,453,788	1,496,935	2,131,593	1,927,859	811,
LPD-0019	Direct Unit Cost			36,429,981	32,601,431	45,518,543	44,644,343	40,770,564	8,684,
LPD-0019	Maintenance - Inte			181,768	737,880	5,413,452	4,509,724	2,510,514	1,677,
LPD-0019	Maintenance & Mo			2,497,114	2,260,242	3,350,156	16,956,789	19,152,038	15,224,
LPD-0019	Other Operating &			989,110	1,126,387	1,118,229	1,320,441	1,679,412	151,
LPD-0020	Direct Unit Cost				30,520,138	34,878,813	35,013,940	41,000,294	15,533,
LPD-0020	Maintenance - Inte				308,427	577,796	13,887,277	2,912,547	714,
LPD-0020	Maintenance & Mo				16,582	2,751,767	25,567,334	12,081,849	40,455,

Figure A-3: Query Output Page of VAMOSC Web-Portal (VAMOSC, n.d.

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APPENDIX B. DAMIR

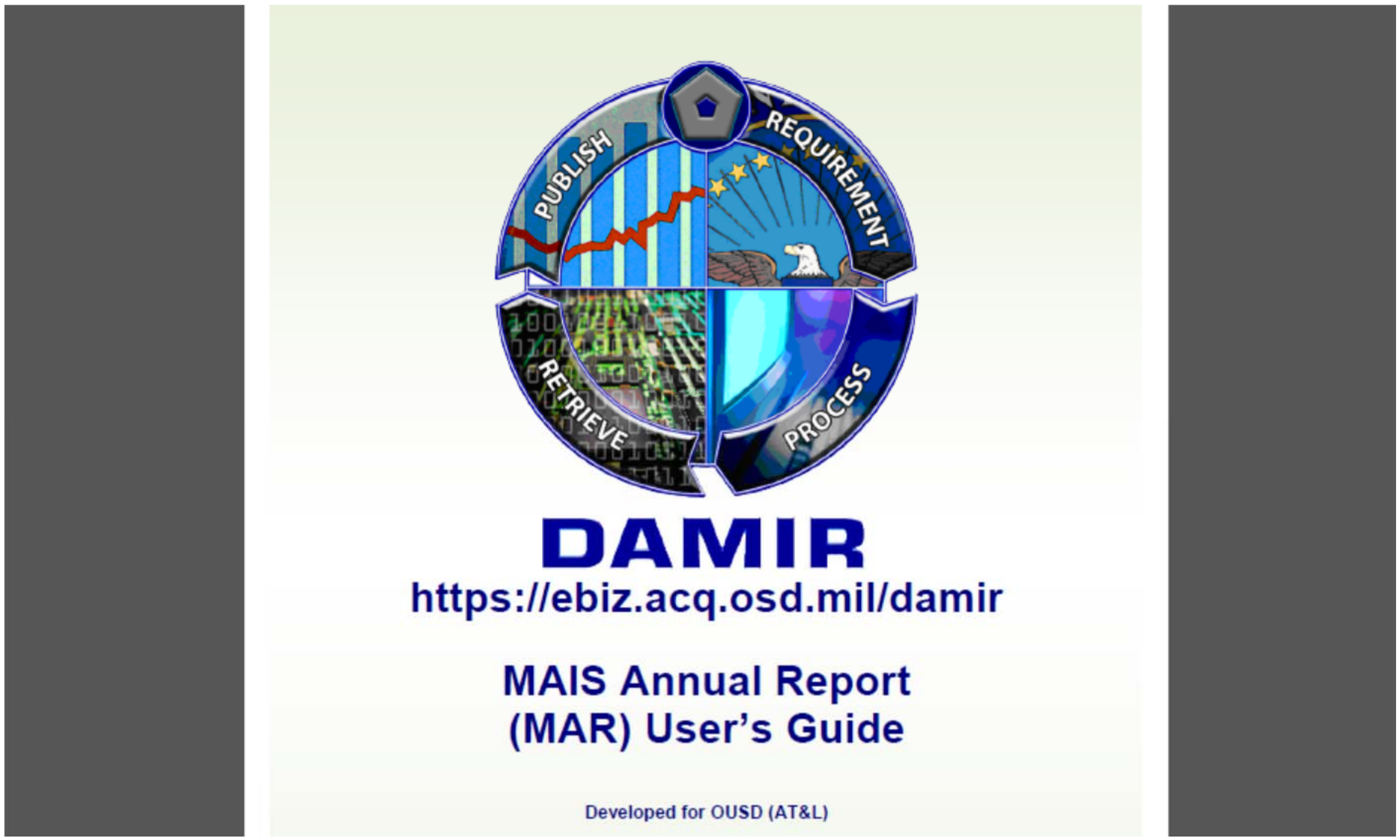


Figure B-1: User's Guide Page of DAMIR Web-Portal (DAMIR, n.d.)

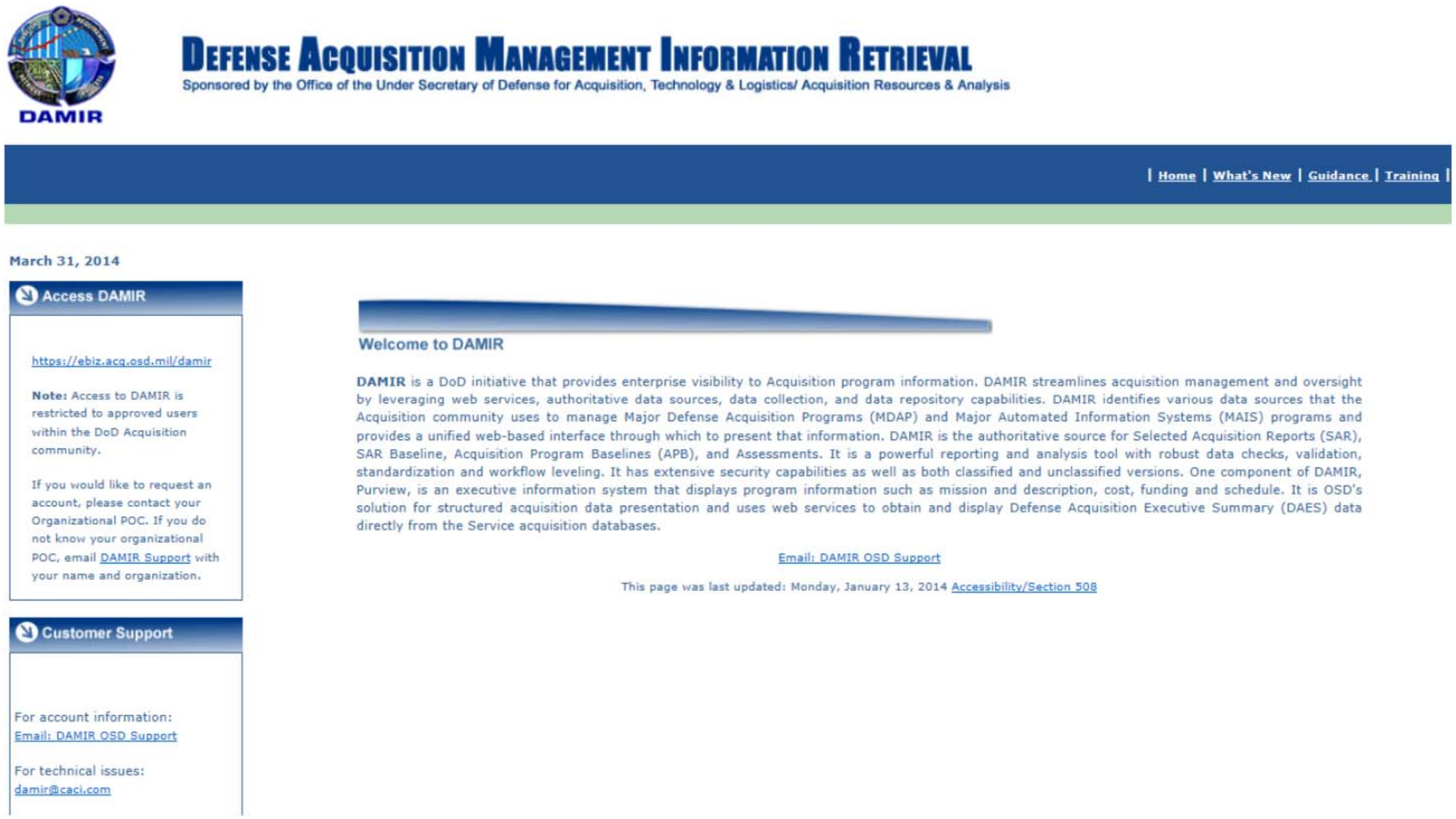
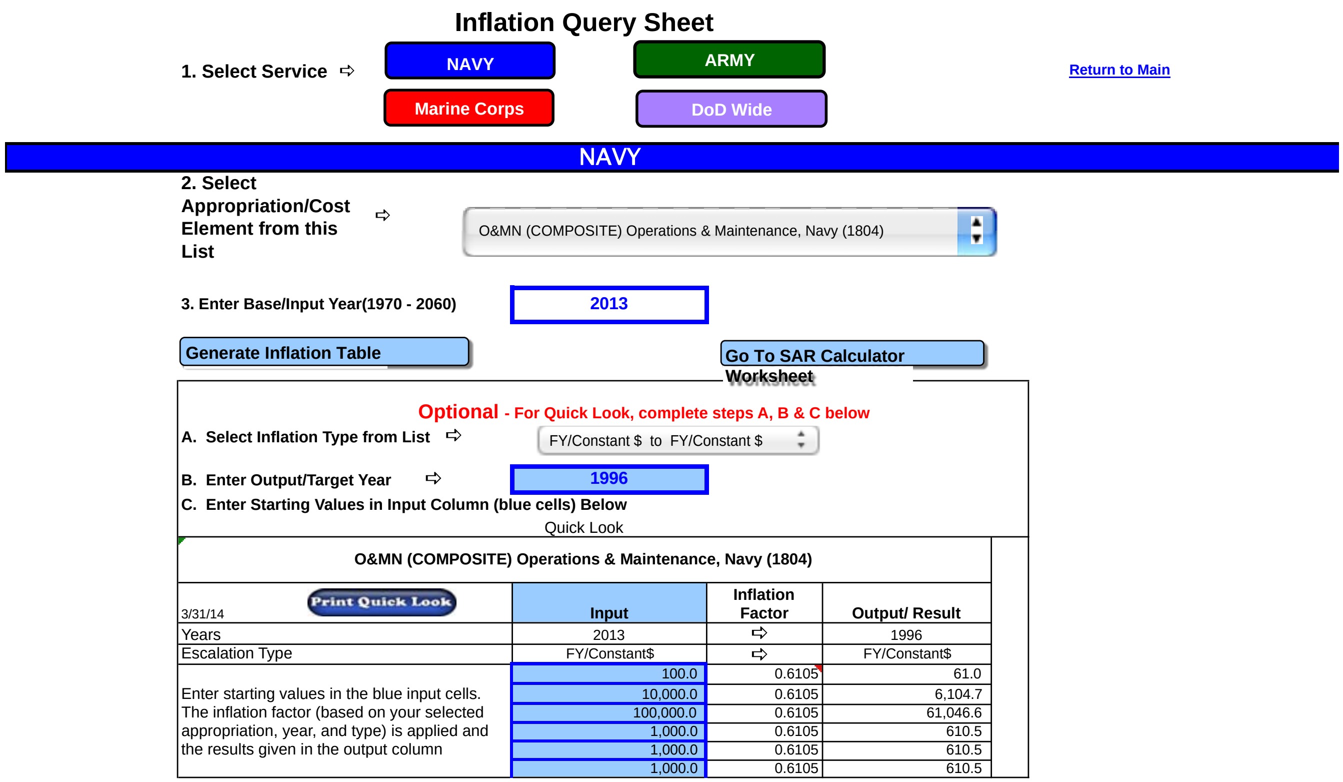


Figure B-2: Front Page of DAMIR Web-Portal (DAMIR, n.d.)

APPENDIX C. JIC



Inflation Query Sheet

1. Select Service ⇨ NAVY | ARMY | Marine Corps | DoD Wide

Return to Main

NAVY

2. Select Appropriation/Cost Element from this List ⇨ O&MN (COMPOSITE) Operations & Maintenance, Navy (1804)

3. Enter Base/Input Year(1970 - 2060) 2013

Generate Inflation Table

Go To SAR Calculator Worksheet

Optional - For Quick Look, complete steps A, B & C below

A. Select Inflation Type from List ⇨ FY/Constant $ to FY/Constant $

B. Enter Output/Target Year ⇨ 1996

C. Enter Starting Values in Input Column (blue cells) Below

Quick Look

O&MN (COMPOSITE) Operations & Maintenance, Navy (1804)

3/31/14 Print Quick Look	Input	Inflation Factor	Output/ Result
Years	2013	⇨	1996
Escalation Type	FY/Constant$	⇨	FY/Constant$
Enter starting values in the blue input cells. The inflation factor (based on your selected appropriation, year, and type) is applied and the results given in the output column	100.0	0.6105	61.0
	10,000.0	0.6105	6,104.7
	100,000.0	0.6105	61,046.6
	1,000.0	0.6105	610.5
	1,000.0	0.6105	610.5
	1,000.0	0.6105	610.5

Figure C-1: Query Creation Worksheet for Joint Inflation Calculator (JIC)

O&MN (COMPOSITE) Operations & Maintenance, Navy (1804)					
NAVY	Base Year = 2013				31-Mar-14
Fiscal Year	**Inflation Rate %**	**Raw Index**	**Weighted Index**	**Budget Year Index**	**Budget Year Inflation Rate %**
1970	7.07%	0.1467	0.1472	0.1461	
1971	6.10%	0.1557	0.1562	0.1550	6.08%
1972	5.86%	0.1648	0.1654	0.1641	5.91%
1973	4.16%	0.1717	0.1738	0.1725	5.10%
1974	9.99%	0.1888	0.1927	0.1912	10.87%
1975	14.71%	0.2166	0.2181	0.2164	13.16%
1976	7.50%	0.2328	0.2342	0.2324	7.40%
197T	2.42%	0.2385	0.2419	0.2401	3.29%
1977	5.75%	0.2522	0.2547	0.2528	5.29%
1978	7.37%	0.2708	0.2745	0.2724	7.76%
1979	8.95%	0.2950	0.2999	0.2975	9.24%
1980	21.98%	0.3598	0.3690	0.3661	23.05%
1981	10.71%	0.3984	0.4055	0.4023	9.89%
1982	7.22%	0.4271	0.4319	0.4285	6.51%
1983	2.55%	0.4380	0.4417	0.4383	2.27%
1984	1.65%	0.4453	0.4494	0.4459	1.74%
1985	2.48%	0.4563	0.4601	0.4565	2.38%
1986	0.35%	0.4579	0.4626	0.4590	0.54%
1987	1.82%	0.4663	0.4717	0.4680	1.97%
1988	1.82%	0.4747	0.4811	0.4773	1.99%
1989	3.76%	0.4926	0.4995	0.4956	3.82%
1990	3.29%	0.5088	0.5160	0.5119	3.30%
1991	8.48%	0.5519	0.5572	0.5528	7.98%
1992	1.58%	0.5606	0.5648	0.5603	1.36%
1993	3.14%	0.5782	0.5808	0.5762	2.83%
1994	2.24%	0.5912	0.5938	0.5892	2.25%
1995	1.06%	0.5975	0.6001	0.5955	1.06%
1996	2.18%	0.6105	0.6128	0.6080	2.10%
1997	2.21%	0.6239	0.6252	0.6203	2.03%
1998	2.68%	0.6407	0.6426	0.6376	2.78%

Return to Main

Go to Query

This sheet holds the inflation table most recently generated from the Query sheet.

The Inflation Rate is the inflation that occurred since the prior year.

Top

Top

Figure C-2: Inflation Index Table Worksheet for Joint Inflation Calculator (JIC)

APPENDIX D. ADDITIONAL GRAPHS

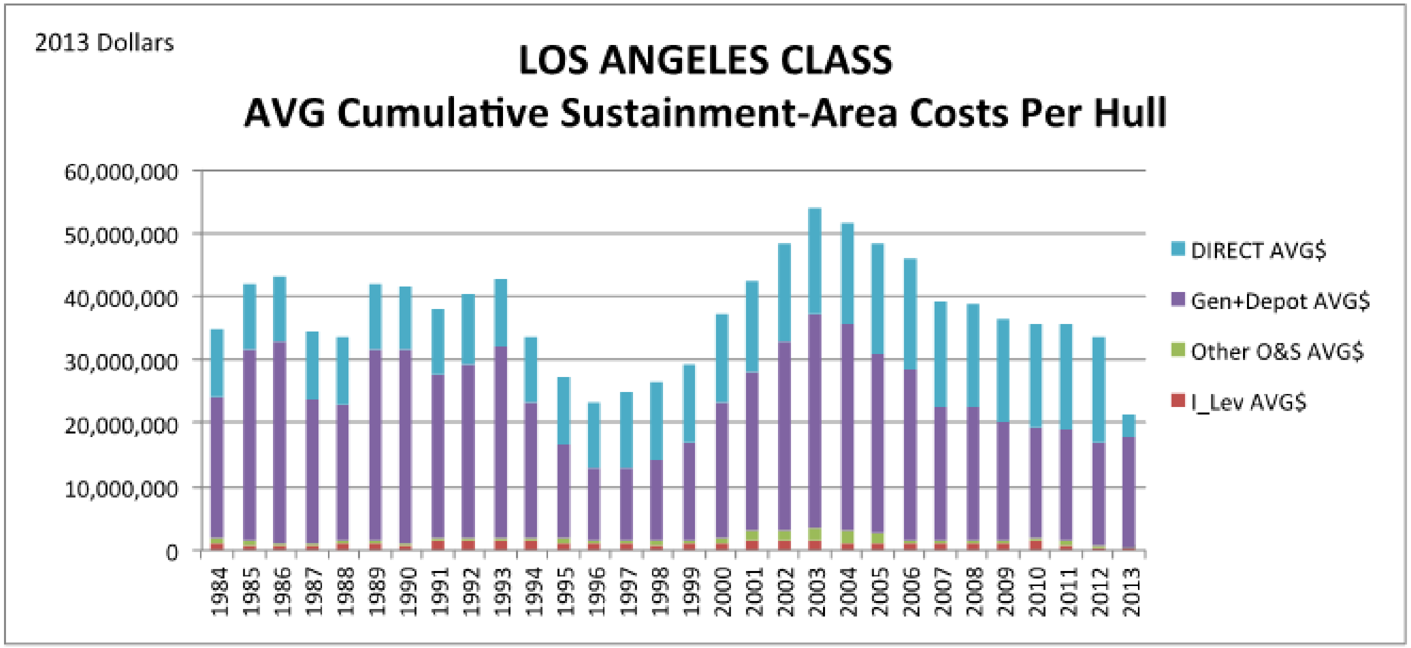


Figure D-1: Los Angeles-Class Cumulative Cost Distribution, Averaged Across All Vessels (after VAMOSC, n.d.)

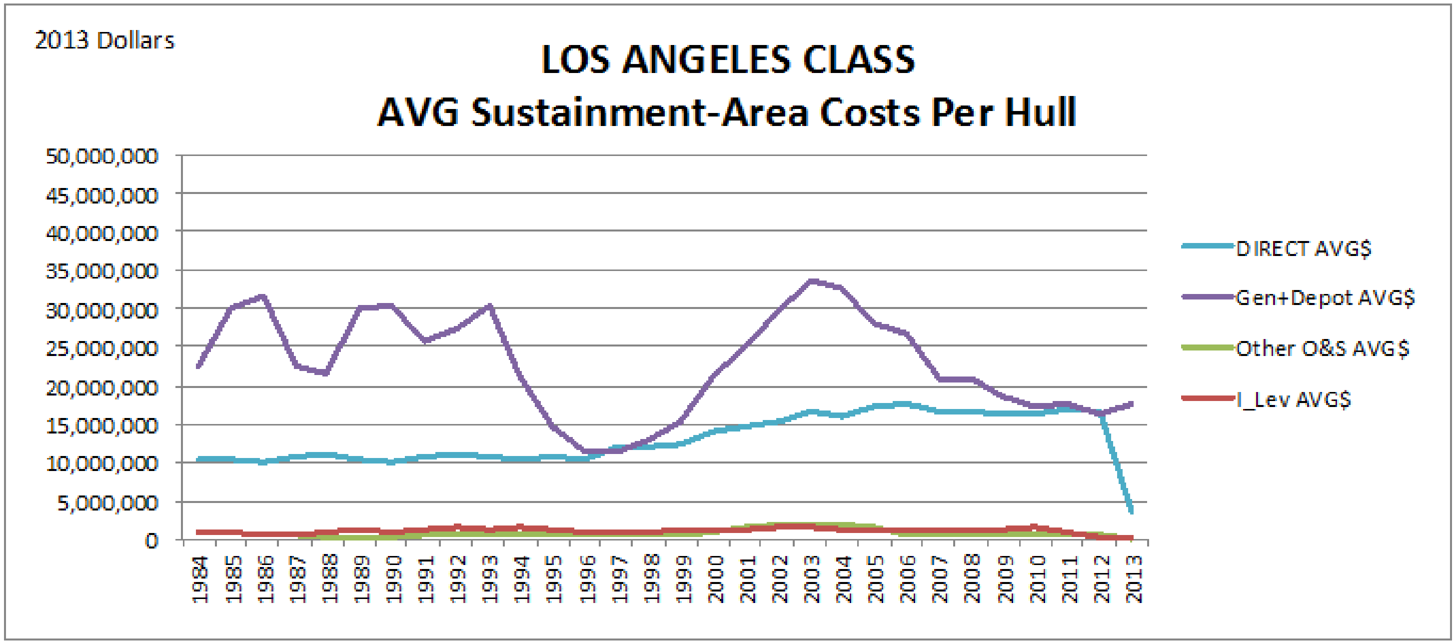


Figure D-2: Los Angeles-Class Cost Distribution for Cost Types, Averaged Across All Vessels (after VAMOSC, n.d.)

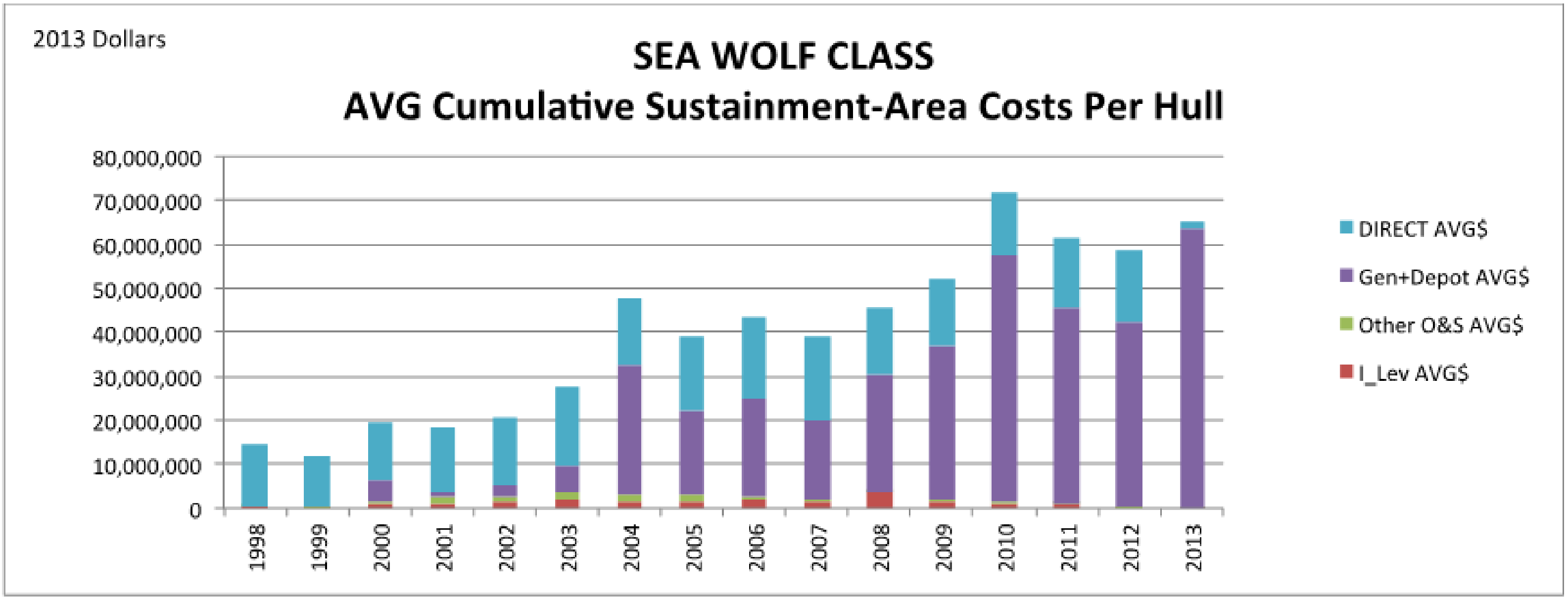


Figure D-3: Seawolf-Class Cumulative Cost Distribution, Averaged Across All Vessels (after VAMOSC, n.d.)

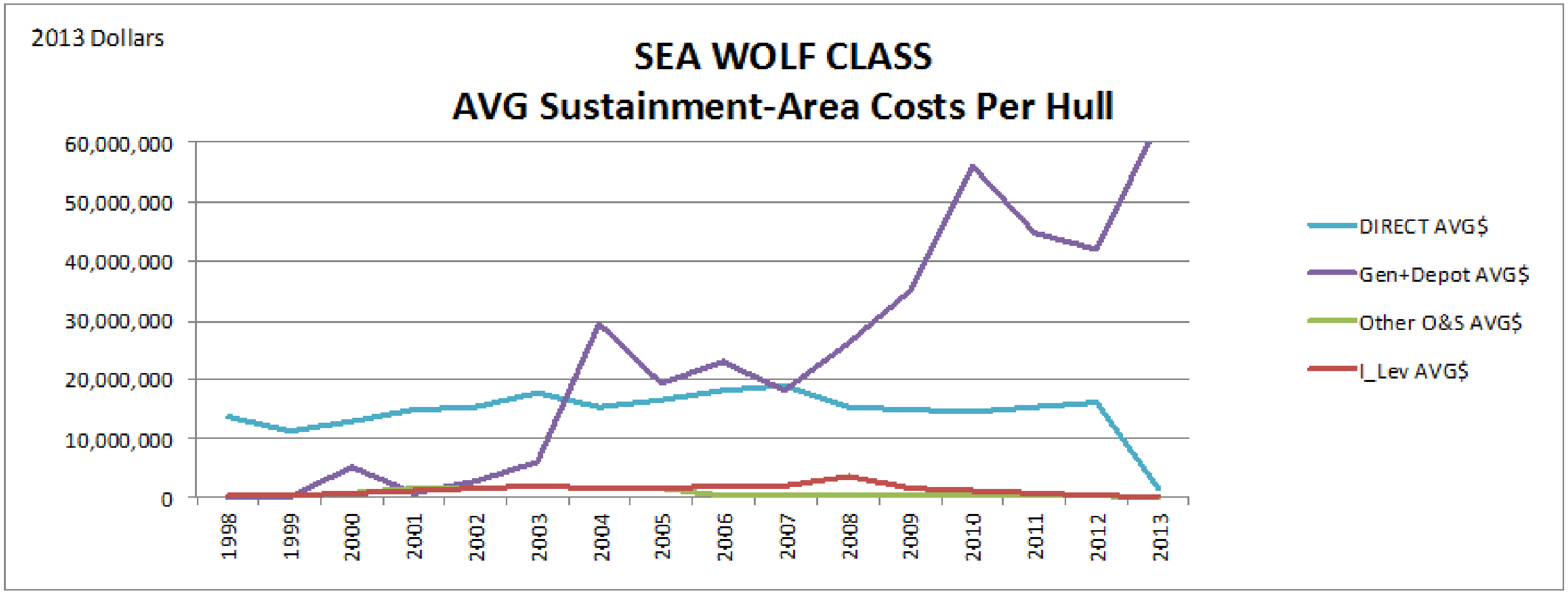


Figure D-4: Seawolf-Class Cost Distribution for Cost Types, Averaged Across All Vessels (after VAMOSC, n.d.)

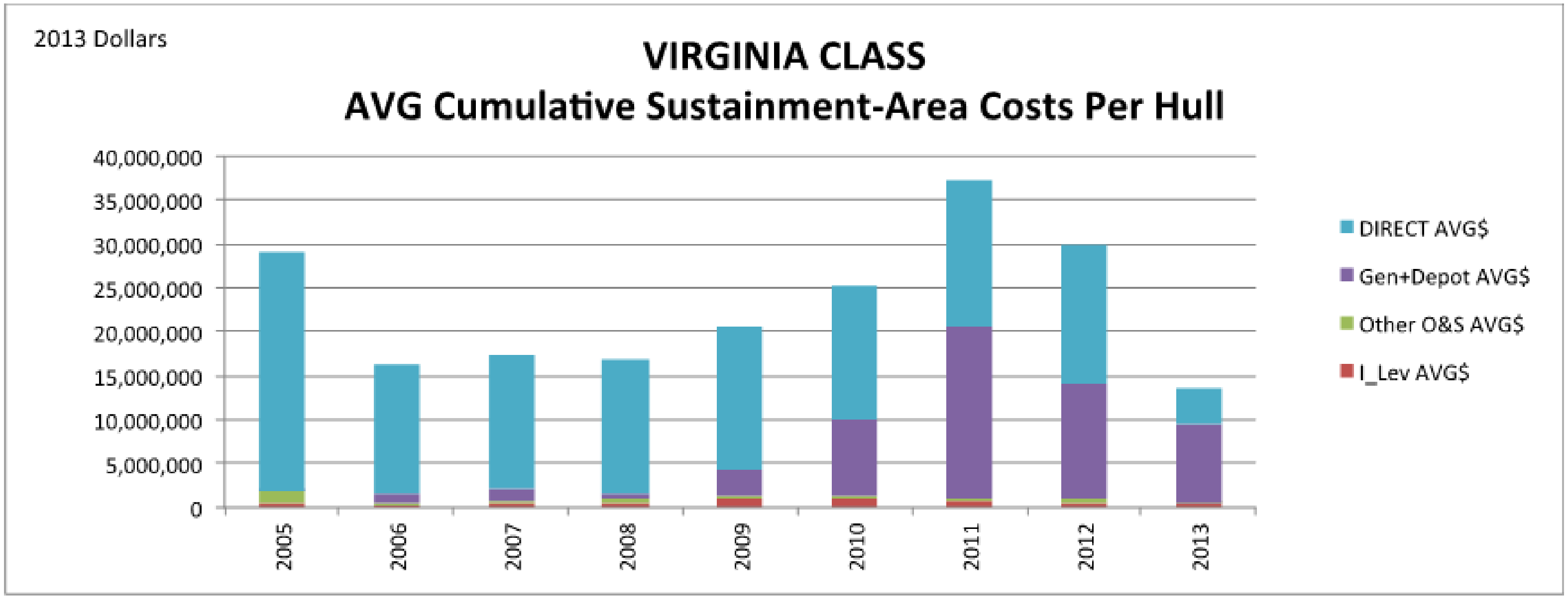


Figure D-5: Virginia-Class Cumulative Cost Distribution, Averaged Across All Vessels (after VAMOSC, n.d.)

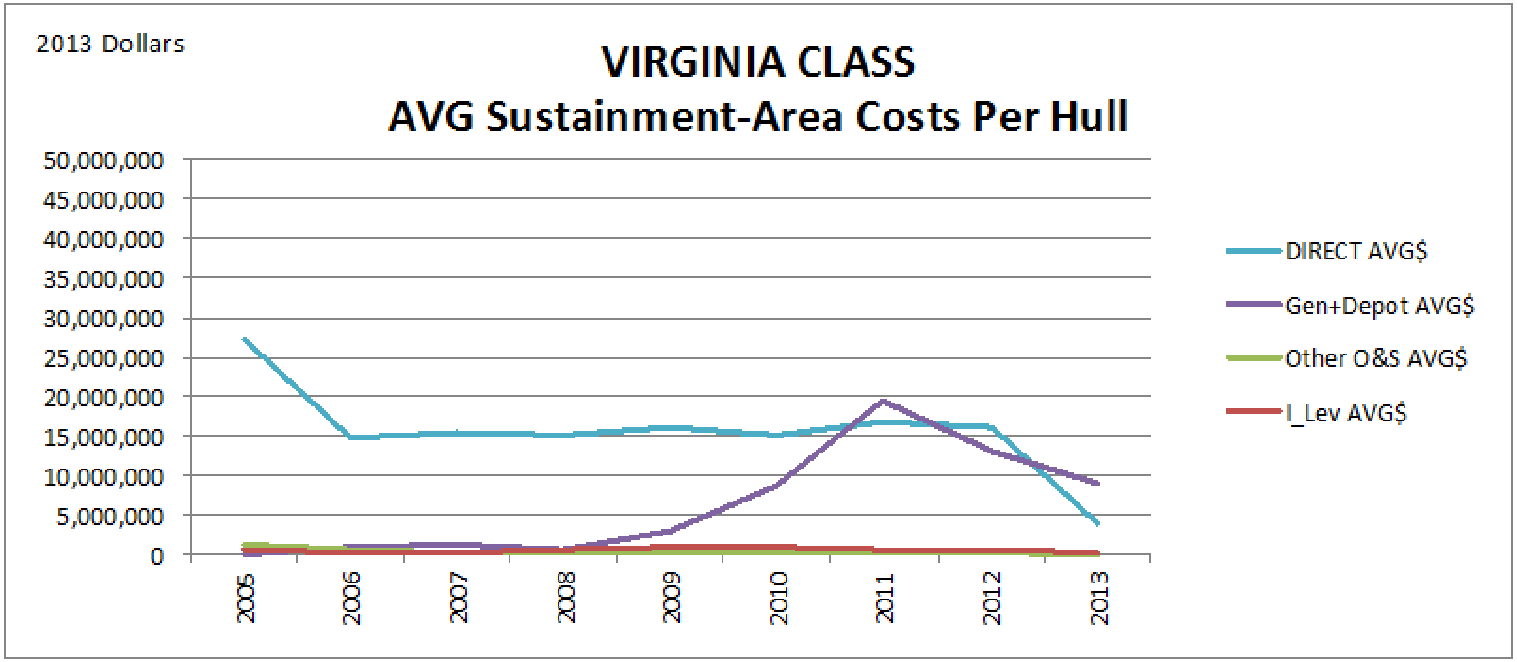


Figure D-6: Virginia-Class Cost Distribution for Cost Types, Averaged Across All Vessels (after VAMOSC, n.d.)

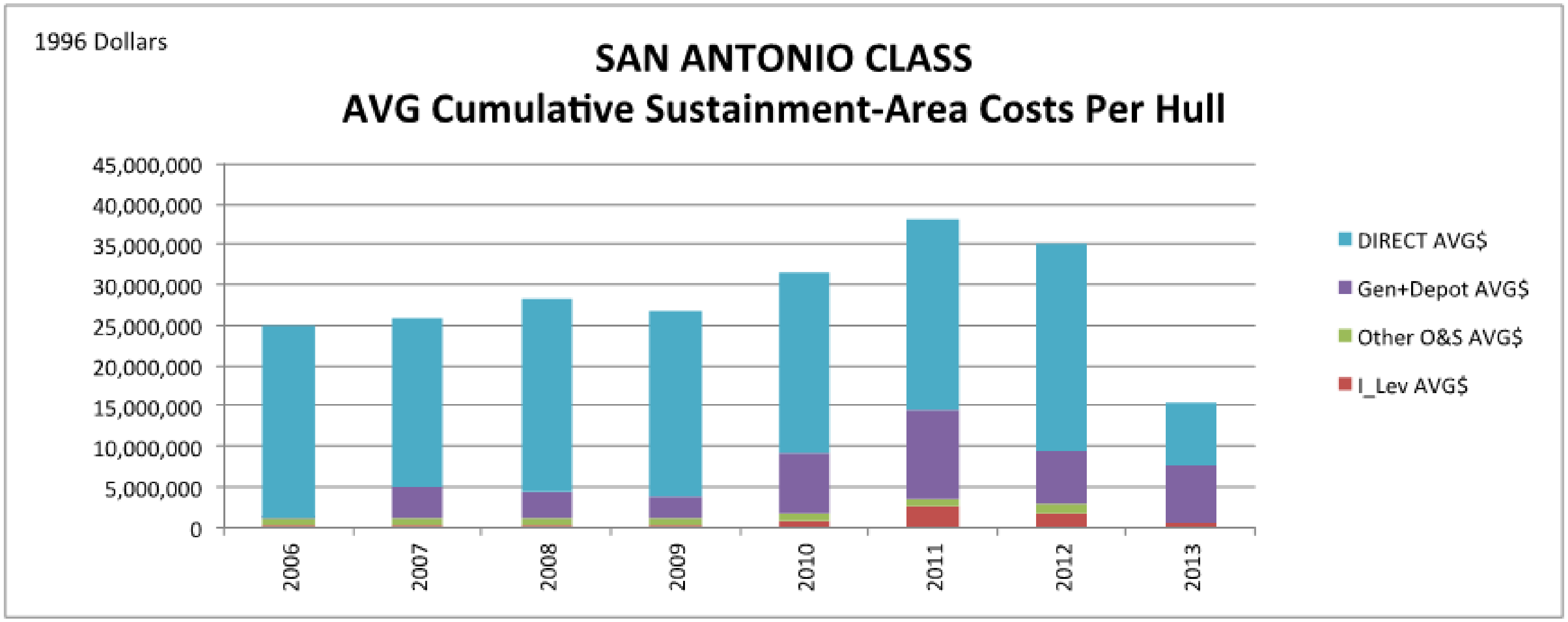


Figure D-7: Los Angeles-Class Cumulative Cost Distribution, Averaged Across All Vessels (after VAMOSC, n.d.)

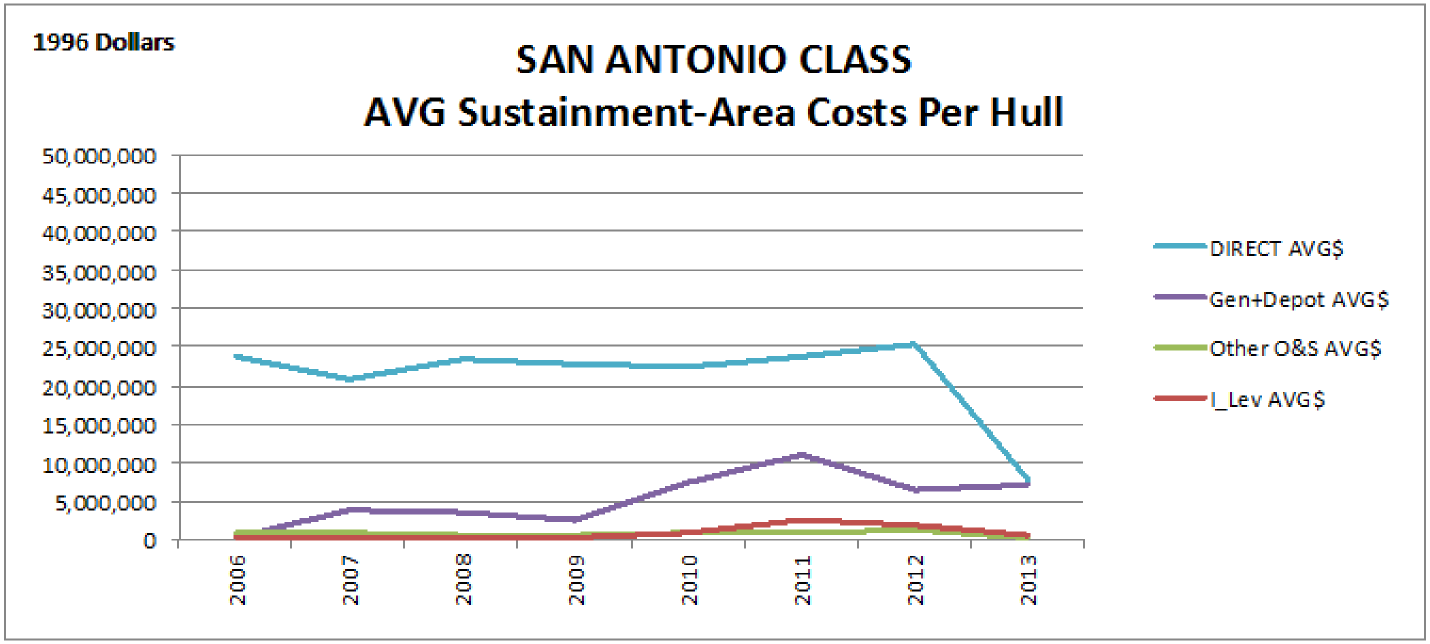
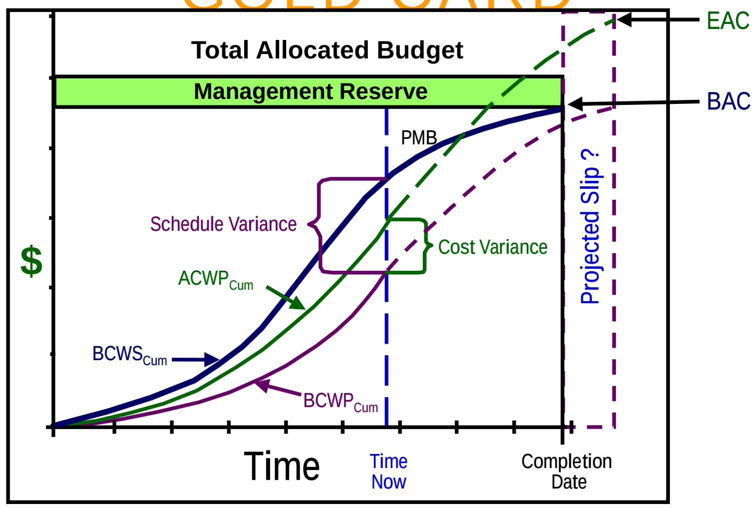


Figure D-8: San Antonio-Class Cost Distribution for Cost Types, Averaged Across All Vessels (after VAMOSC, n.d.)

EARNED VALUE MANAGEMENT 'GOLD CARD'



VARIANCES Positive is Favorable, Negative is Unfavorable

Cost Variance	CV	= BCWP – ACWP
	CV %	= (CV / BCWP) * 100
Schedule Variance	SV	= BCWP – BCWS
	SV %	= (SV / BCWS) * 100
Variance at Completion	VAC	= BAC – EAC
	VAC %	= (VAC / BAC) * 100

OVERALL STATUS

% Schedule	= ($BCWS_{CUM}$ / BAC) * 100
% Complete	= ($BCWP_{CUM}$ / BAC) * 100
% Spent	= ($ACWP_{CUM}$ / BAC) * 100

EFFICIENCIES

Cost Efficiency	CPI	= BCWP / ACWP	Favorable is > 1.0, Unfavorable is < 1.0
Schedule Efficiency	SPI	= BCWP / BCWS	Favorable is > 1.0, Unfavorable is < 1.0

BASELINE EXECUTION INDEX (BEI) & **Hit Task %**

BEI = Total Tasks Completed / (Total Tasks with Baseline Finish On or Prior to Current Report Period)

Hit Task % = 100 * (Tasks Completed ON or PRIOR to Baseline Finish / Tasks Baselined to Finish within Current Report Period)

ESTIMATE @ COMPLETION = ACTUALS TO DATE + [(REMAINING WORK) / (PERFORMANCE FACTOR)]

EAC_{CPI} = $ACWP_{CUM}$ + [(BAC – $BCWP_{CUM}$) / CPI_{CUM}]

$EAC_{Composite}$ = $ACWP_{CUM}$ + [(BAC – $BCWP_{CUM}$) / (CPI_{CUM} * SPI_{CUM})]

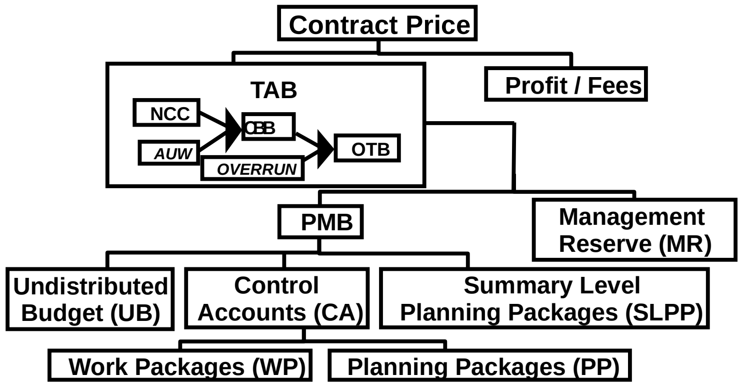
TO COMPLETE PERFORMANCE INDEX (TCPI) § #

$TCPI_{Target}$ = Work Remaining / Cost Remaining = (BAC – $BCWP_{CUM}$) / (Target – $ACWP_{CUM}$)

§ To Determine the TCPI for BAC, LRE, or EAC Substitute TARGET with BAC, LRE, or EAC

To Determine the Contract Level TCPI for EAC, You May Replace BAC with TAB

Figure E-1: "Gold Card" provided from Defense Acquisition University (DAU) website: https://acc.dau.mil/CommunityBrowser.aspx?id=19577



ACRONYMS

ACWP	Actual Cost of Work Performed	Cost actually incurred in accomplishing work performed	= ACTUAL COST
AUW	Authorized Unpriced Work	Work contractually approved, but not yet negotiated / definitized	
BAC	Budget At Completion	Total budget for total contract thru any given level	
BCWP	Budgeted Cost for Work Performed	Value of completed work in terms of the work's assigned budget	= EARNED VALUE
BCWS	Budgeted Cost for Work Scheduled	Time-phased Budget Plan for work currently scheduled	= PLANNED VALUE
CA	Control Account	Lowest CWBS element assigned to a single focal point to plan & control scope / schedule / budget	
CBB	Contract Budget Base	Sum of NCC & AUW	
EAC	Estimate At Completion	Estimate of total Cost for total contract thru any given level generated by Ktr, PMO, DCMA, etc. = $EAC_{Ktr / PMO / DCMA}$	
LRE	Latest Revised Estimate	Ktr's EAC or EAC_{Ktr}	
MR	Management Reserve	Budget withheld by Ktr PM for unknowns / risk management	
NCC	Negotiated Contract Cost	Contract Price Minus profit or fee(s)	
OTB	Over Target Baseline	Sum of CBB + additional budget approved for remaining work	
PAC	Price At Completion	EAC Plus Adjusted Profit or Fee(s)	
PMB	Performance Measurement Baseline	Contract time-phased budget plan	
PP	Planning Package	Far-term CA activities not yet defined into WPs	
SLPP	Summary Level Planning Package	Far-term contract activities not yet defined into CAs	
TAB	Total Allocated Budget	Sum of all budgets for work on contract = NCC, CBB, or OTB	
TCPI	To Complete Performance Index	Efficiency needed from 'time now' to achieve a Cost Target = BAC, LRE, or EAC	
UB	Undistributed Budget	Broadly defined activities not yet distributed to CAs or SLPPs	
WP	Work Package	Near-term, detail-planned activities within a CA	

EVM POLICY: *Interim* DoDI 5000.02, Enclosure 1. Table 8.

EVMS in accordance with ANSI/EIA-748 is required for cost or incentive contracts, subcontracts, intra-government work agreements, & other agreements valued ≥ \$20M (TY \$). Contracts ≥ \$50M (TY \$) require that the EVMS be formally validated by the cognizant contracting officer.

EVM is discouraged on Firm-Fixed Price, Time & Material Contracts, & LOE activities regardless of cost.

Refer to the IPMR Implementation Guide for IPMR Tailoring Guidance.

DoD's EVM CONTRACTING REQUIREMENTS:

DFARS CLAUSES 252.234-7001 "NOTICE OF EVMS" FOR SOLICITATIONS

252.234-7002 "EVMS" FOR SOLICITATIONS & CONTRACTS

252.242-7005 "CONTRACTOR BUSINESS SYSTEMS" FOR SOLICITATIONS & CONTRACTS

CONTRACT PERFORMANCE REPORT DI-MGMT-81466A 5 FORMATS = WBS, ORGANIZATION, BASELINE, STAFFING, EXPLANATIONS & PROB ANALYSES

INTEGRATED MASTER SCHEDULE DI-MGMT-81650 MANDATORY FOR DOD EVMS CONTRACTS

Integrated Program Mngt Report DI-MGMT-81861 * 7 FORMATS = WBS, OBS / IPT, BASELINE, STAFFING, EXPLANATIONS & PROB ANALYSES, IM S, HISTORY / FORECAST COST

INTEGRATED BASELINE REVIEW MANDATORY FOR ALL EVMS CONTRACTS

WBS For Defense Materiel Items MIL-STD-881-C

* Combines & Supersedes DI-MGMT-81466A & 81650; Effective July 1, 2012

Figure E-2: "Gold Card" provided from Defense Acquisition University (DAU) website: https://acc.dau.mil/CommunityBrowser.aspx?id=19577

LIST OF REFERENCES

10 U.S.C. § 181 (1997).

Birkler, J., Schank, J., Smith, G., Timson, F., Chiesa, J., Goldberg, M., … MacKinnon, M. (1994). *The U.S. submarine production base* (MR-456-OSD). Santa Monica, CA: RAND.

Blickstein, I. United States. Department of Defense. Office of the Secretary of Defense., National Defense Research Institute (U.S.), & Rand Corporation. (2012). *Methodologies in analyzing the root causes of Nunn-McCurdy breaches*. Santa Monica, CA: RAND.

Boyer, E. L. (1990). *Scholarship reconsidered.* Princeton, NJ: The Carnegie Foundation for the Advancement of Teaching.

Brown, S. A. (2005). Introduction. In S. A. Brown, *Providing the means of war (1945–2000)* (pp. 5–10). Washington, DC: Industrial College of the Armed Forces and United States Army Center of Military History.

Chairman of the Joint Chiefs of Staff (CJCS). (2012). *Joint capabilities integration and development system.* Washington, DC: Department of Defense.

CJCSI. (2012). *Chairman of the Joint Chiefs of Staff Instruction 3170.01H.* Washington, DC: Deparment of Defense.

Commander, Submarine Forces Atlantic. (2013). *U.S. Navy, Commander Submarine Forces Atlantic*, Retrieved 01 16, 2014, from Commander, Submarine Force: http://www.public.navy.mil/subfor/hq/Pages/VirginiaClass.aspx

Converse, E. V., III. (2005). Into the Cold War: An overview of acquisition in the Department of Defense, 1945–1958. In S. A. Brown, *Providing the means of war (1945–2000)* (pp. 27–30). Washington, DC: Industrial College of the Armed Forces and United States Army Center of Military History.

Defense Acqusition Management Information Retrieval (DAMIR). (1997a). *Selected Acquisition Report: SEAWOLF Class Nuclear Attack Submarine/Combat System* (SSN 21/AN/BSY-2). Washington, DC: Department of Defense.

Defense Acqusition Management Information Retrieval (DAMIR). (1997b). *Selected Acquisition Report: LPD 17 San Antonio Class Amphibious Transport Dock (LPD 17)* (RCS: DD-A&T [Q&A] 823–542). Washington, DC: Department of Defense.

Defense Acqusition Management Information Retrieval (DAMIR). (1998). *Selected Acquisition Report: LPD 17 San Antonio Class Amphibious Transport Dock (LPD 17)* (RCS: DD-A&T [Q&A] 823–542). Washington, DC: Department of Defense.

Defense Acqusition Management Information Retrieval (DAMIR). (1999a). *Selected Acquisition Report: Seawolf Class Nuclear Attack Submarine/Combat System (SSN 21/AN/BSY-2).* Washington, DC: Department of Defense.

Defense Acqusition Management Information Retrieval (DAMIR). (1999b). *Selected Acquisition Report: LPD 17 San Antonio Class Amphibious Transport Dock (LPD 17)* (RCS: DD-A&T [Q&A] 823–542). Washington, DC: Department of Defense.

Defense Acqusition Management Information Retrieval (DAMIR). (1999c). *Selected Acquisition Report: LPD 17 San Antonio Amphibious Transport Dock (LPD 17)* (RCS: DD-A&T [Q&A] 823–542). Washington, DC: Department of Defense.

Defense Acqusition Management Information Retrieval (DAMIR). (2001). *Selected Acquisition Report: LPD 17 San Antonio Amphibious Transport Dock (LPD 17)* (RCS: DD-A&T [Q&A] 823–542). Washington, DC: Department of Defense.

Defense Acqusition Management Information Retrieval (DAMIR). (2004). *Selected Acquisition Report: LPD 17 San Antonio Class Amphibious Transportation Dock (LPD 17)* (RCS: DD-A&T [Q&A] 823–542). Washington, DC: Department of Defense.

Defense Acqusition Management Information Retrieval (DAMIR). (2005). *Selected Acquisition Report: LPD 17 San Antonio Class Amphibious Transport Dock (LPD 17)* (RCS: DD-A&T [Q&A] 823–542). Washington, DC: Department of Defense.

Defense Acqusition Management Information Retrieval (DAMIR). (2006). *Selected Acquisition Report: LPD 17 San Antonio Class Amphibious Transport Dock (LPD 17)* (RCS: DD-A&T [Q&A] 823–542). Washington, DC: Department of Defense.

Defense Acqusition Management Information Retrieval (DAMIR). (2007). *Selected Acquisition Report: LPD 17 San Antonio Class Amphibious Transport Dock (LPD-17)* (RCS: DD-A&T [Q&A] 823–542). Washington, DC: Department of Defense.

Defense Acqusition Management Information Retrieval (DAMIR). (2010a). *Selected Acquisition Report: SSN 774 Virginia Class Submarine (SSN 774).* Washington, DC: Department of Defense.

Defense Acqusition Management Information Retrieval (DAMIR). (2010b). *Selected Acquisition Report: LPD 17 San Antonio Class Amphibious Transport Dock (LPD 17)* (RCS: DD-A&T [Q&A] 823–542). Washington, DC: Department of Defense.

Defense Acqusition Management Information Retrieval (DAMIR). (2011a). *Selected Acquisition Report: SSN 774 Virginia Class Submarine (SSN 774).* Washington, DC: Department of Defense.

Defense Acqusition Management Information Retrieval (DAMIR). (2011b). *Selected Acquisition Report: LPD 17 San Antonio Class Amphibious Transport Dock (LPD 17)* (RCS: DD-A&T [Q&A] 823–542). Washington, DC: Department of Defense.

Defense Acqusition Management Information Retrieval (DAMIR). (2012a). *Selected Acquisition Report: SSN 774 Virginia Class Submarine (SSN 774).* Washington, DC: Department of Defense.

Defense Acqusition Management Information Retrieval (DAMIR). (2012b). *Selected Acquisition Report: LPD 17 San Antonio Class Amphibious Transport Dock (LPD 17)* (RCS: DD-A&T [Q&A] 823–542). Washington, DC: Department of Defense.

Defense Acquisition University (DAU) Press (2008). *Introduction to Defense Acquisition Management (IDAM).* Fort Belvoir, VA: U.S. Government Printing Office.

Defense Acquisition University (DAU). (n.d.). DAU Gold Card—January 2014. Retrieved from https://acc.dau.mil/CommunityBrowser.aspx?id=19577

Defense Contract Managment Agency. (2006). *DOD earned value management implementation guide.* Washington, DC: Department of Defense.

Department of Defense (DOD) Authorization Act of 1983, Pub. L. No. 97–252, 96 Stat. 718 (1982).

Department of Defense (DOD). (1996). *Defense acquisition: Executive summary of DODD 5000.1*. Washington, DC: Author.

Department of Defense (DOD). (2013). *Defense acquisition guidebook.* Washington, DC: Author.

Department of Defense (DOD). (1996, December 17). *Navy announces contract award for LPD 17*. Retrieved from http://www.defense.gov/releases/release.aspx?releaseid=1106

Department of Defense (DOD). (1992).*Cost analysis guidance and procedures* (DOD 5000.4). Washington, DC: Author.

Federal Acquisition Regulation, 48 C.F.R. ch. 1 (2014).

Fireman, H., Nutting, M., Rivers, T., Carlile, G., & King, K. (1998). LPD 17 on the shipbulding frontier: Integrated product & process development. In *Proceedings of the 35th Annual Technical Symposium* (pp. 2–17). Association of Scientists and Engineers, Washington, DC.

General Dynamics–Electric Boat. (2010). *The VIRGINIA Class Submarine Program: A case study*. Groton, CT: General Dynamics Corp.

Goff, C., McNamara, C., Bradley, J., Trost, C., & Jabaley, M. (2012, January 27). Maximizing platform value. *Naval Engineers Journal, 123*(3), 2–19.

Government Accountability Office (GAO). (2003, June 23). *Multiyear procurement authority for the Virginia class submarine program* (GAO-03–895R). Washington, DC: Author.

Government Accountability Office (GAO). (2005). *Defense acquisitions: Improved management practices could help minimize cost growth in Navy shipbuilding programs* (GAO-05–183). Washington, DC: Author.

Government Accountability Office (GAO). (2013). *Opportunities exist to improve practices affecting quality* (GAO-14–122). Washington, DC: Author.

Hooke, R. (2005). *The defence industry in the 21st century*. London, UK: PriceWaterhouseCooper (PWC).

Husband, M., & Kaspersen, K. (2012, May–June). AOA: An early filter to create an affordable program. *Defense AT&L*, 7–10.

IBM. (2013). *Naval visibility and management of operating and support costs (VAMOSC) User's Manual.* Washington D.C.: Author.

Inouye, M. (2012). *Department of Defense Appropriations Bill, 2013.* Washington, DC: U.S. Senate.

Johnson, D. C., Drakeley, G. M., & Smith, G. M. (n.d.). *Engineering the solution: VIRGINIA class submarine reduction.* Unpublished manuscript, obtained from Program Management Submarine (PMS) 450.

Jones, L. R., & McCaffery, J. L. (2005). Defense acquisition and budgeting: Investigating the adequacy of linkage between systems. *International Public Management Review*, *6*(2), 87–115.

Key performance parameters (KPPs). (2013, August 23). In *ACQuipedia: Your online acquisition encyclopedia*. Retrieved January 15, 2014, from Defense Acquisition University website: https://dap.dau.mil/acquipedia/Pages/ArticleDetails.aspx?aid=7de557a6-2408-4092-8171-23a82d2c16d6

Key system attributes (KSAs). (2013, August 23). In *ACQuipedia: Your online acquisition encyclopedia*. Retrieved January 15, 2014, from Defense Acquisition University website: https://dap.dau.mil/acquipedia/Pages/ArticleDetails.aspx?aid=a415765b-dcad-4e68-b792-a6b5de1d6e54

Levit, M. R. (2010, September 17). *The federal debt: An analysis of movements from World War II to the present.* Washington, DC: Congressional Research Service (CRS).

Litton Avondale Alliance. (2000). *Total ownership cost (TOC) operations plan.* New Orleans, LA: Author.

Mandelbaum, J., & Pallas, S. (2001, July). *Reducing total ownership cost in DOD. Program Manager Magazine* , 76–82.

Maxwell, J. A. (1941). *Qualitative research design: An interactive approach.* London, UK: SAGE.

Milestone B. (2012, September 27). In *ACQuipedia: Your online acquisition encyclopedia*. Retrieved January 15, 2014, from Defense Acquisition University website: https://dap.dau.mil/acquipedia/Pages/ArticleDetails.aspx?aid=46512fb1-919a-45f6-9384-32ec2faa049f

Milestone C. (2012, September 27). In *ACQuipedia: Your online acquisition encyclopedia*. Retrieved January 15, 2014, from Defense Acquisition University website: https://dap.dau.mil/acquipedia/Pages/ArticleDetails.aspx?aid=63bc92c2-aaac-4d71–9a4a-4d12daa918a9

Naval Sea Systems Command. (2014a). Attack submarines—SSN [United States Navy fact file]. Retrieved from http://www.navy.mil/navydata/fact_display.asp?cid=4100&tid=100&ct=4

Naval Sea Systems Command. (2014b). Fleet Ballistic Submarines—SSBN [United States Navy fact file]. Retrieved from http://www.navy.mil/navydata/fact_display.asp?cid=4100&tid=200&ct=4

Naval Sea Systems Command. (2014c). Tomahawk Cruise Missile [United States Navy fact file]. Retrieved from http://www.navy.mil/navydata/fact_print.asp?cid=2200&tid=1300&ct=2&page=1

Naval Visibility and Management of Operating and Support Costs (VAMOSC). (n.d.). About VAMOSC. Retrieved February 4, 2014, from https://www.vamosc.navy.mil/webpages/general/about.cfm?color=003366

Nunn–McCurdy Act, 10 U.S.C. § 2433 (1983).

Office of the Chief of Naval Operations. (2010, May 25). *Maintenance policy for United States Navy ships* (OPNAVINST 4700.7L). Washington, DC: Author.

Office of Management and Budget. (2011). *Historical tables—Budget of the U.S. Government, FY 2011.* Washington, DC: U.S. Government Printing Office.

Office of the Inspector General. (1996). *DOD affordability assessments for major defense acquisitions programs.* Washington, DC: Department of Defense.

Office of the Inspector General. (1998). *Acquisition of the Amphibious Landing Transport Dock 17 class of ships.* Washington, DC: Department of Defense.

Office of the Secretary of Defense (OSD). (1996). *Executive summary* (DOD 5000.2). Washington, DC: Department of Defense.

Office of the Under Secretary of Defense (OUSD). (1998). *DOD integrated product and process development handbook.* Washington, DC: Department of Defense.

O'Rourke, R. (2011). *Navy LPD-17 amphibious ship procurement: Background, issues, and options for Congress.* Washington, DC: Congressional Research Service.

O' Rourke, R. (2013). *Navy Virginia (SSN-774) class attack submarine procurement: Background and issues for Congress.* Washington, DC: Congression Research Service.

Parametric Cost Estimate Method. (2011, May 26). In *ACQuipedia: Your online acquisition encyclopedia*. Retrieved January 14, 2014, from Defense Acquisition University website: https://dap.dau.mil/acquipedia/Pages/ArticleDetails.aspx?aid=36157b0b-69b4–4a0c-b16d-2e978b4c425c

Project Management Institute (PMI). (2000). *A guide to the project managment body of knowledge.* Newtown Square, PA: Author.

Project Objective Memorandum (POM). (2010, April 15). In *ACQuipedia: Your online acquisition encyclopedia*. Retrieved January 15, 2013, from Defense Acquisition University website: https://dap.dau.mil/acquipedia/Pages/ArticleDetails.aspx?aid=d72dabd4-f4f5–4864–96a5-f3357ff50280

Reed, D. (2003). *Reduction of total ownership (R-TOC) best practices.* Alexandria, VA: Institute for Defense Analyses.

Reliability Key System Attribute (KSA). (2013, August 5). In *ACQuipedia: Your online acquisition encyclopedia*. Retrieved January 15, 2014, from Defense Acquisition University website: https://dap.dau.mil/acquipedia/Pages/ArticleDetails.aspx?aid=5ef0d04e-392d-4c30–8803–56e5b8fc96ab

Rendon, R. G., & Snider, K. F. (2008). *Management of defense acquisition projects* (Vol. 1). Reston, VA: American Institute of Aeronautics and Astronautics.

Schank, J. F., Arena, M. V., DeLuca, P., Riposo, J., Curry, K., Weeks, T., & Chiesa, J. (2007). *Sustaining U.S. nuclear submarine design capabilities.* Santa Monica, CA: RAND.

Schank, J. F., Ip, C., Lacroix, F. W., Murphy, R. E., Arena, M. V., Kamarak, K. N., & Lee, G. T. (Eds.). (2011). *Learning from experience: Volume II: Lessons from the U.S. Navy's* Ohio, Seawolf, *and* Virginia *submarine programs.* Santa Monica, CA: RAND.

Schwartz, M. (2010a). *Defense acquisitions: How DOD acquires weapons systems and recent efforts to reform the process.* Washington, DC: Congressional Research Service.

Schwartz, M. (2010b). *The Nunn-McCurdy Act: Background, analysis, and issues for Congress.* Washington, DC: Department of Defense.

Shipbuilding History. (2014, February 1). Avondale Shipyards, New Orleans LA. Retrieved from http://www.shipbuildinghistory.com/history/shipyards/2large/active/avondale.htm

Storer, G. B. (2012). *Virginia class cost reduction: Achieving savings in submarine acquisition.* Monterey, CA: Naval Postgraduate School.

U.S. Navy. (2013, November 14). The U.S. Navy fact file: The amphibious ships. Retrieved from http://www.navy.mil/navydata/ships/amphibs/amphib.asp

U.S. Senate. (1992, July 21). *Navy report on new attack submarine.* Washington, DC: Library of Congress.

U.S. Senate. (1994). *The centurion.* Washington, DC: Library of Congress.

Van Gemert, D. K., & Wartenberg, M. (2007). Lessons learned in acquisition. *Defense Acquisition Review Journal*, 384–395.

Weapon Systems Acquisition Reform Act of 2009, Pub. L. No. 111–23, 123 Stat. 1704 (2009).

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