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TOTAL OWNERSHIP COST: A RECOMMENDATION FOR THE ARCHITECTURE INTEGRATION DECISION TOOL

by

John R. Golden

December 2018

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TOTAL OWNERSHIP COST: A RECOMMENDATION FOR THE ARCHITECTURE INTEGRATION DECISION TOOL

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Submitted in partial fulfillment of the
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ABSTRACT

The Future Fleet Architecture team within OPNAV N9I is starting the creation of a fleet decision aid called the Architecture Integration Decision Aid (ArnDT). While containing various functional layers, this study will serve as a focused effort to make a recommendation for how to allocate resources in the development of the cost model to be utilized. Having researched various cost types, the best choice of model will be based on Total Ownership Cost framework. This study shall provide background on cost estimation, the DoD Acquisition System, and the mission of OPNAV N9I. Having established a foundation of applicability, a qualitative look at Total Ownership Cost will be conducted in order to identify the broad aspects of costs that should be addressed within such a model. An exploratory case study demonstrating the supporting systems and ArnDT capabilities will be presented to highlight what a working total ownership cost model will provide to a completed ArnDT. Lastly, a discussion of applications shall lead to a quantitative recommendation for where resources should be invested to bring this cutting-edge capability from an idea to a reality.

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LIST OF ACRONYMS AND ABBREVIATIONS

2LM	Role 2 light maneuver
AOR	area of responsibility
ArnDT	Architecture Integrated Decision Tool
BCA	Budget Control Act
CBO	Congressional Budget Office
CCD	Critical Capabilities Document
CNO	Chief of Naval Operations
COA	course of action
COCOM	Combatant Command
COTS	Commercial off the Shelf
CRS	Congressional Research Service
DACIMS	Defense Automated Cost Information Management System
DAS	Defense Acquisition System
DAU	Defense Acquisition University
DCAPE	Director, Cost Assessment and Program Evaluation
DCARC	Defense Cost and Resource Center
DCNO	Deputy Chief of Naval Operations
DDG	Guided Missile Destroyer
DEFNEWS	Defense News
DEPT	department
DoD	Department of Defense
DoN	Department of the Navy
FFA	Future Fleet Architecture
FLT	flight
FRP	full-rate production
FSA	Force Structure Assessment
GAO	Government Accountability Office
GO	government owned
I.T.	Information Technology
ICD	Initial Capabilities Document

JCIDS	Joint Capabilities Integration and Development System
LCC	Life-Cycle Cost
LRIP	low-rate initial production
MARAD	Maritime Administration
MDAP	major defense acquisition program
MILCON	Military Construction
MILPERS	Military Personnel
MWR	Morale, Welfare, and Recreation
N9	Directorate for Warfare Systems, Office of the Chief of Naval Operations
N9I	Sub-Directorate for Warfare System Integration, Directorate for Warfare Systems
NAVADMIN	Naval Administrative Message
NCCA	Naval Center for Cost Analysis
NDAA	National Defense Authorization Act
NDRF	National Defense Reserve Fleet
O&M	Operations and Maintenance
O&S	Operations and Support
ONR	Office of Naval Research
OPNAV	Office of the Chief of Naval Operations
OPNAVINST	Office of the Chief of Naval Operations Instruction
OSD CAPE	Office of the Secretary of Defense Cost Assessment and Program Evaluation
OSDP	Office of Ship Disposal Programs
OT&E	Operational Test and Evaluation
PM	Program Manager
PPBE	Planning, Programming, Budget, and Execution
R&D	Research and Development
RDT&E	Research, Development, Test and Evaluation
RTCOST	the Naval Center for Cost Analysis cost model
SBP	Ship Building Plan
SECNAV	Secretary of the Navy
SME	subject matter expert

TOC	Total Ownership Cost
U.S.	United States
USN	United States Navy
USS	United States Ship
VAMOSC	Visibility and Management of Operation and Support Costs
WBS	work breakdown structure

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I. INTRODUCTION

One of the greatest attributes of the United State Military is its ability to remain on the cutting edge of defense system capabilities. While this may still remain the case, the costs to own and operate such defense systems have outpaced the rate of inflation (Department of the Navy [DoN], 2014). With a naval fleet that is aging, serious considerations need to be made to outpace the evolving threats presented in the global maritime commons (Office of the Deputy Chief of Naval Operations for Warfare Systems [OPNAV N9], 2016). The requirement to increase the capacity of the U.S. naval force to 355 ships was codified in law and now leaves a significant challenge to overcome (H.R. 2810, 2018). My research will address this challenge and articulate a method to invest current resources toward the development of a long-term solution to address defense system cost concerns, specifically in shipbuilding.

With a goal to establish a direction for resources to be allocated for the development of a cost solution for the naval shipbuilding industry, I opted to conduct an exploratory case study. This study had a two-pronged approach. The first focus was to establish the type of cost model that would need to be developed and provide a high-level, qualitative review of what this model would evaluate and provide. The second was to conduct an exploratory case study depicting how a working Total Ownership Cost (TOC) model would provide a capability from which decision makers at various levels of the DoD could benefit.

In order to understand the landscape, which this type of cost model would be functioning in, a detailed literature review was conducted. The first step was to understand what cost estimation was and how it applies to the various Defense Acquisition Programs (Mislick & Nussbaum, 2015; Department of Defense [DoD], 2017). This included a review in the various types of costs that exist with a particular emphasis on their applicability to shipbuilding (DoN, 2014; Office of the Secretary of Defense Cost Assessment and Program Evaluation [OSD CAPE], 2014; Mislick & Nussbaum, 2015; "Life-Cycle Costs," 2017). Having established an understanding of the environment and the needs for a holistic cost model, the final aspect was to understand the stakeholders concerned with this undertaking and their current efforts (Office of the Chief of Naval Operations [OPNAV], 2015; Greenert, 2012).

Having built a basis for what type of cost model would be most capable in an effort to maximize ownership affordability, a recommendation to allocate current resources into the development of a Total Ownership Cost (TOC) model is provided. To demonstrate the capability provided by such a model, a qualitative review of what cost aspects are addressed by a TOC model is offered. This is done utilizing a defense system's life-cycle phase format as outlined by the Navy Total Ownership Cost Guidebook. Moreover, in a demonstration of how such a capability would benefit Department of Defense (DoD) and Department of the Navy (DoN) decisionmakers, an exploratory case study is provided. This case study demonstrates the manner in which a TOC model can be aligned with the ongoing development of the OPNAV N9I Architecture Integration Development Tool (ArnDT).

Following the case study, a pragmatic discussion of where to allocate resources is provided. The recommendation is a dual-path allocation of resources into a commercial-off-the-shelf (COTS) system that can be modified, as well as a ground-up, government owned (GO) model being developed by the Naval Center for Cost Analysis.

II. BACKGROUND AND LITERATURE REVIEW

A. WHAT IS COST ESTIMATION?

In today's world of funding limitations and scrutiny being applied to the DoD at large, the ability to establish a cost for any type of purchase is important to decision makers. Moreover, when these purchases are major acquisitions on the order of millions of dollars, this becomes a central point of discussion for major decisions in the congressional budget process. Since this is such an important decision point, it is important to understand how these cost figures are developed and applied.

Cost estimation "is the process of collecting and analyzing historical data and applying quantitative models, techniques, tools, and databases in order to predict an estimate of the future cost of an item, product, program, or task" (Mislick & Nussbaum, 2015, p. 11). In simplistic terms, we look at the costs that previous similar items experienced and attempt to apply a "best guess" to the cost of developing a new item. While this may sound like a strictly scientific method that we apply in a standard manner, cost estimation is anything but. In fact, cost estimation can be viewed as more of an art (Mislick & Nussbaum, 2015).

The estimation process cornerstone lies within the available historical data. One of the largest pieces of the cost estimation process is simply finding data that is available for reference. Once the estimator successfully finds data that can be viewed as analogous, the real work begins through the "collection, organization, normalization, and management of the historical data" (Mislick & Nussbaum, 2015, p. 12).

Once armed with a data set, the scientific aspect of the process begins. The development of a quantitative model is the primary tactic that an estimator will use to build a cost estimate. This method arms the cost estimator with a "transparent, rationally defensible, and reviewable quantitative model" (Mislick & Nussbaum, 2015, p. 12) to interpret and evaluate the available historical data. The art of the process is with the application of variables within the model. No one is truly able to see into the future and account for every issue, schedule delay, or cost overrun that a project will be faced with.

However, using the lens of history, the cost estimator attempts to predict issues that may be experience by the program utilizing the data currently available and applying the assumptions that may best fit with the specific program (Mislick & Nussbaum, 2015).

1. Importance of Cost Estimation

Cost estimation is vital to the decision-making process utilized by the Department of Defense (DoD) and the United States Congress. This more specifically applies to the three main decision-making processes of budgeting, choosing between alternatives, and long-term planning (Mislick & Nussbaum, 2015). Before Congress can approve funding for a specific program, it would logically be a point of inquiry as to the cost necessary to fund that program to success. If it is a new program, a cost estimate must be completed to provide a dollar value that is required or expected. If you combine several of these programs over a time period, you end up with a budget proposal. The next logical step would be to look at programs that may be similar in nature, and choose the "most similar" one to place into a budget proposal. This choosing between alternatives also depends on a cost estimate to provide the required financial figures for each program. The decision maker, based on the particular goal that they are trying to achieve, can make program comparisons and ultimately decide which program to request funding for (Mislick & Nussbaum, 2015). Finally, these budget proposals, filled with the chosen programs, will be sent to Congress on an annual basis. This continuous nature leads itself into a planning process that can span across an extended period of time. From this, a long-term planning strategy would be developed. The specific contribution is that "cost estimation fills the critical role of providing affordability analysis" (Mislick & Nussbaum, 2015, p. 15). The cost estimator will develop the program cost while the decision makers can then decide if that cost will or should be afforded. These three main processes are all intrinsically linked and will always look to cost estimates for the required cost data so intelligent and prudent decisions can be made.

2. Characteristics of Quality Cost Estimates

As previously discussed, cost estimations are vital to our decision-making process. The value that is placed into the figures provided by an estimate require that the estimates being utilized are complete, reasonable, credible, and analytically defensible (Mislick & Nussbaum, 2015). Given this understanding, a discussion of characteristics that are within a quality cost estimate needs to be addressed.

A quality cost estimate is derived from data that is analogous in nature with similar program experiences. Simply put, it would not be a good practice to use data from an airplane building program to estimate the future costs of a tank building program. This may seem like common sense; however, if this is not established initially in the cost estimation process, every effort undertaken in the process will be done in vain. Having the best data to utilize, the estimate must then "reflect the current and potential future processes and design improvements" (Mislick & Nussbaum, 2015, p. 13). This is where the scientific nature of the data meets the art of the cost estimation process. The truth of the matter is that the historical data is reflective of older processes. A new project will in turn have the benefit of updated equipment, designs, and efficiencies. Since these newer program characteristics have not yielded a cost, the estimator is reliant on the professional judgement of a subject matter expert (SME) (Mislick & Nussbaum, 2015). In essence, the SME draws on the professional experience to provide a "best guess." This best guess is then applied to the cost estimation model. It is in this blending of scientific data and experience-derived process metrics that will yield the best cost estimations for decision makers.

There are several additional characteristics that are inherent in a good estimate. The estimate needs to have a clear list of assumptions from which the model was built from. Since decision makers may have differing options as to what constitutes the "obvious" items that the estimate should address, a straightforward list of assumptions and ground rules is vital to a cost estimate. Additionally, a good quality cost estimate should "address the risks and uncertainties inherent in the program plan" (Mislick & Nussbaum, 2015, p. 13). The decision makers should be provided an understanding of what the cost estimate is based upon and what factors could affect the accuracy of it. This understanding will be further supported by the estimate since it should be driven by the program requirements (Mislick & Nussbaum, 2015). Assumptions on the program must be clear and based on the requirements of the program while also providing the possible risks inherent in its application. If it does, then it meets the intent of a good quality estimate from which to make decisions.

The last characteristics that need to be addressed are not necessarily in the design of the estimate's model or part of the understanding of risk decisions, but rather they are more directly attributed to the use of the model. Firstly, the model needs to be transparent in nature and auditable, since a good quality cost estimate should be repeatable if the same "data sources, ground rules, and assumptions upon which it is based" are used (Mislick & Nussbaum, 2015, p. 14). An estimate should not be a "black box" for which data goes in and magically an estimate is provided. Rather, a reasonable individual should be able to follow and understand all steps. This leads to the second and final characteristic. A good quality cost estimate must be simple. Time in today's world always seem to be moving at an accelerated rate. This being the case, decision makers do not dedicate or have the time to read deep into complex models so as to have a full understanding of how costs are derived. Therefore, the best estimates are able to provide a quality estimate utilizing simple approaches vice overly complex versions (Mislick & Nussbaum, 2015).

3. What Really is Cost?

In order to better understand how costs are determined, a basic overview of the working definition is necessary. It is essential to understand the difference between a cost and a price. While it may seem simple enough, the confusion of such a detail could allow for a misconstruing of the concepts described later in this research.

The term *cost* is defined as "a quantitative measurement of the resources needed to produce an item." When speaking of a *price*, that can be defined as "the amount that you and I must pay for that item in the marketplace" (Mislick & Nussbaum, 2015, p. 25). The bedrock difference can be understood through a simple example. Professor Greg Mislick, a professor from the Department of Operations Research at the Naval Postgraduate School, utilized a produce example when he was explaining this key differential. I will attempt to explain this example.

Let us suppose that an individual is going to a local supermarket and wants to purchase an apple. The interested and assumedly hungry person would approach the produce aisle of the store and ask the store employee “How much does this apple cost?” In the employee’s mind, they would hear the inquiry and determine that what the individual wants to know is how much money is required to purchase the apple. The store employee would quickly rattle off the price of said apple to the inquiring customer. Now what just happened here? The would-be customer asked what the *cost* of the apple was. However, the employee interpreted that as the *price* of the apple. Herein lies the key difference. The *price* of the apple is what the customer wanted to truly know. They were hungry and wanted to purchase the apple to eat. But if the employee interpreted the original question of “How much does the apple cost?” correctly, then the answer would have been much more complicated. The cost of the apple would include such details like the cost of the seeds, the labor of the farmers to plant the seed, the cost of labor to water and fertilize the seed so that it would grow, the harvesting costs, the shipping of the apples to the processing and packaging plant, the cost of the truck to carry the packaged apples to the store, and so on. It is this key distinction between the price and the cost that a cost estimator must understand when determining the cost of a product or system. In simplest terms, the price of a product is equal to its cost plus the profit made (Mislick & Nussbaum, 2015).

4. Life-Cycle Cost

Now that we have an understanding of what cost is, the next level of understanding that is applicable in this study is the Life-Cycle Cost (LCC). Many of us who have had any amount of training or education in the cost estimation or defense acquisition curricula have heard that a life-cycle cost is the total cost of a system from tooth to tail; that is, from start to finish, or “cradle to grave.” While this metaphor might be helpful in a conversational environment, a more detailed look into it is relevant here.

As defined by the Defense Acquisition University (DAU), a life-cycle cost is “the cost to the government of a program over its full life, including costs for research and development; testing; production; facilities; operations; maintenance; personnel; environmental compliance; and disposal” (“Life-Cycle Costs,” 2017). Moreover, DAU explains that because of the various stakeholders that are interested in life-cycle costs, the manner in which it is broken down and displayed can be shown in three different ways.

Stakeholders such as Congress, who are looking at the funding aspects of the program, may wish to see a Life-cycle cost broken down by the five various funding appropriations ("Life-Cycle Costs," 2017). These appropriations are "Research, Development, Test and Evaluation (RDT&E); Procurement; Operations and Maintenance (O&M); Military Construction (MILCON); and Military Personnel (MILPERS)" ("Life-Cycle Costs," 2017). On the other hand, for the Program Managers and Contractors who are interested in the cost of the system more directly, the life-cycle cost can be shown by the work breakdown structure ("Life-Cycle Costs," 2017). A work breakdown structure (WBS) is a "display of the total system as a product-oriented family tree composed of hardware, software, services, data, and facilities; and relate the elements of work to each other and to the end product" ("Life-Cycle Costs," 2017). With the costs aligned within the WBS, the data can be helpful in the overall management of an acquisition program.

The final method of displaying a life-cycle cost is by the four major cost categories as outlined by 2014 Operating and Support Cost-Estimating Guide produced by the Office of the Secretary of Defense (OSD) for Cost Assessment and Program Evaluation (CAPE) ("Life-Cycle Costs," 2017). For the purposes of this research study, I will be mainly utilizing this method of describing life-cycle costs throughout. Below are the four cost categories and a brief description.

1. <u>Research and Development (R&D)</u>: R&D costs consist of the initial cost incurred in the design phase of a system development (OSD CAPE, 2014). Examples of a few of these costs include the cost of "materiel solution trade studies and advanced technology development; system design and integration; development, fabrication, assembly, and test of hardware and software for prototypes and/or engineering development models" (OSD CAPE, 2014, p. 2–3)

2. <u>Investment</u>: Following the R&D phase, Investment describes the start of the procurement process through the completion of system total deployment (OSD CAPE, 2014). A few of the systems are initially procured for operational test and evaluation by the service department

which is called Low-Rate Initial Production (LRIP) (OSD CAPE, 2014). Once the LRIP is approved, the rest of the systems can be procured in what is called Full-Rate Production (FRP). The cost associated with the investment categories include "producing and deploying the primary hardware; systems engineering and program management; product support elements (i.e., peculiar and common support equipment, peculiar training equipment/initial training, technical publications/data, and initial spares and repair parts) associated with production assets" (OSD CAPE, 2014, p. 2–3).

3. Operations & Support (O&S): O&S costs describe the costs that are incurred once the first system is deployed to service through the totality of all of the systems operations (OSD CAPE, 2014). Examples of these costs include the cost to "operate, maintain, and support a fielded system" which can consist of "personnel, equipment, supplies, software, and services associated with operating, modifying, maintaining, supplying, and otherwise supporting a system in the DoD inventory" (OSD CAPE, 2014, p. 2–3).

4. Disposal: Disposal costs are fairly straight forward in that they describe the associated costs with the disposal and/or demilitarization of a system at the end of that systems' useful life (OSD CAPE, 2014). While the idea of disposal is quite simple, the cost to dispose of a military system can be complex in nature depending on what is being disposed of. The associated costs of disposal can include "disassembly, materials processing, decontamination, collection/storage/disposal of hazardous materials and/or waste, safety precautions, and transportation of the system to and from the disposal site" (OSD CAPE, 2014, p. 2–4).

This method of describing life-cycle cost is generally well suited for a stakeholder who can best be described as a DoD decision maker ("Life-Cycle Costs," 2017). As such, it is paramount for a decision maker to easily understand the impact of cost decisions and where and how they may affect the system or its use. The four categories, in my estimation, enable the rapid understanding of cost choices and can be understood by decision makers that may not have the background in cost estimation or defense acquisition. Figure 1 is a visual representation of the previously described categories that encapsulate a systems life-cycle cost. Examples such as these can quickly explain and display cost data in a way which enable decisions makers to understand impacts and ultimately make an informed decision.

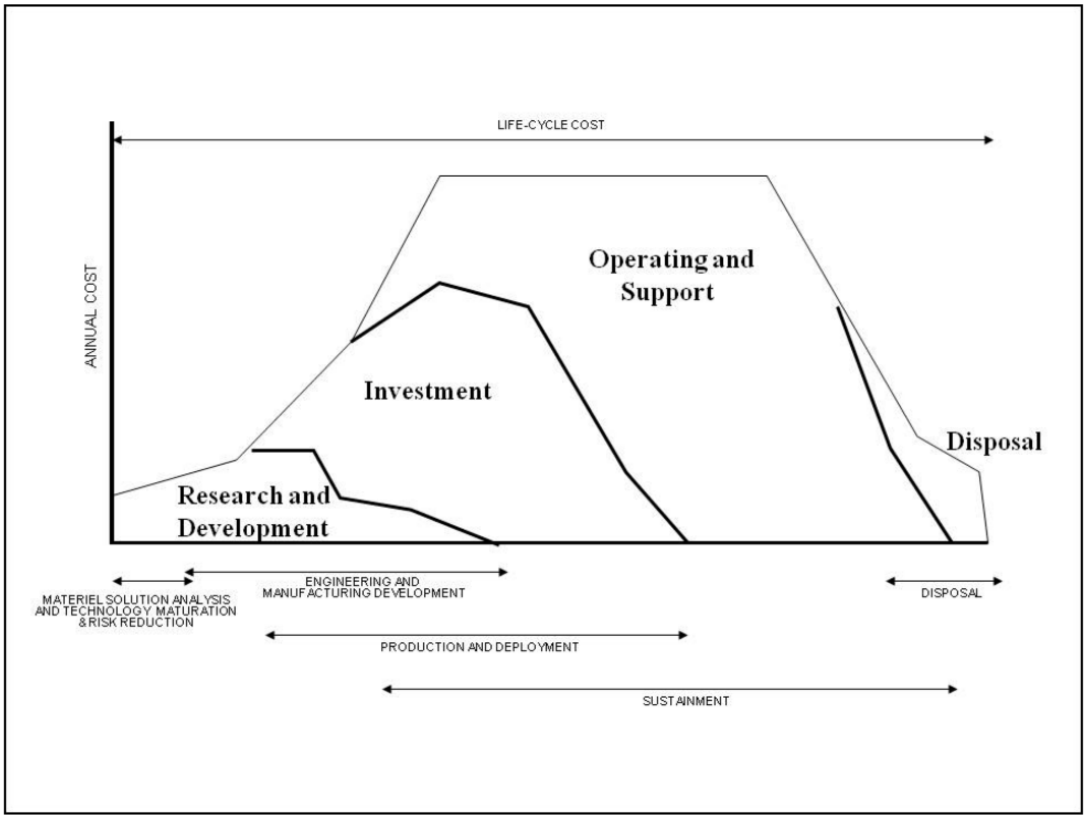

Figure 1. Notional Profile of Annual Program Expenditures by Major Cost Category over the System Life-Cycle. Source: OSD CAPE (2014).

B. DEFENSE ACQUISITION SYSTEM OVERVIEW

Having a rudimentary understanding of what cost estimating is, the next logical inquiry would be "What do I need it for?" For the DoD, the acquiring of new weapon systems, software programs, and all programs is done through the Defense Acquisition

System (DAS). The DAS is an event-driven system that utilizes a step-by-step methodology to acquire and maintain new systems from concept to retirement (Ambrose, 2017). This system works in concert with two other substantial defense support programs which provide the needs of the users and the financing to accomplish various acquisitions for them. These programs are essential to the success of the DAS and as such need a brief description.

The first of these is the Joint Capabilities Integration & Development System (JCIDS) (Ambrose, 2017). Within the Defense Acquisition Guidebook, JCIDS is described as "The systematic method established by the Chairman of the Joint Chiefs of Staff for identifying, assessing, and prioritizing gaps in joint warfighting capabilities and recommending potential solution approaches to resolve these gaps" (Defense Acquisition University [DAU], 2013, p. 6). In laymen's terms, JCIDS is a need-driven process by which the warfighter (or end user) can express their evolving needs to accomplish the mission (Ambrose, 2017). For example, if during a conflict the warfighters on the ground experienced a threat that the current military issued gear was unable to deal with, this need could be sent up through JCIDS for the acquisition community to develop a new or upgraded system to better allow for the warfighter to deal with the threat. Now that we understand what is needed, we need a process in which to fund the efforts.

The second support program is the Planning, Programming, Budgeting & Execution Process (PPBE) (Ambrose, 2017). PPBE is "The Department's strategic planning, program development, and resource determination process" (DAU, 2013, p. 6). Simplifying this definition can be done by stating that the PPBE is a calendar driven process by which programs are able to gain funding for their development and effort (Ambrose, 2017). Funding clearly is a vital piece of the puzzle when it comes to system development. This being the case, the commonly referred to Acquisition process is really more of a three-headed hydra consisting of the JCIDS, PPBE, as well as the DAS (Figure 2). While this multifaceted process is complex in nature, the ability for these three programs to work together is vital when it comes to ultimately providing effective systems for the warfighter to accomplish their mission as designed in the interest of the United States of America (Ambrose, 2017).

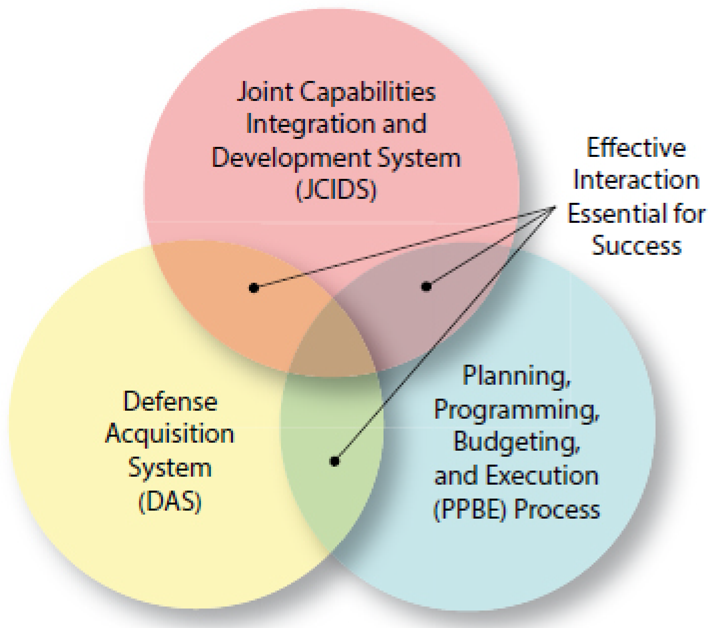

Figure 2. DoD Decision Support Systems. Source: Miller (2017).

1. Defense Acquisition System Design

Once a capability need has been established through JCIDS and the program is funded in the PPBE process, the DAS can begin its own process. The DAS is a five-phase process to take the described capability need from an idea to a sustained system. Figure 3 is a visual representation of the process as shown in the DoD Instruction 5000.02.

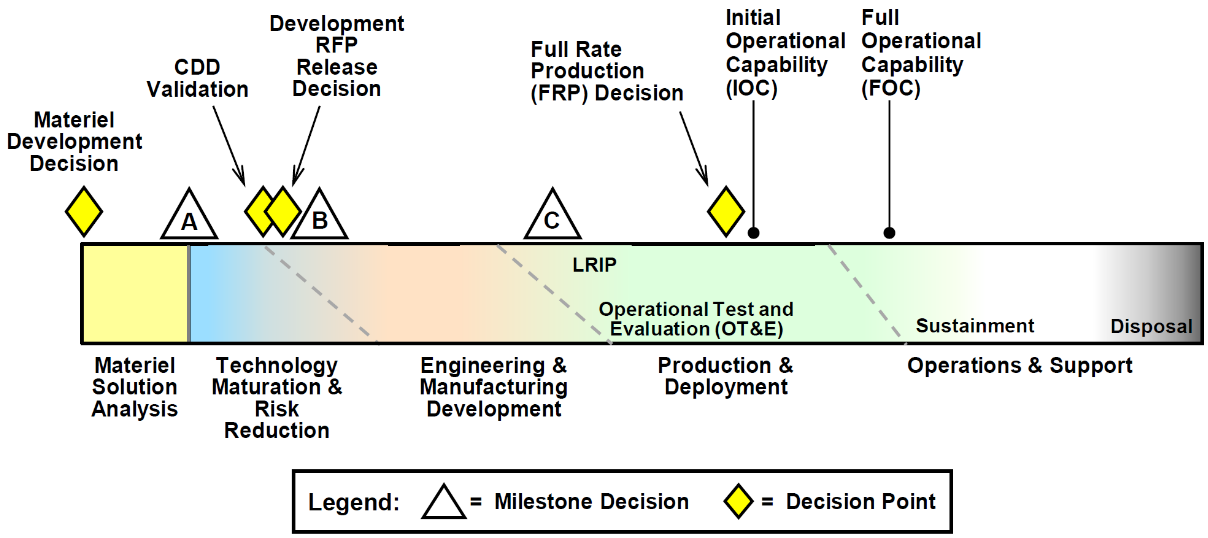

Figure 3. Hardware Intensive DAS. Source: DoD (2017)

The first phase is the Material Solution Analysis. This is the initial phase in which various technologies are evaluated to determine which is the best option available to meet the capability need of the end user (Ambrose, 2017). Once technologies are chosen, the second phase of Technology Maturation & Risk Reduction is the step where those technologies are put to the test (Ambrose, 2017). This "phase focuses on maturing critical, enabling technologies, thereby reducing program risk before commitment" ("Systems Engineering in Technology Maturation and Risk Reduction," 2017). Essentially this phase is where underdeveloped technologies are put to the test in competitive prototypes and overall maturation is conducted to reduce the risk of fielding a subpar and underdeveloped system to the end user (Ambrose, 2017).

Once these required technologies are determined to be mature and ready within a system design, the third phase of Engineering and Management Development can start. This phase is where the actual building of a working prototype begins (Ambrose, 2017). Many ideas may look great on paper and in theory; however, it takes time to establish a manufacturing strategy and actually take design specifications and build a physical system. Several prototypes (ideally) will be built to the design and fielded for testing (Ambrose, 2017). Through this fielding effort, the goal is to prove that the design can actually be produced and that it will meet the needs of the end user.

The fourth phase is Production & Deployment. This phase begins once the design is approved and proven. Production & Deployment has two stages: Low-Rate Initial Production (LRIP) and Full Rate Production (FRP) (DoD, 2017). LRIP is the purchasing of a limited amount of the systems in order to conduct final tests on operational capabilities of the system (DoD, 2017). Once the initial evaluation is completed satisfactorily, FRP is committed to and the purchase of the planned amount of systems occurs (Ambrose, 2017).

The final phase of DAS process is Operations & Support, where all of the fielded systems are maintained through the entirety of their operational life cycle (Ambrose, 2017). This phase also includes the final appropriate disposal of the system from service (Ambrose, 2017). All maintenance, upgrades, and operational system changes are sustained within this phase of the acquisition process (DoD, 2017).

2. Life-Cycle Costs and the Defense Acquisition System

The implementation and use of Life-Cycle Cost is a decisive factor in the DAS. The Department of Defense Instruction 5000.02, Operation of the Defense Acquisition System, establishes the requirement for the DoD Component to develop a cost estimate that "covers the entire life cycle of the program for all Major Defense Acquisition Programs (MDAPs) prior to Milestone A, B, and C reviews and the Full-Rate Production Decision" (DoD, 2017, Encl 10: 2.d.). It continues to further clarify that the Milestone Decision Authority (MDA) "may not approve the engineering and manufacturing development or the production and deployment of an MDAP unless an independent estimate of the full life-cycle cost of the program, prepared or approved by the DCAPE, has been considered by the MDA" (DoD, 2017, Encl 10: 2.c.).

So, it is mandated by the governing documentation that rejection of the program from proceeding further is authorized if the life-cycle cost estimate is not completed. This is good news, correct? Maybe not completely. Scott Gilbreth, a professor of Contract Management at the Defense Acquisition University, explained that while most individuals can understand and agree with the use of life-cycle cost as an evaluating factor, its application has fallen out of favor in DoD source selections (Gilbreth, 2017). There are several reasons that have led to this. Life-cycle cost estimates are not simply estimates that are current in their nature; rather, they evaluate possible costs that will be incurred beyond the timeline of an individual contract (Gilbreth, 2017). Contractors see this and do not want to be evaluated against the validity of a future estimate (Gilbreth, 2017). The contractors see this as "20 or 30 years of theoretical sustainment costs overshadowing current, and real procurement cost" (Gilbreth, 2017, p. 28). For a defense contracting company, this makes perfect sense.

More than just the contractors are incentivized to diminish the role of life-cycle cost in the DAS. The timeline for a Program Manager to lead a MDAP is limited. Since, like many military leadership positions, the PM role is short-lived, the incentives to show positive progress with a MDAP cannot rest on a 30-year theoretical cost outlay. I believe that the incentives for a PM drive that individual to want to "make their mark." This desire would more than likely lead a PM to want to drive down the cost per unit and this is not inherently a bad thing. If a PM could procure a ship for $300 million instead of an original $500 million, that would be worthy of praise. However, I would argue that the life-cycle cost impact and system capabilities degradation from the changes which brought the individual unit cost down would be necessary. If the cost reduction of $200 million was due to a change of propulsion plant, for instance, the fuel cost impact for the life of the ship would be affected. There could be other impacts to include changes in projected maintenance cost, training cost, and even disposal costs. An evaluation should be conducted to calculate the changes in the life-cycle cost over the expected operational life of the ship. From there, the evaluation is simple. If the $200 million in savings was estimated to increase the life-cycle cost of the ship by less than $200 million, then the change in propulsion plant is cost effective. However, if the life-cycle cost increase by $200 million or more, than it is cost effective to purchase the ship for $500 million and keep the lower costs over the lifespan of the ship.

Ultimately, while the life-cycle cost is estimated within the DAS, its application in decision making is controversial and there is a general consensus in opposition to it (Gilbreth, 2017). While perhaps the politics of Defense Acquisition is not ready to look at a life-cycle cost as a driving factor, I believe that decision makers can benefit from understanding the life-cycle cost of a system. Moreover, I believe that expanding a life-cycle cost into a Total Ownership Cost (TOC) would be most beneficial for decision makers. As I believe this is the case, we need to look at individuals that can benefit from a life-cycle cost or TOC estimation.

C. THE OFFICE OF THE CHIEF OF NAVAL OPERATIONS (OPNAV)

The most senior Naval Officer is the Chief of Naval Operations (CNO) (United States Navy [USN], 2018a). As are his responsibilities to the Secretary of the Navy, the CNO is responsible "for the command, utilization of resources, and operating efficiency of the operating forces of the Navy and of the Navy shore activities" (USN, 2018a). The idea of being responsible for the utilization of resources and operating efficiency of the entire naval fleet is quite daunting—it would be for any individual. As this is a plainly understood fact, the CNO has a staff to assist him with the multi-faceted list of job requirements. The staff is known as the Office of the Chief of Naval Operations (OPNAV) (USN, 2018a).

OPNAV is designed to support the CNO through various functional directorates as delineated by codes that describe a specific functional area (OPNAV, 2015). Below is a list of the various functional areas and a brief description of each one (Figure 4).

N1	Manpower, Personnel, Training, & Education/Chief of Naval Personnel
N2/N6	Warfare Dominance/Director of the Office of Naval Intelligence
N3/N5	Operations, Plans, & Strategy
N4	Fleet Readiness & Logistics
N8	Integration of Capabilities & Resources
N9	Warfare Systems

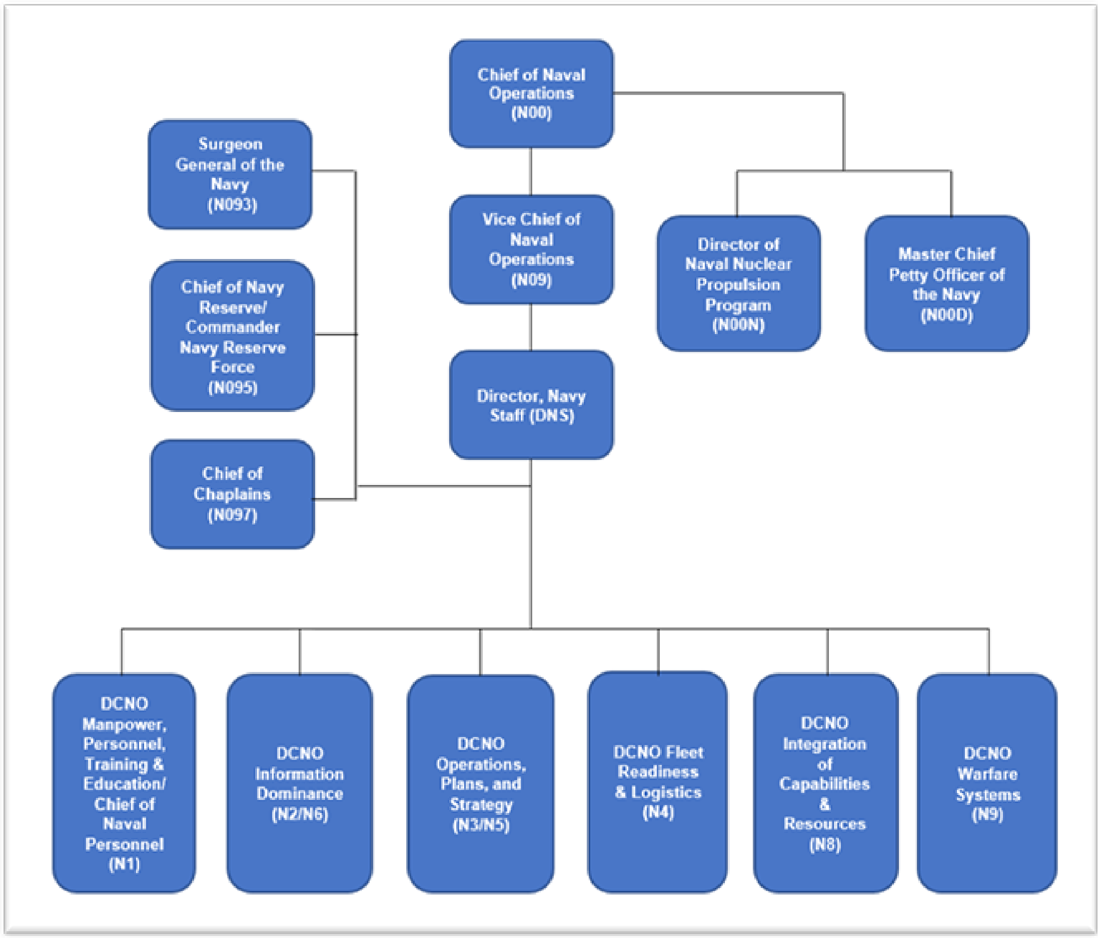

Figure 4. Organizational Chart of the 2018 Office of the Chief of Naval Operations. Source: Johnson (2018).

Each of the listed functional directorates are headed by a Deputy Chief of Naval Operations (DCNO) who serve as principal assistants to the CNO with a specific focus on the specialties that fall into their directorate (OPNAV, 2015). While I believe that any of the individuals that fall into the above-mentioned roles could benefit from a TCO estimation for the assets which they are accountable for, I will be focusing solely on the Warfare Systems directorate N9.

1. N9I, Future Fleet Architecture (FFA)

The N9 functional directorate was established in 2012 when an OPNAV realignment was ordered (Greenert, 2012). The N9 office is "responsible for the integration of manpower, training, sustainment, modernization, and procurement readiness of the navy's warfare systems" (Greenert, 2012). Within the N9 directorate, the supporting directorate N9I was established to focus on the integration of warfare systems.

The integration of warfare systems is a broad reaching task. One such task is the looking into the future and planning strategy around what the fleet will look like. This of course it not as simple as it sounds. There are many facets involved with looking at a future fleet. For example, the first thing I would need to know is how many ships I will have. After that, I would need to identify what kind of ships are within the inventory and what their capabilities are. Next, I might want to have an idea of what kind of capabilities each ship has, where I will locate them, and what purpose they would be serving. Last, but certainly not the least important, I would want to know how much all of this would cost. Keep in mind all of this is a look into the future and can basically be summed up as a "best guess." Simply put, this is not easy and takes an enormous amount of work to accomplish.

In the OPNAV N9I shop, there is an effort to simplify this process. To better understand the many diverse factors that go into these future calculations, decision makers currently do not have an effective decision aid to assist them. OPNAV N9I is working to address this shortfall. In order to provide a tool that our top-level decision makers can utilize, N9I is looking into the current projections for our fleet and attempting to construct a tool to aid in naval decision-making. In order to understand the scope of this, a look at the projections is warranted.

2. The Future Fleet (at least as it stands now)

Before the future can be understood, the present must be addressed. The current deployable fleet size of the United States Navy (USN) stands at 256 ships (United States Navy [USN], 2018b). This number currently falls short of the 653-ship force, listed in the most recent Navy Force Structure Assessment (FSA), as the number that would "fully resource these platform-specific demands, with very little risk in any theater while still supporting enduring missions and ongoing operations" (OPNAV N9, 2016, p. 1). This figure is widely understood to not be attainable as it projects the need to double the Navy's annual budget (OPNAV N9, 2016). In an effort to bring this figure down to a realistic level, the assessors apply a series of filters to address redundant requests from the various Navy Component Commanders and inject risk of shortfalls within each of the theaters of operation (OPNAV N9, 2016). This calculation brought the number of required ships down to a requirement of 459 ships. Recognizing that this figure was also beyond the scope of the resources available, the assessors boiled the study down to a calculous-based estimate around "what it takes to win, on what timeline, and in which theater, for each major class of ship" (OPNAV N9, 2016, p. 2). The results came to a force size of 355 ships across 11 differing ship classes (OPNAV N9, 2016). Figure 5 is the breakdown of those findings.

Type / Class	**2014**	**2016**
Aircraft Carriers	11	12
Large Surface Combatants	88	104
Small Surface Combatants	52	52
Amphibious Warfare Ships	34	38
Attack Submarines	48	66
Guided Missile Submarines	0	0
Ballistic Missile Submarines	12	12
Combat Logistics Force	29	32
Expeditionary Fast Transport/High Speed Transport	10	10
Expeditionary Support Base	3	6
Command and Support	21	23
Total	**308**	**355**

Figure 5. Results of 2016 FSA: Includes the Changes from the 2014 FSA Update. Source: OPNAV N9 (2016).

The 2016 FSA did highlight the need for a larger fleet, however the exact makeup of ships in a 355-ship naval fleet was not truly broken-out. However, a new fleet structure assessment is underway and aims to add fidelity to the 2016 assessment (Gould, 2018). At the second annual Defense News Conference, Vice Admiral William Mertz (DCNO N9) stated that the report would be completed in fiscal year 2019 (Gould, 2018).

In addition to the upcoming Navy FSA, OPNAV N9 also produces an annual ship building plan each year. The most resent ship building plan was published in February of 2018 and lays out a plan that would achieve a balanced force of 236 battle force ships by fiscal year 2023 and ultimately achieving the 355-ship fleet in the early 2050s (Office of the Chief of Naval Operations [OPNAV], 2018). The plan does state that "a plan to achieve today's warfighting requirement in three decades represents an unacceptable pace in the context of the current and predicted security environment" (OPNAV, 2018, p. 6); However, it points to the plan as being scalable.

While the 355-ship fleet is seen as achievable in the 30-year shipbuilding plan, the plan does have its own issues to overcome. Several reviews have been conducted to look into the viability of a 355-ship Navy. The bottom line of the research across the board is that "to enlarge the Navy to 355 ships" it "would require a substantial investment in both money and time" (Congressional Budget Office [CBO], 2017, p. 1).

The Congressional Budget Office (CBO), a non-partisan agency that provides "independent analyses of budgetary and economic issues to support the Congressional budget process" (CBO, 2018), conducted a review of the costs associated with the 355-ship Navy. Several of their findings bring to light possible difficulties in achieving this goal. The first issue are the shipbuilding costs. According to the CBO, it would be necessary to build 329 new ships in the next 30 years if the goal of 355 active battle force ships is to be reached (CBO, 2017). Moreover, they estimated costs for this ship construction would be approximately $26.6 billion per year (CBO, 2017). These costs do not take into consideration the costs of armament, required aircraft, personnel, or operating cost (CBO, 2017). Once all of these additional costs are factored in, the CBO "estimates the cost to build, crew, and operate a 355-ship fleet would average $102 billion per year through 2047" (CBO, 2017, p. 3).

The U.S. Senate Armed Services Committee, through the Subcommittee on Sea Power, conducted a hearing on the options and considerations for achieving a 355-ship Navy. Ronald O'Rourke, a specialist in Naval Affairs, gave testimony on several aspects of the plan that seem to align with CBO observations (Options and Considerations, 2017). O'Rourke points out that the required funding levels to meet a 355-ship Navy would "require reducing funding levels for other DoD programs" if "defense spending in coming years is not increased above the caps established in the Budget Control Act of 2011, or the BCA" (Options and Considerations, 2017, p. 14). He continues by pointing to the 2016 Defense Strategy as the basis for the 355-ship projection (Options and Considerations, 2017). Since we now have a new Presidential Administration and a new National Defense Strategy, the makeup of the fleet may now differ from the 2016 FSA (Options and Considerations, 2017).

With concerns and costs having been debated and considered by numerous agencies and decision makers, the 2018 National Defense Authorization Act (NDAA) codified into law the requirement for this fleet. To be specific, Section 1016—The Policy of the United States on Minimum Number of Battle Force Ships—establishes the "policy of the United States to have available, as soon as practicable, not fewer than 355 battle force ships" (2018 H.R. 2810, 2018, p. 191). This law now requires that a solid plan be established to meet this requirement. The individuals at OPNAV N9I are taking this requirement and working to establish a tool that will enable Navy decision makers to look at various options for optimally completing this objective. Admiral Mertz, DCNO of N9, plans to conduct another FSA in 2019 (Gould, 2018) . In an effort to enable decision makers a way to add fidelity to the 2019 study, as well as beyond, N9I is working to develop their tool to assist in that process.

3. The Architecture Integrated Decision Tool (ArnDT)

The team at N9I have a vision for a tool that would assist the decision makers by enabling them to use an interactive environment for force assessment. The overall goal is to view the investment and requirement decisions on the fleet architecture. More than just the fiscal implications, the tool would serve as a holistic method to demonstrate the construct and capabilities of the future fleet against any expected construct/capabilities of a possible adversary.

In regard to the Navy's Future Fleet, the ArnDT would enable researchers to compare the fleet as it currently stands against what the future plans for what the Navy will become. In this manner, any architecture could be established in an interactive environment so that virtual assessments for fleet capabilities can be evaluated. The execution of war games, strategic maneuver, capability gaps assessments, and even future mission planning could be conducted. While the data required to conduct these types of evaluations does exist, they are separate and not easily accessible. The ArnDT would aggregate all of the data from these various databases and enable the user to interface in a pragmatic way.

The goal ultimately is to provide a user interface that can allow for near real-time simulations of various fleet configuration models and establish the desired fleet. Once the desired component and fleet levels are virtually tested and established by decision makers, the difference between current fleet and desired fleet levels can then be analyzed in an effort to inform the discussion toward critical decision to be made in reaching the desired fleet.

For the purposes of this study, I will be focusing on the financial aspects of the ArnDT. I will attempt to determine the best manner in which the ArnDT should address the monetary requirements needed to bring the current fleet to a desired fleet level. The ArnDT will be capable of aggregating historical costs and apply a model to extrapolate the future cost for fleet assets. The manner in which this is done should be all-inclusive in nature. To accomplish this, I will explain what a Total Ownership Cost (TOC) is and why it makes the most sense. In an effort to then demonstrate how it would apply to the ArnDT, I will conduct a case study toward the application of TCO to the future ArnDT in action.

III. METHODOLOGY

Having established a situational background, the goal of this thesis is to provide answers toward the direction that N9I should dedicate further resources to in the development or acquisition of a cost model. To be specific, the cost model would be for use in the ArnDT.

To establish a direction for further resources to be dedicated, I will conduct an exploratory case study. This case study will focus around a Total Ownership Cost model. The case study will establish the reason why this cost model should be utilized and provide an example for what type of product would be produced. However, in order provide a holistic outlook for what the implementation of this type of model can do in concert with the ArnDT, I will establish a top-level, working definition of Total Ownership Cost (TOC) below.

A. DEFINING TOTAL OWNERSHIP COST

The Total Ownership Cost (TOC) is a single cost that encompasses all cost aspects from a systems conception to disposal (DoN, 2014). However, while this may sound strikingly similar to a systems Life-Cycle Cost, there is a key difference. This key difference is that a TOC includes all of the various infrastructure or process costs that may not be directly linked to a defense system to include losses and waste (DoN, 2014). Some examples of these various unrelated costs could be the various support apparatuses in place to provide personnel training, logistic support, or even support facilities costs (DoN, 2014).

The Department of the Navy does have a published guidebook on the subject of Total Ownership Cost. This guidebook establishes that the definition of TOC must "follow the Life-Cycle Cost (LCC) categories defined by the Office of the Secretary of Defense (OSD) Office of Cost Assessment and Program Evaluation (CAPE)" (DoN, 2014, p. 8). While the guidebook does not go on to delineate the costs associated with each category, the ability to link TOC with LCC seems quite clear. This being the case, I will utilize this framework as a demonstration of various costs that are associated with shipbuilding in each of the various phases. While an effort for a 100% complete cost structure for each of the

LCC categories would require a more significant investment of DoN resources, my intention is not to provide the complete answer. Rather, my goal is to provide several examples to provide a clear understanding of types of costs contained within the shipbuilding industry. The understanding of these types of costs are important so that benefits of implementing a TOC model into the ArnDT can be understood.

As it is described by OSD CAPE, Figure 6 is a diagram of the general percentages that costs accumulate in a typical acquisition program. I will describe each of the four life-cycle phases as they would occur from ship conception to final disposal.

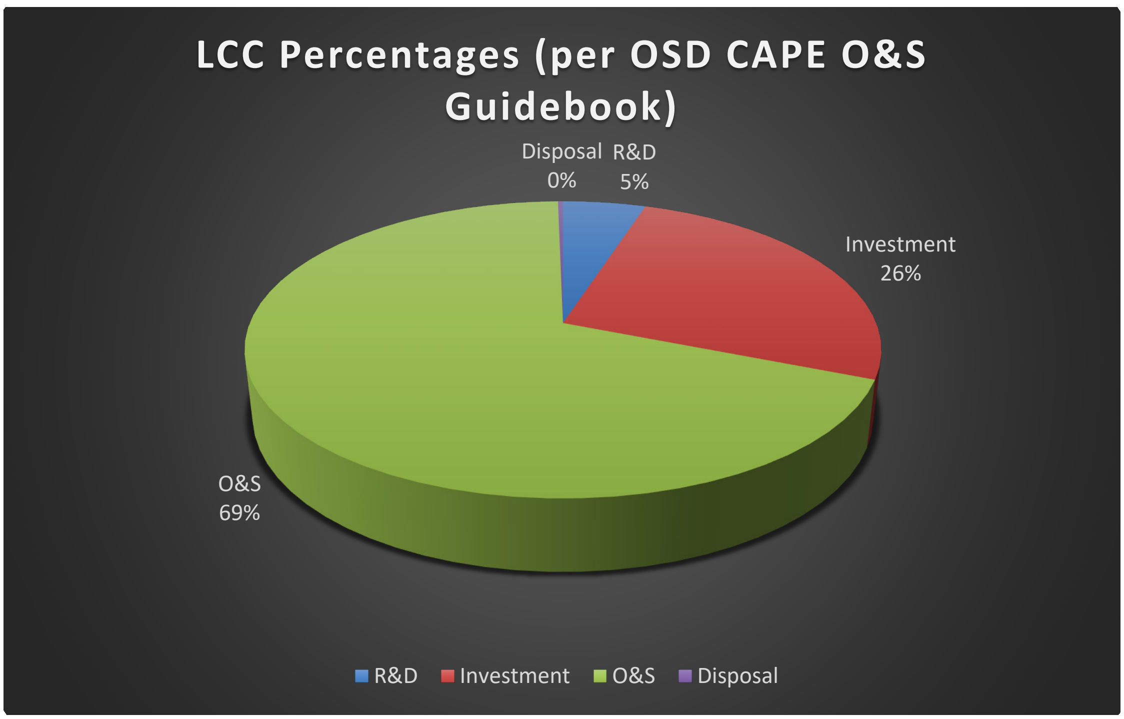

Figure 6. General Percentages of Costs Incurred during the Four Phases of a Surface Ship's Life Cycle. Adapted From: OSD CAPE (2014).

1. Total Ownership Cost in Research and Development

The Research and Development (R&D) phase exists from the time a ship is conceived through the end of its system developmental and demonstration point of the acquisition process (DoN, 2014). The one unique aspect of the shipbuilding industry is while smaller systems can ask for several prototypes to be built for a demonstration and ultimate decision prior to a long-term investment, this is not practical with a ship. In shipbuilding, “the first in the class, or series built to the same basic design, is often the class prototype” (United States Coast Guard [USCG], 2018). As such, all costs that are incurred up to the point of the initial ship construction will be considered R&D TOC costs. To demonstrate how these costs will develop, I am going to discuss the broad categories as if I was beginning the R&D process of a new ship myself.

If I had the concept for a ship, the first thing I would need is to hire personnel to bring my idea to a reality. So, let us first start with types of personnel costs. All of the costs that are associated with employee pay and benefits are known as the fully-burdened cost (Elmendorf, 2010). Examples of these are the employee base pay, assignment incentive pay, housing and sustenance allowances, medical care, and retirement benefits, paid leave time, and training costs to name a few. This includes the additional benefits provided to the members’ family as well. The Navy also must include costs incurred in other forms that are not listed on a paycheck. The cost incurred when a member falls ill and is unable to perform his/her job must also be taken into consideration. Another example would be the cost to the Navy for a member’s initial recruitment and the subsequent money spent to incentivize the members remaining in the military service. There are many aspects of personnel costs that vary from civilians and active military members across a spectrum of rank levels and years of experience. Personnel costs are not exclusive to the R&D phase; rather, the cost associated with personnel span every phase of OSD CAPE Life Cycle. While personnel cost must be considered across all of the life-cycle phases, the impact of costs will vary between each of the phases.

After personnel are accounted for, the actual research and development can begin. The initial idea for a ship will need to be modeled through a process of engineering design and refinement. This design and refinement can include costs such as refinement studies of the concept, baseline model design and integration, fabrication requirement studies, advanced technology development, and hardware/software developmental model establishment (DoN, 2014). These activities and products lay the groundwork for what type of technologies we currently have and what technologies need to be further developed prior to their implementation of the shipboard design. Once this baseline is established, the refinement of the project begins where various alternatives are investigated and analyzed toward the establishment of required performance factors ("Technology Maturation and Risk Reduction," 2017). Once the final requirements and parameters are decided upon, the next stage of the process is to reach out to industry and have companies develop specific development models for consideration.

The opportunity to development design models to meet the requirements previously established are bid upon by companies who show interest in building the ship ("Technology Maturation and Risk Reduction," 2017). There are several costs associated with this process since the Department of the Navy funds the efforts. Without the ability of practically making a full-sized prototype, computer models, technical drawings, and even scale models will be developed by the companies. All of the associated cost for technical drawings, publications, and software models would need to be accounted for in a TOC model (DoN, 2014). Other item that may need to be accounted for could include studies into necessary advanced manufacturing practices that a new design may require or be necessary to meet timeline parameters. All aspects of the design proposals for the bidding process should be evaluated and accounted for.

Overall, the R&D phase of a ship's life cycle has numerous and varying costs. Since the first ship produced will serve as the prototype, great care needs to be taken to ensure the best decision can be made in regard to what bid will be accepted. The decisions made throughout the R&D phase have the greatest effect on the costs incurred in the following three phases of a ship life cycle (Office of Naval Research [ONR], n.d.). This being the case, a detailed and complete study of the TOC within the R&D phase is vitally important to application of a TOC model.

2. Total Ownership Cost in Investment

The Investment phase of the life cycle is considered the time from the start of Low-Rate Initial Production (LRIP) until the completion of deployment (DoN, 2014). For the shipbuilding industry, all of the costs that are incurred from the start of production for the first of class ship until the completed deployment of the final ship in the class is deployed shall be consider the Investment TOC Costs. Just as with R&D, I will proceed in logical progression through a description of the TOC associated with this phase of the life cycle.

There will be significant personnel costs in the investment phase. Individuals are vital in the fabrication, construction, outfitting and testing of a ship. As such, personnel costs for all of the individuals required for this undertaking must be accounted for in a TOC Model.

Once the personnel are available, it stands to reason that you need a location to facilitate the construction of a massive system such as a ship. Currently, “all of the Navy’s new ship construction is performed by five large and two small private shipyards” (CBO, 2017, p. 8). With the current requirement to build “as soon as practicable not fewer than 355 battle force ships” (H.R. 2810, 2018, p. 191), we will need to ensure the shipyards are a top priority. The seven shipyards that the U.S. Navy counts on for its shipbuilding has been assessed as “representing significantly less capacity than our principal competitors” (OPNAV, 2018, p. 6). The CBO has evaluated the state of the current shipyards and assess that all of them will need to “increase their workforces” and several will require “improvements to their infrastructure in order to build ships faster” (CBO, 2017, p. 9). The effort to bolster the industrial base that support our nation’s shipbuilding capability will “require a substantial investment in both money and time” (CBO, 2017, p. 1) if we intend to build the naval fleet to 355 battle force ships. The costs incurred from this effort will need to be researched, quantified, and accounted for in an effective TOC model.

Once the industrial base is accounted for, the practical shipbuilding costs must be taken into consideration. First and foremost, would be the costs associated with the needed materials to construct the vessel. This would include everything from the steel for the hull to the piping running compartments. Once the materials are on hand, the next costs would be the fabrication of the ship and its major structures. While some of these may be produced on-site at the shipyard, inevitably many parts of the vessel will be constructed by sub-contractors. The subcontracting costs, including shipping of parts, will need to be listed in a TOC model. The physical construction of the vessels pieces once fabricated is a major undertaking incurring many different costs. Heavy machinery use, cranes operations, and various automated processes are all occurring at the same time. The overhead costs associated with a shipyard are certainly a significant figure that will require documentation.

In addition to the ship's structure itself, the major equipment systems that make a ship run would need to be purchased, shipped, and installed into the new vessel. The vast majority of systems such as propulsion, auxiliary and damage control systems are all made by civilian companies. These systems would need to be purchased and installed with the associated costs documented. In addition to the primary systems, all of the spare parts for routine and emergent maintenance would need to be procured and accounted for.

The smaller items that a ship needs would fall into a category of outfitting. Navy vessels are designed to hold a crew of sailors who go to sea for extended periods of time. These sailors need items such as showers, beds, storage lockers to live in a space onboard a ship. Moreover, items such as tables, chairs, lights, cooking equipment, laundry equipment, stairs, doors, hatches, lines, life rings, and even the ships haze grey paint would fall into the outfitting category. The amount of these items would vary based on the ship class and the crew compliment allocated to the vessel. All of the required outfitting items would be accounted for in a TOC model.

Once a ship is fully fabricated, constructed, equipped and outfitted, the final step in the investment phase is testing. Since the first-in-class ship serves as the prototype platform, numerous test and checks will need to be conducted (USCG, 2018). All of the costs associated with this will be accounted for in a TOC model. This will include any additional contract work that may be needed to correct deficiencies and the routine maintenance required until the ship deployment to the fleet (DoN, 2014). As required by Title 10, the ship must pass Operation Test and Evaluation (OT&E) prior to full rate production of the ship class can be rolled out (Director of Operational Test and Evaluation, 2018; Operational Test and Evaluation of Defense Acquisition Programs, 2018). OT&E is a final field test that is conducted under combat conditions, to determine its suitability to conduct its mission and use its systems in combat by the sailors that will employ her (Director of Operational Test and Evaluation, 2018).

Upon the successful completion of OT&E, and with a favorable decision to proceed into Full Rate Production (FRP), all of the subsequent ships will start through the Investment phase. All of the costs incurred by each vessel until they successfully pass all of the inspections and tests will be considered an investment cost and contribute as such into the TOC model.

3. Total Ownership Cost in Operations and Support

Having successfully being placed into deployment, the ship passes out of the Investment phase and into the Operations and Support (O&S) phase. This phase "consists of sustainment costs incurred from initial system deployment through the end of system operations" (DoN, 2014, p. 9). These costs can be quite significant as the O&S phase is the longest in a system or ships life cycle and has been estimated to be approximately 69% of the overall LCC (OSD, 2014, p. 2–2). With the recent push to increase the size of the naval fleet, the importance of costing within the O&S phase is only going to increase as ship lives are extended (Eckstein, 2018). Moreover, the growth in the fleet will require more sailors, more maintenance, and more fuel and supplies to operate (CBO, 2017). Therefore, in an effort to understand what kinds of costs are within the O&S phase, let us look at the major cost drivers.

As in the other phases, personnel costs are the logical place to start. As previously mentioned, the fully burdened cost of personnel must be looked at and accounted for in the O&S phase just as much as the others. In fact, "personnel are the largest single element of O&S costs" (Elmendorf, 2010, p. 2). However, more than just the personnel costs of the sailors must be considered since we are working toward a TOC model. Other personnel costs include supporting contractor costs, civilian maintenance personnel costs, and all other non-organic personnel costs that are incurred (DoN, 2014).

The next major cost driver in the O&S phase is the operational cost incurred by a ship or system (OSD CAPE, 2014). Operational costs include a menagerie of items including energy (fuel, electricity, etc.), munitions, sustenance items (food, etc.), support service (docking, trash removal, security services, etc.), and transportation costs (OSD CAPE, 2014). This is a broad reaching category; however, it includes almost all of the costs that are seen in the execution of the ship's mission. Each ship type will have different missions' capabilities, weapons, and propulsion systems and will subsequently have different costs for them. A category such as operational costs is large and diverse; understanding the various factors will thus be necessary in a TOC model.

While a ship is operating, it needs to have maintenance accomplished. The costs that are incurred include the cost of labor for all maintenance that is not conducted by the organic ships' crew, the required consumables for the maintenance to be conducted (grease, cleaning agent, etc.), and the costs for the repair parts required (gasketing, blots, welding rods, etc.) (OSD CAPE, 2014). This maintenance will be conducted at several levels and all of them will need to be accounted for, including organic unit level, intermediate level, and depot level maintenance (OSD CAPE, 2014). Moreover, all other miscellaneous maintenance conducted in or on the ship will need to be accounted for.

Over the course of a ship's operational life, there will inevitably be numerous sustaining support costs incurred. Some of these costs may center around system-specific needs such as various program management requirements, information system needs, technical publication updates and other various support functions to include system specific repairs or replacements (OSD CAPE, 2014). One example of a support system would be the IT servers maintained on the ship. While not a direct piece of shipboard equipage, the ability to utilize computer resources in the application of the day-to-day job at hand is vital to efficiently managing the resources and capabilities that are contained within a warship. All similar natured costs would need to be accounted for under this sustainment cost category.

With the outlook of naval vessels being active for 30 or 40 years or more (Eckstein, 2018), it is expected that technology will evolve and system improvements will be inevitable. These improvements can be in the realm of both software and/or hardware (OSD CAPE, 2014). Whether the improvement is a hardware modification to improve a class issue in the hull design (Global Security, 2011) or a software patch which may improve a system efficiency, the cost for these improvements shall need to be accounted for and estimated in a TOC model.

Lastly, a ship is essentially a floating city. Along with all of the previously mentioned costs, the cost of the indirect support provided to a ship must be captured (OSD CAPE, 2014). A large warship does not pull into and out of ports without a support crew to assist. Costs such as tug services, line handlers, and port security need to be contained in a TOC model. Additional items such as general crew training costs and personnel support (MWR, mail, etc.) also will need to be considered (OSD CAPE, 2014).

In the 2017 study conducted by the Congressional Budget Office (CBO), they estimated that the O&S costs to run a 355-ship fleet would be "67% more than the $56 billion the fleet of 275 ship costs annually to operate" (CBO, 2017, p. 3). With costs that run in the tens of billions of dollars, working through a comprehensive breakdown of costs will prove vital to any TOC model's success. Certainly, these costs will affect our long-term approach to building a 355-ship fleet and the capabilities it will ultimately have.

4. Total Ownership Cost in Disposal

The final phase in a ship's life cycle is the disposal phase. Major weapon systems, such as a ship, is not an item that can simply be tossed into the trash. For this very obvious reason, the costs associated with the disposal effort of a ship must be accounted for in the development of a TOC model.

Just as with all of the other phases, personnel costs must be closely examined. Numerous contractors will be involved in the dismantling of a large navy vessel, and their fully-burdened cost of their labor and all supporting labor costs need to be accounted for.

Dismantling costs would be the next major cost driver in the disposal phase (DoN, 2014). Various costs that could be associated with this category of disposal could include physical disassembling, material processing, safety precautions, and transportation for the dismantled materials (DoN, 2014).

A unique aspect to the defense industry system disposal is the need for demilitarization. Defense systems, warships being included, conduct the operational life utilizing dangerous equipment and munitions. These items within the disposal phase must be removed from service and rendered safe prior to disposal or storage. Some of the various demilitarization costs can include material processing, collection/disposal/storage of hazardous materials and waste, decontamination, safety requirements and environmental impact mitigation procedures (DoN, 2014). As with other costs factors, these requirements will change between ship classes and/or configuration difference, but nonetheless must be account for and applicable TOC costs.

While some ships will get dismantled after the completion of their useful life, it is not unheard of for ships to be sold or even given away to allied countries or historical societies (CBO, 2017). In this individual case, the profit from the sale of a vessel could offset some of the LCC previously incurred. Should a vessel be given away, the would-be cost of a full dismantling could be mitigated. However, a demilitarization of the vessel would more than likely still occur and those costs should be captured.

With all of these aspects of cost needing to be reviewed, the disposal cost incurred by the demilitarization and dismantling of Navy ships "may not always be considered when preparing life-cycle costs estimates" (DoN, 2014, p. 9). This may be attributed to being a relatively low percentage (less than one percent) of the LCC that disposal generally accounts for (OSD CAPE, 2014). However, while being a small percentage of a ship's LCC, the cost to dispose of a vessel can be significant. The ex-USS ENTERPRISE is slated for disposal soon; however, the Government Accountability Office (GAO) released a recent report that shows the cost of disposal could be as high as $1.55 billion and might need to wait until 2024 to start the dismantling process (Oakley, 2018). The costs associated with such an undertaking must be captured for a TOC model "in what likely will be an effort greater than $1 billion that lasts the better part of a decade" (Oakley, 2018, p. 37).

5. Total Ownership Cost Summary

The previous listed attributes for Total Ownership Costs within the structure of the OSD CAPE Life-Cycle structure is not intended to be holistic in its explanation. Rather, it is intended to provide a high-level understanding of what a TOC for a defense system, specifically a naval warship, would encompass. While there are several pieces of literature that focus on specific life-cycle phases for applicable costs, none of them look at a TOC in its entirety. This could occur for several reasons:

1. Every class of warship, and even ships within the same class, have unique configurations, upgrades, and capabilities.

2. The volume of different costs associated in a TOC is complex and can be difficult for a single entity to evaluate, assess and quantify.

3. Data that would be required to evaluate is not kept in a single location. Varying databases that all have different access requirements and are hard to sort through make this a daunting task.

4. The acquisition industry, while required to evaluate Life-Cycle Costs for all of their programs, finds LCC to "be undesirable in Department of Defense (DoD) Source Selections" (Gilbreth, 2017).

While some may disagree with this assessment of the current state of TOC and LCC in the DoD, one certainty is that we need to better understand this cost as we proceed into the task of re-building a fleet to 355 battle force ships. In the following chapter, I will describe what a fully capable TOC model (that is being utilized in the ArnDT) might look like, as well as describe the products that would be delivered to Navy decision makers.

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IV. CASE STUDY: TOC IN A WORKING ARNDT

In an effort to demonstrate what type of capability that a working TOC model will provide to a completed ArnDT, the intention of the exploratory case study is to identify the capabilities and processes that will be contained within and in support of a functioning TOC model. To accomplish this, I will first explain the supporting apparatuses that will be in place to support the TOC model itself. Next, I will describe the manner in which data will be aggregated and configured utilizing the ArnDT advanced technology capabilities. I will then describe the manner in which the aggregated information will be processed by the TOC model itself. Lastly, I will describe the product that would be produced by the ArnDT having successfully utilized a working TOC model (including samples).

A. TOC SUPPORT APPARATUSES

To bring the explanation of what a TOC model is down to a functional level, the model is a mathematic algorithm that utilizes historical cost data to estimate the total cost of a system for its entire lifespan. This being the case, a key supporting apparatus for a functioning TOC model would be a collection of data that the model can use to extrapolate the system's total ownership cost. This data would need to be kept in a database of some type that allows for the active collection, update, and aggregation of the information stored within it. To that end, several cost databases do currently exist that can support a TOC model.

The first database that the Navy maintains is managed by the Defense Cost and Resource Center (DCARC). DCARC "is an organization within OSD CAPE at the Pentagon" who strives to provide reliable data to the cost community (Mislick & Nussbaum, 2015, p. 75). One of the databases that they manage is the Defense Automated Cost Information Management System (DACIMS). The DACIMS database primarily focuses on the accrual of data from the R&D and Investment phases of a systems life-cycle (Mislick & Nussbaum, 2015).

A second database that is of interest would be the Visibility and Management of Operation and Support Costs (VAMOSC) database. This database is managed and hosted by the Naval Center for Cost Analysis (NCCA) and can be accessed through their website (Mislick & Nussbaum, 2015). The O&S data is searchable and "organized by a system, infrastructure, or category" (Mislick & Nussbaum, 2015, p. 76) in an attempt to streamline a user's ability to gather pertinent data.

The final source for information regarding a ship life cycle comes from Maritime Administration (MARAD). The MARAD "maintains the National Defense Reserve Fleet (NDRF) as a reserve of ships for defense and national emergencies" (Maritime Administration [MARAD], 2018). They produce an annual report through their Office of Ship Disposal Programs (OSDP) that provides previous fiscal year information on "the disposition of MARAD's vessels within the NDRF that have been determined obsolete and classified as non-retention vessels" (Office of Ship Disposal Programs [OSDP], 2018, p. 2). While the MARAD may maintain a local database for their own operations, they do not appear to host an accessible database of information with the exception of a record of the annual fiscal year reports.

While these above listed sources do contain pertinent historical data that a TOC model will likely utilize, there are obstacles to overcome. The first issue is that not all of the data is on a readily available database that a TOC model can aggregate from. Rather, the R&D and Investment phase data is separate from the O&S database. Moreover, the disposal data is not even kept on an accessible database from which the model could aggregate from. I can see two options to solve this problem. The first would be to stand-up a new database that would hold all of the data. It would be organized by a systems' various life-cycle stages and become a single source from which to extract data from. The second option would be to utilize the ArnDT technology to convert the data from the various databases into a single homogeneous language that the ArnDT and the TOC model can aggregate from. This technology is one that the ArnDT is working to develop, however it may take time for this option to mature and become practical for use.

Another issue that can be identified is that the current data collected and stored does not contain all of the data that a TOC model would encompass. For example, the data maintained in DACIMS stores data from ships during their R&D and Invest phases. While this is directly applicable, the TOC model will want to consider the projected costs required to retrofit and upgrade the shipyards so that they can meet the pace required to produce a 355-ship naval force. The DACIMS database will not be able to provide any historical data from previous upgrades to shipyards as a historical reference. This is the key differential between an LCC and a TOC. Once the resources are allocated to define a working TOC parameter set, the existing database will need to be expanded to encompass these costs. I believe that this would require a dedication of resources to work across the various organizations that manage the various databases. However, while a concerted effort will be required, the technology maturity and these databases can be expanded.

The next concern that would need addressing is the collection of the expanded data. Once identified, the efforts required to gather the new data will need to be put in place. This may create additional burden on the shipboard operators in the form of additional maintenance requirements or changes in policy. However, resources should be allocated to make the collection of data as autonomous as possible so as to ensure the ease the burden of collection and minimize the possibility of operator error in the collection of the data.

The final concern I can identify is the requirement to maintain the databases. Currently these databases are all managed by separate entities. Should the support structure for these organizations ever falter, the commitment to the collection of the data and/or hosting of a database could come into question. Should a central database be stood-up, this would alleviate the possibility of one of the several organizations faltering to have the data for use. However, the creation of a central database could cause the organizations to protest as it would be a replacement for their systems. Either way, a commitment to the gathering, storing, and managing of this data will need to be addressed.

The simple fact is that all cost estimation is conducted as a function of historical data (Mislick & Nussbaum, 2015). This includes a TOC model for our future fleet. For any model to successfully function for the ArnDT, a well-resourced and managed database of historical costs will be vital. This data will not only inform the model and allow for the extrapolation of a ship's future total ownership cost, it will allow for the flexibility to advance the model to reflect the advancements that inevitably will come in the development of our future fleet. This conglomeration of cost data will serve as the backbone and provide financial legitimacy as the ArnDT comes on line and is utilized by the Navy's decision makers in the future.

B. DATA AGGREGATION METHODS FOR THE TOC MODEL

As mention briefly above, a fully functional TOC model will rely on the historical backbone that cost data will provide. This data will serve three purposes for the model. The first is that the TOC model will aggregate the applicable cost data as the input to the mathematical algorithm that is used to extrapolate a total ownership cost of a ship. The second function of the historical data will be the validation of the model's prediction in a cyclical basis. What this means is that every year, for example, the TOC model would be reviewed. Through the evaluation of how accurate the model was able to predict the real costs incurred during that year, the TOC model could be adjusted in an effort to become more and more accurate. The third function that the data will serve is to evaluate the Navy's expenditure of funds being allocated. This capability will increase the efficiency in which we can observe how we spend the dollars allocated on an annual basis. More than just as a point of reference for decision makers, this type of report could be very useful to other ongoing efforts in the Navy and DoD. One example would be the current effort to successfully audit the money spent in the DoD every year. Having these types of records would show where and how the money is spent. This capability would give documentation for money allocated and spent within the naval fleet and enable the accounting process to observe this as well.

While the data is important, the aggregation of the data for the TOC model to calculate is vital to the functionality of the TOC model and the ArnDT itself. There are two main paths that can be taken, either separately or simultaneously, to accomplish this aggregation capability. The first option is to stand-up a single database that contains all of the cost parameters established by the TOC model. Whether this database draws the data from the current databases maintained by DCARC, NCCA, and MARAD or is completely self-sustaining ultimately will not be of consequence to the functionality of the TOC model. The key is to ensure that all of the cost parameters for the TOC are accounted for and that it is compatible with the ArnDT software. The required technology to accomplish this is mature and in my opinion could be completed in a reasonable amount of time.

The second option would still require an expansion to the current cost databases to include the TOC model parameters; however, the data would be able to remain on the existing databases. One technology that the ArnDT is developing is a software that can reach out to various databases that utilize various software languages and convert the data into a single compatible language for the ArnDT. This technology would include the ability to gather cost data from multiple sources, even if the databases are not compatible with each other, so that the data can be utilized on a TOC estimate. This technology is new in concept and currently is not mature, though the long-term outlook for this technology appears very promising.

My current recommendation is to pursue both avenues. While the ArnDT technology capabilities would be the best long-term solution in my opinion, the ability to establish the ArnDT and use it sooner rather than later must be considered. To this end, I recommend the allocation of resources to expand the current databases to encompass the to-be-established TOC parameters. I also recommend the establishment of a short-term database that would gather data from the established hubs and allow for a single source for data aggregation in support of the ArnDT. This database can serve as a short-term, trans-shipment type of asset to take data from DCARC, NCCA, and MARAD and place it into one location. This approach will allow for the progression of cost data to be utilized by the ArnDT while the emerging technology has time to develop and mature. Once established, the temporary transshipment-like database can be stood-down and resources allocated elsewhere.

C. HOW IT WOULD FUNCTION

With a solid database of data that aligns to the TOC model parameters, and a functional manner with which to aggregate it for processing, the model itself can conduct its task of cost estimation. Again, this estimate will be a function of the historical data and extrapolated to a timeframe as requested by the user. The flexibility that will be provided by the use of ArnDT's narrow-A.I. and machine learning capability will allow for near-real time data extrapolation as desired. Below I will describe the various functions that a working TOC model will provide to the users of the ArnDT.

The first product that the TOC model will provide is a display of the historical data as it relates to the life cycle of a ship. This type of document will be valued by the ArnDT's target user as well as others. For example, the user of the ArnDT would be able to extrapolate the most recent cost data for that ship. Another example would be a Program Manager (PM) that is slated to transfer and must conduct a briefing about the current state of the program to their incoming replacement. The PM could conduct a historical data inquiry associated with their project and be well equipped to show progress to the incoming PM. Another benefit from this type of product is its ability to demonstrate, in a condensed manner, the cost data for a congressional audience. Having the historical costs for a ship available to Congressional decision makers will enable DoD and DoN officials the tools and ability to explain program requirements and build legitimacy in the requests. Overall, the historical cost display capability of a function TOC model will be beneficial for numerous stakeholders in the DoD, DoN, and Congress.

The second, and primary, function that this TOC model will be to provide the ArnDT user a tailored breakdown of the total ownership cost of a ship. To date, I have not been able to find a single display that can provide this data in a holistic manner, such as a TOC model that would produce results utilizing the ArnDT. A user of the ArnDT would be able to sit down at a terminal and request the cost data for a ship at will. Once data is input into the ArnDT system, the advanced technology of the ArnDT would reach through the system and aggregate the historical data required to conduct the calculations. This data would be gathered and computed by the TOC model's algorithm in order to produce the future cost estimate. Then the historical (actual) costs of the ship would be displayed with the future estimates in order to produce a total ownership cost display. As an example, let us suppose that an admiral is interested in how much a new DDG FLT III will cost if the lifespan of the ship is increased from 35 years to 40 years. The Admiral's staff would sit down to the ArnDT terminal and select the USS Jack H. Lucas (DDG 125). This DDG is to be the first of the new flight III variants ("Construction Starts," 2018). The TOC model will engage the destroyer's TOC parameters and reach out to the historical database for the relevant data points. That data would be computed utilizing the algorithm and a total ownership cost for the new DDG 125 which would be displayed with an operational life of 35 and 40 years. The display would allow the admiral to see the cost differential and enable a better-informed decision to be made in regard to the cost of extending the service life of the new destroyer by five years. This type of total ownership cost rendering is the primary function that a TOC model will provide. However, this data can be sorted and displayed in various ways depending upon the user's needs. This capability is what I will address next.

In the example above, the ArnDT was queried for two individual figures and utilized the TOC model to provide the figures requested. While this capability is quite cutting edge, the scale and depth of information that the ArnDT will be able to display will be comprehensive and scalable. The model will be able to look at more than a single ship. In fact, it will be able to look at every ship in the fleet (or future fleet) and display various datapoints based on what the user wants to see. Perhaps the user wants to see the total ownership cost of 26 new DDG Flight III with a 35-year service life. These parameters will be placed into the ArnDT and the TOC model will produce that figure for all 26 ships' total cost of ownership. This can be tailored into an inquiry based on battle group, physical area of responsibility (AOR), or even a random assortment of ships that the user is interested in seeing. More than just the ships configuration, the provided TOC figures shall have a diverse display capability. For example, perhaps the ArnDT user is interested in planning and programing future funding requirements. The requested data will be displayed on an annual basis, listing the costs by the required appropriation. This type of display will enable the planning and programing offices to have long-term planning bases to work with while the programmers can utilize the estimates to inform their requests for the upcoming Program Objectives Memorandum (POM). It is this type of data scalability and dexterity that will allow for cost applications across all ranges of decision-making users of the ArnDT. Whether it is a COCOM commander looking into AOR specific cost concerns or a PM trying to keep future project total ownership costs down, the application of a TOC model into the ArnDT will benefit all stakeholders at all levels.

The last functional aspect of a TOC model in the ArnDT is that it is flexible and adaptable. Having the ability to adapt the TOC model to the changing world is key to maintaining the legitimacy of this type of tool over the course of its development. The near real-time ability for a TOC model to produce a cost estimation, while observing the actual historical costs, provide a built-in capacity to verify the accuracy of the model in a cyclical fashion. This capability delivers the ability to verify the model's accuracy quickly and as frequently as the situation may require.

Let's assume for a moment that we are utilizing the ArnDT to extend the life of all the current destroyers by 10 years to assist in meeting our 355-ship requirement. A user could input that request into the ArnDT and the TOC model would calculate the annual cost for every destroyer for an additional 10 years. That figure can be used in the decision-making process. One year later, the same request can be made of the ArnDT and the actual historical data from the previous year can be compared to the previous estimation. One of two things will happen—either the estimation will matchup with the actual costs, or a differential will be seen. If there is a differential, the cost factors can be analyzed and adjusted as necessary. So, if the price of gas increased considerably higher than the estimate from the previous year, the TOC model can be adjusted to reflect this change in fuel prices. This ability to find, fix, and refine the model will allow for the continual updating and legitimacy of the capability. The change in price-curves and projections is inevitable with advancements in technology and production capabilities. The adaptability the ArnDT will have through the use of a TOC model, which can be updated to account for changes in the world, will keep the capability relevant for as long as is required.

D. SAMPLE FORMAT FOR ARNDT COST DATA

With all of the capability that will be available through the use of the ArnDT and its TOC model, the ability to display that data is just as important as its calculations. All of the data in the world means nothing if it cannot be displayed and understood by an audience of individuals that intend to utilize it to some end. In reference to the DoD and the DoN, it is important that the information displays be compatible with what is widely utilized to brief decision makers at all levels. In my estimation, the basic Microsoft Office programs such as Word, Excel, and PowerPoint must be the basis for how the ArnDT displays its data. This shall include the TOC data. In an effort to demonstrate what type of formatting should be available in the ArnDT data display, the following examples have been provided.

1. Historical Data Inquiry

Having an established database of historical data allows for a user of the ArnDT to access and view a breakdown of the costs that were incurred. Figure 7 is an example of a historical data inquiry utilizing the USS SAMPSON as a model. Given that the USS SAMPSON is currently in the Operations and Support phase of her life cycle, all of the cost data up to the date of request would be shown.

Name:	**USS SAMPSON**
Builder:	Bath Iron Works
Commission: Date:	03 November 2007
Service Life:	35-years (2042)
Type:	Destroyer
Class:	Arleigh Burke-Class
Length:	509 ft 6 in
Beam:	66 ft
Draft:	31 ft
Displacement:	9,200 long tons

Historical Data Inquiry

Research and Development	
Personnel	$0.00
Design & Refinement:	$0.00
Schematics & Drawings	$0.00
Technical Publication	$0.00
Engineer Modeling	$0.00
Facility Support	$0.00
Investment	
Personnel	$0.00
Materials	$0.00
Shipyard facilities	$0.00
Subcontracting	$0.00
Outfitting	$0.00
Testing	$0.00
Misc Support	$0.00
Operations and Support (to date 06DEC2018)	
Personnel	$0.00
Energy	$0.00
Maintenance	$0.00
System Support	$0.00
Upgrades & Retrofitting	$0.00
Operational Support	$0.00

Disposal

- The USS SAMPSON (DDG 102) is not slated for decommissioning until 2042. As of this date (06DEC18), no disposal costs have been incurred.

Figure 7. Historic Data Inquiry Example

2. Simple TOC Inquiry

Another available inquiry would be a simple total ownership cost request. In this example, the forthcoming USS JACK H. LUCAS is used as a model to display how the report could look. All costs having been incurred up to the date of inquiry would be displayed as a single figure. The TOC estimate for the ship, based on the data aggregated and computed by the TOC algorithms, would likewise be displayed as a single figure. Finally, a combining of the previously mentioned costs would be summed together to provide the user a single TOC for the requested ship (Figure 8).

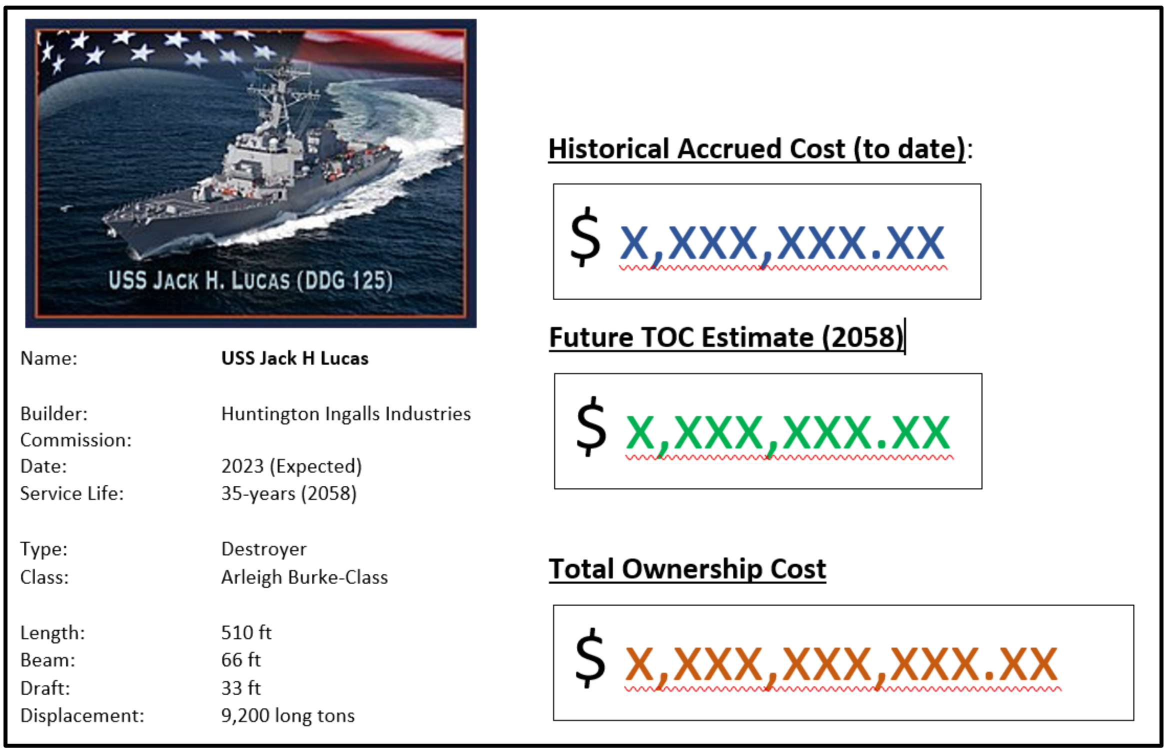


Figure 8. Simple Total Ownership Cost Inquiry Example

3. Vessel TOC Inquiry: Displayed by LCC

Should a user of the ArnDT be wanting a more categorical display of the costs incurred, the vessel total ownership cost inquiry would provide this data. In the given example (Figure 9), a user would have requested this type of data for the USS SAMPSON (DDG- 102). Everything in the simple TOC inquiry would be provided with costs listed by major categories throughout each phase of the ship's life cycle.

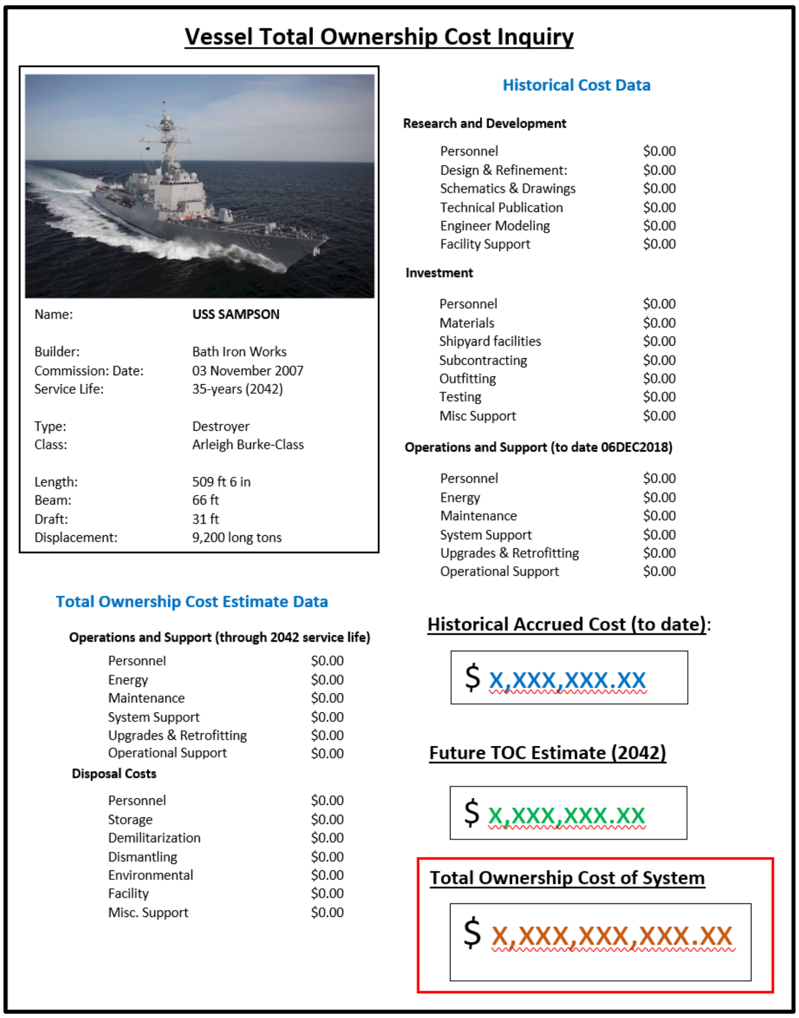
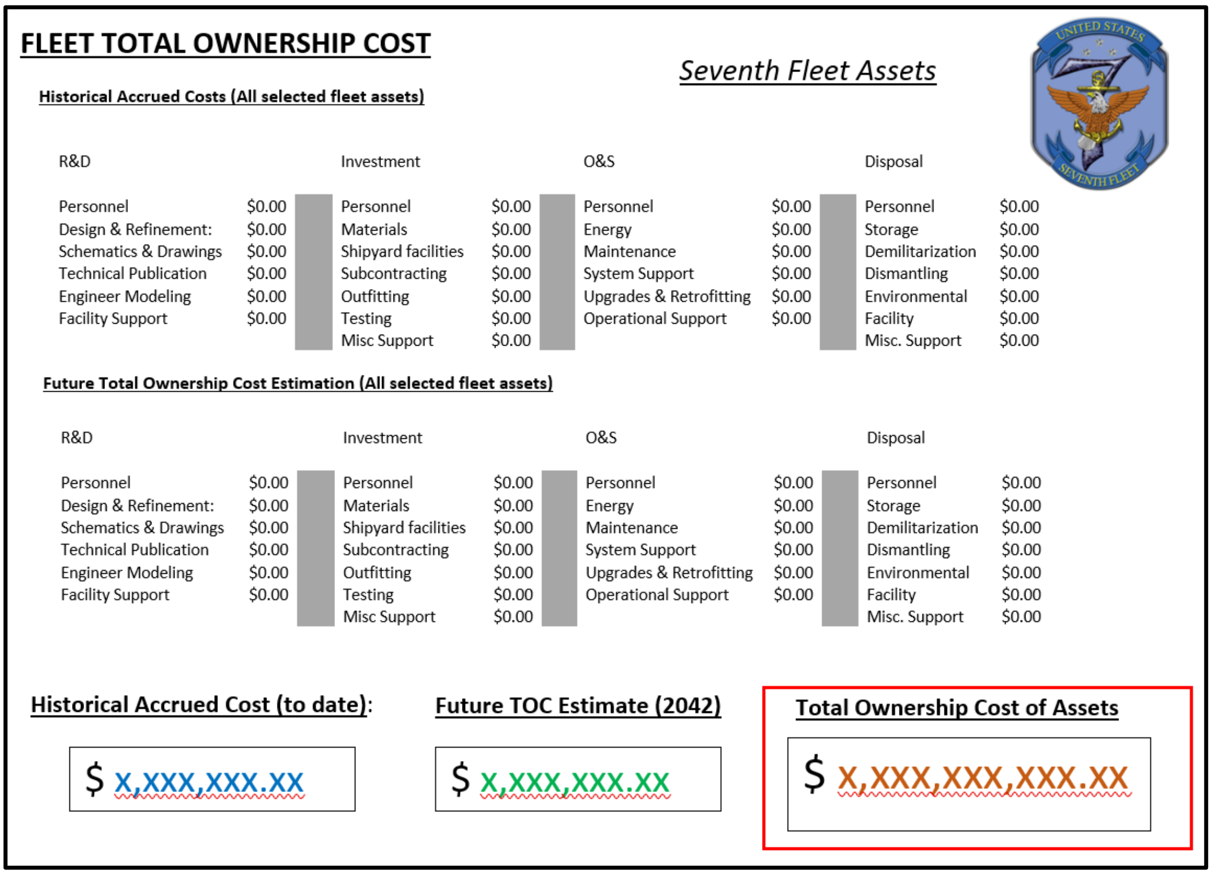


Figure 9. Vessel TOC Inquiry Example

4. Fleet Inquiry: Summary Sheet

The previous example of a vessel TOC inquiry will be scalable in order to provide this data for any and all grouping that a user could be needing data for. Examples could be a fleet inquiry gathering data for all of the Arleigh Burke-Class Destroyers. The example Figure 10 shows how this data would be displayed for all of the ships currently stationed in Seventh Fleet.



FLEET TOTAL OWNERSHIP COST

Seventh Fleet Assets

Historical Accrued Costs (All selected fleet assets)

R&D		Investment		O&S		Disposal	
Personnel	$0.00	Personnel	$0.00	Personnel	$0.00	Personnel	$0.00
Design & Refinement:	$0.00	Materials	$0.00	Energy	$0.00	Storage	$0.00
Schematics & Drawings	$0.00	Shipyard facilities	$0.00	Maintenance	$0.00	Demilitarization	$0.00
Technical Publication	$0.00	Subcontracting	$0.00	System Support	$0.00	Dismantling	$0.00
Engineer Modeling	$0.00	Outfitting	$0.00	Upgrades & Retrofitting	$0.00	Environmental	$0.00
Facility Support	$0.00	Testing	$0.00	Operational Support	$0.00	Facility	$0.00
		Misc Support	$0.00			Misc. Support	$0.00

Future Total Ownership Cost Estimation (All selected fleet assets)

R&D		Investment		O&S		Disposal	
Personnel	$0.00	Personnel	$0.00	Personnel	$0.00	Personnel	$0.00
Design & Refinement:	$0.00	Materials	$0.00	Energy	$0.00	Storage	$0.00
Schematics & Drawings	$0.00	Shipyard facilities	$0.00	Maintenance	$0.00	Demilitarization	$0.00
Technical Publication	$0.00	Subcontracting	$0.00	System Support	$0.00	Dismantling	$0.00
Engineer Modeling	$0.00	Outfitting	$0.00	Upgrades & Retrofitting	$0.00	Environmental	$0.00
Facility Support	$0.00	Testing	$0.00	Operational Support	$0.00	Facility	$0.00
		Misc Support	$0.00			Misc. Support	$0.00

Historical Accrued Cost (to date): $ x,xxx,xxx.xx

Future TOC Estimate (2042) $ x,xxx,xxx.xx

Total Ownership Cost of Assets $ x,xxx,xxx,xxx.xx

Figure 10. Fleet TOC Inquiry Example

5. Appropriation Breakdown: Displayed by LCC

Continuing to utilize the U.S. Navy's Seventh Fleet as a model, an ArnDT user may desire the cost data to be reflected through the appropriations that allocated funds to accommodate that cost. The given example is looking at the Seventh Fleet costs listed by their applicable appropriation under the life-cycle phases that these occurred within (Figure 11).

FLEET TOC APPROPRIATION INQUIRY *Seventh Fleet Appropriations*

Historical Accrued Costs (All selected fleet assets)

Research & Development		Investment		Operations & Support		Disposal	
Appropriation	Cost Total	Appropriation	Cost Total	Appropriation	Cost Total	Appropriation	Cost Total
MPN (COMPOSITE) (1453)	$0.00	MPN (COMPOSITE) (1453)	$0.00	MPN (COMPOSITE) (1453)	$0.00	MPN (COMPOSITE) (1453)	$0.00
MPN (NONPAY Purchases) (1453)	$0.00	MPN (NONPAY Purchases) (1453)	$0.00	MPN (NONPAY Purchases) (1453)	$0.00	MPN (NONPAY Purchases) (1453)	$0.00
CIV PAY = Civilian Payroll	$0.00	CIV PAY = Civilian Payroll	$0.00	CIV PAY = Civilian Payroll	$0.00	CIV PAY = Civilian Payroll	$0.00
FAMHSG (Construction) (0730)	$0.00	FAMHSG (Construction) (0730)	$0.00	FAMHSG (Construction) (0730)	$0.00	FAMHSG (Construction) (0730)	$0.00
FAMHSG (Operations) (0735)	$0.00	FAMHSG (Operations) (0735)	$0.00	FAMHSG (Operations) (0735)	$0.00	FAMHSG (Operations) (0735)	$0.00
FAMHSG (COMPOSITE) (0730)	$0.00	FAMHSG (COMPOSITE) (0730)	$0.00	FAMHSG (COMPOSITE) (0730)	$0.00	FAMHSG (COMPOSITE) (0730)	$0.00
RDT&EN (COMPOSITE) (1319)	$0.00	SCN = Shipbuilding (1611)	$0.00	O&MN (COMPOSITE) (1804)	$0.00	SCN = Shipbuilding (1611)	$0.00
		MILCON (Purchases) (1205)	$0.00	O&MN (Purchases) (1804)	$0.00		
		WPN = Weapons Procure (1507)	$0.00	O&MN/LF (COMPOSITE)(1804)	$0.00		
		PANMC = Ammunition (1508)	$0.00	PANMC = Ammunition (1508)	$0.00		
		OPN = Other Procure (1810)	$0.00				

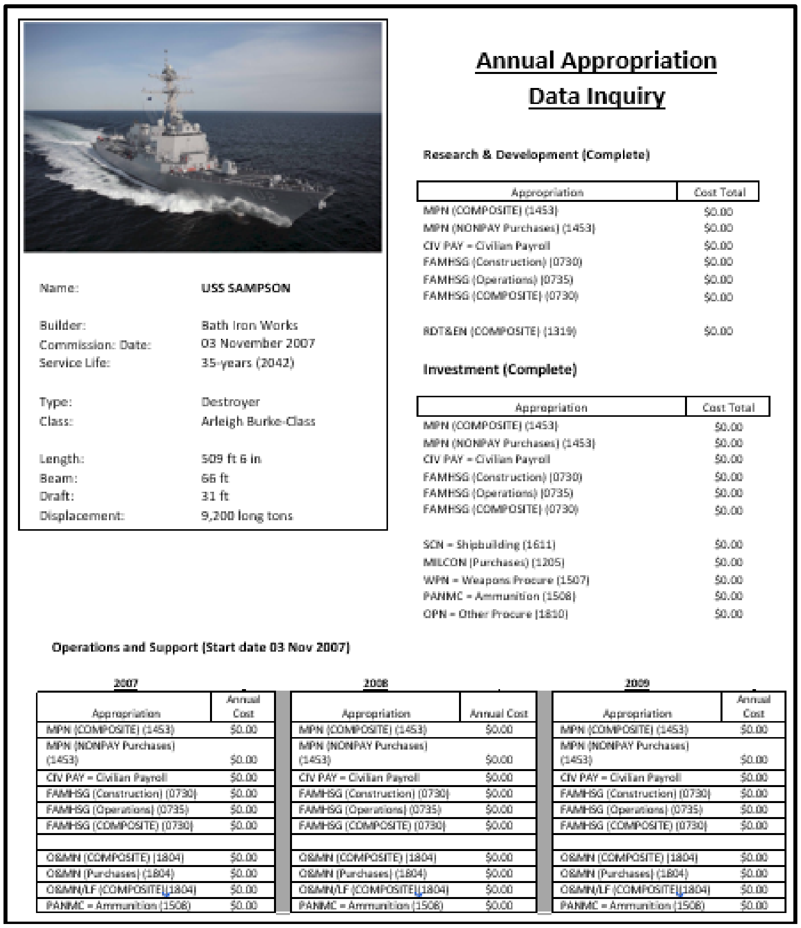
Future Total Ownership Cost Estimation (Listed by Appropriation)

Research & Development		Investment		Operations & Support		Disposal	
Appropriation	Cost Total	Appropriation	Cost Total	Appropriation	Cost Total	Appropriation	Cost Total
MPN (COMPOSITE) (1453)	$0.00	MPN (COMPOSITE) (1453)	$0.00	MPN (COMPOSITE) (1453)	$0.00	MPN (COMPOSITE) (1453)	$0.00
MPN (NONPAY Purchases) (1453)	$0.00	MPN (NONPAY Purchases) (1453)	$0.00	MPN (NONPAY Purchases) (1453)	$0.00	MPN (NONPAY Purchases) (1453)	$0.00
CIV PAY = Civilian Payroll	$0.00	CIV PAY = Civilian Payroll	$0.00	CIV PAY = Civilian Payroll	$0.00	CIV PAY = Civilian Payroll	$0.00
FAMHSG (Construction) (0730)	$0.00	FAMHSG (Construction) (0730)	$0.00	FAMHSG (Construction) (0730)	$0.00	FAMHSG (Construction) (0730)	$0.00
FAMHSG (Operations) (0735)	$0.00	FAMHSG (Operations) (0735)	$0.00	FAMHSG (Operations) (0735)	$0.00	FAMHSG (Operations) (0735)	$0.00
FAMHSG (COMPOSITE) (0730)	$0.00	FAMHSG (COMPOSITE) (0730)	$0.00	FAMHSG (COMPOSITE) (0730)	$0.00	FAMHSG (COMPOSITE) (0730)	$0.00
RDT&EN (COMPOSITE) (1319)	$0.00	SCN = Shipbuilding (1611)	$0.00	O&MN (COMPOSITE) (1804)	$0.00	SCN = Shipbuilding (1611)	$0.00
		MILCON (Purchases) (1205)	$0.00	O&MN (Purchases) (1804)	$0.00		
		WPN = Weapons Procure (1507)	$0.00	O&MN/LF (COMPOSITE)(1804)	$0.00		
		PANMC = Ammunition (1508)	$0.00	PANMC = Ammunition (1508)	$0.00		
		OPN = Other Procure (1810)	$0.00				

Figure 11. Fleet Appropriation Inquiry Example

6. Appropriation Breakdown: Displayed by Fiscal Year

While the ability to categorize a large contingent of vessels by their applicable appropriations is helpful, the ability to scale-down to a single vessel is just as valuable. Figure 12 is another example utilizing the USS SAMPSON to demonstrate how the ArnDT will have the ability to be utilized in the production of an annual appropriation listing. In the given example, the USS SAMPSON is currently in her Operations and Support life-cycle phase. The compiled data from completed R&D and Investment phases are shown in their totality. The various years that USS SAMPSON has been in the O&S phase are listed with line items and applicable costs for each of the appropriations used. While the example is a rendering of the USS SAMPSON's current state, this annual appropriation display will be available in all completed life-cycle phases as well as the future years estimation based on the expected service life (Figure 13).



Annual Appropriation Data Inquiry

Name:	USS SAMPSON
Builder:	Bath Iron Works
Commission: Date:	03 November 2007
Service Life:	35-years (2042)
Type:	Destroyer
Class:	Arleigh Burke-Class
Length:	509 ft 6 in
Beam:	66 ft
Draft:	31 ft
Displacement:	9,200 long tons

Research & Development (Complete)

Appropriation	Cost Total
MPN (COMPOSITE) (1453)	$0.00
MPN (NONPAY Purchases) (1453)	$0.00
CIV PAY = Civilian Payroll	$0.00
FAMHSG (Construction) (0730)	$0.00
FAMHSG (Operations) (0735)	$0.00
FAMHSG (COMPOSITE) (0730)	$0.00
RDT&EN (COMPOSITE) (1319)	$0.00

Investment (Complete)

Appropriation	Cost Total
MPN (COMPOSITE) (1453)	$0.00
MPN (NONPAY Purchases) (1453)	$0.00
CIV PAY = Civilian Payroll	$0.00
FAMHSG (Construction) (0730)	$0.00
FAMHSG (Operations) (0735)	$0.00
FAMHSG (COMPOSITE) (0730)	$0.00
SCN = Shipbuilding (1611)	$0.00
MILCON (Purchases) (1205)	$0.00
WPN = Weapons Procure (1507)	$0.00
PANMC = Ammunition (1508)	$0.00
OPN = Other Procure (1810)	$0.00

Operations and Support (Start date 03 Nov 2007)

2007

Appropriation	Annual Cost
MPN (COMPOSITE) (1453)	$0.00
MPN (NONPAY Purchases) (1453)	$0.00
CIV PAY = Civilian Payroll	$0.00
FAMHSG (Construction) (0730)	$0.00
FAMHSG (Operations) (0735)	$0.00
FAMHSG (COMPOSITE) (0730)	$0.00
O&MN (COMPOSITE) (1804)	$0.00
O&MN (Purchases) (1804)	$0.00
O&MN/LF (COMPOSITE) (1804)	$0.00
PANMC = Ammunition (1508)	$0.00

2008

Appropriation	Annual Cost
MPN (COMPOSITE) (1453)	$0.00
MPN (NONPAY Purchases) (1453)	$0.00
CIV PAY = Civilian Payroll	$0.00
FAMHSG (Construction) (0730)	$0.00
FAMHSG (Operations) (0735)	$0.00
FAMHSG (COMPOSITE) (0730)	$0.00
O&MN (COMPOSITE) (1804)	$0.00
O&MN (Purchases) (1804)	$0.00
O&MN/LF (COMPOSITE) (1804)	$0.00
PANMC = Ammunition (1508)	$0.00

2009

Appropriation	Annual Cost
MPN (COMPOSITE) (1453)	$0.00
MPN (NONPAY Purchases) (1453)	$0.00
CIV PAY = Civilian Payroll	$0.00
FAMHSG (Construction) (0730)	$0.00
FAMHSG (Operations) (0735)	$0.00
FAMHSG (COMPOSITE) (0730)	$0.00
O&MN (COMPOSITE) (1804)	$0.00
O&MN (Purchases) (1804)	$0.00
O&MN/LF (COMPOSITE) (1804)	$0.00
PANMC = Ammunition (1508)	$0.00

Figure 12. Vessel Annual Appropriation Data Inquiry Example

Annual Appropriation Data Inquiry: USS SAMPSON cont.

Operations and Support (Start date 03 Nov 2007)

2010

Appropriation	Annual Cost
MPN (COMPOSITE) (1453)	$0.00
MPN (NONPAY Purchases) (1453)	$0.00
CIV PAY = Civilian Payroll	$0.00
FAMHSG (Construction) (0730)	$0.00
FAMHSG (Operations) (0735)	$0.00
FAMHSG (COMPOSITE) (0730)	$0.00
O&MN (COMPOSITE) (1804)	$0.00
O&MN (Purchases) (1804)	$0.00
O&MN/LF (COMPOSITE)(1804)	$0.00
PANMC = Ammunition (1508)	$0.00

2011

Appropriation	Annual Cost
MPN (COMPOSITE) (1453)	$0.00
MPN (NONPAY Purchases) (1453)	$0.00
CIV PAY = Civilian Payroll	$0.00
FAMHSG (Construction) (0730)	$0.00
FAMHSG (Operations) (0735)	$0.00
FAMHSG (COMPOSITE) (0730)	$0.00
O&MN (COMPOSITE) (1804)	$0.00
O&MN (Purchases) (1804)	$0.00
O&MN/LF (COMPOSITE)(1804)	$0.00
PANMC = Ammunition (1508)	$0.00

2012

Appropriation	Annual Cost
MPN (COMPOSITE) (1453)	$0.00
MPN (NONPAY Purchases) (1453)	$0.00
CIV PAY = Civilian Payroll	$0.00
FAMHSG (Construction) (0730)	$0.00
FAMHSG (Operations) (0735)	$0.00
FAMHSG (COMPOSITE) (0730)	$0.00
O&MN (COMPOSITE) (1804)	$0.00
O&MN (Purchases) (1804)	$0.00
O&MN/LF (COMPOSITE)(1804)	$0.00
PANMC = Ammunition (1508)	$0.00

2013

Appropriation	Annual Cost
MPN (COMPOSITE) (1453)	$0.00
MPN (NONPAY Purchases) (1453)	$0.00
CIV PAY = Civilian Payroll	$0.00
FAMHSG (Construction) (0730)	$0.00
FAMHSG (Operations) (0735)	$0.00
FAMHSG (COMPOSITE) (0730)	$0.00
O&MN (COMPOSITE) (1804)	$0.00
O&MN (Purchases) (1804)	$0.00
O&MN/LF (COMPOSITE)(1804)	$0.00
PANMC = Ammunition (1508)	$0.00

2014

Appropriation	Annual Cost
MPN (COMPOSITE) (1453)	$0.00
MPN (NONPAY Purchases) (1453)	$0.00
CIV PAY = Civilian Payroll	$0.00
FAMHSG (Construction) (0730)	$0.00
FAMHSG (Operations) (0735)	$0.00
FAMHSG (COMPOSITE) (0730)	$0.00
O&MN (COMPOSITE) (1804)	$0.00
O&MN (Purchases) (1804)	$0.00
O&MN/LF (COMPOSITE)(1804)	$0.00
PANMC = Ammunition (1508)	$0.00

2015

Appropriation	Annual Cost
MPN (COMPOSITE) (1453)	$0.00
MPN (NONPAY Purchases) (1453)	$0.00
CIV PAY = Civilian Payroll	$0.00
FAMHSG (Construction) (0730)	$0.00
FAMHSG (Operations) (0735)	$0.00
FAMHSG (COMPOSITE) (0730)	$0.00
O&MN (COMPOSITE) (1804)	$0.00
O&MN (Purchases) (1804)	$0.00
O&MN/LF (COMPOSITE)(1804)	$0.00
PANMC = Ammunition (1508)	$0.00

2016

Appropriation	Annual Cost
MPN (COMPOSITE) (1453)	$0.00
MPN (NONPAY Purchases) (1453)	$0.00
CIV PAY = Civilian Payroll	$0.00
FAMHSG (Construction) (0730)	$0.00
FAMHSG (Operations) (0735)	$0.00
FAMHSG (COMPOSITE) (0730)	$0.00
O&MN (COMPOSITE) (1804)	$0.00
O&MN (Purchases) (1804)	$0.00
O&MN/LF (COMPOSITE)(1804)	$0.00
PANMC = Ammunition (1508)	$0.00

2017

Appropriation	Annual Cost
MPN (COMPOSITE) (1453)	$0.00
MPN (NONPAY Purchases) (1453)	$0.00
CIV PAY = Civilian Payroll	$0.00
FAMHSG (Construction) (0730)	$0.00
FAMHSG (Operations) (0735)	$0.00
FAMHSG (COMPOSITE) (0730)	$0.00
O&MN (COMPOSITE) (1804)	$0.00
O&MN (Purchases) (1804)	$0.00
O&MN/LF (COMPOSITE)(1804)	$0.00
PANMC = Ammunition (1508)	$0.00

2018 (as of 06 DEC 2018)

Appropriation	Annual Cost
MPN (COMPOSITE) (1453)	$0.00
MPN (NONPAY Purchases) (1453)	$0.00
CIV PAY = Civilian Payroll	$0.00
FAMHSG (Construction) (0730)	$0.00
FAMHSG (Operations) (0735)	$0.00
FAMHSG (COMPOSITE) (0730)	$0.00
O&MN (COMPOSITE) (1804)	$0.00
O&MN (Purchases) (1804)	$0.00
O&MN/LF (COMPOSITE)(1804)	$0.00
PANMC = Ammunition (1508)	$0.00

Figure 13. Vessel Annual Appropriation Data Inquiry: Supplemental Page Example

E. CONCLUSION

The establishment and use of a TOC model with the ArnDT will require a dedication of resources to accomplish. These steps will take time, however by utilizing current mature technology as intermediate steps, the Architecture Integrated Decision Tool can be developed and put into use more quickly.

The first task will be centered around the development of a TOC model and its applicable parameters. The end goal will be two-fold. The first step will be to establish an agreed upon set of parameters that will apply to all (or most) vessels as a baseline. While this baseline will serve as the backbone for data resourcing, this only gets us to the second step. The culminating requirement for an accurate TOC model will be TOC parameters tailored for each vessel type. To be specific, each vessel type (even within a similar class) has variations. These variations need to be accounted for in the original establishment of vessel TOC parameters. Moreover, these specific parameters will need to be managed through the life cycle of the assets. The built-in ability to review projected cost estimates, with the subsequent incurred costs, will allow for a cyclical review of ship TOC parameters and periodic updates as both the ship and the mission develop over time.

Once these TOC parameters are set and the model is complete, bolstering of the databases to support the technology must be addressed. While the still-developing narrow A.I. and machine-learning capability will eventually become the preferred method to aggregate data for the ArnDT, the first step is to utilize the TOC parameters to increase the collection of data by our current cost databases. Once the updated cost parameters are being kept and accounted for by the current applicable organizations, a temporary transshipment-like database will need to be stood-up. This will serve as a temporary step to aggregate the data and keep it in a single place for the ArnDT system to aggregate from. This technology is mature and can be relatively quickly established. While it is true this will be an additional requirement of time and resources, it will be key to bring the ArnDT online while allowing some of the more advanced technology a chance to mature. This step will mitigate the risk of premature technology application which would cause further costs from unscheduled resource requirements and program delays.

Once these initial steps are complete, the TOC model will bring the capability of solid data resourcing for decision makers across various levels of the Department of the Navy, as well as the DoD. Specific examples for application of the capabilities will be expounded upon in chapter five. The previously listed inquiry samples and displays demonstrate how both historical data and future cost estimate data will be displayed in a format readily available across the DoD. This is a key component for the ArnDT and TOC model data displays since it will only amplify the effectiveness that this data will yield. Without a universal method by which to display the data for DoD-wide usage, this capability the ArnDT will have shall be considerably mitigated in dissemination capability.

In summary, the application of a TOC model in the ArnDT will deliver cost data in a holistic way that has not been available up until now. By allocating the needed resources to establish and refine ship TOC parameters, bolstering the current life-cycle cost databases, utilizing a phased approach for data aggregation and thereby enabling appropriate ArnDT technology maturation, and lastly ensuring data display capabilities are geared toward the widest possible dissemination, the ArnDT will truly prove to streamline and revolutionize the capabilities of the decision process to a degree that may become larger than can currently be contemplated.

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V. DISCUSSION

The application of TOC model for use in the ArnDT, as demonstrated in the case study above, is not currently in existence. Since this is the case, a more practical discussion about why a TOC model is the most practical choice is required to develop the ArnDT. Also, some specific application scenarios should be explored to establish an initial use for this capability. If this future capability is deemed desirable and practical, the next logical step would be a review of various avenues that resources could be allocated down in an effort to create or acquire this capability. Finally, a recommendation of how to proceed will be offered.

A. PRACTICAL APPROACH THAT TOC OFFERS THE DEPT OF THE NAVY

The diverse nature of cost allows for scalable and focused research to be conducted for a range of practicable applications. For example, personnel costs can be researched to examine various manpower issues. This research can inform the design and intent of forthcoming force-shaping efforts. Since this is the most logical manner for the research to be utilized, the focus on personnel costs makes sense. However, in the shipbuilding industry, the span of various costs is more substantial.

A naval vessel, when looked at as an asset, is a long-term and burdensome commitment. From the design to construction, operation to disposal, the incurred costs are wide ranging and substantial in scope. With this fact, my first instinct was to look toward the life-cycle cost of a ship. The life-cycle cost framework focuses on all of the associated cost to the ship over all four phases of its life. This makes sense because it stands to reason that all of the costs that will be incurred should be accounted for when making decisions that require commitments in the tens of billions of dollars. However, when dealing with ships, and the evolution of their design, size, and capability, it was quickly obvious that a life-cycle cost would not be enough.

A total cost of ownership framework is the most holistic way to identify the burden that investing into a ship will bear. This is simply due to the fact that the costs incurred will not be only localized to the ship, rather, there are numerous indirect costs that will be applicable as well. Examples are the costs necessary to upgrade the aging shipyards to build the newer, bigger, and more advanced ships. Another example might be the now required cost incurred to send a naval officer to in-resident education prior to being assigned to command a ship. These indirect training costs will need to be accounted for because it is now universally required and applicable to every ship. So, as one can observe, for a decision maker to fully understand the cost incurred by choices that pertain to the fleet and its makeup, the only cost framework that can deliver all of the necessary information is total ownership cost.

While the TOC is the most comprehensive cost framework to utilize, it does not mean that it will be a simple model to develop. Resources will need to be allocated toward a level of effort to develop the various parameters for a naval ship baseline TOC model, as well as specific ship parameter sets for each individual ship type and class. The reason for this is that each ship is different. The cost associated with a nuclear propulsion plant are not the same as those associated with a diesel engine propulsion plant. Since these individual characteristics vary between the ships and can be upgraded as time goes on, individual TOC parameter sets will need to be established and updated. The allocation of resources to develop the individual ship TOC parameters will be somewhat extensive, but once established, the updating process could become a regular part of maintenance requirements during ship configuration upgrades.

Once the establishment process is completed, a functional TOC model that works in support of the ArnDT will provide numerous capabilities to decision makers across the leadership spectrum. In an effort to demonstrate how it can be deployed, the following hypothetical examples are shared for review. While the examples below are not in any way the totality of the applications, they will demonstrate some of the capabilities that the ArnDT, using a TOC model, will provide.

B. HYPOTHETICAL AID EXAMPLES (AT VARIOUS DECISION-MAKING LEVELS)

1. OPNAV N9 Perspective: Annual Force Structure Assessment

One of the tasks performed by members of OPNAV N9 is to conduct periodic fleet force structure assessment. This assessment is conducted in an "effort to determine the right balance of existing forces, the ships we currently have under construction and the future procurement plans needed to address the ever-evolving and increasingly complex threats the Navy is required to counter in the global maritime commons" (OPNAV N9, 2016, p. 1). Since the world is continually in a state of flux, the plan for our future Navy Force can require a shift. It is with that necessity to adjust that the TOC model within the ArnDT can assist in the process.

Suppose that we have established the ArnDT and created our Future Fleet Architecture. The TOC model has been instituted and the various TOC parameter sets are loaded in the system. The plan is to achieve 355 battle force ships and we are on track to accomplish this task. However, what if the opening of the Northern Passage was more aggressive than previously thought and it is deemed necessary to increase the number of USN Icebreakers in the fleet? The ArnDT user can pull up the force structure and either add the additional ship or adjust the established force structure to include the Icebreakers but still be at 355 ships. Once the new structure is established, the user will be provided with any of the applicable data that is requested. They could conduct a vessel inquiry for the Icebreaker, a fleet inquiry for the TOC of the fleet makeup, or generate the annual appropriation requirements for the planners and programmers in the Pentagon. Previously, this process would take a considerably long time and a strenuous amount of effort. Now, it can be accomplished in an afternoon with a few keyboard strokes.

This ability to adjust the fleet structure and get near "real time" data in support of the choices will allow for a greater dexterity in our fleet development. What previously would have taken months to research and deliver could be produced at a much more efficient rate. This efficiency means less cost and less time to plan. Ultimately, at all levels of the process, the product will be higher quality data and more flexibility in its application.

2. CNO/SECNAV/Congress: Building Congressional Legitimacy

As the data is collected and organized by OPNAV N9, the decision makers at the executive levels will be applying it to aid in decision-making. Having these high-quality products can allow for the Department of the Navy to clearly and efficiently evaluate the available options. Moreover, this will enable a clear dialog with Congressional decision makers.

Just as with various military members, not all Congressional decision makers have a background in defense system acquisitions or shipbuilding. Since it does fall specifically to Congress to authorize and appropriate funds for the DoD—known as the "power of the purse"—it is important for the dialog between military components and Congressional representatives to be open and effective. The complicated nature that currently surrounds funding for ships can lead to actions being taken without the full-scope of the cost issues being understood. However, the ArnDT using the TOC model will allow the military to concisely demonstrate the impact of financial choices made by our Congressional Representatives.

This clear understanding will build legitimacy in the decision-making process by allowing for a clear transparency in the results of the fiscal needs and decision making. As the funding of the military rises and falls from budget to budget, it will not be a surprise to the cost of the fleet. Rather, ArnDT users can simply run a fleet-wide annual appropriation inquiry and provide the numbers to the appropriate committees. This allows for stability in the planning process, simplicity for the decision makers, and trust to be built for all individuals involved.

3. Program Managers: Rational application to Naval Acquisitions

More than just in the decision-maker realm, a functioning TOC model and the ArnDT could be found quite useful for the Defense Acquisition System. One of the hardest jobs in Acquisitions is that of a Program Manager (PM). Essentially, the PM is the individual in charge of the running of a defense system program. They are charged with organizing the efforts of everyone involved to keep the program moving forward. More than just forward momentum however, the PM is responsible to move forward in a manner that remains within the budgeted time and cost.

As they are conceived, new projects develop through the Research and Development stage to establish these budgeted times and costs. This is where I think the ArnDT and a TOC model could have an immediate and significant impact. The parameters required for a working TOC model are essentially the same parameters that a new project begins with. For example, if a new destroyer was being developed, the development team would need to establish the ship's length, beam, draft, displacement, propulsion type, and more. These parameters for the new design could be built utilizing the software of the ArnDT. In fact, the whole ship could be designed and created in a digital form. The ArnDT would allow for the ship's characteristics to be evaluated individually and even tested in a digital red vs. blue scenario. Should the newly designed destroyer show that it needs a faster speed in the digital analysis provided by the ArnDT, then the PM can adjust the design in an effort to increase the speed of the ship. These analyses can be accomplished to refine the design until an optimal and stable design specification is decided upon. This design now has not only been completed for the engineers to utilize, but the TOC parameter set for the new class of destroyers will have been built as well. It is from this set of TOC parameters that the TOC model can operate.

The TOC model, using this new destroyer's parameter set, can calculate what a future TOC would be for the ship. Just as described above, each of the specifics can be listed and scaled to look at just one new destroyer or a fleet of them. This data can also be used to help the PM as the program progresses into and beyond the R&D phase. Utilizing the ArnDT and it's TOC model, a PM could evaluate the cost relationships that different attributes of the design yield. These attributes can then be a focus when developing the Initial Capabilities Document (ICD) and Capability Development Document (CDD). In fact, these more significant cost drivers could be utilized as an incentive for contractors to focus on when they bid for the contract. The use of the incentives will inspire industry innovation as a means to further drive down costs. This application of the TOC cost evaluation will allow for a Navy focus on long-term cost goals, while at the same time allowing for industry to focus on directly applicable procurement cost-cutting goals during the source selection process (Gilbreth, 2017).

4. Other Possible Applications

The previous examples of the ArnDT's capability utilizing a TOC model are only a few of the applications that this technology could be utilized for. Since both the TOC model and the ArnDT technologies are developing themselves, the possibilities can continue to grow once they are established. This technology could be linked to an auditing software and streamline the future efforts for DoD auditability. Another possibility could be the rendering of adversarial nation's fleets so that we can wargame future conflict possibilities and better understand the actual costs that such a conflict might incur. We could utilize the ArnDT to evaluate the costs associated with future ship upgrades, retrofitting, service life extensions, or even at-sea collisions. The possibilities for this technology are broad and could yield results across the span of the DoN and DoD at large.

C. VARIOUS MODELS REVIEWED

Looking at the application of a working TOC model within the ArnDT does seem quite promising; however, it is quite another undertaking to bring this technology from concept to reality. In an effort to find the best manner for resources to be allocated in support of this effort, it was imperative to look at the current state of TOC models in both the government and private sector. For this purpose, a focus on cost models involving shipbuilding were the driving force in the research.

The first step in the development of a cost model must be the identification of any ongoing efforts. To be specific, it is important to identify any government programs that are working toward the same end. In my research, I was able to identify a single ongoing effort. The Naval Center for Cost Analysis (NCCA) is leading an effort to develop a TOC model. The NCCA has significant expertise and experience in cost estimating as they are the organization which conducts independent cost estimates for the Navy and Marine Corps Acquisition Category 1C and 1D programs (Naval Center for Cost Analysis [NCCA], n.d). Additionally, the NCCA does a have smaller scale cost model which they can use as the backbone from which to build a more robust TOC model (NCCA, n.d.). As this effort to develop a government-owned (GO) model has started and presumably has funding allocated to it, the NCCA must be considered as a viable option for the establishment of a full-scale, TOC model for shipbuilding.

Even though the GO model development may prove to be a viable option, cost estimation is conducted by a wide variety of private industry companies. However, these cost estimations are mostly utilized by the companies for their government contract bidding processes. For example, cost estimates are routinely done at the largest defense contracting companies for their bidding of government contracts. Companies such as Lockheed Martin, Boeing, Raytheon, General Dynamics, and Northrop Grumman all have local cost estimation capabilities and techniques. Researching some of the smaller contractors in the industrial market, there are a variety of companies that work in the sector of shipbuilding that also have cost estimation capabilities. For example, BAE Systems does cost estimations for their ship repair projects. Similarly, a company like KBR tailors their cost estimation services in a consulting capacity throughout various life-cycle stages of shipbuilding. KBR, however, does not seem to focus on cost estimation as a service capability. A company such as SPAR Associates does provide a dedicated cost estimation service and has a base cost model from which to build from in a COTS-type evolution. In a review of these three companies, and an additional seven companies that have a cost estimation capability, their estimation capability may prove to be another viable way to develop a TOC model. The other seven companies include Valkyrie Enterprises, Trident Marine Systems, Pacific Shipyards Incorporated, Q.E.D. Systems, Tecnico Corporation, Life-Cycle Engineering, and International Ship Repair & Marine Services.

In order to evaluate the merits for each of the previously listed 15 companies, a set of factors must be established from which to conduct a comparison. Each of these factors will need to be weighted based on their level of importance as it applies to the best opportunity for a successful TOC model to be developed. The first, and most important, factor would have to be if a company provides a dedicated cost estimation service. While any of these companies could probably conduct cost estimation services in some capacity, having an experienced business would clearly be a benefit. Along the same lines of reason, the next factor would have to be the existence of a cost model that could serve as a backbone from which to build off of. With the expectation that going out into industry would be in search of a COTS-like development, having an existing cost model would be important for the development effort. A third factor that would be especially important would be the company's ability to handle the scope of work that would be involved in the development of a full-scale, TOC model for building a warship. An undertaking such as this TOC model will require a significant amount of effort by a company that would take it under contract. As such, the inherent capability for a company to handle this scale of job is a significant factor that needs to be taken under consideration.

There are several additional factors that need to be considered in this business evaluation that may not be as pivotal, but remain important nonetheless. Any business that would want to develop this model would have to have an understanding of the shipbuilding industry. Having a knowledge base in the industry, the next factor would be the company's ability to communicate with stakeholders in a timely manner. A business that is local to the continental United States would be ideally suited in this regard. The last factor that must be considered would be the independence factor of the company developing the model. Understanding that transparency and wise allocation of resources is important to this process, hiring a company that does not present the possibility of interest confliction would be a positive aspect to this process.

With six distinct factors now established for comparison, the 15 different companies can be evaluated against each other based on the business's merits. To accomplish this, a modified decision matrix will be utilized. The Naval War College teaches the use of a weighted decision matrix when evaluating various courses of action (COA) during military staff decision making (Naval War College [NWC], 2013). This "matrix is not intended to provide a scientific or mathematic solution for what is a decidedly subjective process," however the "strength of the matrix is that it allows the commander and staff to review systematically the specific important strengths and weaknesses of each COA" (NWC, 2013, p. G-1). So, in an effort to evaluate each of the business's important factors, the application of a modified decision matrix would be appropriate.

D. EVALUATION OF CIVILIAN BUSINESS FOR TOC MODEL DEVELOPMENT

Having established six factors from which to compare each of the 15 civilian businesses, an evaluation matrix was created. This matrix is based on the weighted-decision matrix utilized by military staffs to evaluate different COAs in war planning. Each of the businesses were given a numerical identifier to represent them in the matrix and their assignments are shown in Table 1.

Table 1. Industry Company Numerical Assignment for the Evaluation Matrix.

Companies	Assigned number
Lockheed Martin	1
Boeing Company	2
Raytheon Company	3
General Dynamics Company	4
Northrop-Grumman Company	5
KBR	6
BAE Systems	7
SPAR Associates	8
Valkyrie Enterprises	9
Trident Marine Systems	10
Q.E.D. Systems	11
Tecnico Corporation	12
Life-Cycle Engineering INC.	13
Pacific Shipyards International	14
International Ship Repair & Marine Services	15

Next, the evaluation matrix created a way to evaluate the suitability of each of the businesses, which were placed along the x-axis of the table, while the y-axis contained the six decision factors. Table 2 is the evaluation matrix shell.

Table 2. Evaluation Matrix Shell. Adapted from NWC (2013).

	Companies for Comparison														
Comparison Criteria	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Dedicated CE Services															
Model Exists to Build From															
Capability for Scope of Work															
Experience in the Field															
Ease of Communication															
Independence															

The next step in this process was to establish a scoring scale to be applied across the businesses in each of the comparison factors. The evaluation scale I chose was a scale ranging from five to one. The value of “5” represents a highly applicable relationship to the criteria and/or serve as a “Yes” response. On the opposing side of the scale, a value of “1” indicates no applicability and/or a “No” response.

With the establishment of the scoring scale and the evaluation matrix shell, the actual evaluating was conducted. The numbers shown in Table 3 are based on my assessment as to how each applies to the information that I was able to gather concerning the various businesses, obtained from open sources. Because of the exploratory nature of this study, and due to the fact that I am not an agent of the U.S. Government authorized to broker a contract, this purposeful limitation of data collection had to be implemented.

Table 3. Completed Evaluation Matrix. Adapted from NWC (2013).

Comparison Criteria	Companies for Comparison: 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Dedicated CE Services	2	2	2	2	2	3	1	5	2	2	2	2	4	1	1
Model Exists to Build From	1	1	1	1	1	1	1	5	1	1	1	1	1	1	1
Capability for Scope of Work	5	4	4	5	5	3	4	5	2	2	2	2	2	2	2
Experience in the Field	5	3	3	5	5	3	5	5	3	3	3	3	3	3	3
Ease of Communication	5	5	5	5	5	5	5	5	5	5	5	5	5	4	5
Independence	1	2	2	1	1	2	1	5	3	3	3	3	3	3	3

Evaluation Scale: (5) = Highly Applicable/ Yes, (4) = Moderately Applicable, (3) = Applicable, (2) = Somewhat Applicable, (1) = Not Applicable/ No

Now that the raw evaluation scores have been populated in the evaluation matrix, the "weighting" can be applied. The more important factors have been assigned a greater weight to highlight the most important criteria as established previously. This weighting will serve as a multiplier to the score that each of the businesses have within the evaluation factors. The weighting values for each of the comparison criteria are shown in Table 4.

Table 4. Weighting Factors Assigned to Each Comparison Criteria

Comparison Criteria and Weighting Factors

Comparison Criteria	Weighting Factors
Dedicated Cost Estimation Services	3
Model Exists to Build From	2
Capability for Scope of Work	2
Experience in the Field	1
Ease of Communication	1
Independence	1

Having each of the weights assigned to the criteria to indicate their importance, the next step is to apply the weight across the evaluation matrix. The raw evaluation scores from Table 3 for each business will be multiplied by the weight shown in Table 4. The new weighted scores will then be added together to provide the overall weighted score for each of the businesses. The individual weighted scores and the overall total are shown in Table 5.

Table 5. Final Totals after Applying Weighting Factors

	Companies for Comparison														
Comparison Criteria	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Dedicated CE Services	6	6	6	6	6	9	3	15	6	6	6	6	12	3	3
Model Exists to Build From	2	2	2	2	2	2	2	10	2	2	2	2	2	2	2
Capability for Scope of Work	10	8	8	10	10	6	8	10	4	4	4	4	4	4	4
Experience in the Field	5	3	3	5	5	3	5	5	3	3	3	3	3	3	3
Ease of Communication	5	5	5	5	5	5	5	5	5	5	5	5	5	4	5
Independence	1	2	2	1	1	2	1	5	3	3	3	3	3	3	3
Summed Total for Each Company	**29**	**26**	**26**	**29**	**29**	**27**	**24**	**50**	**23**	**23**	**23**	**23**	**29**	**19**	**20**

To illustrate the quality of candidate that each business presents as in reference to the development of a TOC model, I will utilize a Red/Yellow/Green criterion. A total score of 20 points or less will yield a corresponding color of red. Scores ranging from 21 – 40 will receive a yellow indicator. Finally, a score from 41 – 50 will earn a green color code. For ease of understanding, Table 6 provides this data in a visual format and provides a description of the result.

Table 6. Red/Yellow/Green Criteria Legend

Score Range	Evaluation Result	Color Indicator
41-50	Optimal Business Candidate for development of TOC Cost Model	**Green**
21-40	Possible Business Candidate for development of TOC Cost Model	**Yellow**
0-20	Candidate is not well suited for development of TOC Cost Model	**Red**

Having applied the weighted evaluation scale to each comparison factor as it pertained to each business, there emerged a clear standout business amongst the group. Most of the companies ranked in the yellow, leaving only two businesses that did not score well and achieving a red-level score. Most of the yellow-scoring companies have the capability to develop a model and have the requisite experience needed; however, cost estimation is not their primary business focus and their business could be perceived as having a lack of independence. The lowest scoring businesses did not have the capacity or experience to successfully complete the scope of the job. By transferring these color codes to the numerical assignment table, we identify the specific companies that these scores apply to. Overall, Company #8, SPAR Associates, scored the highest by far with a perfect score. Table 7 shows the applicable color codes as they apply to each business.

Table 7. Color-Coded Scores and Numerical Assignment Table

Companies	Assigned number
SPAR Associates	8
Lockheed Martin	1
Boeing Company	2
Raytheon Company	3
General Dynamics Company	4
Northrop-Grumman Company	5
KBR	6
BAE Systems	7

Companies	Assigned number
Valkyrie Enterprises	9
Trident Marine Systems	10
Q.E.D. Systems	11
Tecnico Corporation	12
Life-Cycle Engineering INC.	13
Pacific Shipyards International	14
International Ship Repair & Marine Services	15

The highest scoring company is SPAR Associates. This business scored at the top of the scale across the various comparison factors. The companies scoring in the yellow range from some of the largest defense industry contractors to some of the most prominent shipyard maintenance companies. While scoring well in several of the factors, the shortfalls seem to center around the more heavily weighted considerations. Additionally, the larger defense contractors who actually participate in the current building of warships scored lower due possibly to the lack of business independence. The lowest scored companies are smaller contractors that simply do not have the capability to handle such a large-scale undertaking.

With the evaluation complete, a deeper look into the merits of the "GO" effort (being led by the NCCA) and the highest ranked industry option (SPAR Associates) is now possible. This look into the benefits that each option presents will be discussed in Section E.

E. RECOMMENDED METHODS AVAILABLE FOR TOC MODEL DEVELOPMENT

1. Government-Owned (GO) Model: NCCA RTCOST Model

While it may be the most obvious choice, allocating resources so that the government can continue to develop a TOC model is the first option that resources should be allocated toward. The NCCA "advises the Secretary of the Navy on matters relating to weapon system cost estimates and analysis" (NCCA, n.d.). Additionally, they are the organization that maintains the Navy's Operations and Support Cost database called

VAMOSC (NCCA, n.d.). The job that they currently perform already has the focus on defense system costs. However, their current effort are not quite as broad as the proposed TOC model. That being said, the NCCA has begun an effort to develop a government-owned (GO) TOC model.

This effort to develop a TOC model at NCCA is young in its conception. Additionally, the effort has not yet been aligned with the efforts of N9I in the development of the Architecture Integrated Decision Tool. Should the decision be made to allocate resources into the GO TOC model development, aligning the effort of NCCA and N9I will prove to be beneficial for both groups. With a clearly defined goal and the flexibility to develop this technology in a controlled and innovative environment, the TOC model could yield the long-term cost outcomes that the ArnDT is looking for.

2. COTS Option: SPAR Associates

While developing a purely government-owned model may be a long-term solution for ArnDT, the ability to modify an existing product may yield a working TOC model in a faster timeline. The company SPAR Associates Incorporated is unlike the 14 other companies that were described previously. While the other 14 companies primarily build, repair, or upgrade ships, SPAR Associates does not. Rather, SPAR has been providing planning & production management systems to shipyards for over 40 years (SPAR Associates [SPAR], n.d.). The company focuses on aiding shipbuilding efforts by providing business management tools to aid shipyards in managing and sequencing their business practices (SPAR, 2016). One additional service they provide is independent cost estimations for shipbuilding. This service is not limited to just civilian tankers, yachts, or other such pleasure craft. SPAR Associates has a focused effort in conducting naval ship life-cycle cost estimates.

To conduct this life-cycle costing, Spar has developed their Perception System. This system has been geared to "accommodate almost any hierarchy of LCC configuration" and was "developed as an extension to the acquisition work breakdown structure" (SPAR Associates [SPAR], 2015, p. 17). What this means is that the system already has a backbone to it that aligns with the DoD approach to setting defense system parameters. Moreover, this will lend itself to an effort to build upon the system to encompass all aspects of TOC.

Another key feature to the SPAR Perception system is that it has a range of its own databases from which to estimate costs from, and it is able to add additional inputs (SPAR, 2015). For example, the Navy's O&S cost database, maintained by the Navy Center for Cost Analysis, could be linked to the software. This database, along with the other SPAR databases that it has been building for more than 40 years (SPAR, 2015), could be fused in an effort to create a more refined model.

With a 40-year history in the business, SPAR has already been involved in several military projects for both the U.S. Navy and the U.S. Coast Guard (SPAR, 2016). They have been assisting the major shipbuilding contractors as well to include Lockheed Martin, Raytheon, and Bath Iron Works to name a few (SPAR, 2016). Overall, the SPAR Associates Perception System would serve as a solid foundation from which to further develop a TOC model. The ability to start with an LCC system that is flexible enough to be built upon, will increase the development time and should lower the TOC model development costs. It is for this reason that resources should be allocated to pursue a partnership with SPAR Associates in the development of a TOC model.

VI. CONCLUSION

A. SUMMATION OF RESEARCH

The current state of U.S. Navy shipbuilding is an industry that consistently has cost over-runs and schedule delays. These issues are not simple in nature and will require a concerted effort if they are to be addressed. Moreover, the Navy is now obligated by law to establish a fleet with a force at 355 battle force ships. This environment of cost overruns, coupled with limited resources, will demand a long-term plan if there is any chance for a successful outcome.

The goals being driven toward by OPNAV N9 will prove to be valuable once they are accomplished. The development of the Architecture Integrated Decision Tool will eventually provide a manner in which to clearly delineate the force needs. From these digital evaluations, it will be necessary to translate them into achievable plans that are accomplishable in a resource limited environment.

Through the investment of resources now in an effort to develop a TOC model, this translation from concept to affordable plan can be defined and achieved. Once developed, the ability to digitally render a vessel which fulfills the capability needs while providing a fully-developed scope of costs that will be incurred throughout its service life will prove vital for long-term fleet planning and design. The ArnDT, utilizing a TOC model, will enable decision makers at all levels to render informed decisions no matter what the fiscal environment at the time looks like. From the Acquisition Defense System up to the CNO, this tool will prove to be a critical capability for all future planning efforts.

While the outlook of this developing technology is promising, it is critically important to apply the resources that we currently have in the best manner possible to bring this capability to bear. Through a review of current technologies and capabilities in both the government and civilian sectors, the investment of resources into both arenas is warranted. Utilizing the SPAR Associates Perception System as a COTS-like option to build from appears to be the faster method for the development of a holistic TOC model. The purely government-owned option, being led by the Naval Center for Cost Analysis, does provide the ability to completely control the development and may prove to be the better long-term effort to invest current resources into. Both recommended options could very well prove to develop a viable TOC model for utilization in the ArnDT, and as such, current resources should be allocated to both avenues of development. This dual-path strategy would be a quality investment of current resources and minimize the possibility of project failure should one path not yield a favorable return.

B. SHORTFALLS IN THE STUDY

Inherent in the nature of an exploratory case study is that the research conducted is done when there is a lack of preliminary research previously conducted in the area of interest. While there is a significant amount of research in the areas of cost estimation, life-cycle costing and the theory behind total ownership cost, there is a noted lack of definitive specific examples for TOC in the shipbuilding sector. This lack of previous data draws to the necessity for allocation of resources in a concerted effort to clearly define and implement this type of costing model. While this will not be a simple undertaking, the results that can come from such an endeavor, as shown in this exploratory case study, will provide a much-needed capability to the decision makers throughout the DoD for years to come.

C. RECOMMENDATIONS FOR FURTHER RESEARCH

As outlined in the exploratory case study and discussion chapters, there is a necessity to allocate resources to bring this TOC model from its current state of conception into a functional reality. As I see it, there are two logical topics that can immediately be researched. These areas are in the defining of a generic set of TOC parameters as they would apply to a U.S. Navy Warship, and into the database structure that would need to be established in support of those parameters.

As a first, and vital step, resources need to be allocated to the defining of a set of generic warship TOC parameters. This endeavor needs to be holistic in nature and aim at finding every possible cost that can apply to the process. While the life-cycle costs associated will serve as a good starting point, all costs that can be both directly and indirectly linked to the warship need to be established and defined. While it may end up to be true that all of these parameters will not be calculated in a mathematical TOC model, it is vital to understand them as the Navy looks to build a fleet of 355-ships in the coming decades. This generic warship TOC parameter set will also serve as a point of departure for the refinement of specific ship-class TOC parameters sets. The current state of the world, being that of limited resources and ever-growing requirements, will require a deft strategy to successfully accomplish this future goal. This research could be the benchmark that yields the capability to develop requirements into resources for the future.

The second and equally critical arena that should be explored is in the tailoring of a database structure that can compile all of the data that directly supports the various cost drivers. While several legacy-databases exist and contain various levels of data for individual phases of a defense program's life cycle, these systems will need to be bolstered, linked, and accessible. The ability to expand current data figures or replace them with more applicable data points of interest will require a skilled level of technological know-how with supporting resources to support the effort. Should we only place resources into defining the TOC parameters, they are rendered useless without the data to aggregate for a TOC model to compute. Likewise, without a set of parameters to define the TOC model, all the data in the world will not yield the needed result.

Both of these follow-on research opportunities will be challenging and require the allocation of DoD resources to complete. Since this endeavor has the potential to establish a metric from which every defense system could benefit from, it is not just a "high-tech trend" that can be largely overlooked. Rather, the application of a total ownership cost framework in decision making will ultimately play a role in the fleet that we will have in the next thirty years or more. On our current trajectory, we will not be successful in building the fleet we need with the resources we have. On the other hand, if the necessary resources are provided and given the time needed to properly research and ultimately create a TOC model for the ArnDT, the capability will not only benefit the shipbuilding sector of the Navy, but every defense acquisition for the foreseeable future, as well.

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