3-21-2013

Investigation into the Ratio of System Operations and Support Costs to Life-Cycle Costs for Department of Defense Weapon Systems

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THESIS

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AFIT-ENC-13-M-01

DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY

AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

AFIT-ENC-13-M-01

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THESIS

Presented to the Faculty

Department of Mathematics and Statistics

Graduate School of Engineering and Management

Air Force Institute of Technology

Air University

Air Education and Training Command

In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Cost Analysis

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March 2013

AFIT-ENC-13-M-01

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Abstract

As the arsenal of weapons managed by the Department of Defense (DoD) ages, the country's leadership is forced to make decisions regarding what to do with current and projected funding to maintain military defensive and offensive capabilities. One important piece of this decision is the operations and sustainment (O&S) cost for the system. The acquisition community at many levels has stated that O&S costs are about 70 percent of the total life-cycle costs of the average system, the other 30 percent being spent in the acquisition phase. This "golden ratio" appears to come from estimates created during the acquisition phase of a weapon system's life cycle. Although some programs may have used (or attempted to use) some actual data, whether from antecedent systems or preliminary testing data, as a basis for their estimates, there has been little research into the actual ratio of O&S-to-acquisition costs.

This research has found a significant departure from the "golden ratio" in currently fielded systems. Using 37 Air Force, Navy, and Joint programs, the average program was estimated to realize closer to 55 percent of its costs in the O&S phase, though this figure does not come close to telling the whole story. Significant deviances, both high and low, from this 55 percent average were seen in most of the weapon system categories analyzed due to many factors, such as life expectancy, acquisition strategy, and level of annual sustainment costs for each category. Due to these significant differences, using a single ratio to describe the cost envelope of the "average" weapon system is not recommended.

I dedicate this work to my wife, for enduring the tough, lonely times when work needed to be accomplished for months on end, and to my daughter, who didn't quite understand why I needed to be working for so long in my office, but still tried her hardest to play with me.

Acknowledgments

We would like to thank all of the people who contributed to the body of knowledge included herein. The professors from the Defense Acquisition University, the professionals at the Air Force Cost Analysis Agency and the Naval Center for Cost Analysis, and many other invaluable members of the acquisition and cost communities provided the insight needed to assemble and analyze the pertinent data used for this analysis.

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Investigation into the Ratio of System Operations and Support Costs to Life-Cycle Costs for Department of Defense Weapon Systems

I. Introduction

Background

Operations and support (O&S) costs have long been overlooked in the acquisitions community and at higher levels in the Department of Defense (DoD). As evidenced in the overabundance of studies into acquisition costs and much smaller body of work in O&S costs, more focus seems to be placed on the beginning of the life cycle of a DoD weapon system (acquisition) and tend to neglect the other significant portion of the weapon system's life cycle (sustainment). Though this portion of the weapon system must be included in many cost analyses for Major Defense Acquisition Programs (MDAPs), there is more emphasis on trying to discern the cost of developing and procuring a system than in how the system will be sustained and how long the system will be operating. This matter is complicated further by the difficulty in determining the true life cycle of a weapon system. Some systems, such as automated information systems (AIS), may see a short life cycle due to the ever-changing information security and cryptologic standards and concerns of the DoD. Other systems, such as the B-52, have proven themselves to be so useful and versatile, not to mention costly or burdensome to replace, that they have been extended far beyond their expected life.

General Issue

Although the DoD has not historically given the O&S side of weapon system costs enough attention, they are not without resources to help cost analysts and program managers develop at least a rough estimate of what those costs should be. From all levels of acquisition leadership, managers and analysts are taught that there is a certain ratio of costs attributable to each of the stages in a weapon system's life, generally 30% towards acquisition and 70% for O&S (Carter, 2011). Everyone in the defense acquisitions industry has most likely been indoctrinated with a chart similar to the one in Figure 1 (OSD CAIG, 1992) showing increasing costs going from research and development through procurement, leading to a significant jump in funding in the O&S phase and a relatively insignificant disposal cost. This is touted as the standard cost profile under which most programs operate. Notable exceptions to this profile are satellite systems that require relatively minimal O&S costs once the system is in orbit.

Many studies by the Government Accountability Office (US GAO, 2000; 2010; 2012) have cited this same ratio or used similar graphics as part of the Background section in Congressional reports, illustrating how ingrained these two acquisition "facts" are in the culture. If this "golden ratio" is correct, then we should be able to predict O&S costs for a weapon system somewhat reliably based on its acquisition cost.

One important question remains unanswered: Where did this golden ratio originate? In many cases, documents state that "historical" or "generally-accepted knowledge" is the source of the information, if any source is referenced at all. Some reports give different ratios depending on weapon system types. For instance, the Institute for Defense Analyses prepared a report in 1999 that showed non-space programs estimated their O&S costs ranging from 33% for rotary-wing aircraft to 70% for AIS (IDA, 1999).

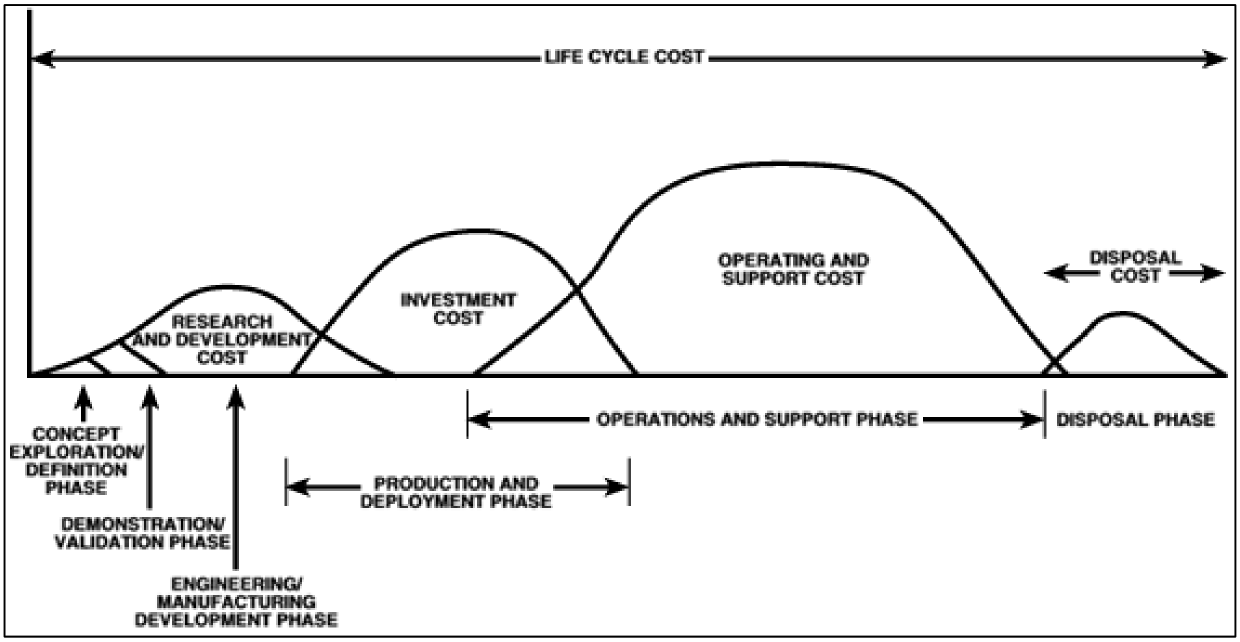

Figure 1: Notional Life-Cycle Costs for a DoD Weapon System (OSD CAIG, 1992)

Although some studies have looked into O&S costs, they are usually specific to a weapon system or group of similar systems and typically only look at the estimates of O&S in the Future Years Defense Program (FYDP). Very little research has been performed using actual O&S costs of weapon systems to determine how this phase in the life cycle compares to the life cycle as a whole. Part of the problem of performing this kind of analysis is the difficulty in obtaining actual system-specific cost data with good fidelity for the duration of the O&S phase. In almost all cases, data is either incomplete or does not exist.

Research Questions

The primary focus of this thesis is to identify the original source of the widely-accepted 70% O&S cost figure and attempt to validate the methodology that gave rise to it or develop a model that more closely represents reality. Specifically, the following questions will be explored:

Is there an identifiable source for the "golden ratio"? Identifying the original source of this information should give insight into the intent and methodology behind the ratio and should help dispel false information added through oral tradition. Spreading information by word-of-mouth is both dangerous and effective: dangerous because it may not be able to be traced to its source and information tends to stray from the original facts, and effective because information, whether true or false, can spread very quickly, especially in command or educational environments.

If a source can be found, are the source and/or methodology credible? Many factors need to be considered when analyzing data, especially in the DoD. Across the services, a wide variety of weapon system types are available for analysis. A look through the history of acquisition data available for MDAPs yields incomplete data and ever-changing program reporting trends. These changes and data holes need to be correctly accounted for in order for a methodology to be credible.

If a source is found and was valid at some point, is the information still valid? The information from any relevant study can be evaluated with current tools and updated with current information on the systems that were initially analyzed, if any. As time progresses, so does technology. Systems designed to operate in a combat environment 30 years ago are undoubtedly less complex and less costly to develop and possibly maintain. This disparity in complexity could lead to a shift in costs, or costs in both the acquisition and O&S phases could have risen proportionally equally, leaving previous ratios intact.

Can a more accurate model be developed? As previously discussed, an obvious exception to the 70% rule of thumb is in space systems. It follows that other systems would stray from this percentage, as well. The B-52, for example, entered service in 1955 and has the possibility of being used beyond 2040 (B-52 Stratofortress, 2011), potentially pushing sustainment costs for the system above 70% of life-cycle costs. We may be able to introduce more realistic ratios that are dependent on type of weapon system, lead DoD service (Air Force, Navy), or some combination of these or other factors.

Methodology

The database used for this paper is the one assembled in the dissertation Cost-Based Decision Model for Valuing System Design Options (Ryan, 2012). A complete description of the methods used to derive the operations and support costs for the specific systems used are given in this dissertation. Acquisition data were derived from the Selected Acquisition Reports (SARs) available through the Defense Acquisition Management Information Retrieval (DAMIR) system. Although the SAR has been the subject of criticism by some due to the lack of consistency throughout time and from program to program (and sometimes within a program) (Hough, 1992), it is the most thorough and readily available data on any type of acquisition program in the DoD. Since we are limited to SAR data, we are also limited to programs designated as Acquisition Category I (ACAT I) or Major Defense Acquisition Programs (MDAPs). These are programs that exceed $365 million (BY2000) in Research, Development, Test, & Evaluation (RDT&E) funding or $2.19 billion (BY2000) in Procurement funding, or have been designated by Congress or the DoD as an ACAT I program due to high visibility or interest.

Operations and support (O&S) actual cost information was retrieved from the Naval Visibility and Management of Operating and Support Costs (VAMOSC) system for the Navy and the Air Force Total Operations Cost (AFTOC) system for the Air Force. Due to concerns about the fidelity of the data from the Army's Operating and Support Management Information System (OSMIS), O&S data from this system was not used. O&S costs attributable to personnel, contractor logistics, fuel, and software, among other areas, were deficient or missing for entire weapon systems in OSMIS, without any reasonable method of obtaining these costs and attributing them to the correct program (Ryan, 2012).

To identify the programs to be analyzed in the dissertation, two major criteria were applied to the available SARs in DAMIR.[1] First, the programs needed to have a valid O&S estimate. Even though the analysis in this thesis did not require this limitation and reduced the number of systems available for analysis, this criterion was retained to reduce the amount of error, specifically, the error due to the collection of data and miscalculation of the Annual Unitized Cost (AUC), described later. Although all

[1] For a more complete description of the methodology used to create the database, read "A Proposed Methodology to Characterize the Accuracy of Life-Cycle Cost Estimates for DoD Programs" (Ryan, Jacques, Colombi, & Schubert, 2012)

programs are required to consider O&S costs, many MDAPs do not include an O&S cost estimate in the SAR until later in the program.

Second, the program needed to have stable operations costs. Newly fielded systems tend to have periods of ramp-up where the full capability has not been fielded and true annual costs are not known. The final database included 37 programs – seven from the Air Force, 24 from the Navy and six joint programs[2,3] - with operational data from 1989 through 2010. These programs came from eight different categories: Missiles, Cargo/Tanker/Bomber Aircraft, Fighter Aircraft, Rotary-Wing Aircraft, Ships, Electronic Equipment, Unmanned Aerial Vehicles, and Tilt-Rotor Aircraft. These categories were determined based on the categories given for life expectancies in the 2007 *Operating and Support Cost Estimating Guide* published by the Office of the Secretary of Defense Cost Assessment and Program Evaluation (OSD CAPE).[4]

One of the metrics calculated from the information in the VAMOSC and AFTOC systems was an actual Annual Unitized O&S Cost (AUC) per program. This metric generally describes the cost to operate and sustain one unit (individual plane, ship, etc.)

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[2] One program from the original database could not be used due to the nature of the program. Evolved Expendable Launch Vehicle (EELV) involved purchasing a launch capability and not necessarily specific units that could be assigned an annual cost.

[3] The AIM-9X, Advanced Medium Range Air-To-Air Missile (AMRAAM), Joint Air-to-Surface Standoff Missile (JASSM), Joint Primary Aircraft Training System (JPATS), and the Joint Standoff Weapon (JSOW) are the joint programs used by the Air Force and Navy. The Joint Surveillance Target Attack Radar System (JSTARS) is a joint program between the Air Force and Army.

[4] The UAV and Tilt-Rotor classes are relatively new classes of systems that were not mentioned in this guide. They were listed as their own class due to the unique capabilities of these systems.

per year. Using the AUC facilitated the approximation the life-cycle costs of a program by multiplying the AUC by the number of units procured and the life expectancy. Using the simple ratio of O&S costs to LCC, we were able to determine more probable cost ratios for different systems using life expectancies from the SARs for each program and the O&S cost estimating guide published by OSD CAPE (OSD CAPE, 2012). Simple descriptive statistics were then used to determine the basic characteristics of each set of data according to the weapon system type and service.

Assumptions/Limitations

Since we are using data from two different O&S cost systems, we are assuming the data was entered into the system using similar categories or in such a way that any significant discrepancies can be corrected to obtain similar life-cycle data among programs and services. By using the AUC, we are assuming the unitized cost is the annual average cost from fielding through disposal. This assumption is known to be false since the first years of fielding will have ramp-up costs and limited fielding (generally costing less per year than an average year) and the last few years will have costs associated with disposal or demilitarization. Disposal and demilitarization costs are not specifically addressed and are beyond the scope of this analysis.

We were limited by the information contained in the SARs and O&S cost systems. SARs have been known to have discrepancies or to be incomplete (Hough, 1992; Drezner, et al., 1993; Jarvaise, et al., 1996; US GAO, 2012). The AFTOC and Naval VAMOSC systems are dynamic systems that change as regulations are enacted and policies change, allowing the possibility of costs being allocated differently through the years. Anecdotal evidence also suggests O&S costs are not properly attributed to the correct units as a common practice. For example, in the Air Force there are stories about "hangar queens," aircraft that have been cannibalized to repair other aircraft. While one aircraft was waiting for funding for a single repair, maintenance crews used other parts from this aircraft to fix the systems on other aircraft. This artificially lowers the sustainment costs for the other aircraft while dramatically increasing the cost of the first aircraft. This highlights a problem in using these systems – some costs have not been entered correctly into the system, whether by oversight, ignorance, or procedure. By using Naval VAMOSC and AFTOC, we are accepting this risk and assume any discrepancies will not substantially degrade the fidelity of our results.

The data in either O&S cost system reflects a snapshot in time. The data retrieved from VAMOSC or AFTOC does not necessarily represent the normal operating expenses under typical conditions. For example, in 2011, the Air Force grounded the entire fleet of F-22s due to pilot-oxygen issues. Also, the United States has been engaged in wartime activities for more than a decade and is preparing to draw down forces in Afghanistan by 2014. Although the data collected for this research did not include operations data past 2010, these circumstances illustrate some of the many unplanned situations that can occur in the life cycle of a weapon system. These types of perturbations in cost would be evened out over longer periods of time, but for newly-fielded systems, these types of changes will significantly impact metrics like the AUC.

Both of the O&S cost systems have limited availability of data. Although much information can be obtained through these systems, they are limited in that they capture costs for systems that were operational while VAMOSC or AFTOC were online. In the

2011 SAR for the F/A-18E/F, the program office reported it could not include antecedent O&S costs since "[t]he cost data for platforms in existence prior to 1997 is either unavailable or incomplete" (US Navy, 2011). These retired systems would be a valuable source of cost information since they not only would be able to provide a true life-cycle cost picture, but would also give insight into the actual life expectancy of a weapon system. All of the work in this paper uses actual sustainment data combined with estimates of life expectancies of DoD weapon systems. A review of actual life cycle durations and costs of retired DoD weapon systems is beyond the scope of this paper and may be impossible for many systems due to the lack of available information regarding their O&S costs.

Implications

Many professionals at all levels in the defense acquisitions industry are told that the O&S portion of a weapon system's life-cycle costs will be around 70 percent. If the relative proportion of O&S costs is truly 70 percent (or greater), then those people in the acquisition community need to stress the importance of doing whatever is necessary in the acquisition phase to reduce costs in the O&S phase. If this is not true, then our focus should be on the other aspects of a weapon system that are driving costs higher throughout the life cycle of the system.

If O&S costs can rightfully be reduced to a simple function of their acquisition costs, then an accurate estimate of the acquisition cost should be able to give a rough estimate of the O&S costs, thereby giving decision makers another tool for determining affordability or performing portfolio analyses. Even if the ratios need to change by service, weapon system type, length of expected life cycle, or some other metric, this research will be able to provide greater insight into the true costs of supporting our weapon systems.

Preview

In Chapter 2, we review the current literature that has contributed to this research. Chapter 3 provides the methodology used to research the topic and analyze the findings. Chapter 4 is a discussion of the analysis and results. Chapter 5 is a summary and review of the implications of this research.

II. Literature Review

Chapter Overview

This chapter reviews the effort made to trace the source of the "golden ratio" of acquisition to operations and support costs. We review some terms to ensure a common understanding of the terms as they will be used in this review and continue with a chronological history of cost ratios in DoD literature.

Description

First, we define what is meant by "operations and support costs." According to the Office of the Secretary of Defense Cost Analysis Improvement Group (OSD CAIG) *Operating and Support Cost-Estimating Guide* from October 2007, a system's O&S cost:

> "Consists of sustainment costs incurred from the initial system deployment through the end of system operations. Includes all costs of operating, maintaining, and supporting a fielded system. Specifically, this consists of the costs (organic and contractor) of personnel, equipment, supplies, software, and services associated with operating, modifying, maintaining, supplying, training, and supporting a system in the DoD inventory" (OSD CAIG, 2007).

This definition allows for some costs that are outside of the Operations and Maintenance (O&M)[5] appropriation to be used as support costs. Some examples of this would include structures paid for with military construction funding, procurement funding for software patches, and the cost of specific military and civilian personnel assigned to a weapon system funded through the military personnel and civilian pay appropriations, respectively. Some studies further define what O&S means to their particular area of focus, but this definition has generally held true throughout recent government acquisition history. Disposal costs are not discussed in detail in many sources but have been lumped together with the O&S costs in some reports and studies (OSD CAIG, 1992; US GAO, 2000).

Two other terms in the DoD vocabulary need to be addressed: life-cycle costs and total ownership costs. These terms, though similar, are separate concepts that encompass different realms of the defense environment. The Defense Acquisition Guidebook (DAG) defines life-cycle costs in the following manner:

> "For a defense acquisition program, life-cycle cost consists of research and development costs, investment costs, operating and support costs, and disposal

[5] The Operations and Maintenance (O&M) appropriations for each DoD service should not be confused with O&S costs. Some O&M costs (such as Fuel) are attributable to specific weapon systems and their sustainment costs, while other O&M costs (such as base utility costs) are not included in the O&S costs for any particular weapon system.

costs over the entire life cycle. These costs include not only the direct costs of the acquisition program but also indirect costs that would be logically attributed to the program. In this way, all costs that are logically attributed to the program are included, regardless of funding source or management control" (DAU, 2012).

Total ownership costs a little more broad in scope. The DAG defines this to include "the elements of a program's life-cycle cost as well as other related infrastructure or business processes costs not necessarily attributed to the program in the context of the defense acquisition system" (DAU, 2012). These costs are not typically seen in acquisition O&S estimates, since they are usually accounted for in other budgetary realms. These other costs generally pertain to other infrastructure costs, such as the support to the equipment used for acquisition activities, support to military personnel (administration, medical care, etc.), and base communications infrastructure. These costs would be included in other types of cost estimates, such as a business case analysis for reengineering a process or operation, and is well beyond the scope of this paper.

When dealing with the life of a weapon system, we discuss its service life and its life expectancy. According to the DAU glossary online, the service life describes the period of time "from first inception of the weapon until final phaseout" (DAU, 2012). Realistically, some costs incurred in the very early stages of a program, such as those before Milestone A, may not be fully captured due to the immaturity of the technology or divergence from some original concept. According to the 1992 and 2007 versions of the CAIG (CAPE) O&S Guides, life expectancy should include the phase-in period, a period of steady-state operations, and a phase-out or decommissioning period (OSD CAIG, 1992; 2007). The draft version of the 2012 CAPE Guide we reviewed wasn't as clear, though it stated that "[t]he O&S estimate should extend over the full life expectancy of the system," alluding to the idea that life expectancy only pertains to the O&S phase. This distinction is important since, as will be shown in the following review, these terms appear to be used interchangeably even though they are clearly defined to be different in scope.

One last distinction to be made is that between Base Year (BY) and Then Year (TY). In performing financial analyses that span many years, the effects of inflation need to be understood in order to be able to directly compare events that happened in different periods of time. For example, the price of a loaf of bread 50 years ago is less than the price of the same loaf of bread today. The Base Year (BY, or Constant Year) describes past and future costs as they would appear in a certain year of reference. Then Year (TY, or Current Year) describes costs as they would appear when costs are incurred or when purchases are made, usually taking into account the effects of inflation or other factors over time. For example, if a military unit estimates it will use $1,000 this year in administrative costs and they do not expect the cost to change per year, the BY2013 cost will be $1,000 per year for as many years as the estimate covers. To calculate the TY costs, the military unit needs to escalate the annual cost using some factor to account for the general rise in prices over time. According to the 2012 SAF/FMCEE inflation calculator, the administrative cost for this illustrative budget would be estimated to be about $1011 in 2013, $1,029 in 2014, $1,047 in 2015, and $1,066 in 2016. The BY estimate for 2013 – 2016 in this example is $4,000, with a TY estimate of $4,153. Over small amounts of time, the effects of this difference between BY and TY may be somewhat insignificant, but over the life of a 30-year program where budgets are measured in the millions or billions of dollars, this difference is significant.

All SARs provide an estimate of costs based on the year in which the program was initiated or achieved a certain major event, such as a Milestone or major rebaselining of the program due to a significant cost or schedule breach, as well as provide an estimate that has been escalated for inflation. Except where noted, the discussion as to whether an analysis was conducted under BY or TY assumptions was never broached. Discussions with those in the cost analysis community have revealed that when presenting costs for comparison, an analyst will typically use a BY estimate. In this research, we assume that the BY is the framework for analysis in the literature reviewed, unless it is specifically noted.

Relevant Research

The earliest documented mention of operations costs of military operations appears to be in Sun Tzu's *The Art of War* (Tzu, Sixth century B.C.). In his second chapter on waging war, Sun Tzu writes, "government expenditures, those due to broken-down chariots, worn-out horses, armor and helmets, arrows and crossbows, lances, hand and body shields, draft animals and supply wagons will amount to four-tenths of its total revenue."[6] This may sound like the information we are seeking but it should be sidelined as merely an interesting quote due to the significant differences in the development efforts and logistical planning between the weapon systems of sixth-century China and today.

The earliest modern report we found to tackle the subject of O&S cost ratios was a report on life-cycle costing written in 1975 by Marco Fiorello of the Rand Corporation (Fiorello, 1975). Figure 2 is one rough approximation of the life-cycle cost of a DoD weapon system. The dotted lines show the period of time in which costs for a certain period in the life cycle are affected by decisions made by the program managers and other influential participants. The solid lines show when costs are incurred for that particular phase. The author stated that for the costs of ownership, "…these costs in general make up over 50 percent of the LCC of aircraft weapon systems" (pg. 5). There are no further citations showing how this figure was derived, though some of his methodology is included further along in an example given in the paper. The author assumes a 15-year operational period for his aircraft case example with a 5% discount rate, all adjusted for inflation to BY73. This example was provided by the author to illustrate the basic ideas of weapon system costs before going further into his discussion,

[6] This quote appears to have been translated to read "60 percent" instead of "four-tenths" in at least one translation since it has been cited to read this way in a few documents, such as the third edition of the Defense Systems Management College Acquisition Guide. (Defense Systems Management College, 1997) Most translations we reviewed, however, stated "four-tenths".

but it bears noting what his underlying assumptions were as they give insight into the state of cost estimating at the time of publication.

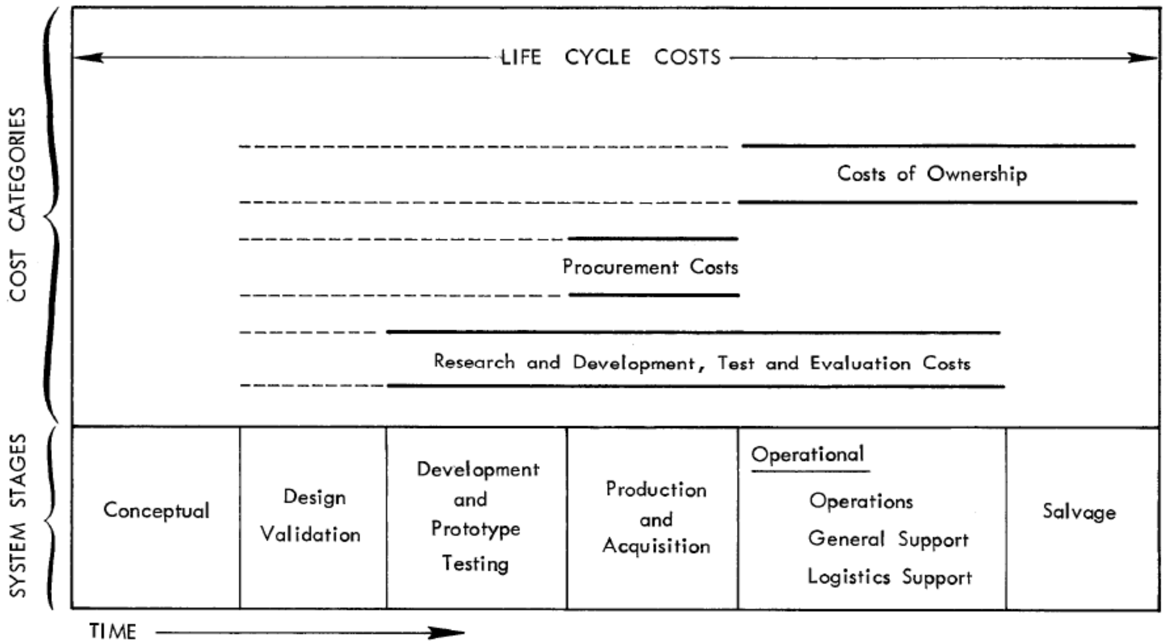

Figure 2: Weapon System Life-Cycle Stages and Costs (Fiorello, 1975)

Another report of note in the same year was published by the Army Electronics Command regarding the Tactical Radio Communication System (TRCS) (Otto, Jr., 1975). Although this report was not specifically concerned with the relative cost of supporting the fielded system, it does provide a life-cycle cost estimate (LCCE) of the system. The results are summarized in Table 1. This estimate assumes a 15-year life expectancy and is in BY75 dollars. The immediate difference between this data and the data that will be used for the rest of this thesis is the size of the program: even with inflation figured into the totals, the TRCS is not a Major Defense Acquisition Program

(MDAP). The implication of this is not immediately clear, but it does bear mentioning since MDAPs may behave significantly differently from smaller programs.

Table 1: LCCE for TRCS (Otto, Jr., 1975)

	$ BY1975	**Percent of Total**
R&D	$ 24,870,000	6.71%
R&D Other	$ 290,000	
Procurement - Recurring	$ 235,911,133	67.36%
Procurement – R, Other	$ 16,810,000	
Procurement – Non-Recurring	$ 2,650,000	1.52%
Procurement – NR, Other	$ 3,050,000	
O&M	$ 91,606,886	24.42%

In October 1977, a report in two parts was given to the US Senate Committee on Appropriations by the Comptroller General of the United States on the O&S costs of new systems compared to the systems they are replacing (US GAO, 1977). In Part 2 Appendix IV of this report, we find Table 2, which was the most recent cost estimate for a fleet of 800 F-18s as of October 1976 in FY1975 dollars. The information in Table 2 was based on an estimate that used the actual performance and logistics of the F-14 as an analogy to the F-18 and used an estimated life expectancy of 15 years. As of October 2012, the F/A-18 aircraft is still in operation and recently went through a major upgrade with the E/F variants. (US Navy, 2011) The Selected Acquisition Report (SAR) for

2011 for the F/A-18E/F shows a 20-year life expectancy was used for the estimate of O&S costs.

Table 2: Summary of Life-Cycle Cost Estimate for 800 F-18s (US GAO, 1977)

	Millions	Percent
Operating and Support	$ 5,809.3	42.2%
Production	$ 6,524.1	47.4%
Full-scale development	$ 1,429.3	10.4%
Total	$ 13,762.7	100%

This example illustrates a few of the difficulties in identifying O&S costs for a weapon system. First, the life expectancy has changed. Better materials and technologies can extend the life expectancy of a weapon system. This life expectancy may change again in the future. Second, the F/A-18 is going through an evolutionary acquisition and has already lived through variants A through D. Are each of these variants considered part of the same program or completely different programs? For each iteration of this airframe, two versions of essentially the same aircraft are produced. The most visible difference between variants E and F (as well as between variants A and B and variants C and D) is that the former has a single-seat configuration and the latter has a two-seat configuration primarily for training. The two variants are developed and produced in tandem and considered the same program. Some additions to the E/F variants include airborne Forward Air Controller enhancements and the ability to act as a tanker aircraft for refueling other aircraft. Even though the new variants don't look much different externally, the amount of funding that went into the development ($5.9B

BY2000) and procurement ($40.7B BY2000) of the new variants was enough to classify the E/F variant program as its own MDAP. The use of variants can be seen throughout the DoD with varying levels and strategies of development, modernization, and replacement of older variations. Identifying a valid ratio for any system with variants, whether the variants were originally planned or unplanned, may prove more complicated. The AH-1 Cobra and Bradley M2/M3 Fighting Vehicles weapon systems illustrate this difficulty well.

In 1981, the US Comptroller General delivered a report to Congress on logistics planning for the M1 tank. (US GAO, 1981) The report was aimed at convincing Congress that more funding should be spent on research and development and initial procurement to reduce the O&S costs, arguing "the costs of operating and supporting a system, such as the M1, may be 70 to 90 percent of the system's life-cycle cost" (pg.18). No further citation is given as the source of this information.

With the release of the *Operating and Support Cost-Estimating Guide* by the OSD CAIG in 1992, more official guidance was given regarding O&S cost estimates (OSD CAIG, 1992). This guide does not designate any particular ratio of O&S costs to acquisition costs, but does give an example of how costs vary from program to program. It states, "To show how the cost distribution can vary from one program to the next, [Table 3] provides a breakout of the costs incurred during the key acquisition phases for two different weapon systems." (Section 2.2) No further methodology into the information in the table was provided.

Table 3: Percentage of Life-Cycle Costs Incurred in Various Program Phases (OSD CAIG, 1992)

	R&D	Investment	O&S
F-16 Fighter	**2%**	**20%**	**78%**
M-2 Bradley Fighting Vehicle	**2%**	**14%**	**84%**

Immediately prior to this table is the figure given earlier in this paper (Figure 1, also appears here as Figure 3) on the notional life-cycle costs. Figure 3 can been seen reproduced in many training materials or adapted to include milestone decision points or any number of concepts related to the acquisition of DoD weapon systems. One substantive difference to note between this figure and the other variations on this figure is that some sources lump O&S and Disposal together, either as "O&S/Disposal" or just "O&S," and put RDT&E and Procurement together as "Investment." In the OSD CAIG guide, Figure 3 has the caveat that "[d]epending on the system, costs or spending rates can peak at any phase in the program life cycle."

Since 1992, the OSD CAIG (now Cost Assessment and Program Evaluation [CAPE]) has issued one other O&S cost-estimating guide (2007) and prepared an update for 2012, which has not been released as of the publication of this thesis, but was given for reference by a member of the Air Force Cost Analysis Agency (AFCAA) to the authors. Figure 4 is the updated version of Figure 3 given in these guides. This seems to illustrate more of the overlapping tendencies of the stages in the life cycle. Neither of the two more recent versions of the guide includes any further information on cost ratios, though all of them include assumptions about system life expectancy. Table 4 summarizes the system life expectancy conventions for 1992, 2007, and 2012.

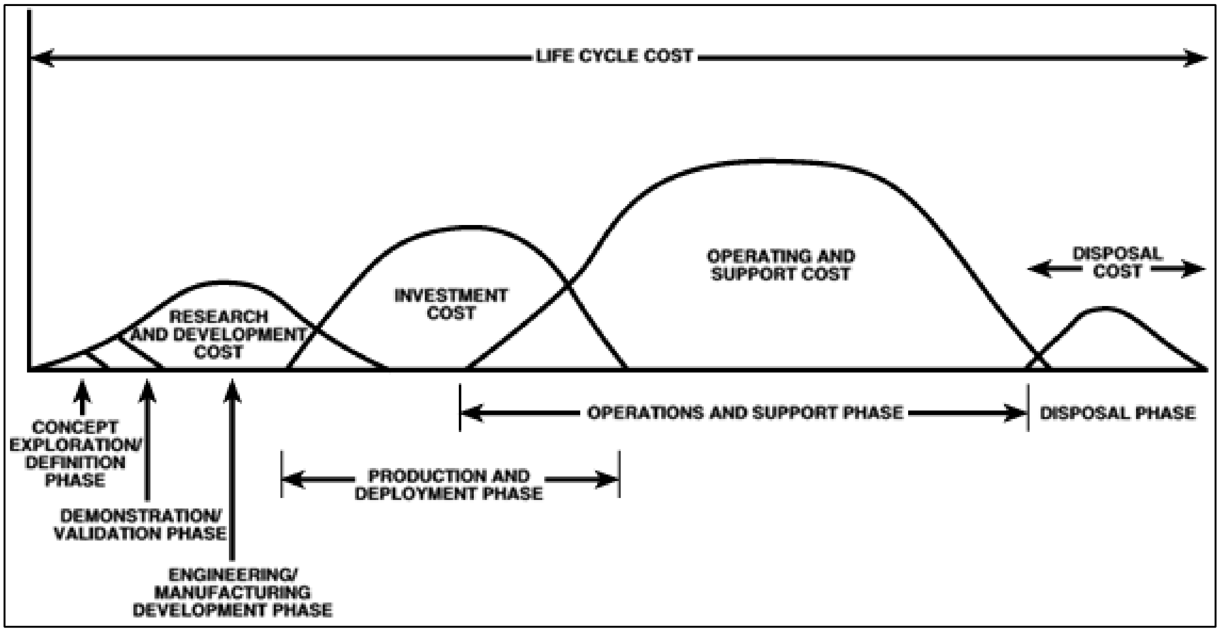

Figure 3: Notional Life-Cycle Costs for a DoD Weapon System (OSD CAIG, 1992)

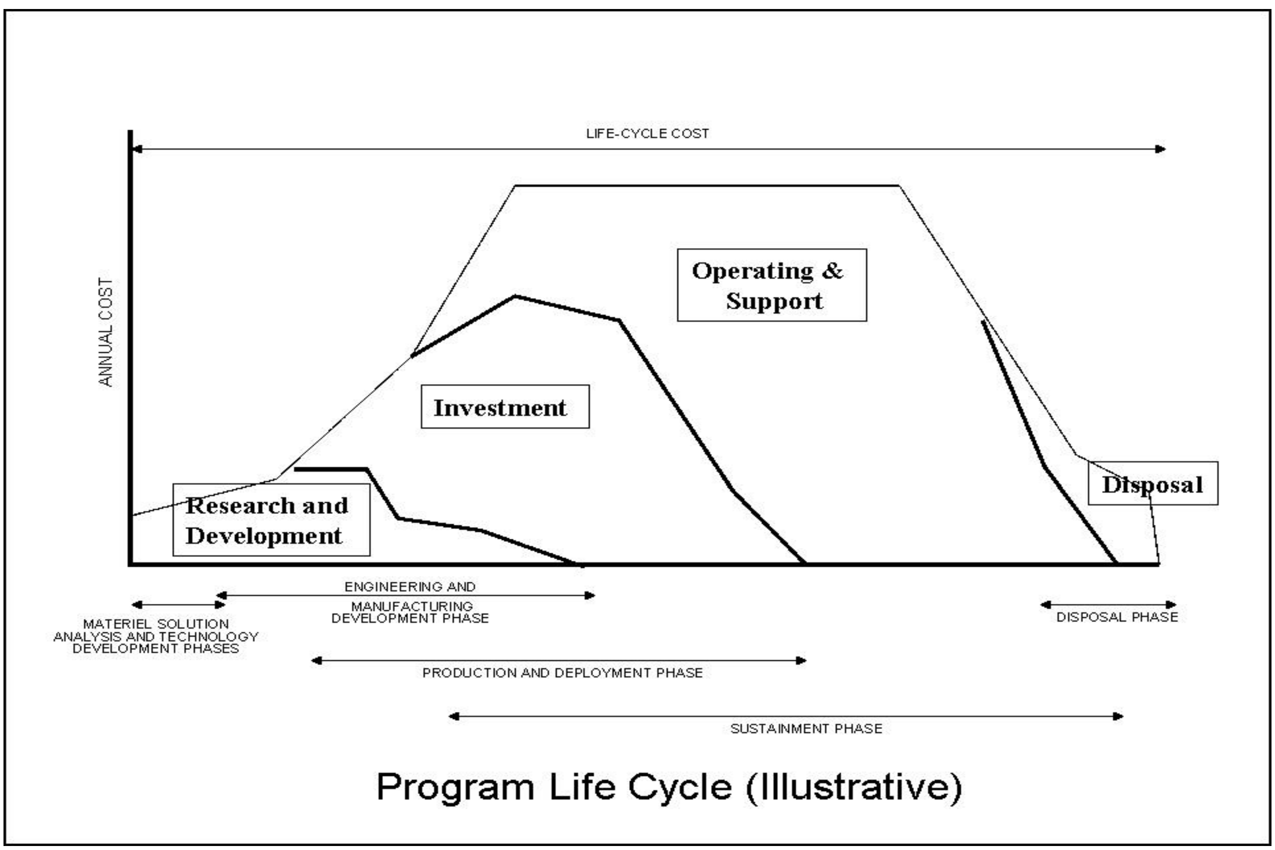

Figure 4: Illustrative System Life Cycle (OSD CAIG, 2007; OSD CAPE, 2012)

Table 4: Summary of Differences in Life Expectancy

Weapon System Life Expectancy (in years)			
	1992	**2007**	**2012**
Cargo	25	25	**30-40**
Bomber	25	25	**(30-40)**
Tanker	(25)	(25)	**30-40**
Fighter	20	20	**20-30**
Helicopter	20	20	**20-30**
Small Missiles	15	(15)	**10-20**
Large Missiles	20	**(15)**	**10-20**
Electronic Equipment	10	10	**10-30**
Ships	20-40	20-40	20-40
Ground Combat Vehicles	20	20	20
UAVs	N/A	N/A	**15-25**

The numbers in bold in Table 4 show the changes from the previous edition, and those in parentheses are assumed due to changes in terminology among the three guides. As illustrated above, life expectancy has increased for most systems, most notably for the Cargo/Bomber/Tanker and Electronic Equipment categories. Electronic Equipment, though, being a very ambiguous category, also includes certain equipment whose replacement may require a shorter life expectancy (less than five years) due to changes in cryptologic requirements, fragility, and technological obsolescence, among other things. This includes items such as radios, mobile antennas, and portable computers. Even though these life expectancies are listed as "nominal," due to natural human tendencies, "nominal" can easily be perceived as normal reality.

This comparison of conventions was included to show how estimates of life expectancy have changed over time. Although the 2012 CAPE O&S guide seems to have changed life expectancy estimates based on trends seen in the real world, no source we found has shown the actual life cycles of fielded systems by category.

In 1997, the Defense Systems Management College put out the third edition of their *Acquisition Logistics Guide*, which included the following:

> For software in particular, the development of a life-cycle management plan, with emphasis on the planning for transition to the support phase, is of paramount importance, since the majority of the cost of software (60 to 80 percent) is associated with postproduction support.

As with many other sources, the standard issues were observed – no further citations were given, though this quote shows this ratio may apply more specifically to software. This interval (60 to 80 percent) was also observed in an article in the *Defense AT&L* magazine on designing systems for supportability. (Dallosta & Simcik, 2012) The authors state that "…total ownership costs (TOC) incurred during the operations and support (O&S) phase may constitute 65 percent to 80 percent of total life-cycle cost (LCC)." Figure 5 accompanies this quote and has no further citation. Note that the horizontal axis seems to denote a 30-year service life.

One seemingly influential document is one prepared by the Institute for Defense Analyses (IDA) on a presentation by a panel of representatives from the Office of the Secretary of Defense (OSD), Naval Center for Cost Analysis (NCCA), Air Force Cost Analysis Agency (AFCAA), and the US Army Cost and Economic Analysis Center (USACEAC). The presentation was given at the 32nd Annual DoD Cost Analysis

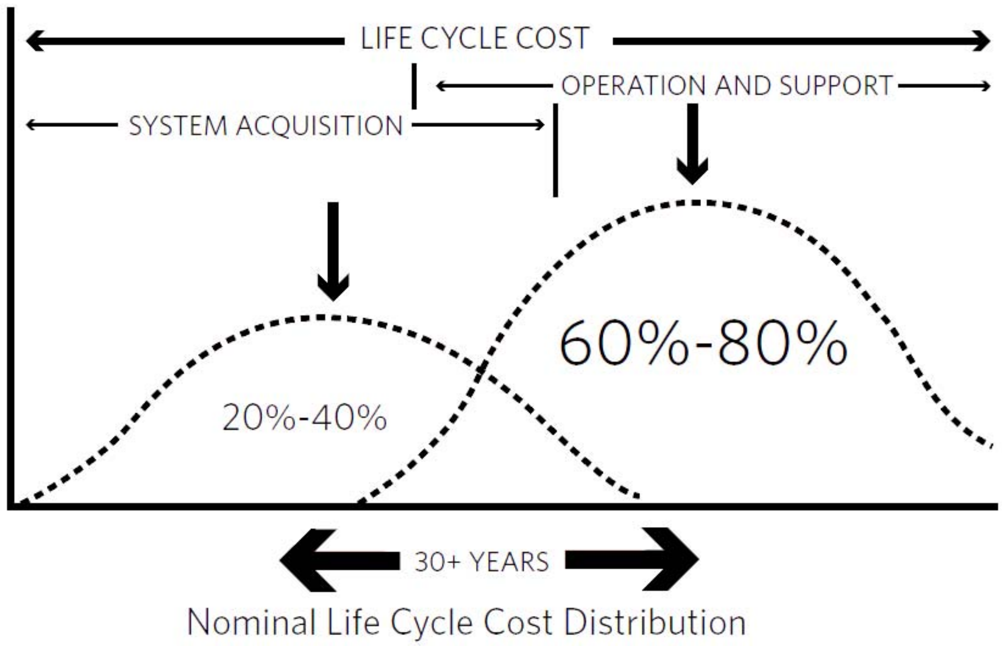

Figure 5: Nominal Life-Cycle Cost Distribution (Dallosta & Simcik, 2012)

Symposium (DoDCAS) conducted 3-5 February, 1999, in Williamsburg, Virginia (IDA, 1999). In this document, weapon system types are split out and presented in terms of their RDT&E, Procurement, and O&S costs, where the information is available. Table 5 is a summary of the information presented, which is cited in the Life-Cycle Cost article from the Defense Acquisition University's ACQuipedia website. (Defense Acquisition University, 2008)

For most system types, the percentages reflect what was considered, at the time, to be "typical" percentages of life-cycle costs. The exceptions were in the Rotary Wing Aircraft category, where the percentages came from the Comanche estimate in the 1997 Selected Acquisition Report (SAR), and the Missiles and Surface Vehicles categories, which did not specifically state what the percentages represent, but we assumed them to

Table 5: Cost Ratios by Weapon System Type (IDA, 1999)[7]

System Type	R&D	Investment	O&S/Disposal
Space	18%	66%	16%
Fixed-Wing Aircraft	20%	39%	41%
Rotary-Wing Aircraft	15%	52%	33%
Missiles	27%	33%	39%
Electronics	22%	43%	35%
Ships (Note 1)	1%	31%	68%
Surface Vehicles	9%	37%	54%
AIS (Note 2)		30%	70%

be "typical" since no other discussion led us to believe otherwise. The only two categories that come close to, or meet exactly, the golden ratio are the Ships and Automated Information Systems (AIS) categories. This lends credence to the idea that members of the acquisition profession may have been taught that O&S costs can be "up to 70 percent" of total operational costs, being later revised through the deleterious effects of oral tradition to just "70 percent." This chart, and the presentation from which it was gleaned, still do not show the methodology of how the O&S/Disposal numbers were derived, whether from actual data or estimates from SARs.

The data in Table 5 appear to be the source for the GAO Cost Estimating and Assessment Guide (US GAO, 2009) and some DAU material (DAU, 2009). Figure 6

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[7] Note 1: Most ship design costs are included in production cost of lead ship of a class.
Note 2: Available data precludes split of pre-O&S costs into R&D and Investment categories.)

comes from the GAO guide. The following paragraphs from the GAO guide describe what is being illustrated in the data.

> “While approaches may vary, an affordability assessment should address requirements at least through the programming period and, preferably, several years beyond. Thus, LCCEs give decision makers important information in that not all programs require the same type of funding profile. In fact, different commodities require various outlays of funding and are affected by different cost drivers. [Figure 6] illustrates this point with typical funding curves by program phase. It shows that while some programs may cost less to develop—for example, research and development in construction programs differ from fixed-wing aircraft—they may require more or less funding for investment, operations, and support in the out-years. (pg. 40)
>
> Studies have shown that information technology (IT) services outside software development and maintenance (for example, hardware cost, help desk, upgrade installation, training) can make up a majority of total ownership costs. In fact, OMB reports that 77 percent of the overall IT budget for fiscal year 2009 will support steady state IT operations while only 23 percent will be used for development, modernization, and enhancement.” (pg.139)

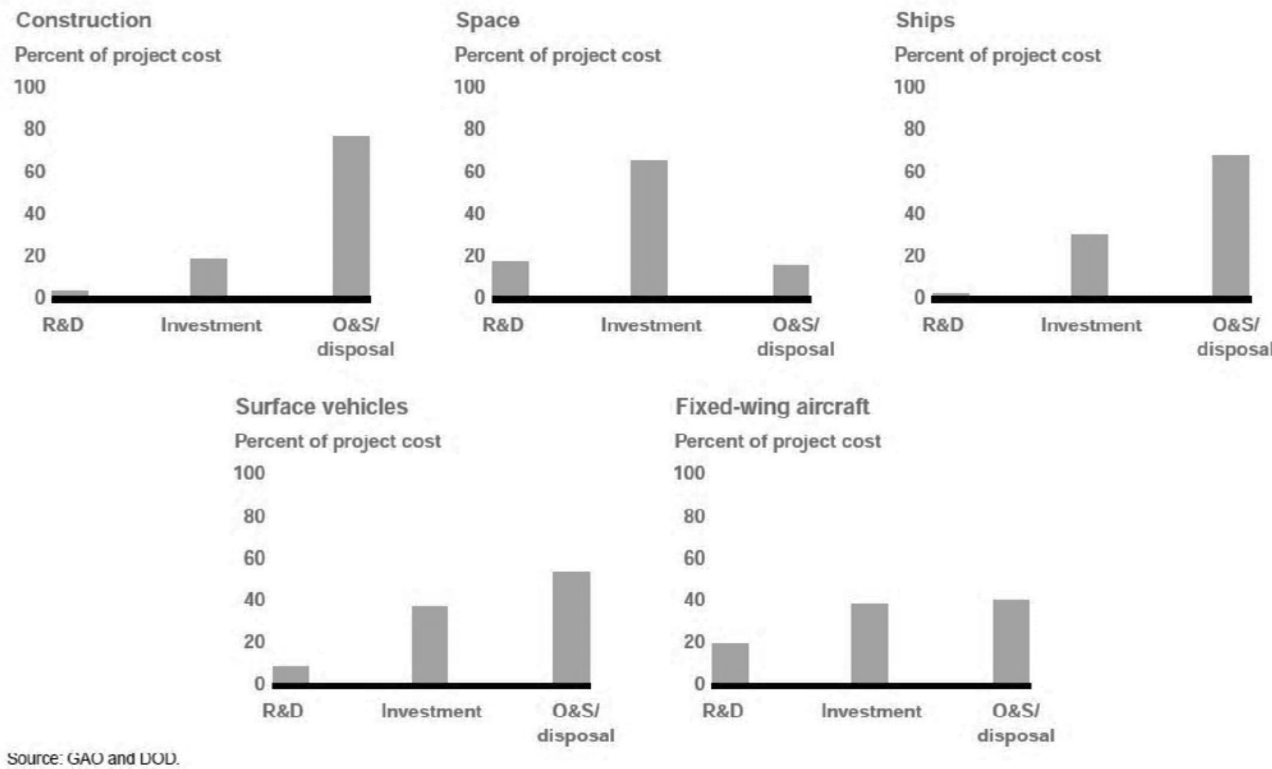

Figure 6: Funding Profiles by Weapon System Types (US GAO, 2009)

The brief discussion on the differences in funding profiles is very pertinent since every weapon system type seems to have its own nuances that will tend to deviate from the collective mean, whatever that may be. This excerpt from the GAO guide raises questions regarding the way cost ratios for weapon systems are determined and reported. First, it mentions total ownership costs, which was defined previously as being similar but different than life-cycle costs. Second, if total ownership costs or life-cycle costs are going to be discussed, we would not be necessarily interested in the amount spent on support operations for a given year. We would need to know the support costs of a given program over the total life of the system. Although the information on the IT budget for a particular year is certainly worthy to know in some respects, it can be misleading to mix the ratios of a fiscal year with discussion on LCC.

In 1997, the Defense Systems Management College published its *Acquisition Logistics Guide*, in which it illustrates “the dominant role that logistics plays in system life-cycle cost” (DSMC, 1997), as portrayed in Figure 7. This is the first time a ratio with this level of specificity is given (72% of life-cycle costs attributed to O&S). It is also accompanied by a caption which gives insight into the data that supports the graphic, but does little else to enlighten the reader as to how the numbers were obtained. The caption reads “Typical 1980 DoD Acquisition Program with A Service Life of About 30 Years.” This raises questions as to what was “typical” in the 1980’s, whether only programs with an expected service life of 30 years were considered or if a 30-year service life was used to normalize data, and whether this was an estimate from the SARs or from actual costs, among other important questions. This also addresses the discussion between service life and life expectancy. Even if this ratio were based on actual costs for systems that have already been fielded and retired, the fact that it was based on systems from the 1980s raises concerns on current validity.

Figure 7 was found in at least four other sources – a 2000 GAO report entitled *Air Force Operating and Support Cost Reductions Need Higher Priority* (US GAO, 2000), a 2003 GAO report on reducing TOC through setting requirements (US GAO, 2003), the Naval Postgraduate School’s *Management of Defense Acquisition Projects* (NPS, 2008), and an acquisition research paper through the NPS entitled *Total Ownership Cost – Tools and Discipline* (Naegle & Boudreau, 2011). The 2000 GAO report gave a familiar commentary, stating “[operating and support] costs typically account for about 70 percent

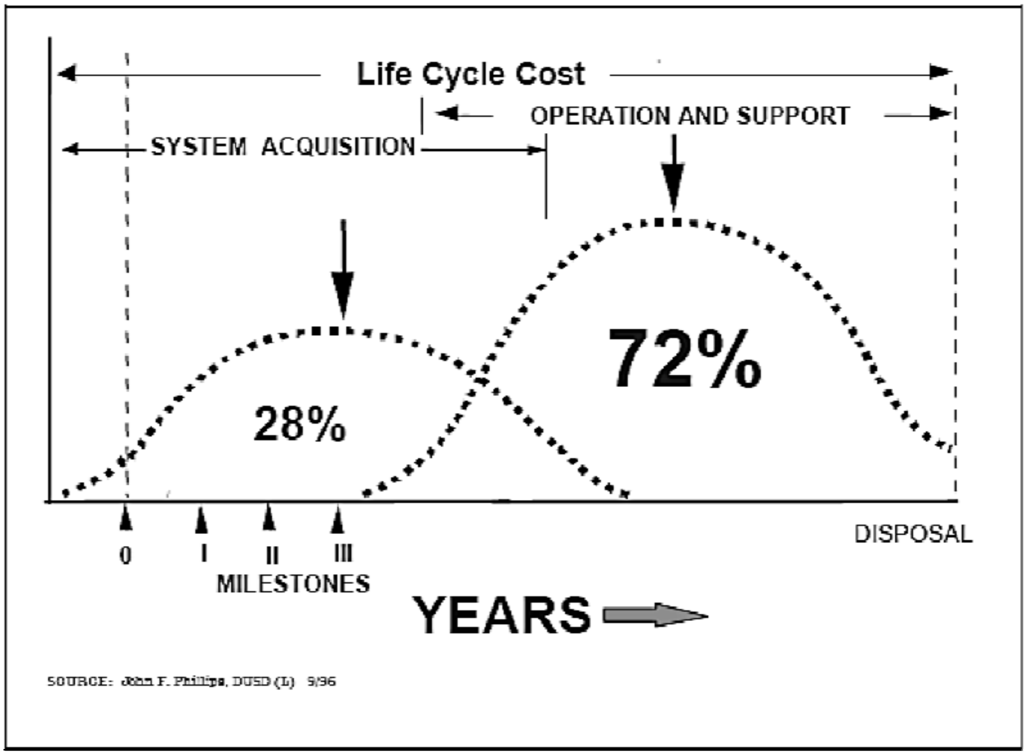

Figure 7: Nominal Life-Cycle Costs – (DSMC, 1997)

or more of life-cycle costs, depending on how long a system remains in the inventory. [Figure 7] depicts the typical life-cycle cost distribution of many weapon systems." As with many other reports and publications, this report gives some inkling of a research effort into actual costs of previous systems by adding some bit of "expert language", as it states that this relationship of costs remains true "[a]ssuming these new systems are … consistent with past programs." (pg. 15) However, as shown previously, guidance on the lengths of life expectancies (and by extension, the service lives) of weapon systems appears to be increasing, adding more weight to the idea that any past relevance or accuracy of the "golden ratio" is fading.

Figure 7 shows its source to be from John F Phillips, Deputy Undersecretary of Defense (Logistics) from September 1996. Unfortunately, we were unable to obtain the source document or briefing for this citation. In a conversation with a former program director for the DAU we learned this information came from one of many Pentagon briefings that were updated occasionally, making it difficult to track down a copy of the source material. In a presentation to INCOSE, this former DAU director used Figure 7 and another remarkably similar figure (Figure 8) to illustrate system supportability. Figure 8 was described as a "typical 1970 DoD acquisition program with a service life of about 20 years." (Gourley, 2008)

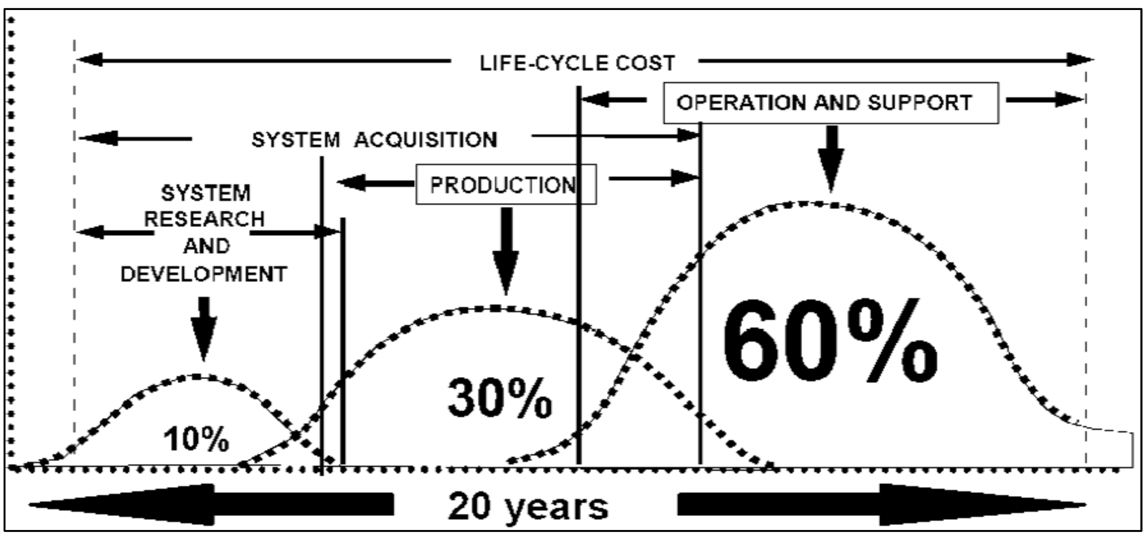

Figure 8: Nominal Life-Cycle Costs from DAU Presentation (Gourley, 2008)

In the discussion concerning Base Year versus Then Year, these two figures help to serve as a visual aid to show the magnitude of the difference between the two terms. Assuming Figures 7 and 8 are based on estimates from the acquisition phase and represent the BY, transformation of these costs into a TY estimate would significantly increase the costs of the program in the later years. Since these figures show the last half of the program's life cycle is O&S, a TY estimate would greatly escalate the costs in those years, potentially increasing the apparent portion of the sustainment phase to well over 80 percent in Figure 7. If the converse is true, and these figures are built upon the TY, then the opposite effect would occur, possibly deescalating the O&S phase to below 60 percent of LCC in Figure 7. As discussed previously, since these figures appear to come from a comparison of systems, it is prudent to believe the analysis was done in BY. In any event, since the initial analyses that were performed to arrive at these ratios appear to have been on programs in the acquisition phase ("Typical 1980 DoD *Acquisition* Program with A Service Life of About 30 Years", [DSMC, 1997; emphasis added]), and occurred at least as early as 1997, we are confident that these analyses are not necessarily valid for actual O&S and life-cycle costs for recent programs.

Beyond the articles and papers examined thus far, there was little else to be found in the area of possible original sources for the "golden ratio". We find more recitation of "established" knowledge, particularly in GAO reports. A report on the littoral combat ship (LCS) was particularly interested in educating the reader on O&S costs, as it stated six times throughout the report that O&S costs are "about" or "over 70%" of a program's total costs. Table 6 is a list of the other sources that shows roughly the same information.

If we review current instructional material, we start to notice some shifting of ratios in data sources. Some more recent DAU (DAU, 2012) and OSD CAPE (OSD CAPE, 2010) materials show different cost ratios than the 1999 IDA ratios, though no

Table 6: Additional Sources for Cost Ratios[8]

Source	Report/Article (Year of Publication)	Quoted Percentage
GAO	*GAO/NSIAD-00-197 Higher Priority Needed for Army O&S* (2000)	about 60-70%
GAO	*GAO-10-257 LITTORAL COMBAT SHIP* (2010)	about/over 70%
GAO	*GAO-12-340 Improvements Needed to Enhance Oversight* (2012)	about 70%
DoD	*DoD Weapon System Acq Reform: Product Support Assessment* (2009)	60-75%
USD, ATL	*Pentagon Efficiency Initiatives,* Remarks given at Heritage Foundation (2011)	70%
Boeing	*Military Aerospace Support*, Seemingly abandoned webpage on C-17 (2001)	70%

methodology is given for the origin of these data. Figure 9 was taken from a slide presentation for DAU course BCF-215: Operating and Support Cost Analysis (DAU, 2012). Figure 10 was taken from a guest lecture to the same DAU course and, according to the guest lecturer Walt Cooper, was based on a sampling of SAR estimates in 2010 (Cooper, 2010). Both charts appear to have the same underlying data. Again, these show O&S costs settling around 60-70% of LCC.

Summary

We have looked at the lengthy history of operations and support cost ratios, though this list is likely incomplete. We have seen the general track of how we have settled on 70% as a talking point for O&S costs, though by now the reader should have a healthy skepticism of what that number really means. Table 7 is a summary of the

[8] The Boeing source listed was found at https://acc.dau.mil/adl/en-US/22468/file/2189/Aerospace_Support.htm. No mention of cost ratios appear to exist on Boeing's current website.

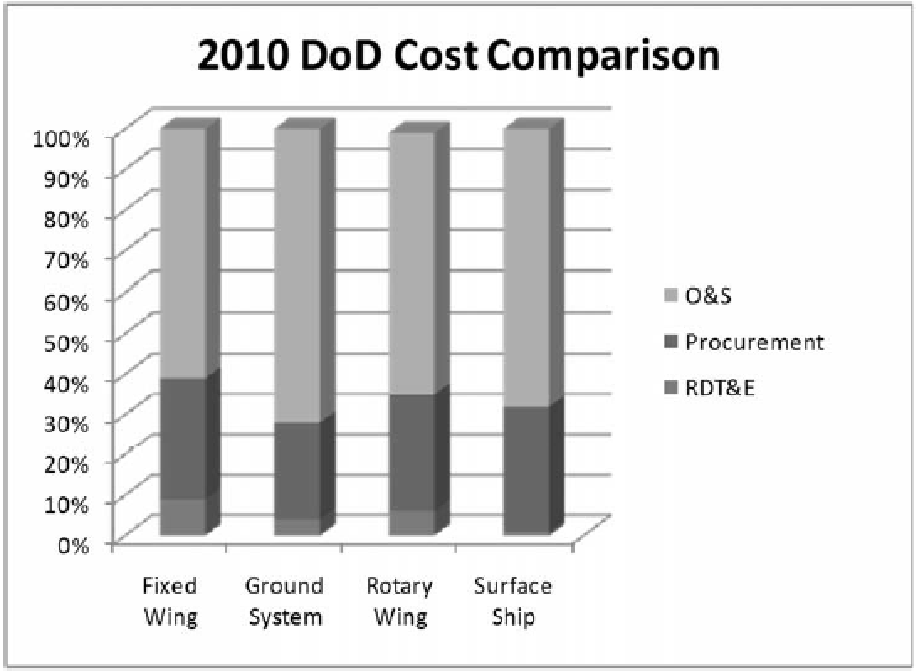

Figure 9: Cost Comparison from DAU Material (DAU, 2012)

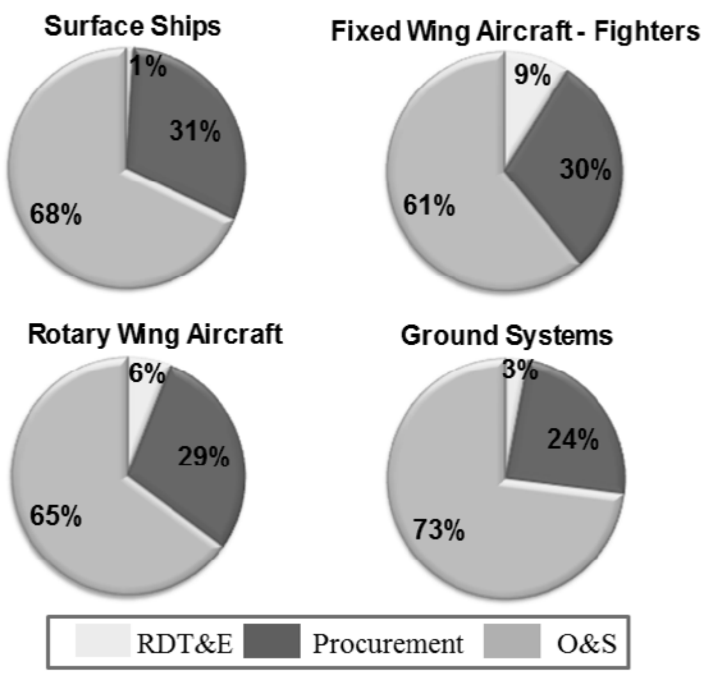

Figure 10: Chart from Presentation by Walter Cooper (Cooper, 2010)

findings of the literature review. It does not appear to be grounded in historical O&S data, but rather based on *estimates* of how long a weapon system will last and how costly it is to repair/replace/sustain/maintain/operate.

Table 7: Summary of Findings from Literature Review

Source	O&S Portion of LCC
Sun Tzu, *The Art of War*, Sixth century B.C.	40%
Marco Fiorello, *Getting "Real Data for Life-Cycle Costing*, 1975	50%
T. W. Otto, Jr., *Life Cycle Cost Model*, 1975	24.4%
US GAO, *O&S Costs of New Weapon System*, 1977	42.2%
US GAO, *Logistics Planning For The M1 Tank*, 1981	70-90%
OSD CAIG, *Operating and Support Cost Estimating Guide*, 1992	78%, 84%
DSMC, *Acquisition Logistics Guide*, 1997	60-80%, 72%
IDA, *Status of DoD's Capability to Estimate*, 1999	Varies by Type
US GAO, *Higher Priority Needed for Army O&S*, 2000	60-70%
DoD, *DoD Weapon System Acquisition Reform*, 2009	60-75%
US GAO, *Cost Estimating and Assessment Guide*, 2009	Varies by Type
US GAO, *Littoral Combat Ship*, 2010	70%
US GAO, *Improvements Needed to Enhance Oversight*, 2012	70%
USD, ATL, *Pentagon Efficiency Initiatives*, 2011	70%
Dallosta & Simcik, *Designing for Supportability*, 2012	65-80%
Taylor & Murphy, *OK, We Bought This Thing*, 2012	45%, 60-80%

Over time, we have learned a great deal about refurbishing weapon systems, to the point where we can sustain systems that are well beyond their originally planned useful life. According to the USAF, the B-52, which had its first flight in 1954, has a place in our arsenal until 2040, if not beyond. (B-52 Stratofortress, 2011) We also know there are systems on the other end of the spectrum that require much less O&S funding due to the nature of the system, such as space systems. To state that a “typical” DoD weapon system will have 70% of its total ownership costs attributed to O&S costs seems premature since there is a great deal of doubt that any person can properly identify what a “typical” DoD weapon system acquisition program would look like. In the next chapter, we will review the methodology of how data was collected, analyzed, and interpreted.

III. Methodology

Chapter Overview

In this chapter, we review the methods for collecting, analyzing, and interpreting the data used for analysis. We review our assumptions and limiting factors, as well as any problems that may have arisen due to difficulties in data collection or analysis.

Data Collection

The initial phase of data collection started with trying to determine the source of the 70% O&S cost ratio. To find articles, presentations, or publications that may have included this information, we used publicly available search resources. Websites such as www.dtic.mil and www.gao.gov provided valuable starting points for literature on the topic. The Defense Acquisition University's website (www.dau.mil) provided information on current instruction materials. We were able to communicate with some of the DAU instructors to determine sources for some of the data from the training materials they use. Members of the Air Force Cost Analysis Agency (AFCAA), Naval Center for Cost Analysis (NCCA) and Naval Postgraduate School (NPS) provided further information on sources of information. Most of the people we interviewed led us back to the OSD CAIG/CAPE O&S Cost Estimating Guides (OSD CAIG, 1992/1997; OSD CAPE, 2012) and the GAO Cost Estimating and Assessment Guide (US GAO, 2009).

The collection of actual cost and acquisition data for various programs was primarily performed in the published dissertation (Ryan, 2012). The acquisition data were retrieved from the Defense Acquisition Management Information Retrieval (DAMIR) system. The operations and support cost data were obtained from the Naval

Visibility and Management of Operations and Support Costs (Naval VAMOSC) and the Air Force Total Ownership Cost (AFTOC) systems. Army O&S data available through the Operating and Support Management Information System (OSMIS) was reviewed for possible analysis. Due to data issues related to the allocation of costs, no Army system could be used for comparison. Specifically, the fuel and personnel costs, among others were available at a top level, but could not be easily or readily allocated down to specific programs.

The O&S data contained in the VAMOSC and AFTOC systems are arranged according to the OSD CAPE Cost Element Structure (CES). The categories of the OSD CAPE CES are listed below. These categories are listed in Chapter 6 of the 2007 OSD CAIG O&S Cost Estimating Guide (OSD CAIG, 2007).

1.0 Unit-level Manpower

Cost of operators, maintainers, and other support manpower assigned to operating units. May include military, civilian, and/or contractor manpower.

2.0 Unit Operations

Cost of operators, maintainers, and other support manpower assigned to operating units. May include military, civilian, and/or contractor manpower.

3.0 Maintenance

Cost of all system maintenance other than maintenance manpower assigned to operating units. Consists of organic and contractor maintenance.

4.0 Sustaining Support

Cost of central support activities that can be attributed to a system and are provided by organizations other than operating units.

5.0 Continuing System Improvements

Cost of hardware and software modifications to keep the system operating and operationally current.

6.0 Indirect Support

Cost of support activities that provide general services that cannot be directly attributed to a system. Indirect support is generally provided by centrally managed activities that provide a wide range of activities.

The list of programs to analyze was determined by a few factors. First, since we are limited in the availability of acquisition data, we are confined to the programs that report to Congress through Selected Acquisition Reports (SARs). These programs are Major Defense Acquisition Programs (MDAPs) that exceed $365 million (BY2000) in Research, Development, Test, & Evaluation (RDT&E) funding or $2.19 billion (BY2000) in Procurement funding, or have been designated by Congress or the DoD as an ACAT I program due to high visibility or interest. This also excludes classified programs.

Second, the program had to have O&S data, both in the SARs and the O&S cost systems. The database did not contain any program that did not have an O&S estimate in the SAR due to the nature of the research for the dissertation. Since O&S estimates were mandated to be included in SARs in 1989, this filtered the list further to those programs that still submitted SARs from 1991 (when O&S estimates started to appear in SARs) through the present. Each of these programs had to have fielded operational units and have a stable[9] period of O&S costs. This was to ensure the program was past the initial ramp-up in fielding and was able to produce a realistic estimate of annual costs.

The last major selection criterion was that each program needed to have produced 20% or more of the planned procurement quantities. Early in production, contractors may run into difficulties that could change the production schedule or increase costs due to factors unknown when production commenced. Until these issues are resolved, the acquisition cost has a significant risk or increasing.

In all, the number of programs we were able to use for analysis was 37 – seven Air Force, 24 from the Navy, and six Joint programs. Table 8 is the complete list of programs analyzed. For Joint programs, the lead service is listed first.

For each program, an annual unit cost (AUC)[10] was derived to provide a way to compare programs at the unit level. Each program presented unique challenges in calculating its own AUC. A detailed methodology for determining the AUC for each program is given in the dissertation. The general method used to derive the AUC was to take the annual cost for a system from VAMOSC or AFTOC and divide by the number of

[9] "Stable" was understood to be a period where annual costs or AUC appear to be similar from year to year without obvious perturbations in costs for ramp-up or ramp-down.

[10] The AUC is not to be confused with the Program Acquisition Unit Cost (PAUC) or the Average Procurement Unit Cost (APUC) commonly used in DoD acquisitions.

units operational in the year. The AUCs for the individual years were then averaged to provide one average AUC for the program.

Table 8: List of Programs Analyzed

Ships		**Cargo/Tanker/Bomber**	
AOE 6	Navy	C-130J	AF
CVN 68 (74/75)	Navy	C-17A (BY96)	AF
CVN 68 (76)	Navy	E-2C	Navy
DDG 51	Navy	JSTARS (BY1998)	Joint - AF/Army
LHD 1	Navy	KC-135R	AF
LPD 17	Navy	**Missiles**	**Service**
MHC 51	Navy	AMRAAM	Joint - AF/Navy
SSGN	Navy	JASSM	Joint - AF/Navy
SSN 21	Navy	AIM-9X	Joint - Navy/AF
SSN 774	Navy	JSOW (AGM-154)	Joint - Navy/AF
STRATEGIC SEALIFT	Navy		
T-AKE	Navy	**Helicopters**	
T-AO 187	Navy	C/MH-53E	Navy
Fighters		MH-60R (BY2006)	Navy
F-16C/D	AF	MH-60S	Navy
F-22 (BY2005)	AF	**UAV**	
JPATS (BY2002)	Joint - AF/Navy	GLOBAL HAWK	AF
AV-8B REMAN	Navy	PREDATOR	AF
EA-18G	Navy	**Electronic Equipment**	
F/A-18E/F (BY1990)	Navy	NESP	Navy
F-14D	Navy	**Tilt-rotor**	
T-45TS (BY1995)	Navy	V-22 (BY2005)	Navy

Before performing this calculation for AUC, the annual cost data were normalized to FY2010 using various DoD inflationary sources, such as the Joint Inflation Calculator

(Jan-11), Naval VAMOSC ATMSR User Manual FYs 1997-Present v10 (28-Feb-11), and the SAF/FMCEE Inflation Calculator – FY2011 Edition, among others as appropriate. Once normalized to FY10, the costs per year were deescalated back to the base year of the program.[11]

Certain programs reported more than one baseline year due to changes or milestones in the program. For example, the V-22 Osprey changed its baseline year from BY1986 to BY2005 due to the program passing Milestone C (the decision to move from development to production). This artificially provided more units for analysis. Since we were not concerned with previous estimates of acquisition costs, the earlier baseline on all programs that presented multiple baselines were removed from analysis. This was done under the assumption that the most recent acquisition report has the most accurate acquisition data.

Analysis

One of the unknowns in this analysis was the expected life of each program. To get an idea of the range of percentages for O&S costs we could expect, we took the life expectancies from the OSD CAIG/CAPE guides to use as a starting point. The life expectancies of each program as given in their respective SARs were also considered.

[11] All acquisition costs in SARs are normalized to a particular base year representing a major occurrence in the program, such as program initiation or a major milestone decision. Due to unknown factors not described in the SARs for every program, this method was far easier and more reliable than normalizing the acquisition data to FY2010.

From these estimates, we chose the highest and lowest expectancies to use as an upper and lower range, respectively. Multiplying the actual AUC derived earlier by the highest (or lowest) life expectancy for a program and by the number of units to be procured (as given by the last or most recent SAR) provided our estimate of O&S costs. To get the ratio of O&S-to-LCC, we divide the O&S estimate by the total of the O&S estimate and the acquisition actual cost.

This method does not take into account ramp-up or ramp-down, demilitarization, changes in operations tempo, or attrition. It assumes all units will be operational from the first year of fielding through the last year of its life expectancy. This method does not take into account any service life extensions or modification programs. Since the costs for each of these programs included wartime costs from 1989 - 2010, there is no assumption of peacetime operations that normally accompanies O&S estimates.

For comparison among groups, simple descriptive statistics were derived using Microsoft Excel 10 for each category of weapon system, for both the high and low ends of the range. Results were graphed using a histogram against the mean to determine the existence and effect of outliers on the average. We determined that the median was more representative of most results. As will be explained later, certain categories showed significant skew in a direction contrary to what the data appeared to show when using the mean.

Summary

Much of the data collection originated from the dissertation mentioned previously. Although relaxing the inclusion criteria for DoD weapon systems would have provided additional systems for analysis, the original database was kept intact to reduce the error due to data collection and the calculation of the AUC and to maintain a level of homogeneity. The analysis of the data utilized standard statistical concepts and tools to determine estimates for each of the major weapon system categories given in the 2007 OSD CAPE guide (OSD CAPE, 2007). Chapter Four reviews the results of the analysis and reviews some of the complications encountered.

IV. Analysis and Results

Chapter Overview

The results in this chapter show a different picture of sustainment costs than what is presented in the DoD acquisition community. Although not all weapon system categories are represented or are represented by few data points, this should provide the basis for new insights into sustainment costs. Throughout this chapter, the reader is cautioned to remember that the relative cost to sustain the weapon system, as it will be portrayed here, is related to its acquisition cost.

Results

The first set of results pertains to the life expectancies of each program. For most systems, the life expectancy from the SARs fell within the ranges given in the OSD O&S guides. These expectancies are presented in Table 9 and are given in years. One of the interesting pieces of information in this table is that of the Missiles group – only one of the programs fell within the 10-20 year expected life given in the OSD guides. This illustrates the notional aspect of the life expectancy ranges.

Using these ranges, we were able to estimate an approximate range of 43-56% (mean) or 48-63% (median) for the proportion of life-cycle costs attributable to O&S. These ranges are for all weapon systems and both services. The "high" end of the range (using the upper estimate of life expectancy) went from 4.91% (JSOW) to 88.79% (KC-135R) with a standard deviation of 22.48%. The "low" end (using the lower estimate of life expectancy) started at 1.69% (JSOW) and went through 83.19% (KC-135R) with a standard deviation of 21.56%. Table 10 is the summary of some of the statistics for all programs. Figure 11 is a chart of the average O&S cost percentages by program.

Table 9: Life Expectancies for Various Weapon Systems

Ships	High (yrs)	Low (yrs)
AOE 6	40	20
CVN 68 (74/75)	50	20
CVN 68 (76)	50	20
DDG 51	40	20
LHD 1	40	20
LPD 17	40	20
MHC 51	40	20
SSGN	40	20
SSN 21	40	20
SSN 774	40	20
STRATEGIC SEALIFT	40	20
T-AKE	40	20
T-AO 187	40	20
Fighters		
F-16C/D	30	20
F-22 (BY2005)	30	20
JPATS (BY2002)	30	20
AV-8B REMAN	30	20
EA-18G	30	20
F/A-18E/F (BY1990)	30	20
F-14D	30	20
T-45TS (BY1995)	30	20

Cargo/Tanker/Bomber	High (yrs)	Low (yrs)
C-130J	50	25
C-17A (BY96)	40	25
E-2C	40	20
JSTARS (BY1998)	40	25
KC-135R	40	25
Missiles		
AMRAAM	40	10
JASSM	20	10
AIM-9X	33	10
JSOW (AGM-154)	30	10
Helicopters		
C/MH-53E	30	20
MH-60R (BY2006)	30	20
MH-60S	35	20
UAV		
GLOBAL HAWK	34	15
PREDATOR	25	15
Electronic Equipment		
NESP	30	10
Tilt-rotor		
V-22 (BY2005)	43	30

Table 10: Summary Statistics for All Programs

	Mean	Median	Std Dev	-1 Std Dev	+1 Std Dev	IQR
High	55.92%	62.57%	22.74%	33.18%	78.66%	24.56%
Low	43.85%	48.33%	21.96%	21.89%	65.81%	24.88%
Average	49.88%	54.09%	23.02%	26.87%	72.90%	32.96%

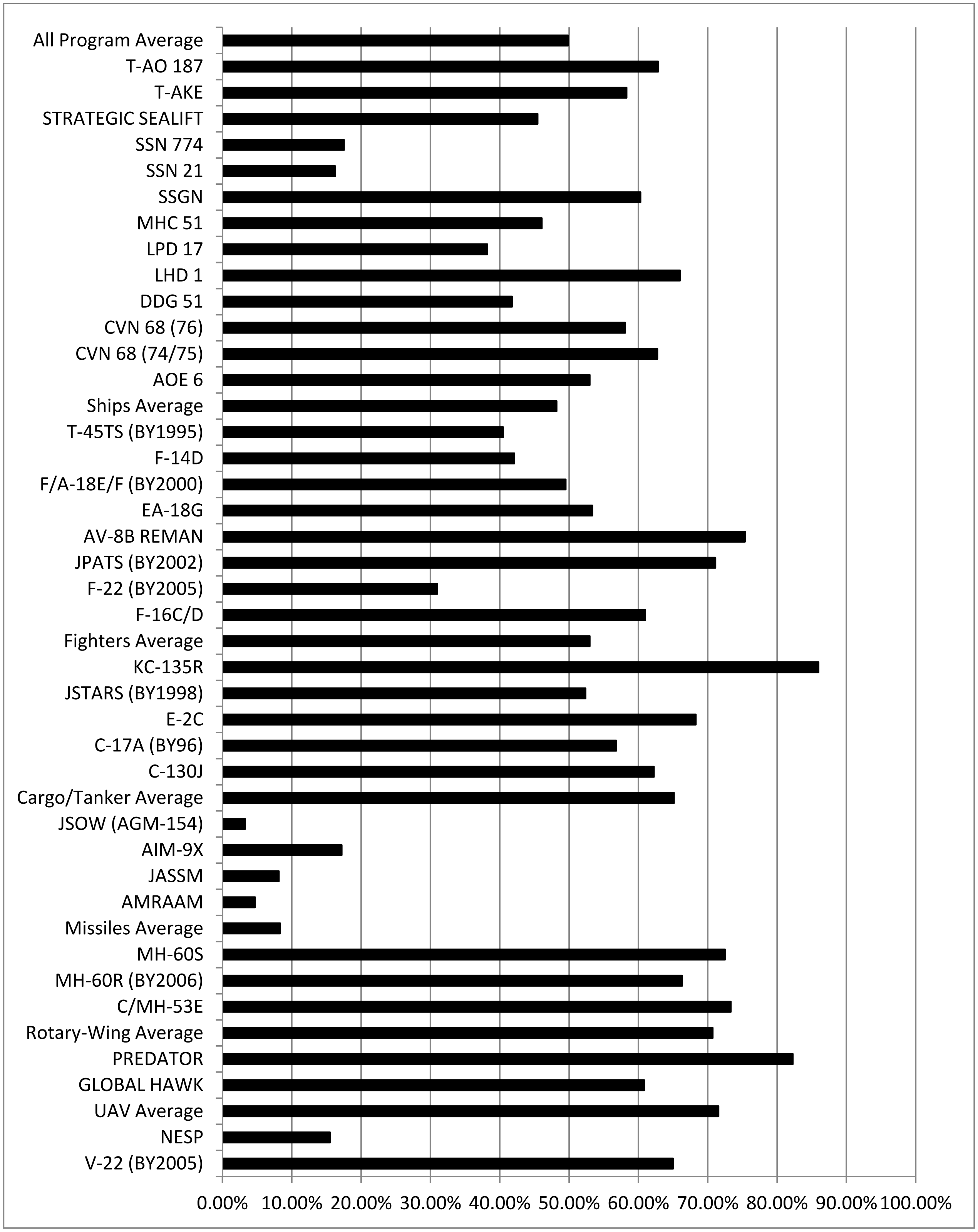

Figure 11: Averages of O&S Percentages by Program

The wide dispersion of data highlights the vast differences among the weapon systems in terms of sustainment and emphasizes the need to further reduce the set of programs into different types. Logically, the weapon system types given by the OSD O&S guides (Table 9) seem reasonable. The Tilt-Rotor class is not given in the OSD guides and was treated separately due to the unique nature of its operations. We review each class next.

Ships

The Ships category includes all types of naval vessels designed to operate on or under the sea. Thirteen ships were included in this analysis. There are significant differences in the types of ships being used in the Navy today, from size to mission and capabilities to logistical support structure. In terms of proportions of O&S costs to LCC, only two programs fell outside two standard deviations from the mean. Although both of these programs were submarines, we could not determine that this difference is inherent to the entirety of the class of submarines. As will be discussed, other factors are clearly at work to add to the large disparity observed. Table 11 provides the summary statistics for the Ships category. Figure 12 depicts the averages of O&S percentage of each program in the Ships category.

Table 11: Summary Statistics for Ships Category

	Mean	Median	Std Dev	-1 Std Dev	+1 Std Dev	IQR
High	56.30%	61.53%	17.78%	38.52%	63.33%	18.91%
Low	40.12%	44.44%	15.09%	25.03%	44.25%	18.65%
Average	48.21%	51.12%	18.14%	30.07%	66.35%	23.62%

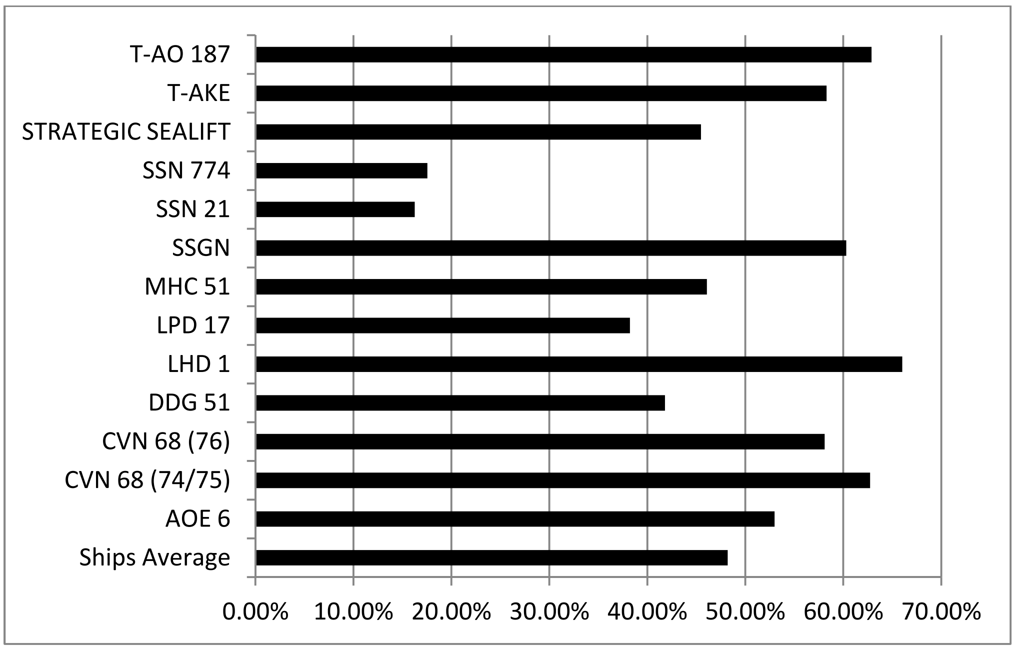

Figure 12: Averages of O&S Percentage by Program – Ships

Figure 12 shows the dramatic difference between two of the submarine programs and the rest of the Ships category. The two programs in question are the SSN 21(*Seawolf* class) and SSN 774 (*Virginia* class). There was one other submarine in the class, SSGN (*Ohio* class), which held an estimate for O&S proportion closer to the other ships in the class. The SSN 21 O&S proportion was estimated to fall within 11.65% and 20.87%, and the SSN 774 was estimated to fall between 12.65% and 22.46%. Although the average for each ship falls just within two standard deviations of the mean for the category, analysis specifically on the high and low ranges for each system compared to the other systems showed a significant impact on the mean. To remove this possible bias, we removed all submarines from the Ship category and ran another analysis. Table 12 presents the summary statistics of the Ships category after removing the three submarines.

Table 12: Summary Statistics for Ships category without Submarines

	Mean	Median	Std Dev	-1 Std Dev	+1 Std Dev	IQR
High	62.01%	64.09%	10.10%	51.90%	72.11%	16.28%
Low	44.52%	45.80%	9.60%	34.91%	54.12%	14.57%
Average	53.26%	53.12%	13.13%	40.13%	66.40%	16.97%

As expected, the mean and median increase somewhat and look more alike. The standard deviation decreases, though it is still over 13%. The Interquartile Range (IQR), which contains the middle 50% of the data, decreases, as well, showing a smaller dispersion of the data. Since the submarine classes of Ships appear to be troublesome, we reviewed this class a little more to determine certain qualities that might be significant factors in sustainment.

The estimated sustainment proportions for the three submarine systems are summarized in Table 13. The SSGN range falls closer to the average of the Ships than to the other submarine types. A look into the acquisition and sustainment costs for these systems sheds more light on the apparent reasons for the disparity. Table 14 is a summary of the acquisition and estimated sustainment costs for these systems. Next is a brief look into each system.

Table 13: Summary Acquisition and Support Costs – Submarines

Submarines	High	Low	Average
SSGN	68.51%	52.11%	60.31%
SSN 21	20.87%	11.65%	16.26%
SSN 774	22.46%	12.65%	17.56%

Table 14: Summary Acquisition and Support Costs - Submarines

Program Name	Acquisition Costs ($M)	Sustainment Estimate (20 yrs $M)	Sustainment Estimate (40 yrs, $M)	Annual Unit Costs ($M)	# of Units
SSGN (BY2002)	$ 3,867.40	$ 4,207.57	$ 8,415.14	$ 52.59	4
SSN 21 (BY1990)	$ 12,332.10	$ 1,626.19	$ 3,252.38	$ 27.10	3
SSN 774 (BY1995)	$ 63,219.50	$ 9,156.59	$ 18,313.17	$ 15.26	30

The SSGN is an *Ohio*-class guided-missile submarine that is roughly 560 feet long (42-foot beam) and displaces 18,750 tons (submerged) (US Navy, 2012). Its crew complement is 15 Officers and 144 Enlisted members, with the capacity to host up to 66 Special Operations Forces (SOF) members (US Navy, 2012). The SSGN program converted four SSBN ("B" designation is for ballistic missile) submarines to the guided-missile configuration, as well as add communications and mission capabilities (US Navy, 2012).

The SSN 21 is a *Seawolf*-class submarine measuring 353 feet (40-foot beam) and displaces 9,138 tons (submerged) (US Navy, 2012). There are two other submarines in this class – the SSN 22 with the same characteristics, and the SSN 23 measuring 453 feet with a displacement of 12,158 tons (submerged) (US Navy, 2012). The crew complement is 14 Officers and 126 Enlisted (US Navy, 2012). The SSN 21 program included costs for all three submarines and all three were newly constructed.

The SSN 774 is a *Virginia*-class submarine measuring 377 feet (33-foot beam) and displacing 7,800 tons (submerged) (US Navy, 2012). The crew complement is 15 Officers and 117 Enlisted members (US Navy, 2012). The SSN 774 program includes costs for 30 planned, newly-constructed submarines (US Navy, 2012).

Although the SSGN is the largest of the three classes, it had the smallest acquisition cost due to its acquisition strategy of conversion vice new construction. The SSGN also has the largest AUC of the three classes, presumably due primarily to its size and crew complement. These appear to be the main factors driving the disparities among the submarines. As far as what makes a submarine different than surface ships in terms of O&S/LCC cost ratio, that analysis is beyond the scope of this analysis and is recommended as a follow-on research topic.

For surface ships, the expected O&S cost ratio from this analysis is 55% - 64% of LCC. Most of these ships were new development and construction. Due to the dispersion of the ship systems seen in Figure 12, we believe there is ample evidence that the Ships category may be further broken down into other categories, though what those categories should be is beyond the scope of this research.

Fighter Aircraft

The Fighter Aircraft category included eight weapon systems, including two training systems, JPATS (Air Force/Navy) and T-45TS (Navy). As with the Ships category, the data has a wide dispersion, though this time it is from opposite ends of the spectrum. The summaries are broken out by All Programs, Air Force, and Navy in Tables 15-17.

Table 15: Summary Statistics for All Fighter Programs

	Mean	Median	Std Dev	-1 Std Dev	+1 Std Dev	IQR
High	57.60%	56.48%	15.17%	42.43%	72.77%	21.53%
Low	48.38%	46.41%	15.69%	32.70%	64.07%	22.07%
Average	52.99%	51.46%	15.65%	37.34%	68.64%	23.42%

Table 16: Summary Statistics for Air Force Fighter Aircraft

	Mean	Median	Std Dev	-1 Std Dev	+1 Std Dev	IQR
High	58.77%	65.77%	20.88%	37.89%	79.66%	19.99%
Low	49.93%	56.16%	20.87%	29.07%	70.80%	20.16%
Average	54.35%	60.97%	19.29%	35.06%	73.64%	26.17%

Table 17: Summary Statistics for Navy Fighter Aircraft

	Mean	Median	Std Dev	-1 Std Dev	+1 Std Dev	IQR
High	56.90%	54.58%	13.53%	43.37%	70.42%	11.36%
Low	47.45%	44.48%	14.49%	32.96%	61.95%	11.15%
Average	52.17%	47.68%	14.12%	38.05%	66.30%	12.74%

The low end of the range is occupied by the F-22 program with a range of 26.66% to 35.29%. The F-22 started to be developed in 1986 and delivered its first aircraft from the production line in June 2003 (USAF, 2007). The upper end is occupied by the AV-8B Harrier II Remanufacture program with a range of 71.64% to 79.12%. This program modified existing Harriers to the most recent configuration, limiting program funding to Procurement (no development) (US Navy, 2002). As seen with the submarines, the significant difference between the newly developed system and the conversion/reconfiguration of older systems is significant.

As mentioned earlier, in this data set are two training programs. The Joint Primary Aircraft Training System (JPATS) is a joint program between the Air Force and Navy (Air Force is the lead service) utilizing the T-6A Texan II, a derivative of the Raytheon Beech/Pilatus PC-9 Mk II (US Navy, 2007). The T-45 Training System (T-45TS) is a Navy program utilizing a derivative of the British Aerospace Hawk (USAF, 2010). The JPATS O&S ratio range (66.97% - 75.26%) came close to that of the AV-8B, while the T-45TS range (35.63% - 45.36%) was closer to the F-22. The differences do not appear to be due to the service lead (AF vs. Navy), but rather to the characteristics of the program. A summary of actual costs of the programs appears in Table 18.[12]

Table 18: Summary of Training Programs

Program Name	Acquisition Cost ($M, BY1995)	AUC ($M, BY1995)	# of Units	Sustainment Estimate (30 yrs)	Sustainment Estimate (20 yrs)
JPATS (BY1995)	$ 3,941.2	$ 0.6	747	75.26%	66.97%
T-45TS (BY1995)	$ 6,735.4	$ 1.2	161	45.36%	35.63%

JPATS experienced a lower acquisition cost and will experience a higher O&S cost, contributing to the stark difference between the two programs. Though other programmatic factors undoubtedly played a role, the fundamental difference between the acquisition costs of these two systems is the aircraft being used. JPATS uses an aircraft powered by a turbo-prop engine and can take off and land on traditional land-based runways (USAF, 2010). The T-45 is powered by a turbofan engine and was modified to be able to take off and land on a carrier using the catapult and tail-hook systems (US Navy, 2007).

Even with the extremes of these systems, all eight fell within two standard deviations of the means and medians of the Fighter category. This analysis estimated a

[12] By chance, each program experienced a baseline event in FY1995. Since initial analysis by Ryan, et al. was performed for BY1995 for each program, the data was not converted further to any other base year.

range for the ratios of O&S costs to be 48.38% - 57.60% (mean) and 46.41% - 56.48% (median).

Cargo/Tanker/Bomber Aircraft

Five airframes were included in this category: three Air Force, one Navy, and one joint (J-STARS, Air Force/Army). One program stood out as anomalous in this group: the KC-135R. Overall, the ratios for this category were 59.19% - 71.11% (mean) and 54.20% - 70.30% (median). The KC-135R ranges were 83.19% - 88.79%. Although the upper estimate for the KC-135 fell within two standard deviations of the mean, the estimate for the low end exceeded two standard deviations. This airframe was removed and the analysis was performed again on the remaining four systems. Without the KC-135R, the Cargo/Tanker/Bomber category was estimated to have ranges of 53.18% - 66.70% (mean) and 52.65% - 66.44% (median). The results are summarized in Tables 19 and 20.[13]

The KC-135R program converted existing KC-135A aircraft into a different configuration with, among other updates, more efficient engines (USAF, 2011). Development costs were greatly diminished over a newly constructed airframe, making the O&S portion of the LCC the overwhelming portion of this platform's costs.

[13] Summaries were not broken out by service since only one weapon system in this category was managed by the Navy and one system was a joint program.

Table 19: Summary Statistics for Cargo/Tanker/Bomber Aircraft

	Mean	Median	Std Dev	-1 Std Dev	+1 Std Dev	IQR
High	71.11%	70.30%	11.97%	59.14%	83.08%	13.12%
Low	59.19%	54.20%	14.40%	44.79%	73.58%	9.79%
Average	65.15%	61.73%	13.98%	51.17%	79.12%	19.13%

Table 20: Summary Statistics for Cargo/Tanker/Bomber Aircraft without KC-135R

	Mean	Median	Std Dev	-1 Std Dev	+1 Std Dev	IQR
High	66.70%	66.44%	7.80%	58.89%	74.50%	10.17%
Low	53.18%	52.65%	6.02%	47.16%	59.20%	5.91%
Average	59.94%	59.55%	9.68%	50.26%	69.62%	11.08%

Missiles

The Missile category consisted of four programs, each of them being jointly acquired. The Air Force and Navy each acted as lead service on two of the programs. The O&S ranges were estimated to be 4.64% - 12.06% (mean) and 3.81% - 9.07% (median). The Navy had simultaneously the highest and lowest estimates, revealing no trend in management differences between the services. The AIM-9X had the highest estimated percentage range in this group. This program was also the only one of this group to be considered a variant, being in its fifth generation (US Navy, 2011).

One other piece of information to note in this set of results is that the life expectancies for all but one missile system (JASSM) were well beyond the guidance given in the OSD guides. For the Missiles category, the rule of thumb for life expectancy is 10-20 years. Per the SARs for each program, the expectancies for each program were 40 years (AMRAAM), 33 years (AIM-9X), 30 years (JSOW), and 20 years (JASSM). Logically, the length of time a system is in the operations and sustainment phase of its life cycle has a considerable impact on the funding needed in later years. Whether or not these missile systems will exist for as long as they are planned to exist, only time will tell. If missile systems can be expected to last beyond 30 years, the guidance should be updated to reflect reality. The descriptive statistics are shown in Table 21.

Table 21: Summary Statistics for Missiles

	Mean	Median	Std Dev	-1 Std Dev	+1 Std Dev	IQR
High	12.06%	9.07%	9.06	3.00%	21.12%	7.46%
Low	4.64%	3.81%	3.56%	1.08%	8.20%	4.63%
Average	8.35%	6.56%	7.51%	0.84%	15.85%	5.43%

Rotary-Wing

All three rotary-wing systems were managed by the Navy, and all three are considered variants. Two of the systems, the MH-60 R and MH-60S, are very similar platforms, sharing a “common cockpit” and having the same general dimensions and propulsion system (NAVAIR, 2012). The dissimilarities in mission and the number of fielded units presumably cause these two aircraft to be on the opposite sides of a narrow range of estimated O&S costs. Table 22 summarizes this category.

Table 22: Summary Statistics for Rotary Wing Aircraft

	Mean	Median	Std Dev	-1 Std Dev	+1 Std Dev	IQR
High	74.88%	76.52%	3.51%	71.37%	78.40%	6.41%
Low	66.57%	68.48%	4.12%	62.45%	70.70%	3.78%
Average	70.73%	70.13%	5.70%	65.03%	76.43%	6.39%

Unmanned Aerial Vehicles (UAVs)

Only two UAV systems managed by the Air Force were analyzed – the Global Hawk (RQ-4) and the Predator (MQ-1B). The range of O&S proportions was 64.92% - 78.20% (mean and median) with an average of 71.56%. The Predator occupies the top spot in this category, having more flying hours per year (191,070 versus 6,679 for FY2010) than the Global Hawk (AFCAP, 2013), as well as having a less-expensive acquisition program ($3.46 billion [BY2008] versus $11.29 billion [BY2000]) (USAF, 2009; 2010).

The fundamental differences among UAV systems are magnified greatly when taking into consideration the UAV systems being employed by the Army. For example, the Global Hawk, operated by the US Air Force, has a wingspan of 130.9 feet with a range of 8,700 nautical miles (USAF, 2012). The Raven, operated by the US Army, has a wingspan of 4.5 feet and a range of 5.4 nautical miles (AeroVironment, 2012). The former takes off using a normal runway. The latter can be launched by hand. Due to these vast differences, it would not be practical to recommend an O&S cost ratio for the entire range of UAVs. Separate analysis should be performed to determine different classes of UAVs and their cost ratios.

In early 2012, the US Air Force announced it will retire its fleet of Global Hawk – Block 30 aircraft (Majumdar, 2012). Although other blocks of the Global Hawk may still be used by the Air Force and Navy in the future, removing this particular version of the aircraft will drastically change the life cycle proportions. The data collected for this analysis went through FY2010 and did not include any adjustments for this announcement.

Electronic Equipment

The category of Electronic Equipment potentially contains more numbers of systems that could be considered than the other categories we analyzed. Unfortunately, only one system was reviewed – the Navy Extremely High Frequency (EHF) Satellite Communications (SATCOM) Program (NESP). This system provides command, control, and communications (C3) capabilities to land- and sea-based operating locations utilizing existing MILSTAR I and II satellites (US Navy, 2004). The range of the sustainment portion of LCC was 8.74% - 22.32% with an average of 15.53%.

The category of Electronic Equipment can encompass so many subcomponents of many DoD weapon systems utilizing different acquisition and maintenance strategies that it may be difficult to identify an acceptable target for O&S costs. The NESP was developed specifically for the Navy. Some communications or computing systems can be acquired using mainly commercial off-the-shelf (COTS) equipment with little or no modification for military use, drastically reducing or eliminating development costs. Some systems cannot be maintained by the contractor that produced the equipment due to obsolescence or the collapse of the company before the completion of the life cycle of the system. Although we did determine a range of the expected O&S proportion of LCC, we cannot in good faith determine this range to be true for all or most electronic systems.

Tilt-rotor

Tilt-rotor weapon systems are new to the inventory of fielded DoD systems. As such, there is only one system to analyze – the V-22 Osprey. The range of sustainment costs was estimated to be 60.95% - 69.11%. This range was derived using the calculated AUC and the estimates for life expectancies from the SARs (vice the OSD CAPE guide) for the V-22 since there is no guidance from other sources.

This program is currently developing and producing three variants concurrently, each of which will log a different number of flight hours per year. Contrary to the other systems we analyzed, the V-22 is still being fielded with a significant number of units to be fielded in future years (112 of 459 units fielded by December 2010). This could lead to the sustainment costs being a substantially greater portion of LCC than we estimated.

Another point to consider with this program is the significant learning curve that was surmounted to produce this technology. Many technical challenges concerning the underlying physical and dynamic properties of this aircraft took significant effort to understand and overcome. This program came under fire for a number of fatalities that occurred in the development and testing phases due to some of these challenges (Congressional Research Service, 2005). The program is fielding a now-proven technology at considerable cost that will provide an important stepping stone for further development efforts. The development costs (relative to the sustainment costs) for future iterations of this weapon system type may be significantly less thanks to the effort exerted through this program.

New Development

Since the work performed on this database to this point has shown a possible connection between high O&S proportions and variant/modification programs, an additional analysis was performed on all newly-developed systems. The resulting list included 22 systems. The ranges for O&S proportions for this group were 35.09% - 47.00% (mean) and 36.97% - 53.98% (median). The decreases in proportions from the larger group of systems including variant and modification programs seems to show there is some credence to the notion that new systems will have more life-cycle costs devoted to acquisition than to sustainment. Table 23 summarizes the results.

Table 23: Summary Statistics for New Programs

	Mean	Median	Std Dev	-1 Std Dev	+1 Std Dev	IQR
High	47.00%	53.98	23.60%	23.40%	70.60%	44.18%
Low	35.09%	36.97%	21.27%	13.82%	56.36%	38.44%
Average	41.04%	45.84%	22.99%	18.05%	64.04%	37.91%

Investigative Questions Answered

To conclude this chapter, we revisit the questions we identified as our major points of research. The main theme of this research was to determine the source of the widely-held and published belief that O&S costs for a Department of Defense weapon system comprise 70% of the total life-cycle costs of the system.

Did the figure come about through an identifiable study or through common practice? The "golden ratio" espoused by many in the acquisition community does not appear to have come from any single study. Further, some of the terms being used to describe life-cycle costs, and specifically O&S costs, are not readily distinguished from other similar terms, complicating the understanding of the topic at hand. Although some O&S actual cost data may have been used for a few systems, whether from antecedent systems or from test data for the system being acquired, this data was not widely collected or analyzed to determine the ratio in question.

If a source can be found, are the source and/or methodology credible? The sources found gave limited, if any, information based on the estimates of life expectancy, annual cost, and other factors not immediately known due to the lack of detailed methodology for each program. A credible methodology could not be discovered or determined due to this absence of information. Therefore, there appears to be no empirical data to support this notion of 70% of life-cycle costs being attributable to the O&S phase for a "typical" DoD weapon system.

If a source is found and was valid at some point, is the information still valid? Since no empirical source was found, questions of validity are quickly dismissed. However, regardless of historical validity, any cost information for previous systems needs to be evaluated for current validity. Logically, as systems are built using more robust technologies and materials, these estimates of life-cycle proportions should change. Sometimes a system proves to be more valuable and flexible than originally intended and is kept alive in the nation's arsenal far longer than anyone could have expected. As investors have been instructed by any investment broker, past performance is no guarantee for future performance.

Can a more accurate model be developed? Although this analysis lacks a certain level of completeness, it illustrates the great differences among the weapon system types in terms of proportional life-cycle costs. Instead of talking about the "standard" exceptions to the 70% mantra, namely space systems and the B-52, the acquisition community should embrace the variability of sustainment costs in DoD weapon systems. We have shown that even within the Submarine category there can be a great deal of variation depending on how the vessel is acquired and its size. As some programs reviewed in this analysis have shown, it is sometimes more cost-effective, in terms of acquisition costs, to have modification or life-extension programs than to create new systems. Under times of increasing budget consciousness, modification programs may become more normal. More analysis needs to be done to more properly identify cost ratios, but this analysis has shown a better model is possible.

Summary

This chapter presented our findings on each of the weapon system categories in our research. Due to the selection criteria used to identify the programs to be used, certain categories, such as Space Systems, Electronic Equipment, and Rotary Wing

Aircraft, were underrepresented and deserve further research. For the systems analyzed, the average percentage of life-cycle costs attributable to O&S is 49.88% (mean) and 54.09% (median). Due to the great variability in the averages for each type of weapon system type, further analysis was performed on each weapon system category. Table 24 summarizes the averages derived for each weapon system type.

Table 24: Summary of Average O&S Cost Percentages

	Mean	Median
Ships	48.21%	51.12%
Ships – No Submarines	53.26%	51.46%
Fighter Aircraft	52.99%	51.46%
Cargo/Tanker/Bomber Aircraft	65.15%	61.73%
C/T/B – No KC-135R	59.94%	59.55%
Missiles	8.35%	6.56%
Rotary Wing Aircraft	70.73%	70.13%
Unmanned Aerial Vehicles	71.56%	71.56%
Electronic Equipment	15.53%	15.53%
Tilt Rotor Aircraft	65.03%	65.03%

V. Conclusions and Recommendations

Chapter Overview

The conclusions of this research can be useful in understanding the impact of certain factors of weapon systems acquisition on the sustainment of DoD systems. The recommendations herein are meant to provide for a more informed acquisition community and spawn future research efforts into O&S costs.

Conclusions of Research

The main conclusion of this research is that a "golden ratio" of 70% O&S to 30% Acquisition costs for a "typical" DoD weapon system is not supportable at a macro level in the DoD. The variability of the data also shows that a ratio for the DoD at any percentage is unreasonable due to the great differences in acquiring and sustaining each weapon system. The use of any such ratios to describe "typical" systems in portfolio analysis or elsewhere is inadvisable. Although it is important to consider certain aspects of the data analyzed in this thesis when determining affordability of current and future systems, the DoD needs to more completely understand the implications of the story being told by the actual costs being incurred by the weapon systems it possesses.

The notion of O&S costs being 70% of LCC has been circulating around the Department of Defense acquisition community for more than 15 years. Its inception appears to come from an amalgamation of estimates of the O&S weapon system costs given by program offices or other official sources, such as Selected Acquisition Reports, at some point in the 1990s. This collection of estimates also appears to contain "typical" (whatever this was intended to mean) DoD programs with a 30-year service life from the

1980s. An analysis of actual sustainment costs of already fielded systems and how these costs relate to LCC had not been performed in the past, at least not in any readily-available literature. With the recently increasing focus on O&S costs, an earnest look into actual sustainment costs needed to be performed.

One of the interesting items to come out of this research was the variable nature of life expectancies. In two decades, many weapon system categories experienced an increase in their recommended life expectancies, as given by the OSD O&S cost estimating guides from 1992 through 2012. There also seems to be a mixing of terminology – a possible misunderstanding between the related, but very different, terms "service life" and "life expectancy." A look at the actual useful lives, as well as the expected lives, of our systems will show that not only are we capable of sustaining our weapon systems far beyond their intended lives, we are able to extend the capabilities of existing seaframes and airframes through modification with lower acquisition costs than a newly created system.

This analysis was intended to be a first-pass look at a topic of great concern and scrutiny in recent years. The level of analysis for operations and support costs using actual cost data can be greatly expanded to include the other aspects of a weapon system, such as normal steady-state unit levels, typical attrition rates, and ramp-up and ramp-down activities, to name a few.

Although our approach was simplistic, it underscores the great differences in sustainment ranges among the weapon system categories. The need to identify exemptions to the 70% "rule", or any supposed rule for that matter, does not properly illustrate the categorical differences of DoD weapon systems – in acquisition, sustainment, logistics, etc.

Significance of Research

By illustrating the variability of life-cycle proportions among weapon system categories, we have started to show a more realistic picture of what program analysts and portfolio managers can expect in terms of sustainment costs. This research has begun to open a window into the real effects of acquisition strategy on life-cycle costs. In the face of looming budget cuts over the next decade, leaders across the DoD and Congress are struggling to make tough decisions regarding our nation's arsenal. Only with a full understanding of how our acquisition decisions affect our long-term sustainment costs can we make the right decisions on what capabilities are needed and how we will acquire those capabilities.

Recommendations for Action

This research is intended to be a first-pass at a new line of research into actual sustainment costs of DoD systems. The body of knowledge in the realm of actual O&S cost proportions is relatively small. Further study into the differences between what we *estimate* as an annual cost and what we *realize* as an annual cost for our weapon systems is needed to provide more accurate estimates for affordability assessments. The government has sponsored many studies on the problems of the acquisition process, but has not spent the necessary capital to understand the problems, or even current state, of actual sustainment costs for fielded systems. We recommend more intensive study into the true costs of sustaining DoD weapon systems, both past and present.

Recommendations for Future Research

Future research related to this analysis can be performed in each of the weapon system categories to better determine the expected proportions of O&S costs to life-cycle costs. The method of analysis for this paper was limited and did not take into account normal phasing of weapon systems or demilitarization and disposal. Some categories were underrepresented, such as Electronic Equipment and UAVs, and would require further study into the great diversity of these systems. The Space Systems category was not represented at all. Other categories, such as Ships, could be reviewed to determine the significance of certain factors of shipbuilding, including the type of ship or submarine, and how they affect O&S costs. Army systems were not considered due to data deficiencies or the omission of pertinent data for weapon systems. Systems that have been through their entire life cycle were not reviewed due to a lack of timely data, such as missing, incomplete, or unavailable actual O&S costs, though these retired systems would provide a valuable trove of information on sustainment.

Increasing life expectancies, the true impact of acquisition strategy (new system, variation, retrofit, etc.) on O&S costs, the reality that estimates of O&S costs during the acquisition phase do not consider certain real events (war time, program life extensions, aging fleet costs) – these issues need to be explored with more fervor to provide for a more complete analysis of current and future costs, as well as set the stage for a more reasonable and realistic picture of what to expect for future systems.

Some of our results showed that new development efforts may devote more resources (proportionally) to the acquisition of the system than to its sustainment. Conversely, variant or modification programs, such as the SSGN and the MH-60R/S, show how leveraging the work of past development efforts can reduce the relative cost of acquisition for future capabilities. For each category of weapon system, future work could be performed in determining how much the acquisition strategy affects the life-cycle proportions.

Summary

To reduce the life-cycle costs of all DoD weapon systems down to a single ratio is impractical and imprudent. Although the average percentage of O&S costs observed in this thesis was around 50-55% of LCC, the significant deviations from this percentage, both from individual weapon systems and categories of systems, that was demonstrated in this analysis illustrate the need to accept the differences among weapon system categories. The differences within certain categories or sub-categories, such as Ships and Submarines, illustrate the need to further distill these groups into more meaningful and homogeneous types of systems before assigning a "typical" O&S/Acquisition cost ratio.

In order to understand its costs, the DoD must also understand the other forces at play. Life expectancies of systems and individual units, both estimated and realized, are increasing as more durable materials and sustainment methods are developed. This can have a profound impact on not only the costs to sustain these systems, but also the decisions on how the DoD will acquire new capabilities. Service life extension and capability upgrade programs have the potential of reducing the acquisition costs to fill identified capability gaps, allowing for better use of public funds.

In order to make informed decisions regarding our nation's arsenal, leaders and portfolio managers need to have the right information at the right time. The Department of Defense has begun to accumulate valuable information into its sustainment costs through systems like AFTOC, VAMOSC, and OSMIS. Now this historical information needs to be reaped and processed to obtain the valuable insight it contains into the future of DoD systems. We have a wealth of study into the acquisition of weapons. Now is the time to better understand the inner workings and characteristics of the other side of the life of a DoD weapon system.

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REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 074-0188*

1. REPORT DATE *(DD-MM-YYYY)*	**2. REPORT TYPE**	**3. DATES COVERED** *(From – To)*
21-Mar -2013	Master's Thesis	03-Oct-2011 – 21-Mar-2013

4. TITLE AND SUBTITLE
Investigation into the Ratio of System Operations and Support Costs to Life-Cycle Costs for Department of Defense Weapon Systems

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Jones, Gary L., Captain, USAF

5d. PROJECT NUMBER
N/A

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAMES(S) AND ADDRESS(S)
Air Force Institute of Technology
Graduate School of Engineering and Management (AFIT/ENV)
2950 Hobson Way, Building 640
WPAFB OH 45433-8865

8. PERFORMING ORGANIZATION REPORT NUMBER
AFIT-ENC-13-M-01

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
INTENTIONALLY LEFT BLANK

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
DISTRIBUTION A: APPROVED FOR PUBLIC RELEASE; DISTRIBUTION IS UNLIMITED

13. SUPPLEMENTARY NOTES

14. ABSTRACT
As the arsenal of weapons managed by the Department of Defense (DoD) ages, the country's leadership is forced to make decisions regarding what to do with current and projected funding to maintain military defensive and offensive capabilities. The acquisition community at many levels has stated that O&S costs are about 70 percent of the total life-cycle costs of the average system, the other 30 percent being spent in the acquisition phase. This "golden ratio" does not appear to come from empirical evidence. There has been little research into the actual ratio of O&S-to-acquisition costs.
This research found a significant departure from the "golden ratio" in currently fielded systems. Using 37 Air Force, Navy, and Joint programs, the average program was estimated to realize around 55 percent of its costs in the O&S phase, though this does not come close to telling the whole story. Significant deviances from this 55 percent average were seen in most of the weapon system categories analyzed due to many factors, such as life expectancy, acquisition strategy, and level of annual sustainment costs. Due to these significant differences, using a single ratio to describe the cost envelope of the "average" weapon system is not recommended.

15. SUBJECT TERMS
Operations and support, Cost Ratio, Life Cycle Costs, Life Expectancy, Golden Ratio

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
					White, Edward D., Ph.D, AFIT/ENC
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			**19b. TELEPHONE NUMBER** *(Include area code)*
U	U	U	UU	91	(937) 255-3636 ext 4540 (Edward.white@afit.edu)

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39-18