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The Use of Collaborative and Three-dimensional Imaging Technology to Achieve Increased Value and Efficiency in the Cost-estimation Portion of the SHIPMAIN Environment

18 October 2007

by

David H. Cornelius, Jr., LCDR, USN

Advisors: Thomas Housel, Professor, and

Albert Barreto, Lecturer

Graduate School of Operational & Information Sciences

Naval Postgraduate School

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Abstract

Maintenance and modernization efforts of the US. Navy's fleet are essential to the US's ability to project power and deter adversaries from around the world. This maintenance and modernization requires substantial allocation of funds from the already stretched-thin budget. In order to facilitate the most cost-effective way of allocating funds, the Navy has invested substantial fiscal and human resources to standardize the processes used to accomplish maintenance, modernization and repair of its fleet. In order to realize the full benefit of the available technology, reliable and quantitative measures which capture and measure the full range of benefits provided by technology resources are essential. The Knowledge Value Added (KVA) methodology will be used in this thesis to identify and quantify the benefits that can be realized within the cost-estimation portion of the ship maintenance and modernization (SHIPMAIN) program.

In this discussion, a proof-of-concept case is developed to analyze the current cost-estimation process within SHIPMAIN. After the completion of the baseline as-is process, the KVA methodology is applied to a notional scenario which uses 3D laser scanning and Product Lifecycle Management to reengineer the current cost-estimation process. The notional scenario demonstrates positive returns from the reengineered cost-estimation process, and the KVA methodology establishes evidence which suggests that operating costs will be reduced by over $176 million and that cost-estimation efficiency will increase.

Keywords: Knowledge Value Added, KVA, Ship Maintenance and Modernization, Return on Investment, ROI, Return on Knowledge, ROK, Information Technology, IT, Laser Scanners, Collaboration, Planning Yards, Navy Shipyards, PLM, Product Lifecycle Management, Lifecycle Management, SHIPMAIN

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Without the endless support and love of my wonderful family and friends, this work would never have been completed. Thanks for patiently listening to me when I did not think I would finish. More importantly, thanks for never letting me forget that your faith in me would pull me through.

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This work could never have been accomplished without the help of several Subject-matter Experts from Naval Sea Systems Command. Thank you for taking time out of your busy schedules to help me understand the scope and complexity of the many processes involved in maintaining, modernizing and repairing the finest combat fleet of ships in the world. Your dedication to doing the right thing for the right reason will have a lasting effect on the Navy’s modernization efforts.

Finally, I would like to thank Megan and Binky for your patience with me and all the late nights. Your motivation and support got me through. I love you both.

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List of Abbreviations and Acronyms

3D	THREE-DIMENSIONAL
3DIS	3D IMAGING SYSTEM
AFOM	ALTERATION FIGURE OF MERIT
ALT	ACTUAL LEARNING TIME
ASE	ADVANCED SHIPBUILDING ENTERPRISE
CBA	COST-BENEFIT ANALYSIS
C5I	COMMAND, CONTROL, COMMUNICATIONS, COMPUTERS, COMBAT SYSTEMS AND INTELLIGENCE
CM	CONFIGURATION MANAGEMENT
DoD	DEPARTMENT OF DEFENSE
DoN	DEPARTMENT OF THE NAVY
DP	DECISION POINT
FMP	FLEET MODERNIZATION PLAN
FY	FISCAL YEAR
IEDP	IMPROVED ENGINEERING DESIGN PROGRAM
ILS	INTEGRATED LOGISTICS SUPPORT
IT	INFORMATION TECHNOLOGY
KVA	KNOWLEDGE VALUE ADDED
KVA+RO	KNOWLEDGE VALUE ADDED PLUS REAL OPTIONS
L6S	LEAN SIX SIGMA
NAVSEA	NAVAL SEA SYSTEMS COMMAND
NDE	NAVY DATA ENVIRONMENT
NSRP	NATIONAL SHIPBUILDING RESEARCH PROGRAM

OPNAV	OFFICE OF THE CHIEF OF NAVAL OPERATIONS
PLM	PRODUCT LIFECYCLE MANAGEMENT
RLT	RELATIVE LEARNING TIME
ROI	RETURN IN INVESTMENT
ROK	RETURN ON KNOWLEDGE
SC	SHIP CHANGE
SCD	SHIP CHANGE DOCUMENT
SES	SENIOR EXECUTIVE SERVICE
SHIPMAIN	SHIP MAINTENANCE
SHIPMAIN EP	SHIP MAINTENANCE ENTITLED PROCESS
SIS	SPATIAL INTEGRATED SYSTEMS
SME	SUBJECT-MATTER EXPERT
SSCEPM	SURFACE SHIP AND CARRIER ENTITLED PROCESS FOR MODERNIZATION
SPAWAR	SPACE AND NAVAL WARFARE SYSTEMS COMMAND
TYCOM	TYPE COMMANDER

I. INTRODUCTION

A. BACKGROUND

This thesis builds upon previous research by Lieutenant (LT) Nathan L. Seaman, USN, utilizing the Knowledge Value Added/Real Options (KVA+RO)[1] valuation framework to evaluate the effects of three-dimensional (3D) terrestrial laser scanning technology and Product Lifecycle Management (PLM) technologies to increase value in the SHIPMAIN environment of the Fleet Modernization Plan (FMP). LT Seaman's research demonstrated that adding 3D terrestrial laser scanning tools and PLM technologies to reengineer the current process demonstrated positive returns and realized total operating cost savings of $78 million annually. A study completed by the Naval Shipbuilding Research Program (NSRP) in March 2007 found that adding 3D terrestrial laser scanning tools to just the ship check process[2] found the following:

> Estimated cost savings of 37% and time savings of 39% for ship check data capture/post processing with the available COTS laser scanning technology hardware and software tools compared to the traditional ship check using tape measures, plumb bobs, and 2D sketches. This is above the project goal of 35% time savings and 30% cost savings. More cost savings will be realized with the use of laser scanning technology for ship checks from cost avoidance, minimized rework, material scrap reduction, reduced revisit to ships, etc. (p. 5)

The Department of Defense (DoD) currently supports material maintenance operations for roughly 280 ships, 14,000 aircraft, 900 strategic missiles and 30,000 combat vehicles (Office of the Deputy Under Secretary of Defense, Logistics and Material Readiness, 2007, p. 3). Maintenance of these various weapons systems is critical to the readiness and sustainability of our forces. This maintenance is accomplished by either depot-level or field-level activities. For Fiscal Year (FY)

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[1] See Appendix A for a detailed discussion of the KVA+RO framework.

[2] Ship check is one of seven core processes of the planning yard (Komoroski, 2005, p. 32).

2006, approximately $81 billion is projected to conduct maintenance on these activities (Office of the Deputy Under Secretary of Defense, Logistics and Material Readiness, 2007, p. 3). Considering that this budget number will likely increase over time, the importance of refining the maintenance process to achieve the “right” work at the “right” time for the “right” cost cannot be overstated.

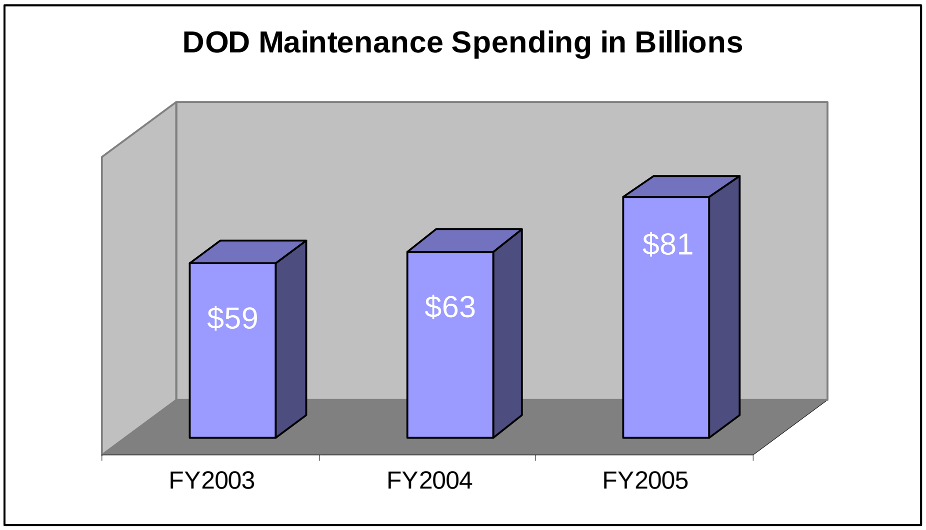

Figure 1. DoD Maintenance Expenses
(Seaman, 2007)

B. RESEARCH OBJECTIVES

This thesis will expand the scope of LT Seaman’s work by applying 3D terrestrial laser scanning and PLM technologies to the cost-estimation portion of the ship maintenance and modernization (SHIPMAIN) process. This research will introduce the concept of incorporating 3D terrestrial laser scanning and PLM technologies into the SHIPMAIN Environment to achieve more accurate cost-estimation of ship modernization, repair, and maintenance. To prove the benefits of these technologies, a current as-is state of the cost-estimation process will be developed. The as-is state can then be modified to include the benefits of adding 3D laser scanning and PLM technologies. The resulting to-be model can then be used to determine the potential of various cost-estimation improvement initiatives.

An as-is analysis will be limited to the SHIPMAIN cost-estimation process as defined in current directives. Once reliable Knowledge Value Added (KVA) estimates are obtained, the process will be reexamined factoring in the capabilities of 3D terrestrial laser scanning and PLM technologies for a to-be model. The to-be analysis will then be used to highlight the more precise cost estimates that are created by the addition of 3D laser scanning and PLM technologies to the SHIPMAIN process.

C. RESEARCH QUESTIONS

To determine potential outcomes from acquiring and using 3D terrestrial laser scanners and collaborative PLM tools in the cost-estimation portion of the SHIPMAIN process, this discussion will answer the following questions:

- Will incorporating 3D terrestrial laser scanning and PLM technologies into the SHIPMAIN Environment lead to more precise cost estimates for ship modernization, repair, and maintenance?
- What are the additional potential benefits of using the two technologies in such processes as ship maintenance, modernization and repair?

Previous research demonstrated promising results through quantitative evidence derived from the use of the KVA methodology to assess the impact of Information Technology (IT) systems, specifically 3D terrestrial laser scanners and collaborative PLM technologies, in the legacy planning yard processes.

D. METHODOLOGY

This thesis will model the cost-estimation portion of the current SHIPMAIN process and predict the potential value added from a reengineered process model that incorporates 3D terrestrial laser scanning and PLM technologies. For the cost-estimation portion of the SHIPMAIN process, the KVA methodology will be applied to measure the ROI impact that 3D laser scanning and PLM technologies will have on the current cost-estimation process model.

First, all major cost-estimation process inputs, sub-processes, and respective outputs will be identified by a comprehensive review of current SHIPMAIN directives. This model will then be validated by SHIPMAIN subject matter experts (SMEs) in cost-estimation. The sub-process analysis will include estimates for the time required to learn each process, the number of personnel involved, and the number of times each process is executed. Market comparable values will be used to help estimate cost figures. The market values will be identified in the literature review by identifying companies that specialize in cost estimating. The use of market comparables will add value to the methodology.

E. SCOPE

The scope of this thesis is to identify the potential benefits, increased efficiencies, and return on investment (ROI) that could be realized in the cost-estimation portion of the SHIPMAIN environment. The SHIPMAIN process is a 5 phase program that should provide a common planning process for fleet maintenance and increase the efficiency of the process so as to accomplish the right work at the right time for the right cost. Because the cost-estimation process can be impacted in each of the five phases, the scope of this thesis will range across all the phases, but the quantitative scope of this research will be limited to the cost-estimation portion of the SHIPMAIN process.

F. ORGANIZATION OF THESIS

The first chapter will include an overview of existing research and will identify the primary purposes and questions of focus. In addition, the chapter also introduces the methodology applied to the research questions, which thus lead to the conclusions and recommendations identified in the closing chapter. Chapter II contains a literature review to introduce relevant concepts for understanding the cost-estimation problem in the military and commercial businesses as well as to identify potential companies for the market comparables research. In addition, it will provide a brief discussion on the overall missions of the Fleet Modernization Plan

(FMP), SHIPMAIN, 3D terrestrial laser scanning and PLM technologies. The third chapter will include a more detailed discussion of previous research on the potential of 3D laser scanning and collaborative PLM technologies to support SHIPMAIN's goals[3] and will map the results to specific areas of cost-estimation within the SHIPMAIN environment using the KVA methodology. Chapter IV will begin with a brief discussion of the KVA valuation framework along with underlying assumptions. It will continue by applying the KVA methodology to the cost-estimation of the SHIPMAIN environment. A proof of concept case study applying the KVA methodology to the cost-estimation phase of SHIPMAIN will analyze the potential impact of 3D terrestrial laser scanning technology and collaborative PLM solutions under two scenarios: current as-is and potential to-be. The final chapter will conclude with specific recommendations and conclusions.

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[3] LT Nate Seaman's thesis indicated that the addition of 3D laser scanning and collaborative PLM technologies to the current SHIPMAIN process would result in positive returns from the reengineered process, and the KVA methodology establishes evidence which suggests that operating costs will be reduced by nearly $78 million annually.

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II. LITERATURE REVIEW

A. THE FLEET MODERNIZATION PLAN

Lockheed Martin is designing the Littoral Combat Ship (LCS) to provide an effective weapons system against an increasing littoral[4] threat as well as to maintain dominance of the coastal water battle space. The cornerstone of this ability to dominate is the platform's rapidly interchangeable modules and open architecture command and control systems (C^2). Lockheed Martin (2007) reported:

> Modularity maximizes the flexibility of LCS and enables commanders to meet changing warfare needs, while also supporting spiral development and technology refresh. LCS will be networked to share tactical information with other Naval aircraft, ships, submarines, joint and coalition units and LCS groups, providing commanders with the right information quickly and efficiently. With low manning and reduced operations and maintenance requirements, LCS is an affordable means to increase fleet size. (p. 1)

On January 12, 2007, the Navy issued a stop-work order on LCS-3. The stop-work order was immediate and was to last 90 days. The stop-work order was a consequence of significant cost increases that were plaguing LCS-1 and LCS-3. The increases came to light as a result of an audit that indicated the cost for the LCS would come in at around $400 million. This was double the $197.5 million that was initially budgeted. At least one Navy Admiral and one Navy Captain have been relieved or reassigned because of these significant cost-estimation errors.

In response to these types of errors in the execution of maintenance and shipbuilding funds, the US Navy has been forced to reengineer many of the modernization processes that are currently in use throughout the Fleet. The Fleet Modernization Plan (FMP) is the result of this reengineering. The FMP mission is to provide a disciplined process to deliver operational and technical modifications to the

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[4] Littoral is defined as the region associated with shallow (shoreline area) water.

Fleet in the most operationally effective and cost efficient way (Commander, Navy Sea Systems Command, 2002, p. 1-1). Then the FMP, in theory, should provide the blueprint to effectively plan, budget, and engineer shipboard improvements and modernizations in a timely manner while getting the most for each taxpayer dollar. Because the US Navy has to keep a fleet of 276 ships and over 4000 aircraft operational and deployable on a moments notice, the importance of the FMP cannot be underestimated.

According to Commander of Naval Sea Systems (2002), to leverage technology and innovation, the FMP:

- Keeps the war-fighting edge.
- Fixes systemic and safety problems.
- Improves Battle Force Interoperability.
- Improves platform reliability and maintainability.
- Reduces the burden on the sailor (p. 1-1).

The FMP should reduce the costs that are attributable to unauthorized and non-supported alteration by preventing such alterations. The costs associated with this loss of configuration control, inefficiencies due to unexpected installation interference, and unavailable logistics support are significant in nature. When taken in context of today's budgetary restraints, these cost reductions are often critical to funding other, more important weapons systems.

Another adverse impact of unauthorized and un-supported alterations is a reduction of interoperability of highly computerized and integrated combat systems. A loss of integration and interoperability across a weapons system or platform reduces the combat effectiveness of that platform. In a fleet where the requirements sometimes exceed capabilities, any loss of effectiveness can lead to mission failure.

B. THE SHIPMAIN PROCESS

The Navy's Sea Power 21 vision provides a blueprint for how the Naval forces of the future will fight in support of national interests. In support of that vision, Sea

Enterprise is transforming the way tomorrow's fleet is resourced. Sea Enterprise's vision is balancing the priorities of the future Naval forces to optimize resource allocation, increase productivity, and enhance procurement activities to increase combat capability. SHIPMAIN is a Navy-wide initiative to create a surface ship maintenance and modernization program that will support the vision of Sea Power 21 and its Culture of Readiness (COR) (Commander, Naval Sea Systems Command, 2007, module 1, slide 2). It is being utilized by fleet sailors and shipyards to change the culture of how ship work gets completed.

The overall SHIPMAIN maintenance and modernization goals are:

- Increase the efficiency of the maintenance and modernization process without compromising their effectiveness.
- Define a common planning process for surface ship maintenance and alterations.
- Install a disciplined management process with objective measurements.
- Institutionalize the process and a continuous improvement method. (Commander, Naval Sea Systems Command, 2007, module 1, slide 4)

The SHIPMAIN initiative will reduce the FMP by collapsing an existing 40+ types of alterations into two (Fleet and Program).

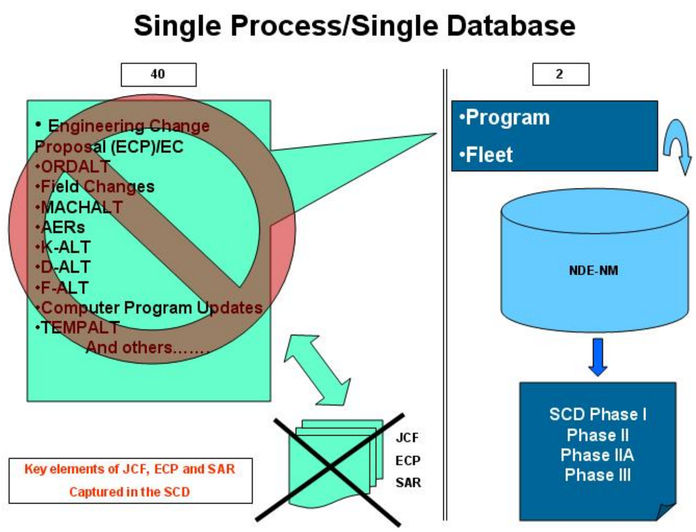

Figure 2. Collapsing 40+ Alterations into Fleet and Program
(Commander, Naval Sea Systems Command, 2007, module 1, slide 8)

The SHIPMAIN initiative will contain a single data repository of ship changes. The decision-making process will be a single, hierarchical process. Another key factor of the process is the development of a balanced modernization plan for surface ships. Finally, SHIPMAIN will minimize the churn in the system and provide the timely installation of alterations. It is about doing the right maintenance at the right time, in the right place for the right costs.

The SHIPMAIN process is comprised of five distinct phases[5] and three decision points (DP)[6]. This process will use a single document to take a proposed change from inception to completion. This document is the Ship Change Document (SCD). The SCD is defined as:

> The single authorized document for all ship changes in the single authoritative database know as the Navy Data Environment (NDE). The SCD becomes a Ship Change after the first decision point in the Entitled Process. Installation is authorized after Phase II approval for non-permanent changes or Phase IIa/III for permanent changes. No other databases are authorized for use to enter ship change information. Ship changes entered in any database other that NDE will NOT be considered and will NOT be funded. (Commander, Naval Sea Systems Command, 2007, module 2, slide 9)

Appendix B provides a detailed description of each of the five SHIPMAIN phases.

C. COST-ESTIMATION

The decision to produce a product or proceed with a project is often dependent on the cost estimate associated with the product or project. The cost estimate is a mathematical representation of the future costs attributable to the project. Because cost is often used to determine where to proceed with a given

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[5] Five Phases: I-Conceptual, II-Preliminary Design, III-Detailed Design, IV-Implementation, V-Installation (Commander, Naval Sea Systems Command, 2006).

[6] DPs occur at the conclusion of Phases I-III. Each DP is an approval for funding of successive phases and has an associated Cost Benefit Analysis (CBA), Alteration Figure of Merit (AFOM) and Recommended Change Package (RCP) (Commander, Naval Sea Systems Command, 2006).

project, it must be factored into everything from the budget plan to the tracking metrics.

Cost-estimation is not a new science, but has become the focus of more interest in the past couple of years because of the dramatic discrepancies that exist between initial cost projections and the actual final costs. The goal of an organization should be for the final costs to match or only slightly vary from the initial cost estimates. Sadly this is not the rule but the exception. According to the *Journal of the American Planning Association:*

- Costs are underestimated in almost 9 out of 10 projects.
- For a randomly selected project, the likelihood of actual costs being larger than estimated is 86%. The likelihood of actual costs being lower than or equal to estimated costs are 14%.
- Actual costs are on average 28% higher than estimated costs. (Flyvbjerg, Holm & Buhl, 2002, p. 282)

The histogram below, from the APA Journal, shows the inaccuracy of cost estimates in 258 transportation infrastructure projects.

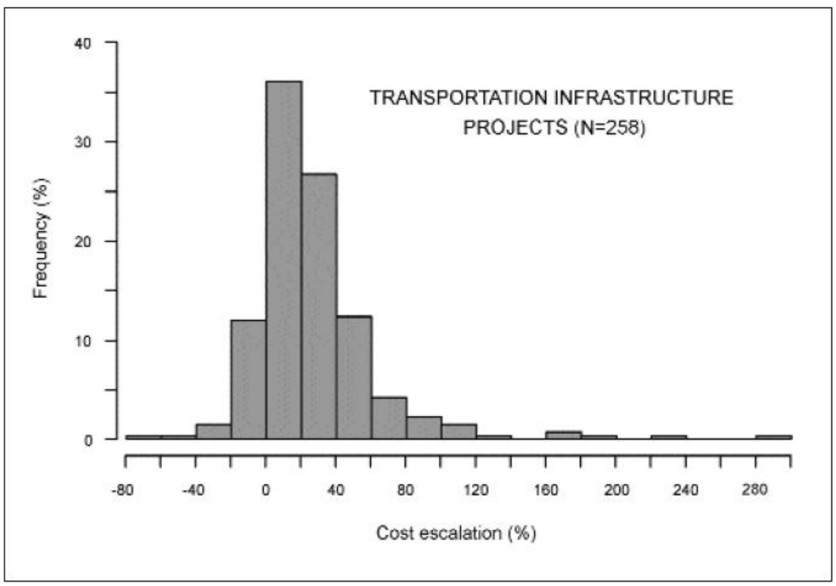

Figure 3. Inaccuracy of Cost Estimates of Transportation Infrastructure Projects
(Flyvbjerg, Holm & Buhl, 2002, p. 283)

Underestimation of costs can lead to a misallocation of precious resources and undermine important organizational projects. While fighting for every dollar available, organizations have to be very careful to prevent deception and misinformation and to stop bad projects from going forward. These flawed projects will eventually reveal their weakness as the actual costs become more apparent. Underestimation of costs to push a project is ultimately unfair to those who finance the project and the end-user.

D. COST-ESTIMATION PROCESS WITHIN SHIPMAIN

To ensure the correct and fair evaluation of a bid or proposal to provide a service for the government, the Federal Acquisition Regulation (FAR) requires that the government generate an independent cost estimate. This government cost estimate will then be evaluated against the contractor estimate.

> Cost estimates form the basis for management decisions by Fleet and Naval Sea Systems Command (NAVSEA) customers in the planning, programming, and budgeting of repair and modernization work, including repair work brokering decisions, and in determining the developmental costs for ship alterations. (Commander, Fleet Forces Command, 2007, p. 5-1)

Regional Maintenance Centers (RMC) produce five types of cost estimates in the process of ship repair, ship alterations, or ship modernizations. The five types of contract estimates are Pre-contract Award, Post-contract Award, Preliminary Costs, Contract Costs, Predicted End Costs, and Costs for Contract Modifications.

Cost-estimations are further broken down into five different classifications: Class A, C, D, F and X. Class A is the “detailed cost estimate” and should be extensive and precise. Class A estimates are based on the detailed engineering drawings, material lists, and man-hours required. The variance of Class A estimates should not exceed 10% . Class C is the “budget quality estimate” that is prepared for ship repair work prior to the start of a ship's availability period[7]. Class C estimates are considered to be the best to use in the determination of a budget submission. The variance associated with Class C should not exceed 15%. Class D estimates are generally considered feasibility estimates. As they are based on incomplete information D estimates are exploratory in nature. The variance in a Class D estimate should not exceed 20%. Ballpark estimates fall into the Class F designation and are based on gross approximations. These estimates are often driven by time and information limitations and can have a variance not to exceed 40%. Class X estimate is called a "directed estimate." These estimates can either set a total cost restriction or be used for modification to the Classes A-F estimates.

To prepare an accurate and viable assessment, the estimator must understand the current estimating environment and have a keen awareness of the required tasks. A typical repair sequence is shown in Figure 4.

TYPICAL REPAIR SEQUENCES				
WORK ACTIVITY	SEQUENCES			
	A	B	C	D
1	REMOVE	OPEN	PREP AREA	RIP OUT
2	DISASSEMBLE	INSPECT	MASK	FOUNDATION
3	INSPECT	REPAIR	PAINT	LAND EQUIP
4	REPAIR	CLOSE	CLEAN	HOOK UP
5	TEST	TEST	TOUCH-UP	COLD CHECK
6	REINSTALL		CLOSE OUT	HOT CHECK
7	TEST			TEST

Figure 4. Typical Repair Sequences
(Commander, Fleet Forces Command, 2007, pp. 5-11)

Expert consultation is recommended whenever the estimator does not have a clear understanding of the activities that must be accomplished. Once the estimator understands the "what" and "how", he will prepare a detailed listing of activities to be

[7] Ship's availability is a period of time that the ship undergoes maintenance and/or upgrades at an industrial activity.

estimated separately. As this list is often driven by the estimator's experience, inexperienced estimators tend to break the work down into more activities than an experienced estimator. Once this list is complete, the estimator can then began to assign labor and material costs to the specific activities.

E. TERRESTRIAL LASER SCANNING TECHNOLOGY

> In terms of its impact on the more broadly defined "science of measurement," I believe 3D laser scanning has the potential to be the most important technological breakthrough of anything that has come before it. (Roe, 2007, p. 3)

The use of terrestrial laser scanning is becoming commonplace in many industries. Sales of terrestrial 3D laser scanning hardware, software and services reached $253 million in 2006, a growth of 43% over 2005 (Greaves and Jenkins, 2007). Figure 5 contains data that illustrates the dramatic increase in usage. Because laser scanning provides businesses or organizations a cost-effective and timely way of capturing existing conditions, there is no indication of a slowdown in the market. According to Spar Point Research:

> Developing accurate as-built /as-maintained documentation is in the critical path of all revamp projects, and maintenance, repair, retrofit, revamp and decommissioning need up-to-date documentation of existing physical conditions of the asset or structure. Yet this information is almost never available when needed. The most widely used manual techniques for collecting it remain slow, expensive and error-prone. As a result, engineering and construction work suffer from estimating errors, inaccurate bids, design and fabrication mistakes, expensive field rework, delays, penalties, lost capacity, and squandered profit and opportunity. While estimates vary by industry, many believe that from 2% to 5% project cost savings can be achieved with better capture of existing conditions information and intelligent use of this information to inform design and constructions work processes. (SharePoint LLC, 2007, p. 1).

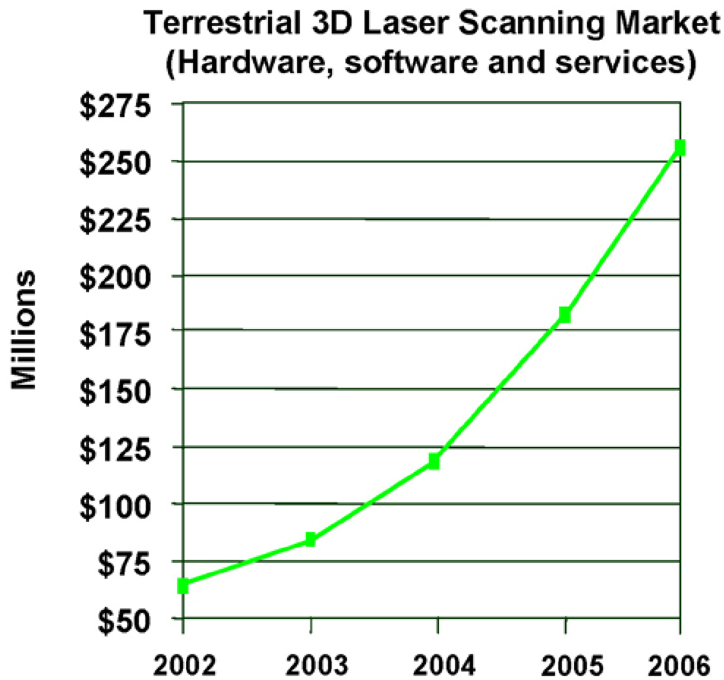

Figure 5. 3D Laser Scanning Market
(Greaves and Jenkins, 2007)

Most manufacturers' laser scanners use a mirror to deflect a laser onto a target space or object. The laser light is scattered by the object or objects within a space. The scattered light is then collected by a video camera located at a precise triangulation distance from the laser source. The surface points of the objects are then computed using trigonometry. The incorporation of a digital camera allows for the simultaneous, 360-degree field-of-view capture of a color photograph of the target. Once the capture phase is complete, the laser scanners automatically execute proprietary point processing algorithms to process the captured image. The systems can generate an accurate digital 3D model of the target space, automatically fuse image texture onto 3D model geometry, export file formats ready for commercial high-end design and import into 2D and 3D Computer Aided Design (CAD) packages.

There are many advantages associated with the use of terrestrial laser scanning. The primary advantage of laser scanning is that the process is a fast, non-contact way of obtaining very detailed surface point measurements of an object or space. Laser scanning can be especially beneficial in the reverse engineering of an object that has very complex geometries. Whereas a touch probe system can be "fooled" by certain geometries, the laser scanner is much more dependable and less prone to error. In the absence of detailed drawings, laser scanning can provide detailed information on an object or space, which can allow more accurate planning, modernizations or renovations.

There are many options for an organization that wants to implement laser scanning models and capture technologies. The Naval Undersea Warfare Center (NUWC) recently purchased the DS-3060 Surveyor from Laser Design to reverse-engineer components with complex geometries to facilitate competitive bidding. In addition to the DS-3060, NUWC also purchased the SLP-330 laser scanning probe. The SLP-330 does not require an operator, weighs less than one pound and has the capability to capture 50,000 points per second. This capture rate far exceeds the rate of a coordinate measure machine (CMM). According to NUWC, "The time needed to reverse engineer a typical component, including both measurement and modeling time, has been reduced from 100 hours with a CMM to 42 hours with a laser scanner (Laser Design 2007, ¶ 1). This reduction in the time needed to capture data allowed NUWC to realize a $250,000 cost savings.

Research conducted by NSRP (2005) evaluated products from Faro, Leica, Z+F, VisiImage and 3Dguru. In this study, NSRP used the different products to prototype a process for ship check data capture that could be applied to the Fleet and shipbuilding industry. The study was conducted on Torpedo Weapons Retrieval (TWR) ship in Newport, RI. NSRP, in conjunction with commercial partners, did data capture in the engine room, main deck aft and pilot house. Initial findings of the study indicated that 3D laser scanning technology required optimal lighting. The laser was not affected by minimal ship roll due to sea-state. Findings also indicated that shiny objects inhibited accurate point data. Preliminary conclusions of the study were:

- 3D laser scanning technology process has several potential benefits to shipyard during:
  - Overhaul and repair
  - Ship alterations
  - New construction
  - Facilities re-design

F. COLLABORATIVE TECHNOLOGY

Businesses and organizations are constantly attempting to improve their product development process. To improve the process, the organization has to address a variety of challenges. These challenges can include:

- Frequent design changes
- Legacy systems that cannot communicate because of incompatible data
- Current regulatory compliance

In the drive to meet these challenges, organizations are looking to enterprise solutions to increase their competitive position. PLM is one such solution.

CIMdata[8] defines PLM as:

> The strategic business approach that puts your products and services, and the processes by which they are defined at the heart of your company, directly linked to your business strategy. PLM empowers the business, enables product and process innovation, and enhances both top and bottom line business performance. In its early days PLM created competitive advantages. In today's global economy, PLM is a competitive necessity. (CIMdata, 2007, p. 2)

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[8] CIMdata is a consulting firm with over 20 years of experience in strategic IT applications and is an acknowledged leader in the application of PLM and related technologies (CIMdata, 2007a).

A common misconception is that PLM is a technology solution applied to solve problems or increase efficiency in business. PLM cannot be viewed as a single product but as a collection of both software tools and identified processes that, when integrated, create efficiencies. PLM can be seen as an integration of software tools with methods, people, and processes across all stages of a product's development. PLM is one of the four cornerstones of a corporation's information technology structure (Evans, 2004, p. 2).

Figure 6. PLM as a cornerstone of IT structure
(Evans, 2004)

PLM's impressive market growth can be seen in Figure 7. As long as more organizations realize the strategic benefits of managing the entire lifecycle of a product, this growth is forecasted to continue. The CIMdata research predicts that by 2009 the overall PLM market will be approximately $25 billion (CIMdata, 2005, slide 8). Some specific benefits of utilizing PLM technology are:

- A ~40% improvement in product change cycle-times
- A 15-30% reduction in prototypes
- A 40% reduction in lead-time
- A 25% productivity increase in design engineering
- Reduced development time for a household product by 75%
- Reduced time to cost a product from 5 days to 5 minutes
- Reduced a engineering review process by 83% (CIMdata, 2002, p. 9)

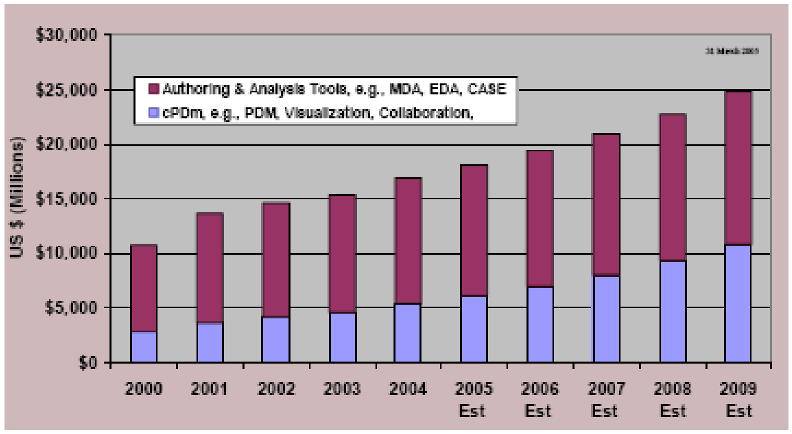

Figure 7. PLM Market Growth History and Forecast
(CIMdata, 2005, slide 8)[9]

An example of a successful PLM technology is UGS PLM software. UGS recently won numerous lucrative contracts across various industry and global areas. UGS utilizes a Service Oriented Architecture (SOA) in its PLM solutions. SOA-based PLM solutions provide the ability to expand the level of functionality available, improve the users work experience within the PLM environments, and reduce the cost and complexity of deploying and maintaining a distributed PLM environment (CIMdata, 2006, p. 6). UGS' SOA architecture, to be complete with the release of Teamcenter 2007, will give their customers unparalleled ability to upgrade their PLM technology.

G. IMPROVED ENGINEERING DESIGN PROCESS

The Navy has been moving toward the establishment of a common interoperable IT framework in the areas of ship construction and lifecycle management enterprises. NDE and Integrated Shipbuilding Environment (ISE) are results of this vision. The NDE will act as a central repository of data concerning ship repair, maintenance and modernization. The objective of the ISE is:

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[9] CIMdata segments the overall PLM market into two primary sub-sectors: PLM information authoring and analysis applications (Tools), and collaborative Product Definition management (cPDm) (2005).

> To improve shipyard interoperability by expanding the deployment of ISE to designing, developing and demonstrating prototype exchanges of CAD and CAE data for information describing compartment geometry and properties, and enabling CAD-in-dependent interchanges of steel fabrication work packages. (NSRP, 2007, p. 1)

The Improved Engineering Design Process (IEDP) currently being developed by Naval Sea Systems Command (NAVSEA) is an attempt to:

> Improve productivity, reduce cost, improve design processes, collect technical data quickly, and allow a greater sharing of information between all activities involved in lifecycle management, modernization and maintenance programs using an easy on-line collaboration process. (Stout & Tilton, 2007)

Central to the IEDP is the 3D terrestrial laser scanning to acquire as-built images of shipboard spaces for repair, maintenance and modernization activities. To promote integrated design environments and cross-functional collaboration, the IEDP will use UGS' Teamcenter PLM solution. Within the IEDP, each ship will have an individual "folder"[10] that contains all the relevant data about that ship. These folders will enable the IEDP to address the needs of ship design and sustainment/modernization throughout the ship's lifecycle.[11] The IEDP fills a void that has long existed in the shipbuilding industry. Benefits currently realized in the IEDP include[12]:

- Enabled Lean Six Sigma implementation for model/drawing development and sustainment processes that leverage 3D scanning and collaborative environment.
- Reduced site visits by ship check planning team.
- Captured data can be used to verify dimensional information anytime after site visit (reuse).
- 3D models can be used for many applications such as:

[10] "Folder" is a concept that acts as a central database for all information on a specific ship. It can be accessed and updated so as to maintain the most up-to-date data for a ship (Stout, 2007,August 10).

[11] Common lifecycle for a Navy ship is 30-40 years (Stout & Tilton, 2007).

[12] Taken from directly from Seaman (2007).

    - Preplanning.
    - Generating cost estimates.
    - Virtually reviewing tasks with contractors.
    - Perform what-if scenarios for rip outs and installation of new equipment.
- Engineering collaboration allows cross-functional effort on the same project and data exchange between remote sites.
- Improved Configuration Management and Validation processes:
    - Automated Identification Technology (AIT) (e.g., Bar Codes, RFID).
    - ILS Product Management and visibility (Stout and Tilton, 2007).

Figure 8 below provides a visual representation of the IEDP architecture as envisioned by NAVSEA.

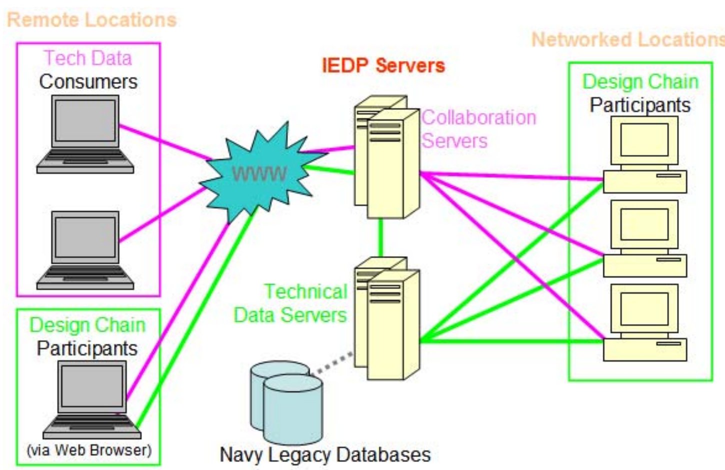

Figure 8. IEDP Architecture
(Stout and Tilton, 2007)

Crucial to the success of the IEDP is the idea of Naval Open Architecture (OA). Because of its modular design and open standards for key interfaces, OA will allow software components to work across various systems. It also provides for interoperability between software components on local and remote systems. According to Admiral Mullen in a memorandum for the Assistant Secretary of the Navy for Research, Development and Acquisition:

> Naval OA leverages open business models for the acquisition and spiral development of new systems that enable multiple developers to collectively and competitively participate in cost-effective and innovative capability delivery to the Naval Enterprise." (Mullen, 2006)

Execution of the IEDP solution for NAVSEA is currently being done by SIS under a $1.8 million FY 2007 appropriation. Within IEDP, engineers and managers will have unprecedented access to view as-built images and related project information in a virtual, collaborative environment. The visions of a "cradle to grave" view of an individual hull or ship class can be realized through the IEDP. Access to lifecycle information throughout a ship's life will provide a more accurate picture of total cost of ownership of our Naval assets.

H. LEAN SIX SIGMA

Albert Einstein once said, "We cannot solve our problems with the same thinking that we used to create them."[13] Realizing the significance of this statement, a broad range of businesses, including DoD, have embraced L6S to reengineer their business processes.

> To this end, the Department of the Navy (DoN) is committed to enterprise transformation and continuous process improvement through L6S activities. (LeValley & Fairclough, 2007, p. 1)

Lean Six Sigma (L6S) is defined by the Lean Six Sigma Institute as:

> A business improvement methodology that maximizes shareholder value by achieving the fastest rate of improvement in customer satisfaction, cost, quality, process speed, and invested capital. (Lean Six Sigma Institute, 2007)

"Lean" in L6S is focused on the elimination of non-value adding activities. In a lean system the goal is continuous process improvement based on customer value, elimination of waste and process perfection. Improved cycle-times are a result of a "lean" system. Six Sigma in Lean Six Sigma utilizes the Define-Measure-

[13] Quoteworld.org, retrieved 14 August 2007, http://www.quoteworld.org/quotes/4091.

Analyze-Improve-Control (DMAIC) approach to improve processes. Six Sigma is about reducing variation and producing repeatable processes. Another goal of L6S is the creation of customer satisfaction. When utilized, Lean Six Sigma provides a method for improving the process, for focusing on removing barriers and for eliminating non-value added process steps, thus providing better support to the people doing the work (LeValley & Fairclough, 2007, p. 4).

Because Lean Six Sigma has become so effective in modern business transformation activities, the adoption of initiatives is being implemented from the level of Assistant Secretary of Defense down to the command level. Throughout the DoD, all services have implemented guidance for how and when to apply L6S principles and some have established L6S training sites/programs for their personnel.[14] The DoN has joined with the American Society of Quality to develop a Lean Six Sigma Black Belt certification process (Coulomb, 2006, p. 1).

Naval Supply Systems Command (NAVSUP) recently completed a Lean Six Sigma project to streamline the bearer-walkthrough for high priority requirements. To reduce Average Customer Wait Time (AWCT) by 50%, Fleet and Industrial Center (FISC) Pearl Harbor led the continuous process improvement effort. This successful effort is projected to produce $200K in savings over the next year and can be replicated at six other FISC sites (Defense Business Transformation, 2007, p. 5).

1. L6S Enabled By PLM

L6S and PLM are enterprise initiatives that focus on business value in the selection of tools and methodologies (Affuso, 2004, p. 1). The DoD is continuously seeking ways to improve quality, process efficiency, strategic alignment and sustainable growth to get the most out of its scarce resources. Lean Six Sigma is

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[14] DoN currently has 3,399 L6S Green Belt trained, over 4,400 L6S Champion trained, and 935 L6S Black Belts. (Defense Business Transformation, 2007, p. 1).

the current method to achieve these desired goals. Common benefits of L6S initiatives and PLM are listed in Figure 9:

Proven Benefits of Six Sigma	Proven Benefits of PLM
□ Productivity increases □ Cycle time reduction □ Higher throughput □ Reduced defects □ High levels of outgoing quality □ Standardized improvement methodology across the organization □ A set of techniques and tools to simplify improvement efforts □ Greater customer satisfaction and dramatic improvement to the "bottom-line". □ Improve/reengineered processes	□ Productivity increases □ Cycle time reduction □ Higher throughput □ Reduced defects □ High levels of outgoing quality □ Fast easy access to information □ 100% BOM accuracy □ Controlled access □ Improved collaboration with customer □ Improved Reuse □ Technology to simplify and control improvement efforts □ Greater customer satisfaction and improvement to the "bottom-line" □ Effective and efficient process control not possible otherwise

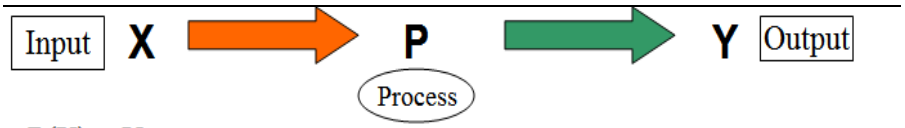
Figure 9. Proven benefits of Six Sigma and PLM
(Affuso, 2004, p. 4)

PLM tools capture, store and distribute longitudinal data necessary for accurate and reliable statistical measures. Lean Six Sigma provides the statistical measure of factors to help organizations meet desired goals. Ship construction, maintenance, modernization and repair ship information are areas in which the DoD has struggled to keep accurate, longitudinal lifecycle information. Because of this lack of historical data, accurate cost-estimation and effective planning remain problematic. The collaborative environment created by PLM will allow all properly authorized entities to share historical information via a web-based portal. The shared data environment created by the PLM technology will reduce cycle-time and the associated change costs. Reduction of cost in the value chain will come from the increased collaboration with suppliers. These PLM benefits outcomes will enable the Navy and shipyards to meet targeted Lean Six Sigma goals. PLM technology utilized in the IEDP is helping NAVSEA attain its goal of a common, interoperable IT framework for ship construction and lifecycle management by providing data management and product change management to all stakeholders in a collaborative environment.

2. Lean Six Sigma Supported By KVA[15]

The KVA methodology provides a framework for quantitative analysis of knowledge assets in an organization and has been applied in academic research and various business consultations for nearly 20 years. "KVA theory is based on an entropic concept, which is predicated upon changes in the environment" (Housel and Bell, 2001, p. 95). As organizations process inputs, value is added to the original input as it is transformed into an output. The value that is added during the process is proportionate to the amount of change necessary to effectuate the transformation as shown in Figure 10. Therefore, a unit of change is simply considered as a unit of complexity. This assertion provides a means to measure all outputs in common units.

[15] This section taken entirely from Seaman (2007).



P(X) = Y

Fundamental assumptions:

1. If X = Y no value has been added.
2. "value" ∝ "change"
3. "change" can be measured by the amount of knowledge required to make the change.

So "value"∝ "change" ∝"amount of knowledge required to make the change"

(Principle of replication)

Figure 10. Fundamental Assumptions of KVA
(Housel & Bell, 2001)[16]

Lean Six Sigma has two key methodologies: DMAIC (Define, Measure, Analyze, Improve and Control) and DMADV (Define, Measure, Analyze, Design and Verify) (Affuso, 2004, p. 5). Regardless of which methodology is used, measurement is a primary means to determine if the initiative is having the desired results. When enterprise implementations are initiated without metrics, there is no way to measure the value achieved, and that often results in a failed implementation. A client of UGS (a market leader of PLM products) explains the importance of measurement in the following way:

- We don't know what we don't know.
- If we can't express what we know in the form of numbers, we really don't know much about it.
- If we don't know much about it, we can't control it.

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[16] "The principle of replication states that, given that we have the knowledge necessary to produce the change, then we have the amount of change introduced by the knowledge. By definition, if we have not captured the knowledge required to make the changes necessary to produce the output, we will not be able to produce the output as determined by the process. This allows a test to determine if the amount of knowledge required to produce an output has been accurately estimated" (Housel & Bell, 2001, p. 94).

- If we can’t control it, we are at the mercy of chance (Affuso, 2004, p. 7).

Performance metrics for productive DoD assets may use many different units of measure for benefits. It is easy to discuss cost because it is usually monetized, but discussing value in a non-profit environment proves much more difficult. KVA methodology provides a way to measure value as common units of output (dollars, for instance) and it provides a more accurate comparison for developing key metrics supporting Lean Six Sigma initiatives in the DoD.

A metric commonly used in business and government is ROI. ROI can be derived by subtracting the cost to produce an output from the revenue, or value, generated by the output and dividing that value by the cost (Rev-Cost/Cost). The denominator, cost, is usually easy to determine and quite reliable. The numerator, revenue, can be a bit more difficult to determine especially in government and non-profit organizations. It is difficult to estimate ROI on organizational assets such as IT systems, but KVA provides a framework to allocate revenue to productive assets by describing all outputs in common units. Consequently, the DoD can utilize a reliable and standardized measure of value for ROI or other metrics that require a quantitative measurement of value in support of Lean Six Sigma initiatives.

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III. PREVIOUS RESEARCH

A. SEAMAN'S ANALYSIS AND FINDINGS

In 2007, LT Seaman conducted research which evaluated:

> Will 3D terrestrial laser scanning and PLM technologies provide better ROI for the Navy in the SHIPMAIN environment of the Fleet Modernization Plan than are currently being realized? (Seaman, 2007, p. 3)

In his work, LT Seaman applied LT Komoroski's[17] research, with appropriate conditional modifications, to the SHIPMAIN process. The potenti**al** cost-savings and reduction in cycle-time attributed to this application were then evaluated. "An as-is analysis will include the SHIPMAIN process, Phases IV and V, as defined in current directives and once reliable Knowledge Value Added (KVA) estimates are obtained, the process will be reexamined factoring in the capabilities of 3D terrestrial laser scanning and PLM technologies for a to-be model "(Seaman, 2007, p. 3).

The as-is baseline was developed through interviews, conversations and correspondence with a select group of subject matter experts (SMEs) from NAVSEA. A group interview with 3 SHIPMAIN SMEs was conducted at NAVSEA, Washington Navy Yard, DC. Each of the SMEs had accumulated over 30 years of experience in the areas of ship maintenance, repair and modernization. Using business rules from Phases IV and V, the SMEs were interviewed about the amount of knowledge required, average learning time (ALT), and relative learning time (RLT) required for each of the core processes. With regards to the reliability of the data, "SMEs provided individual and uninfluenced RLT and rank order estimates which led to a correlation of greater than 80%, thereby establishing a high level of reliability on the ALT figures obtained" (Seaman, 2007, p. 32).

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[17] LT Komoroski's research will be reviewed in the next section.

To develop an accurate as-is process, LT Seaman first identified 8 core processes in Phases IV and V of the SHIPMAIN. These 8 core processes were identified from the SHIPMAIN business rules. All Naval vessels completing an overhaul/refit will be affected by these core processes. The core processes in phase IV are made up of blocks 250-280. For phase V the core process are blocks 300-330. LT Seaman also noted that phases IV and V are still not widely used at all shipyards due to their relative early stage of development. The core processes are identified in Figure 11.

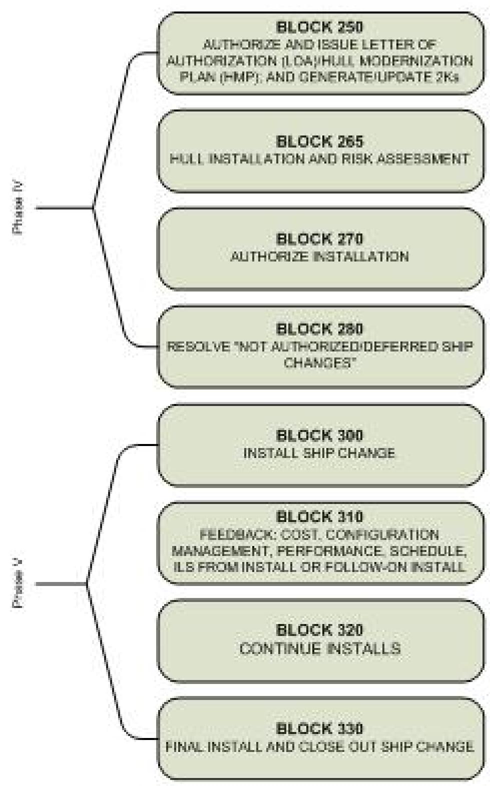

Figure 11. SHIPMAIN Core Processes
(Adapted from Commander, Naval Sea Systems Command, 2006)

The results of the KVA analysis conducted on the as-is scenario is depicted in Table 1. The outcomes were based on the surveys and interviews conducted with NAVSEA SMEs and data drawn from NDE.

As Is SHIPMAIN Process Overview

Core Process	Process Title	Number of Employees	Total Benefits	Total Cost	ROK	ROI
Block 250	Authorize and Issue Letter of Authorization (LOA)/Hull Maintenance Plan (HMP); Generate 2Ks	9	$22,619,472	$5,311,299	426%	326%
Block 265	Hull Installation and Risk Assessment	44	$94,928,918	$130,071,059	73%	-27%
Block 270	Authorize Installation	4	$24,710,347	$3,161,555	782%	682%
Block 280	Resolve "Not Authorized/Deferred SC	1	$3,706,552	$619,523	598%	498%
Block 300	Install SC	46	$94,722,998	$40,617,720	233%	133%
Block 310	Feedback: Cost, CM, Performance, Schedule, ILS	2	$1,853,276	$619,523	299%	199%
Block 320	Continue Installs	5	$4,633,190	$3,068,367	151%	51%
Block 330	Final Install, Closeout SC	1	$926,638	$309,762	299%	199%
			$248,101,392	**$183,778,809**	**135%**	**35%**

Table 1. SHIPMAIN Phases IV and V As-is Core Process Model
(Seaman, 2007, p. 34)

The first notional environment, the to-be scenario, evaluated the effects of reengineering the process to include 3D laser scanning and a suite of PLM technologies. The 3D laser scanning allowed for the generation of accurate representations of the spaces scanned. These 3D images can then be easily transferred via the network or stored in data repository for future reference. The PLM suite allowed all relevant stakeholders to have near real-time access to the highly accurate 3D laser scans. The cost savings attributable to the addition of 3D laser scanning and PLM are depicted in Table 2.

Core Process	Process Title	Annual As-Is Cost	Annual To-Be Cost	Difference (Cost Savings)	As-Is ROI	To-Be ROI
Block 250	Authorize and Issue Letter of Authorization (LOA)/Hull Maintenance Plan (HMP); Generate 2Ks	$5,311,248	$2,287,671	**$3,023,577**	326%	**565%**
Block 265	Hull Installation and Risk Assessment	$130,060,112	$63,437,554	**$66,622,558**	-27%	**155%**
Block 270	Authorize Installation	$3,161,600	$3,217,805	**($56,205)**	682%	**668%**
Block 280	Resolve "Not Authorized/Deferred SC	$619,424	$427,964	**$191,460**	498%	**766%**
Block 300	Install SC	$40,616,160	$33,433,420	**$7,182,740**	133%	**183%**
Block 310	Feedback: Cost, CM, Performance, Schedule, ILS	$619,424	$242,107	**$377,317**	199%	**665%**
Block 320	Continue Installs	$3,068,520	$2,510,944	**$557,576**	51%	**131%**
Block 330	Final Install, Closeout SC	$309,712	$304,059	**$5,653**	199%	**205%**
	Totals:	**$183,766,200**	**$105,861,524**	**$77,904,676**		

Table 2. As-is and To-be Cost and ROI Value Differences
(Seaman, 2007, p. 46)

Approximately 86% of the potential cost savings can be found in the core process of block 265. The use of 3D laser scanning tools significantly impacts block 265.1 by enabling the planning yard to acquire very precise images and produce their drawings in a highly accurate and electronically transferable 3D format as opposed to paper drawings that have to be delivered and are difficult to update.

The cost saving of approximately $78 million takes into account the expense incurred by implementing the 3D laser scanning and PLM suite technologies. As 3D laser scanning and PLM technologies mature, and work processes are modified to maximize their potential, cost savings and ROI should continue to improve over time (2007, p. 46).

B. KOMOROSKI'S ANALYSIS AND FINDINGS

LT Komoroski's research identified seven sequential core processes, shown in Figure 12, utilized by planning yards to accomplish ship alterations on US Navy surface ships. A further breakdown into the sub-processes is shown in Figure 13. A baseline as-is environment was modeled and compared to notional environments representing "maximum utilization of the new IT resources" (Komoroski, 2005, p. 44). The as-is baseline was developed through extensive interviews with SMEs at the Puget Sound Planning Yard. "Key KVA data points of actual learning time (ALT), ordinal ranking, and relative learning time (RLT) were compared and a correlation of greater than 80% was attained, proving the estimates as credible" (Komoroski, 2005, p. 23).

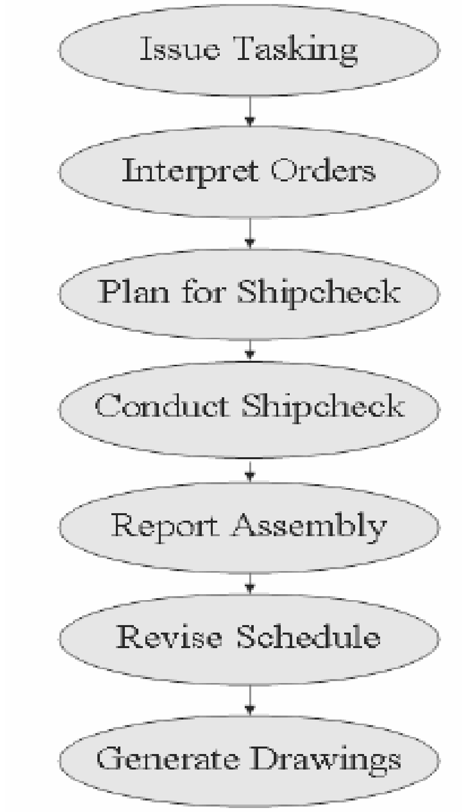

Figure 12. Planning Yard Core Processes
(Komoroski, 2005)

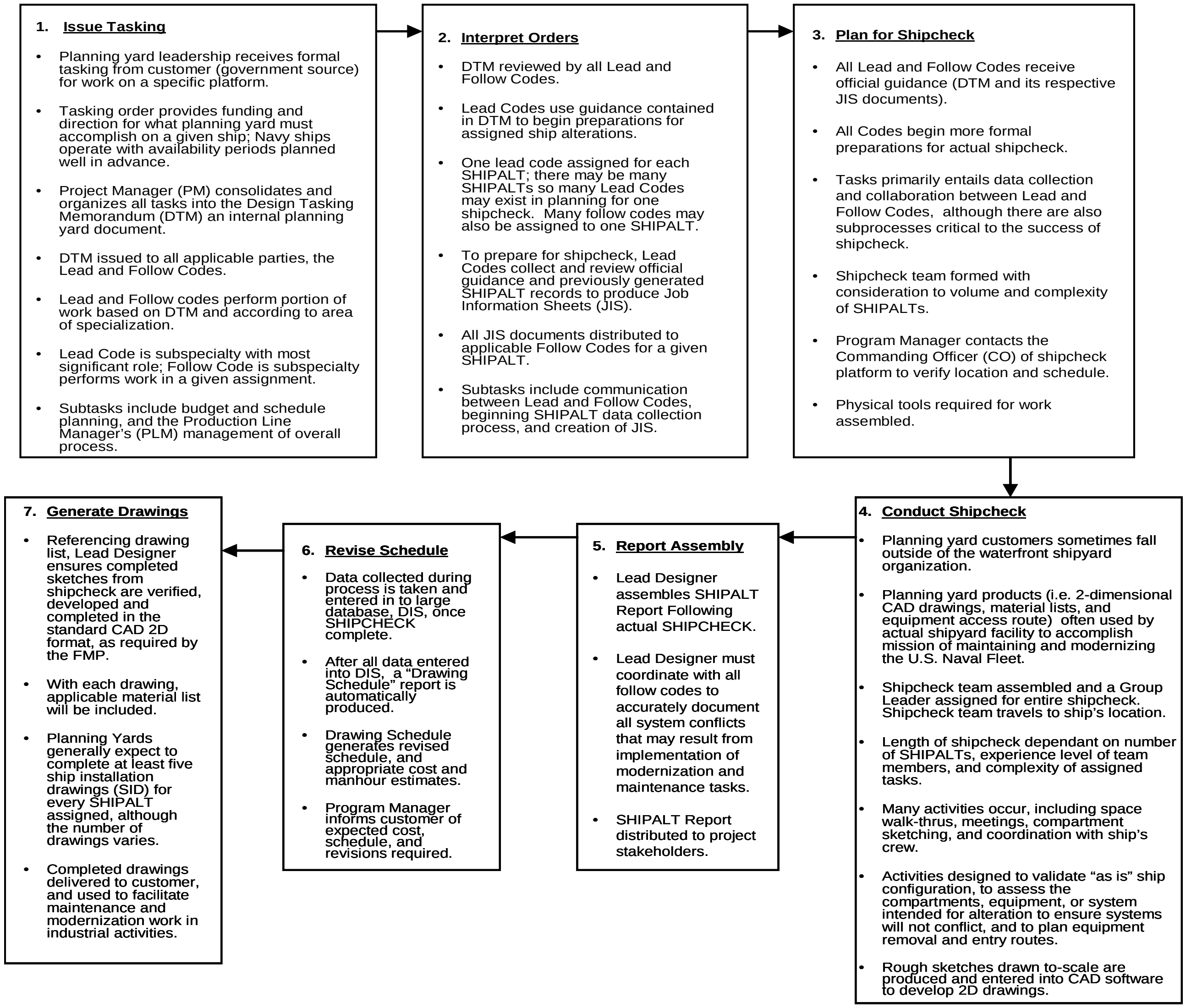

Figure 13. Planning Yard Core Processes
(Komoroski, Housel, Hom, & Mun, 2006)

In the to-be scenario, LT Komoroski evaluated the effects of adding 3D laser scanning to the as-is baseline. Approximately $45 million was spent annually in the as-is environment to execute the defined shipyard planning process cycle 40 times across the four public shipyards. As a result of the addition of 3D laser scanning to the planning process cycle, costs were forecast to drop 84% to less than $8 million as seen in Table 3. Introduction of 3D laser scanning in the to-be environment had a profound effect on process steps 3, 4 and 7 leading to a cost savings of nearly $37 million (Komoroski et al., 2006).

LT Komoroski also evaluated a second notional environment, the radical-to-be scenario. This to-be scenario added both 3D laser scanning and a collaborative PLM suite of software to the as-is baseline numbers. Cost savings of approximately $40 million could be realized from this scenario, a 90% reduction. This reduction came, from increased savings in process steps 3, 4 and 7 and additional savings realized in steps 2 and 5.

	Process Title	"AS IS"	"TO BE"	"RADICALTO BE"	"AS IS" & "TO BE" Cost Savings	"AS IS" & "RADICAL" Cost Savings
1	ISSUE TASKING	$173,500	$173,500	$173,500	$0	$0
2	INTERPRET ORDERS	$520,000	$520,000	$328,000	$0	$192,000
3	PLAN FOR SHIP CHECK	$1,655,000	$714,000	$374,500	$941,000	$1,280,500
4	CONDUCT SHIP CHECK	$2,604,500	$1,364,000	$1,041,000	$1,240,500	$1,563,500
5	REPORT ASSEMBLY	$235,000	$235,000	$122,000	$0	$113,000
6	REVISE SCHEDULE	$131,000	$131,000	$131,000	$0	$0
7	GENERATE DRAWINGS	$39,386,000	$4,716,000	$2,319,000	$34,670,000	$37,067,000
	TOTALS	**$44,705,000**	**$7,853,500**	**$4,489,000**	$36,851,5000	$40,216,000

Table 3. KVA Results—Analysis of Costs
(Komoroski et al., 2006)

LT Komoroski's research was focused on the core processes of the planning yard as shown in Figure 2. When viewed in respect to the overall process leading to installation, modernization and repair of surface ships, the planning yard processes could be considered a small segment of a much larger process. Through application of 3D laser scanning and PLM technologies to the SHIPMAIN process as a whole, the impact of these technologies can be more readily and accurately evaluated.

Because of the potential benefits of new technologies on the ship check process, LT Komoroski also reviewed the NSRPs' Ship Data Capture Project 2005. This project, funded by NSRP, evaluated the use of laser scanning, close-range photogrammetry,[18] and other technologies to create as-built ship conditions digitally. The captured data can then be used to create 3D electronic models and used with PLM technologies to provide cost effective solutions to the lifecycle cost management of ships. The preliminary results, depicted in Figure 14, were very promising.

SMALL SHIP CHECK:

	Traditional	Laser Scanning	Realized Savings
Cost	$9,351	$6,398	32%
Labor Hours	112	72	36%

LARGE SHIP CHECK:

	Traditional	Laser Scanning	Realized Savings
Cost	$47,650	$26,465	44%
Labor Hours	660	336	49%

Figure 14. NSRP Ship Check Data Project Preliminary Results
(Komoroski et al., 2006)

Specific benefits from the software and hardware tested include:

- Creation of as-built 3D models and validation of as-built models to design models
- Reduction of costly design changes, improved design capability
- Reduced construction rework
- Accurate factory-fabricate in lieu of field-fabricate
- Reduced ship check costs: fewer days, fewer personnel
- Elimination of return visits to the ship for missed measurements
- Obtaining measurements which are difficult or unsafe for human reach (NSRP ASE, 2005, slide 144)

[18] Photogrammetry is a remote sensing technology in which geometric properties about objects are determined from photographic images (Photogrammetry, 2007).

C. NSRP SHIP CHECK DATA CAPTURE APRIL 2006-JANUARY 2007

In April 2006, NSRP funded a follow-on project to the NSRP ship check data capture completed in 2005. By utilizing laser scanning technology to conduct ship checks on Maintenance and Repair vessels and a submarine, NSRP hoped to refine the data-capture process initially employed in the earlier study. In ship check data capture and post-processing, 3D laser scanning can reduce cost by 37% and time by 39% compared with traditional methods using tape measures, plumb bobs and 2D sketches (NSRP, 2007, p. 1).

The follow-on project resolved some issues identified in the initial FY05 ship check, specifically:

- Conducting a traditional total station survey during the ship checks is necessary to merge the laser scan data sets accurately.
- Scan data measurements need to be validated on-site during the first use of a scanner.
- Field-verifying the completeness of data collection before leaving the ship check site, through use of a software application such as Cyclone or LFM control software applications, is a must to eliminate return visits to the ship.
- Data analyzed and processed from the 3Dguru, FARO LS880, and Z+F Imager 5003 laser scanners in this project is accurate within the desired tolerance of +/-3/16 inch on the as-built measurements of components (Jenkins, 2007, p. 7).

It should be noted that although the report sang the praise of the laser scanning technologies, NSRP recognized that there is still a need for the traditional ship check approach in the areas where the laser and data capture are not effective.

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IV. METHODOLOGY PROOF OF CONCEPT

A. INTRODUCTION

The cost-estimation process flow portion of the SHIPMAIN process was developed from input and discussion with various stakeholders at NAVSEA, recognized cost-estimation SMEs and a thorough review of the current map of SHIPMAIN processes as identified in appendix D of the SSCEPM dated 11 December 2006. The SHIPMAIN process map establishes the business rules that govern the flow of a maintenance action as it moves through each of the five phases. The business rules are regularly reviewed and modified to ensure a proper balance between the rules and the business goals and requirements as identified by the Fleet Commanders. By analyzing the cost-estimation process across all five phases of the SHIPMAIN process this proof of concept will provide a more accurate representation of the cascading effects of cost-estimation.

The following proof of concept case will use the as-is process information compiled from interviews, conversations and correspondence with a select group of SMEs from NAVSEA and other recognized experts. A statistical analysis of their input will check for reliability. All estimates will be aggregated to reflect the cost and number of process executions averaged over five years. The KVA methodology will be applied to determine the potential effects of introducing 3D terrestrial laser scanning and PLM technologies into the cost-estimation portion of the SHIPMAIN process. The effects of adding 3D laser scanning and PLM technologies to phases IV and V have been evaluated by LT Seaman (2007). An analysis of adding only 3D laser scanning was conducted by LT Komoroski (2005) and NSRP (2006 & 2007). Information from both analyses are useful in the development of the notional scenario. An increased return on knowledge and investment, (ROK/ROI) provides proof of the positive effects of the addition of 3D and PLM to the cost-estimation process. The figures developed will be utilized in a comparison of the current as-is scenario to the to-be scenario using defendable future process estimates.

B. DATA COLLECTION AND METHODOLOGY

The researchers gathered aggregate data during an initial KVA knowledge audit conducted via survey and a group interview setting at NAVSEA, Washington Navy Yard, DC. A SHIPMAIN SME was present at the group interview and had over 30 years of expertise related to the SHIPMAIN process. A SME recommended by NAVSEA was also included in the initial KVA knowledge audit. This SME was a recognized expert in the area of cost-estimation and provided valuable guidance and information. The cost-estimation process flow-model developed from the business rules of the SHIPMAIN process guided the interviews and surveys.

1. Learning Time Method

The researchers analyzed this proof of concept using the Learning Time method[19]. A thorough review of current SHIPMAIN business rules and discussion with SMEs and other experts established the processes that constituted the core of the SHIPMAIN cost-estimation process, identified the inputs and outputs of those processes, and determined the frequency of core process iterations. To effectively apply the KVA methodology and properly identify and valuate the knowledge required for each process, the researchers established boundaries between the defined processes. They identified five core processes and developed detailed descriptions with information from the NAVSEA SMEs and from other organizations. The SHIPMAIN business rules were also critical to developing accurate descriptions of the core processes. Each core process requires a certain level of knowledge in one or more of the following areas: administration, management, scheduling, budgeting, basic computer skills, engineering, shipboard systems, logistics or project management.

The SMEs spent considerable time contemplating the amount of knowledge associated with each core process, and provided ALT estimates for each. The

[19] See appendix A for a detailed discussion of Learning Time.

established baseline level of knowledge for consideration was a GS-13 employee with 1 year of experience and a college degree (no field specified). The team of SMEs also provided individual and uninfluenced RLT and rank order estimates, which lead to a correlation of 99% and established a high level of reliability on the ALT figures obtained.

C. THE COST-ESTIMATION PROCESS FLOW IDENTIFIED IN SHIPMAIN

The current as-is cost-estimation process must be understood before the process can be reengineered or automated. The business rules of the SHIPMAIN describe six core processes, referred to as blocks, which affect the cost-estimation process. Each block has an official title to reference the core process it accomplishes as shown in Figure 15.

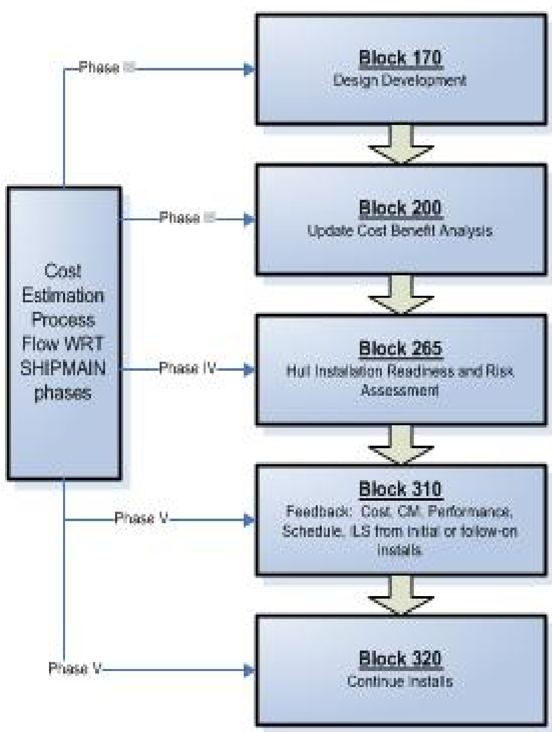

Figure 15. Cost-estimation Process Flow

Cost-estimation in SHIPMAIN is made up this chain of core processes and is executed for every Naval vessel as it approaches, enters and completes a shipyard availability period. Navy leadership establishes the schedule timeline and location for ship availabilities far in advance, but calendar dates and work assigned may be affected by budget considerations and other prioritization factors. The availability schedules may also be affected if world events trigger an unanticipated demand for operational Naval assets.

The core processes for SHIPMAIN cost estimating, phase III (block 170 and 200), phase IV (block 265), and phase V (block 310 and 320), are described in greater detail in appendix D. A key assumption for the purpose of this study is that cost-estimation is being conducted as described in the business rules listed in appendix D of the SSCEPM dated 11 December 2006.

D. KVA ANALYSIS OF AS-IS SCENARIO

A summary of the high level as-is KVA analysis is depicted in Table 4. These estimates were compiled from interviews of SMEs at NAVSEA and point estimates derived from high and low range estimates of the required data. All estimates contained in this analysis are as conservative and accurate as possible.

Cost Estimation SHIPMAIN: Core Process Level

Core Process	Process Title	Number of Employees	Total Benefits	Total Cost	ROK	ROI
170	Design Development	40	$ 360,388,939.26	$ 215,699,377.80	167%	67%
200	Update Cost Benefit Analysis	2	$ 5,660,559.26	$ 935,311.52	605%	505%
265	Hull Installation Readiness and Risk Assessment	44	$ 57,991,301.30	$ 95,759,387.57	61%	-39%
310	Feedback: Cost, CM, Performance, Schedule, ILS from Initial or follow-on Install	2	$ 1,132,111.85	$ 780,361.30	145%	45%
320	Continue Installs	5	$ 2,830,279.63	$ 3,864,962.77	73%	-27%
			$428,003,191	$317,039,401	135%	35%

Table 4. Cost-estimation SHIPMAIN: Core Process Level

1. Number of Employees

The number of employees value used to build this model represents the number of employees assigned to complete the given process for each cycle or iteration. The numbers assigned to blocks 265, 310 and 320 are based on interviews with SMEs from NAVSEA. The number of employees assigned to blocks 170 and 200 came from point estimates as explained above. By accounting for the number of personnel involved in each process, it can be determined how often knowledge is used. It also provides an approximate way to weight the cost of using knowledge in each process.

2. Times Performed in a Year

The researchers base estimations for the number of times each process is executed per year on the aggregated number of installation performed in that year. For each installation that occurs, an SCD is generated. Because of this relationship, the number of SCDs provides a reliable proxy for the number of installations. SMEs provided data and analysis which estimates an average of 20 SCDs are initiated per week leading to 1,040 SCDs generated annually. For the purpose of this study, only the SCDs that make it through block 320 will be analyzed. Once a SCD is through block 320 it is either approved for follow-on installs or cancelled.

3. Actual Learning Time

In order to determine the ALT from a common point of reference, researchers instructed the SMEs to imagine a baseline individual of a college graduate at the GS-13 civilian rank level with a year of experience in some sector of the shipyard industry. All experts understood that each process learning time estimate must adhere to the basic assumptions that knowledge is only counted if in use, and the most direct path to achieve a unit of output must be considered. Researchers broke down each core process into its component sub-processes and assigned respective ALT values for each sub-process. The ALT values for blocks 265, 310 and 320 were taken from the previous research conducted by LT Nate Seaman. The ALT values for blocks 170 and 200 were estimated using a high and low range value then conducting an average. The final ALT value for each core process is a summation of the sub-process ALT estimates. Finally, all ALT values are based on the following time assumptions:

- One year = 220 work days
- One month = 20 work days
- One week = 5 work days
- One day = 8 hours

4. Determining Value

To accurately account for knowledge embedded in the technology resources, the amount of automation in a given process must be identified. The percentage of automation associated with any given process ranges from 0 to 100. The amount of automation is directly related to how much knowledge is embedded in IT supporting the automation. The percent automation for blocks 265, 310 and 320 were taken from the previous research of LT Nate Seaman. The percent automation of blocks 170 and 200 were based upon a review of the SHIPMAIN business process and interviews with SMEs. The researchers then used this percentage of automation to calculate Total Learning Time (TLT), by dividing ALT by the percent automation attributable to a given process.

The researchers then multiplied the TLT by the number of employees and the resulting product by the number of times the process is performed in a year. They used that number to establish a Total Knowledge factor. The Total Knowledge factor is then multiplied by a price per common unit, based on market comparables, to derive the "value" of each process. The resulting number is then used as the numerator for determining ROK and ROI.

5. Market Comparables

The cost of government employees involved in the processes was estimated using the 2007 civilian pay chart. To account for various unique factors associated with a given job, civilian pay grade has associated "steps." All pay estimates are based on step six of the associated pay grade. To reduce variation locality pay differentials were not considered. IT cost is not include in the as-is analysis because basic computing hardware and software is utilized in every scenario. The as-is scenario assumes that each employee in this process has an email account, laptop or desktop computer with identical software, and access to a printer. To isolate labor costs, material, travel, and other miscellaneous costs are not included in this analysis.

By comparing the pay given to contractors that perform the same type and scope of work to that of the government employee, a market comparable value was established. The contracted base pay was on average 35% higher than the government employees. To establish this rate, benefits, locality pay differential and other variables were excluded and only base pay was considered. All government employee rates were increased by 35% to achieve the values for the market price used to establish a price per common unit of output.

6. As-is Process Data Analysis

To best capture the effects of adding 3D laser and PLM technologies to the cost-estimation process, the core processes had to be broken down into their respective sub-processes. The core processes and their sub-processes are presented in a table format. Each table contains the process instructions and values derived in the calculations.

a. Key Assumptions

This analysis is based on information collected from previous research by LT Nate Seaman (2007), LT Christine Komoroski (2005), SMEs from NAVSEA, and current directives/business rules. In this study, all maintenance and modernization efforts are assumed to occur as described in the current business rules listed in appendix D of the SSCEPM dated 11 December 2006. Maintenance and modernization actions can have significant variation with regards to number, manpower requirements, duration and complexity. After conducting extensive interviews with SMEs and conducting a thorough review of current directives, related research and existing data, the following assumptions were made:

- Blocks 170.1 and 170.2 are so closely related and overlapped that this study will treat them as one block.
- In the absence of available data, point estimates will be utilized by taking a high and low estimate and then averaging.
- On average, 20 SCDs are generated per week.
- Of the SCDs generated per year, only the SCDs that are approved for follow-on installs will be considered. Point estimate average of 63% based upon a high of 100% and a low of 25%.
- The market comparable labor rate is 35% greater than the government labor rate.

b. Block 170 KVA Analysis

Table 5 shows key KVA estimates used to determine the total process benefits, annual cost, ROK and ROI for block 170.

Block 170 Design Development													
	Sub process	Hourly Personnel Cost	Head count	Times Perf. Per Year	Time to Complete (Hrs)	Annual Personnel Cost	%IT	ALT (Hrs)	Total Knowledge	Total Benefits	Annual Cost	ROK	ROI
170.1/2	Develop Supporting Documentation, Equipment Specifications and class/system integration requirements. Determine applicable ship/class/site/flight unique characteristics.	$ 43.10	38	655	200	$214,570,061.68	25%	300	9956000	$358,502,086.18	$214,570,061.68	167%	67%
170.3	POA&M is required for equipment development and complete SCD	$ 43.10	2	655	20	$1,129,316.11	0%	40	52400	$1,886,853.09	$1,129,316.11	167%	67%
									Process Totals:	**$360,388,939**	**$215,699,378**	**167%**	**67%**

Table 5. Block 170 As-is KVA

In block 170, the goals are to complete engineering drawing, design and development of system/equipment specifications to produce design specifications (Commander, Naval Sea Systems Command, 2006, Appendix D). Associated sub-tasks are:

- Develop supporting documentation
- Develop equipment specifications
- Determine applicable ship/class/site unique characteristics
- Develop class/system integration characteristics

- Determine flight-unique characteristics
- POA&M is required for equipment development
- Complete SCD

An approved SCD, the supporting documentation, planned material list, planned removal list and planned cost estimates are all output from block 170.

In conjunction with a review of the business rules, point estimation was used in the development of the number of employees, ALT, percent automation and average time to complete for block 170. This estimation was achieved by determining a high value and low value for each process variable. The high and low numbers would then be averaged. This average was then used as the point estimate for the required value.

c. Block 200 KVA Analysis

Table 6 shows key KVA estimates used to determine the total process benefits, annual cost, ROK and ROI for block 200.

Block 200 Update Cost Benefit Analysis														
	Sub process	Hourly Personnel Cost	Head count	Times Perf. Per Year	Time to Complete (Hrs)	Annual Personnel Cost	%IT	ALT (Hrs)	Total Knowledge	Total Benefits	Annual Cost	ROK	ROI
200	Update CBA	35.70	2	312	20	$445,522.43	80%	24	157200	**$5,660,559.26**	**$445,522.43**	**1271%**	**1171%**

Table 6. Block 200 As-is KVA

The purpose of block 200 is to review the updated CBA of a SC in the detailed design phase in order to ensure the accuracy of the alteration total SC cost estimate in support of the phase III Decision Board approval/disapproval decision. Associated sub-tasks are:

- Assign the appropriate CBA reviewers to review SCD
- Analyze CBA data
- Provide comments to submitter as required
- Review and respond to CBA reviewer comments
- Forward package to decision board

The deliverables from block 200 are cost feedback (such as ROI), net present value, pay back period lifecycle costs and cost savings/avoidance numbers.

In conjunction with a review of the business rules, point estimation was used in the development of the number of employees, ALT, percent automation and average time to complete for block 200. This estimation was achieved by determining a high value and low value for each process variable and then averaging those numbers. This average was then used as the point estimate for the required value.

d. Block 265 KVA Analysis

Table 7 shows key KVA estimates used to determine the total process benefits, annual cost, ROK and ROI for block 265.

Block 265 Hull Installation and Risk Assessment													
	Sub process	Hourly Personnel Cost	Head count	Times Perf. Per Year	Time to Complete (Hrs)	Annual Personnel Cost	%IT	ALT (Hrs)	Total Knowledge	Total Benefits	Annual Cost	ROK	ROI
265.1	Installation Procurement, Design & Advance Planning	$24.62	35	655	160	$90,292,604.35	25%	40	1222667	$44,026,571.99	$90,292,604.35	49%	-51%
265.2	Hull Installation Readiness Review	$24.62	2	655	40	$1,289,894.35	80%	40	262000	$9,434,265.43	$1,289,894.35	731%	631%
265.3	Evaluate Maturity Status	$50.16	1	655	20	$657,135.87	0%	40	26200	$943,426.54	$657,135.87	144%	44%
265.4	Provide Risk Assessment	$50.16	1	655	40	$1,314,271.74	0%	56	36680	$1,320,797.16	$1,314,271.74	100%	0%
265.4.1	Formally Propose Install for Readniess Assessment and Auth.	$50.16	1	655	20	$657,135.87	0%	40	26200	$943,426.54	$657,135.87	144%	44%
265.5	Risk/Readiness Determination	$59.01	4	164	40	$1,548,345.39	0%	56	36736	$1,322,813.64	$1,548,345.39	85%	-15%
									Process Totals:	**$57,991,301.30**	**$95,759,387.57**	**61%**	**-39%**

Table 7. Block 265 As-is KVA

In block 265, the design in finalized, material is procured, pre-installation testing is performed and all required risk certification/assessments are obtained prior to installation. The identification of technical shortfalls, costs and operational impacts is developed in block 265. These items are used to clarify the resolution of any hull-level discrepancy. Associated sub-tasks are:

- Installation procurement, design and advanced planning
- Hull installation readiness assessment
- Installation readiness
- Submission of risk assessment

Because of its relative complexity, block 265 has many deliverables. These required deliverables are:

- Final drawings
- Hull-specific material
- Updated ILS
- Completed certifications
- SPM authorization
- Risk assessment (if needed)
- Approval or disapproval with requirements for initial installation plans

e. Block 310 KVA Analysis

Table 8 shows key KVA estimates used to determine the total process benefits, annual cost, ROK and ROI for block 310.

Block 310 Feedback: Cost, CM, Performance, Schedule, ILS, from initial or follow-on install														
	Sub process	Hourly Personnel Cost	Head count	Times Perf. Per Year	Time to Complete (Hrs)	Annual Personnel Cost	%IT	ALT (Hrs)	Total Knowledge	Total Benefits	Annual Cost	ROK	ROI
310	Provide feedback data to support future installation decisions	$29.78	2	655	20	$780,361.30	0%	24	31440	**$1,132,111.85**	**$780,361.30**	**145%**	**45%**

Table 8. Block 310 As-is KVA

As shown in this table, there is no automation for this process. The process involves taking the raw feedback data and manually entering it into required forms and databases. This manual process could become much more efficient with some form of automated tool leading to lower process cost and increased benefits.

The goal for block 310 is to verify that all planned installations for this SC have been completed. The only deliverable is a decision on whether this is the final installation.

f. Block 320 KVA Analysis

Table 9 shows key KVA estimates used to determine the total process benefits, annual cost, ROK and ROI for block 320.

Block 320 Continue Installs													
	Sub process	Hourly Personnel Cost	Head count	Times Perf. Per Year	Time to Complete (Hrs)	Annual Personnel Cost	%IT	ALT (Hrs)	Total Knowledge	Total Benefits	Annual Cost	ROK	ROI
320	Using feedback information from completed installs, determine impact on follow-on installs	$59.01	5	655	20	$3,864,962.77	0%	24	78600	**$2,830,279.63**	**$3,864,962.77**	**73%**	**-27%**

Table 9. Block 320 As-is KVA

As with block 310, block 320 has no automation. It is simply made up of using the raw feedback from previous installs to determine the impact on follow-on installs. This feedback is made up of the following:

- Cost
- CM
- Performance specifications in accordance with requirements
- Schedule
- ILS
- Quality assurance

Block 320 produces a risk assessment resolution, a closed 2K, a completed SCD with planned and actual cost and closeout of the SC in MP.

E. TO-BE PROCESS DATA ANALYSIS

This scenario represents a combination of notional and verified data to portray current activities contained in the SHIPMAIN process reengineered to maximize utilization of 3D laser scanning and PLM assets. Not every sub-process will be affected in this scenario; instead, only affected processes will be used for comparison. All others may be assumed static as described in their as-is state.

1. Cost of 3D Terrestrial Laser Scanning Technology[20]

The cost for laser scanning equipment and required software was provided by the IEDP Project Manager for SIS. SIS's IEDP Project Manager stated that the

[20] Because these numbers are current, sections 1-2 were taken directly from Seaman (2007).

current cost has not changed from the estimates LT Komoroski used in her 2005 research (B. Tilton, personal communication, May 16, 2007). For this study, the cost for IT used in LT Komoroski's 2005 study will be increased by 3% to account for inflation and will be amortized over a 10 year period. Cost and assumptions for the 3DIS are:

- Current inflation adjusted initial cost is $90,640 for one 3DIS scanner and its applicable software suite.
- Maintenance/upkeep annual cost estimate is 20% .
- Use estimate of 200 days per year.
- A lifespan estimate of 10 years
- The resulting cost per unit per day is $135.96.
- For analysis of the to-be KVA model, this cost is absorbed by the actual scanning process contained in block 265.1.

The six planning yards that support Naval surface force assets are:

- Bath Iron Works, Bath , ME
- Norfolk Naval Shipyard, Norfolk, VA
- Northrop Grumman Ship Systems, Avondale OP, New Orleans, LA
- Northrop Grumman Ship Systems, Ingalls OP, Pascagoula, MS
- Puget Sound (DET) Boston, Boston, MA
- Puget Sound Naval Shipyard, Bremerton, WA (NAVSEA Shipbuilding Support Office, 2007)

To properly account for the enterprise-wide cost of the 3DIS product, the daily cost was increased by a factor of six under the assumption that each planning yard received one scanner with the required software. Accordingly, the daily cost to introduce 3DIS across the enterprise would be $815.76.

2. Cost of PLM Technology

SIS is a Value Added Reseller of UGS' PLM suite of software called Teamcenter. Under the IEDP, Teamcenter products will be introduced to establish an Integrated Data Environment using team collaboration and configuration data management platforms. The Teamcenter suite contains the following specific product solutions:

- Community Collaboration
- Compliance Management
- Engineering Process Management
- Enterprise Knowledge Management
- Lifecycle Visualization
- Maintenance, Repair and Overhaul
- Manufacturing Process Management
- Portfolio and Program Management
- Reporting and Analytics
- Simulation Process Management
- Supplier Relationship Management
- Systems Engineering (UGS Corporation, 2007)

For the scope of this study, Community Collaboration, Engineering Process Management, Lifecycle Visualization, Portfolio and Program Management, Reporting and Analytics and the Supplier Relationship Management solutions will be considered. These solutions will be part of the complete PLM solution evaluated in the to-be model. Cost-estimation for these tools has proven to be difficult. According to a leading PLM provider,

> Identifying an accurate, average or generalized pricing schema for respective toolsets within the PLM space is almost unachievable. It is safe to say, however, that vendor's price-models have been decreasing over the years — (Anonymous, personal communication, June 2007).

To establish a reasonable cost for the Teamcenter solution, the following cost-estimation will be used:

- An assumption was made that PLM and Enterprise Resource Planning (ERP) initiatives are similar in cost and scope.

- DoD spent an average of $250 million per ERP initiative in FY 06 (Service Cost Estimating Organizations, 2007).
- The Department of the Navy (DoN) budget for FY 06 was $122.9 billion including supplemental transfers (Bozin, 2006)
- DoN budget for Ship Depot Maintenance was $3.72 billion or 3% of the entire DoN budget (Bozin, 2006).
- 3% of $250 million (the cost for an ERP) is $7.5 million.

The $7.5 million PLM solution will be deployed at the six planning yards listed earlier in this section and all SYSCOMs/TYCOMs supporting surface force combatant assets. The cost for the PLM suite will be amortized over 10 years with a 2% annual increase for the cost of version upgrades bringing the total cost to $9 million which will be amortized over a ten year period. It is assumed that the PLM software will be used 230 days per year making the daily cost of PLM software $3,913. This cost will be distributed equally across the cost-estimation portion of the SHIPMAIN process.

3. Reengineered Processes

The cost-estimation portion of the SHIPMAIN process was reengineered by adding 3D laser scanning tools and a comprehensive suite of PLM products to the as-is state. Implementation of 3D laser scanning tools will have the most effect on blocks 170 and 265. The addition these technologies will enable the planning yard to acquire images and output their drawings in a highly accurate and electronically transferable 3D format, as opposed to static installation drawings delivered on paper. In accordance with current FMP policy, the 3D scanning tools can also produce a 2D output. The PLM technologies will allow for the sharing of the generated 3D images across the enterprise that will allow all stakeholders real-time access to highly accurate as-built imagery through a single interface.

Core Process	Process Title	Annual As-Is Cost	Annual To-Be Cost	Difference (Cost Savings)	As-Is ROI	To-Be ROI
170	Design Development	$ 214,570,062	$ 91,999,022	**$122,571,040**	67%	487%
200	Update Cost Benefit Analysis	$ 1,129,316	$ 432,559	**$696,757**	505%	2517%
265	Hull Installation Readiness and Risk Assessment	$ 95,146,354	$ 42,612,154	**$52,534,200**	-39%	149%
310	Feedback: Cost, CM, Performance, Schedule, ILS from Initial or follow-on Install	$ 1,548,345	$ 179,362	**$1,368,983**	45%	1162%
320	Continue Installs	$ 780,361	$ 1,936,999	**-$1,156,638**	-27%	251%
	Totals:	**$313,174,438**	**$137,160,097**	**$176,014,341**	**35%**	**386%**

Table 10. As-is and To-be Cost and ROI Value Differences

4. To-be Data Analysis

By combining a review of the currently defined business rules with SME assessments, this study was able to model the notional to-be scenario. Each core process is described in terms of its sub-processes and the assumptions affecting key parameter changes from the as-is to the to-be scenario.

a. Block 170 To-be KVA Analysis

Table 11 shows all KVA estimates used to determine the total process benefits, annual cost and ROI of the notional to-be revision of block 170. Assumptions for block 170 are as follows:

- The PLM product suite would provide the means for increasing the amount of automation by 50% in blocks 170.1/2 and 170.3.
- A conservative estimate of 15% greater efficiency was applied to the times fired per year for blocks 170.1/2 and 170.3 due to automation.
- The addition of 3D laser scanning and PLM will allow for reducing personnel by 50% due to the increased automation.

Block 170 (To-Be) Design Development													
	Sub process	Hourly Personnel Cost	Head count	Times Perf. Per Year	Time to Complete (Hrs)	Annual Personnel Cost	%IT	ALT (Hrs)	Total Knowledge	Total Benefits	Annual Cost	ROK	ROI
170.1/2	Develop Supporting Documentation, Equipment Specifications and class/system integration requirements. Determine applicable ship/class/site/flight unique characteristics.	$ 43.10	19	655	170	$91,437,245.49	75%	300	14934000	$537,753,129.27	$91,437,245.49	588%	488%
170.3	POA&M is required for equipment development and complete SCD	$ 43.10	1	655	17	$561,776.62	50%	40	52400	$1,886,853.09	$561,776.62	336%	236%
									Process Totals:	**$539,639,982**	**$91,999,022**	**587%**	**487%**

Table 11. KVA Analysis of To-be for Block 170

b. Block 200 To-be KVA Analysis

Table 12 shows all KVA estimates used to determine the total process benefits, annual cost and ROI of the notional to-be revision of block 200. Assumptions for block 200 are as follows:

- Added automation, due to PLM, will allow for a 50% reduction in personnel.
- Percent automation will increase 15% to 95%.
- Review time will be reduced because of increased accuracy. Cycle-time will be reduced by 25%.

Block 200 (To-Be) Update Cost Benefit Analysis													
	Sub process	Hourly Personnel Cost	Head count	Times Perf. Per Year	Time to Complete (Hrs)	Annual Personnel Cost	%IT	ALT (Hrs)	Total Knowledge	Total Benefits	Annual Cost	ROK	ROI
200	Update CBA	35.70	1	655	15	$432,559.09	95%	24	314400	**$11,321,118.51**	**$432,559.09**	**2617%**	**2517%**

Table 12. KVA Analysis of To-be for Block 200

c. Block 265 To-be KVA Analysis

Table 13 shows all KVA estimates used to determine the total process benefits, annual cost and ROI of the notional to-be revision of block 265. Assumptions for block 265 are as follows:

- The added technology will allow for a 33% reduction in personnel (conservative estimate).
- Because of the increased availability and visibility of the 3D scans, suppliers and purchasers can realize a 35% decrease in cycle-time.
- The addition of PLM and 3D laser scanning allowed for a 50% increase in automation for the processes associated with block 265.

Block 265 (To-Be) Hull Installation and Risk Assessment													
	Sub process	Hourly Personnel Cost	Head count	Times Perf. Per Year	Time to Complete (Hrs)	Annual Personnel Cost	%IT	ALT (Hrs)	Total Knowledge	Total Benefits	Annual Cost	ROK	ROI
265.1	Installation Procurement, Design & Advance Planning	$24.62	23	655	104	$38,649,658.27	75%	40	2410400	$86,795,241.92	$38,649,658.27	225%	125%
265.2	Hull Installation Readiness Review	$24.62	2	655	26	$920,248.60	85%	40	349333	$12,579,020.57	$920,248.60	1367%	1267%
265.3	Evaluate Maturity Status	$50.16	1	655	13	$508,955.59	50%	40	52400	$1,886,853.09	$508,955.59	371%	271%
265.4	Provide Risk Assessment	$50.16	1	655	26	$936,093.90	50%	56	73360	$2,641,594.32	$936,093.90	282%	182%
265.4.1	Formally Propose Install for Readniess Assessment and Auth.	$50.16	1	655	13	$508,955.59	0%	40	26200	$943,426.54	$508,955.59	185%	85%
265.5	Risk/Readiness Determination	$59.01	4	164	26	$1,088,241.77	0%	56	36736	$1,322,813.64	$1,088,241.77	122%	22%
									Process Totals:	**$106,168,950.08**	**$42,612,153.71**	**249%**	**149%**

Table 13. KVA Analysis of To-be for Block 265

d. Block 310 To-be KVA Analysis

Table 14 shows all KVA estimates used to determine the total process benefits, annual cost and ROI of the notional to-be revision of block 310. Assumptions for block 310 are as follows:

- PLM will enable a 50% reduction in staff by having all related information available through a single interface.
- Because the feedback can now be centrally collected via the PLM, automation will increase by 75%.
- Time to complete the tasks will be reduced by 75% by eliminating lengthy manual data collection and aggregation.

Block 310 (To-Be) Feedback: Cost, CM, Performance, Schedule, ILS, from initial or follow-on install													
	Sub process	Hourly Personnel Cost	Head count	Times Perf. Per Year	Time to Complete (Hrs)	Annual Personnel Cost	%IT	ALT (Hrs)	Total Knowledge	Total Benefits	Annual Cost	ROK	ROI
310	Provide feedback data to support future installation decisions	$29.78	2	655	5	$179,362.43	75%	24	62880	**$2,264,223.70**	**$179,362.43**	**1262%**	**1162%**

Table 14. KVA Analysis of To-be for Block 310

e. Blocks 320 To-be KVA Analysis

Table 15 shows all KVA estimates used to determine the total process benefits, annual cost and ROI of the notional to-be revision of blocks 320. Assumptions for block 320 are as follows:

- Addition of technology will allow for a 75% increase in automation.
- PLM will allow for a 33% reduction in the number of employees.
- Cycle-time will be reduced by 20% due to increased accuracy.

Block 320 (To-Be) Continue Installs													
	Sub process	Hourly Personnel Cost	Head count	Times Perf. Per Year	Time to Complete (Hrs)	Annual Personnel Cost	%IT	ALT (Hrs)	Total Knowledge	Total Benefits	Annual Cost	ROK	ROI
320	Using feedback information from completed installs, determine impact on follow-on installs	$59.01	5	655	16	$1,936,999.40	75%	24	188640	**$6,792,671.11**	**$1,936,999.40**	**351%**	**251%**

Table 15. KVA Analysis of To-be for Blocks 320

V. CONCLUSIONS AND RECOMMENDATIONS

A. RESEARCH LIMITATIONS

The KVA models in this study were generated primarily from data gathered by interviewing SMEs at NAVSEA. The data was then generalized across enterprise management and shipyard and activities. To ensure reliability, a high degree of correlation across key KVA data points of ordinal ranking, ALT and RLT were calculated and verified. Because the cost-estimation process within SHIPMAIN has never been precisely mapped, there may be some disparity between the identified process and actual process. Due to time constraints and the exceptionally large footprint of cost-estimation within SHIPMAIN, the scope was limited to only the identified core processes and the first level of sub-processes. An in-depth and more precise mapping of the cost-estimation process will lead to even higher levels of accuracy with respect to valued added and increased efficiency.

B. RESEARCH QUESTIONS

This study identified the significant potential value that 3D laser scanning and PLM technologies have to offer with regards to cost-estimation in the SHIPMAIN process. The combination of high quality, reliable, accurate and reusable digital 3D data captured from the laser scanner and PLM, with its storage, distribution and collaboration capabilities, will provide the ideal mechanism for tracking product data of US Navy warships from initial build to decommission. As mentioned in Chapter II, this captured digital data will allow for the creation of “folders” on each type/class/platform. These folders, because of their accurate and easily accessible data, will allow decision-makers to make more accurate, timely and cost-effective choices. The central repository of data and its accessibility multiplies capabilities in the cost-estimation decision-making process. Even with this multiplier, it is important that the decision-makers continually evaluate the overall environment and adapt to changing economic, political and technical environments, without losing site of their strategic goals. Application of this KVA methodology to cost-estimation within the

SHIPMAIN process has yielded one type of decision support model to demonstrate the potential impact of 3D laser scanners and PLM technologies within this environment.

1. Cost Savings

The US Navy currently spends over $313 million per year to accomplish the completion of 655 SCDs. This figure is fully attributable to labor rates but does not include other expenses such as travel or required materials. In the to-be scenario, this cost drops to just over $137 million. This represents a 56% reduction in costs. In today's funding environment, $127 million could be better spent.

It would be lacking to only consider cost when evaluating ROI. By focusing only on cutting costs, the US Navy could be negating benefits or value attributable to the process. The total benefit increased from over $428 million to just over $666 million. This is a remarkable increase of 56% as well. As shown in Table 16, the to-be ROI of 386% is a vast improvement over the as-is ROI of 35%.

Core Process	Process Title	Annual As-Is Cost	Annual As-Is Benefits	Annual To-Be Cost	Annual To-Be Benefits	As-Is ROI	To-Be ROI
170	Design Development	$214,570,062	$360,388,939	$91,999,022	$539,639,982	67%	487%
200	Update Cost Benefit Analysis	$1,129,316	$5,660,559	$432,559	$11,321,119	505%	2517%
265	Hull Installation Readiness and Risk Assessment	$95,146,354	$57,991,301	$42,612,154	$ 106,168,950.08	-39%	149%
310	Feedback: Cost, CM, Performance, Schedule, ILS from Initial or follow-on Install	$1,548,345	$1,132,112	$179,362	$2,264,224	45%	1162%
320	Continue Installs	$780,361	$2,830,280	$1,936,999	$6,792,671	-27%	251%
	Totals:	$313,174,438	$428,003,191	$137,160,097	$666,186,946	35%	386%

Table 16. As-is and To-be ROI Comparison

2. Lifecycle Planning and Improved Business Process Efficiency

The US Navy has no single repository of data that tracks an individual warship from cradle to grave. As mentioned above, the addition of 3D laser scanning and PLM would allow for the creation of just such a mechanism. By combining the highly accurate digital representations/renderings generated using 3D laser scanning with PLM, one can create a viable and manageable data structure.

This combination would also allow for the consolidation of as-designed, as-planned, as-built and as-maintained warship data into a single record of the respective ship. The ability to access a single repository will allow for a more informed cost-estimation decision.

The highly accurate models derived from the 3D laser scanning will also allow for more accurate cost estimates from the Navy and contractors alike. Suppliers and contractors will be able to produce better cost estimates because the ship or space will be correctly represented in exacting detail. They will have accurate measurements to include any interference or ship-specific details that might be missed in the traditional approach. Suppliers and contractors can then plan for the interferences in their initial estimates instead of having to work around it once they are working the ship or space. Prior planning upfront will lead to increased efficiency further in the process.

With PLM, the central repository will allow more suppliers and contractors (once properly vetted) to access the 3D laser scans of the ships or spaces. PLM provides horizontal collaboration with a vast array of business partners and suppliers working in concert (Teresko, 2004). The increased number of suppliers or contractors will lead to increased competition. This increased competition will lead to more efficient work and will force increased cost-estimation accuracy among the prospective bidders. This will be necessity for the bidders to stay in the running for contracts.

Another cost-estimation benefit of the central repository is a more accurate understanding of the actual costs associated with a given maintenance or modification. The actual costs are captured in block 320 and added to the central repository. Because most ships in a class are similar (with minor exceptions), the fact that the actual costs are captured will allow for a further refinement of the cost estimates over time. The process can even be extrapolated to other ships, considering that most US Navy ships use similar equipment in similar spaces. This increasing refinement will make the generated cost estimates more accurate.

The DoN has embraced Lean Six Sigma to create a more efficient business organization. Historical data is essential for Lean Six Sigma initiatives to produce the optimal results. PLM will provide the product information across the enterprise to support Lean Six Sigma. Both PLM and Lean Six Sigma are both enterprise initiatives that focus on business value as the driver for change, not just cost. The combination of the two will provide the current DoN leadership with the means to accomplish desired enterprise business transformation.

C. REAL OPTIONS

While this research is not specifically conducting a Real Options analysis, the technologies presented in this research can be implemented in many different ways including phased-in acquisitions, several up-front purchases, and ways to extend use of the technology to other areas. Several scenario options are listed below:

- Do nothing and allow the as-is process to continue.
- Immediately acquire the 3D laser scanning capability for the public planning yards without PLM tools. If successful, expand to all planning yards.
- Immediately acquire the 3D laser scanning capability for the public planning yards and phase in the PLM tools. If successful, expand to all planning yards.
- Immediately acquire both 3D laser scanners and PLM technologies for the public planning yards. If successful, expand implementation across all planning yards.

D. RECOMMENDATIONS TO THE NAVY

According to the Chief of Naval Operations (CNO), Admiral Mike Mullen, "In almost every conceivable way, we are not the same Navy we were five years ago. We don't think the same; we don't plan the same; we don't operate the same or fight the same" (Mullen, 2005).

The Navy should immediately begin a field experiment across a ship class to test if the addition of 3D laser scanning and PLM will impact the cost-estimation process. The research indicates significant positive benefits, but actual data is generally more accurate than the predictive nature of this research. The outcome of this field test can then be used to apply 3D and PLM to all ship classes in the fleet.

As Navy warships, equipment and systems age, the demand for spare parts will continue to increase. Without 3D laser scanning and PLM, the Navy must often depend on old 2D drawings, if they are available, to reengineer the required parts. Because DoN components are typically unique in their geometries, they are very difficult to reverse engineer. If the detailed drawings are non-existent or unavailable, then the DoN must depend on the original supplier. Such an arrangement where there is only one bidder tends to create a situation where the contractor can set the price wherever he desires. The capability of 3D laser scans and PLM collaboration will be invaluable. Now, many suppliers can look at a highly-detailed rendering of the space or required parts and create proposals. The increasing competition among the suppliers will result in lower costs for the DoN. The use of 3D intelligent models is rapidly becoming the norm in every field of engineering design, (Roe, 2007, p. 5)

Traditionally, PMs were only accountable with regards to how they met project goals such as cost, schedule and performance. PMs must be encouraged to look at initiatives such as SHIPMAIN and OA to determine how their decisions will affect the total lifecycle costs versus focusing only on initial objectives. PMs that are focusing on providing the means for effectively managing the lifecycle of Naval assets must be rewarded.

Any major shift in business practices comes with risk. The introduction of 3D and PLM technologies involves risk and significant costs up front. This type of risk must be assessed in proportion to the potential benefits of adding the IT. The addition of 3D and PLM may provide significant benefits in the future that may not be evident in the short term. The DoN will have to continue to refine and modify processes to maximize their potential. The analytical methodology presented in this research validates the potential benefits to be realized from the addition of the IT.

E. FOLLOW-ON AND FUTURE RESEARCH OPPORTUNITIES

Cost-estimation of new construction, maintenance and modernization of Navy warships will continue to be important in today's budgetary environment. This research examined only the very top level of the cost-estimation process as it exists in the SHIPMAIN environment and how 3D laser scanning and PLM could affect ROK and ROI. A more detailed mapping of the cost-estimation process to include decomposition and extending to lower levels would add value and further refine the findings of this study.

If a field experiment is conducted, as recommended above, valuable data could be gathered at the lower levels of the cost-estimation process. This data could then provide the necessary momentum to propel cost-estimation to increased efficiencies.

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APPENDIX A. KVA+RO METHODOLOGY

A. KVA+RO[21]

The Naval Postgraduate School (NPS) developed the Knowledge Value Added/Real Options (KVA+RO) valuation framework that quantifies elements of uncertainty and risks and includes ways to mitigate these risks through strategic options. KVA+RO analysis is designed to support IT portfolio acquisitions and to empower decision-makers by providing performance-based data and scenario analysis (Komoroski et al., 2006). Analyses like Return on Investment (ROI) on individual projects, programs and processes within a portfolio of IT acquisitions can be derived through KVA methodology. With historical data provided by KVA, potential strategic investments can then be evaluated with Real Options analysis. The analysis applied is a robust and analytical process incorporating the risk identification (applying various sensitivity techniques), risk quantification (applying Monte Carlo simulation), risk valuation (Real Options analysis), risk mitigation (Real Options framing), and risk diversification (analytical portfolio optimization).

B. THE VALUE PROBLEM[22]

Before investigating the potential returns or benefits that knowledge assets, either human or IT, can provide, one must understand the concept of "value." When new and promising IT resources are introduced into an organization, the value derived may take a variety of intangible forms, such as improved market competitiveness, expanded markets, new capabilities, or increased efficiency. What value an organization receives from that IT asset depends on many factors beyond the entire capability of the asset, such as organizational culture, the management climate, and the organization's commitment to training and maintenance. Also

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[21] This entire section is taken directly from (Komoroski et al., 2006).

[22] Sections B-D are taken directly from (Komoroski, 2005).

important to note is the percentage of the IT resource's full potential that is actually utilized. If the asset is rarely used or used at baseline functionality, then the perceived and actual value derived from the IT asset is likely low. Leveraging people, technologies, and information effectively within an organization can promote team cohesion and provide value.

In other definitions of value, financial metrics tend to prevail. In fact, most value assessments focus on return and cost of ownership for IT investments. Monetary benefits are determined in commercial applications by assigning a price per unit to each process output. However, these financial-based methods seldom capture the benefit streams produced by processes and resources in common, comparable units of measurement. At the same time, financial metrics and benefits are difficult to apply in private-sector and government organizations. The DoD, for example, will not be able to establish the monetary benefits, or the value added from combat effectiveness, operational readiness, and national defense. Therefore, an alternative common unit must be used to determine the value added in public-sector process analysis.

C. THE KVA SOLUTION

The Knowledge-value Added (KVA) methodology provides a framework for the analytical analysis of organizational knowledge assets. Developed by Drs. Thomas Housel (Naval Postgraduate School) and Valerny Kanevsky (Agilent Lab), the theory of KVA has been published internationally, and has been applied in academic research and 20 various business consultations for over 15 years. Executed properly, KVA will measure the value of knowledge embedded in an organization's core processes, employees, and IT investments. This measure is quantified in a return-on-knowledge (ROK) ratio, which can be used to identify how much value knowledge assets provide within each core business process. In instances in which revenue comparisons or other market-comparable values are available, a return on investment (ROI) figure can be ascertained.

1. The Theory of KVA

With its roots in the Information Age, the theory behind KVA follows the basic principles of thermodynamics by purporting that organizational outputs can be described in units of complexity. More specifically, KVA theory is based on the concept of entropy, which connotes changes in the environment. It follows that as all organizations collect input from various sources and add value in some way, the inputs are transformed to outputs, and the value added during that transition is proportionate to the amount of transformation necessary to change the inputs to the desired output. A unit of change, therefore, is considered simply as a unit of complexity. Belief in this assertion provides a method by which all organizational outputs can be measured in common units. The value added to each process comes from organizational knowledge assets: people, processes, capabilities, or information technology. Through estimation of this value, an analytical method for estimating the return on knowledge, using the knowledge inherent in organizational assets to describe process outputs with a common unit of measurement, is achieved.

The knowledge used every day in the core processes of an organization can be translated to a numerical format, because knowledge is a surrogate for the process outputs measured in common units. By capturing corporate knowledge into value, with clear figures to measure the value contained in each process, decision- and policy-makers can reengineer processes to maximize value. Then, by seeing the returns each process generates, better choices can be made for an organization. Whether the knowledge is contained in IT systems or in the minds of an organization's employees is irrelevant, because common units of knowledge can be observed in the organization's core processes, and measured in terms of cost. Similarly, this approach provides management a verifiable way to assign benefit streams and costs to sub-organizational outputs produced by its knowledge assets, and can effectively redirect management's investment focus from cost containment to value creation.

Figure 16, below, shows a visual depiction of the KVA methodology's underlying model and primary assumptions.

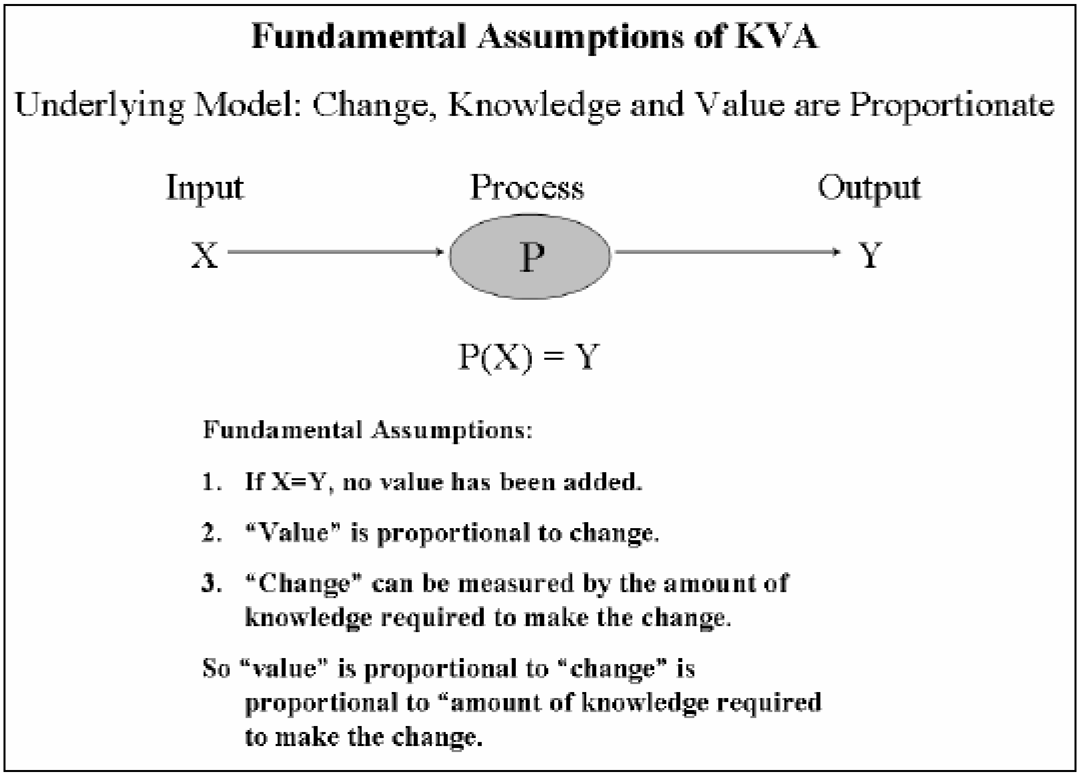

Figure 16. Assumptions of KVA (Housel & Bell 2004)

The assumptions presented in Figure 16 are the foundation of the KVA process. Accepting these assumptions allows the methodology to work in a way that breaks all input down into a common unit of output, allowing all processes to be evaluated from a common baseline reference. Because of this, how data is collected, analyzed, and how easily it can be monetized, the methodology functions much like accounting. As such, KVA results can be utilized in corporate finance and valuation problems.

2. Core Process Identification

In order to translate the knowledge utilized in an organization's core processes to numerical form, it is important to accurately define what those core processes are, and to define the amount of change each process produces. Typically, corporate executives or other Subject Matter Experts are able to identify the main processes executed by their organization. In some instances, work flow models exist and may be referenced. In most instances, five to seven core processes sufficiently cover the core processes executed by an organization. For each of those processes, boundaries must be established by identifying the end output of the process, including all sub-process outputs that eventually create the end product. Any contribution IT provides to the process must be isolated.

3. Approaches to KVA

The knowledge within a process can be represented as learning time, process instructions, or information bits. In theory, any approach that satisfies the basic KVA assumptions will create the same results; however, it must capture the "know-how" in the production of process outputs, given particular inputs. Table 21 illustrates the steps used in three primary methods used to apply KVA. The Binary Query Method will not be addressed in this research.

Steps	Learning time	Process description	Binary query method
1.	Identify core process and its subprocesses.		
2.	Establish common units to measure learning time.	Describe the products in terms of the instructions required to reproduce them and select unit of process description.	Create a set of binary yes/no questions such that all possible outputs are represented as a sequence of yes/no answers.
3.	Calculate learning time to execute each subprocess.	Calculate number of process instructions pertaining to each subprocess.	Calculate length of sequence of yes/no answers for each subprocess.
4.	Designate sampling time period long enough to capture a representative sample of the core process's final product/service output.		
5.	Multiply the learning time for each subprocess by the number of times the subprocess executes during sample period.	Multiply the number of process instructions used to describe each subprocess by the number of times the subprocess executes during sample period.	Multiply the length of the yes/no string for each subprocess by the number of times this subprocess executes during sample period.
6.	Allocate revenue to subprocesses in proportion to the quantities generated by step 5 and calculate costs for each subprocess.		
7.	Calculate ROK, and interpret the results.		

Table 17. Three Approaches to KVA
(Housel & Bell, 2001)

a. Learning Time Approach

In the learning time approach, the amount of knowledge embedded in a core process is represented by an estimate of the amount of time it would take an individual of average ability to learn that process's execution well enough to successfully create the same process output. In capturing this estimate, learning time is proportional to the amount of knowledge learned, and thus indicates how much knowledge is embedded in that process. In the context of this methodology, this figure is called "Actual Learning Time," or ALT. Learning Time must be measured in common units of time, and these units represent common units of output, which are described by the variable *K*. Following this line of thought, a single execution of any process is equal to a single unit of output, represented by a given number of common units, K.

The obvious question, then, is how one correctly estimates how long it would take for an average person to learn a certain process. In practice, most Subject Matter Experts can provide quality estimates based on formal training times, on-the-job training, training manuals, and other programs, given a minimum explanation of what ALT is in terms of the KVA methodology. It is important that SMEs understand that for each estimate, knowledge must only be counted when it is in use; otherwise, there is a tendency to overestimate the amount of knowledge contained in a given process. Further, knowledge must only be counted if it is truly necessary to execute the process. The shortest, most succinct approach to the process output must be considered, again, to avoid overestimation.

b. Establishing Reliability

Critics would argue that the Learning Time Approach is subjective and anecdotal. However, several methods exist to ensure reliability and confidence of all estimates. The most common way of ensuring reliable estimates is by calculating the correlation between the ALT, ordinal ranking, and relative learn time (RLT) for each process. A correlation value greater than or equal to 80% is sufficient for establishing reliability, and is the preferred method of proving the estimates credible. The three terms are described in detail below:

- Actual Learn Time (ALT) is an estimate for the period of time it would take to teach an average individual to execute a given process. There is no limit to the amount of time required.
- Ordinal Rank is a measure of process complexity described as its difficulty to learn. Subject Matter Experts, or Executives within an organization are asked to rank the processes in order from that which is easiest to learn, to that which is the most difficult to learn.
- Relative Learn Time (RLT) is a measure of the time it would take to teach an average individual the core processes of an organization given only 100 hours, days, months, or other unit of time.

Subject Matter Experts or Executives must allocate the time appropriately to each process, with regard to that process's complexity. Estimates may also be verified using actual knowledge measures such as on-the-job training time, or the number of process instructions within each core process. However, attaining a high degree of correlation and reliability between ALT, RLT, and Ordinal Rankings is the preferred method (Housel & Bell, 2001).

c. Total Learning Time

The amount of knowledge embedded into the existing IT used in each core process must be captured. This estimate is best achieved by considering what percentage of a process is automated. This percentage estimate for IT is used to calculate the total learning time (TLT), and revenue is allocated proportionally. Interestingly, the revenue attributed to IT-based knowledge, plus the cost to use that IT, often reveals that the value added to processes by IT applications, shown in the resulting ROK ratio, is not always equal to the percentage of IT and automation used in a process (Housel & Bell, 2001).

d. Process Instructions Approach

In some cases, the Process Instruction Approach must be used to gain reliability of estimates. This approach requires Subject Matter Experts to truly break apart each core process into the various subtasks that comprise it, in order to describe the products in terms of the "instructions required to reproduce them." By capturing the actual learning time of the sub-processes, one is better able to assign reliable estimates of the knowledge contained therein. Just as the case in the Learning Time Approach, it is important that the estimates cited in Process Instructions only contain the knowledge required, or "in use" during execution of each individual process, without overlap. By adding the ALT results for each sub-process within a core process, one has a more reliable estimate of the core process's ALT.

4. Measuring Utility and Knowledge Executions

A count must be taken to determine the number of times the knowledge is executed (value) and the time is takes to execute (cost) in a given sample period. These values are needed to determine the ROK value. The actual time is takes to execute the process, multiplied by cost, is a flow-based estimate of its cost. It is important to note that process costs alone, without reference to value, present a different picture of the core process's value.

5. The Relevance of Return on Knowledge (ROK)

The return ratio known as ROK is expressed with a numerator representing the percentage of revenue allocated to amount of knowledge required to complete a given process successfully, in proportion to the total amount of knowledge required to generate the total outputs. The denominator of the equation represents the cost to execute the process knowledge. With knowledge as a surrogate for the process outputs measured in common units, a higher ROK signifies better utilization of knowledge assets. In this way, KVA makes is possible to measure how well a specific process is doing in converting existing knowledge into value. Similarly, it gives decision-makers an idea of how an investment in knowledge and learning is paying off, and not simply how much it costs. The ROK value provides decision makers an analytical way to determine how knowledge can be more effectively used to produce better return on performance. If increased automation does not improve the ROK value of a given process, steps must be taken to improve that process's function and performance.

D. REAL OPTIONS

Real Options Analysis is a market-based methodology invented to address the investment challenges faced by corporations in the modern day economy. It suggests that corporate valuation depends less on traditional fundamentals, and more on future expectations. The traditional discounted cash flow analysis methods: the income, cost, or market approach, tend to view risk and return on investment in a static view. Dr. Jonathan Mun, an expert in Real Options Theory, and credited with making it operational in practice, theorizes that not all risk is bad; in fact, upside risk can often be advantageous. Upside risk is defined simply as the opportunities that coincide with the threats for any given risk. Dr. Mun's interpretation of Real Options is often described as "a new way of thinking," and he views capital investments in terms of a dynamic approach, since all decision making processes have generic and dynamic options associated with them. Real Options Analysis is done by considering these real options, then using options theory to evaluate physical, vice financial assets.

Dr. Mun identifies eight phases in the real options process framework. The first phase begins with the qualification of projects through management screening, which eliminates all but those projects management wants to evaluate. The second phase starts with the construction of a discounted cash flow model under the base case condition. Next, Monte Carlo simulation is applied, and the results are inserted in the real options analysis. This phase covers the identification of strategic options that exist for a particular project under review. Based on the type of problem framed, the relevant real options models are chosen and executed. Depending on the number of projects as well as management set constraints, portfolio optimization is performed. The efficient allocation of resources is the outcome of this analysis. The next phase involves creating reports and explaining to management the analytical results. This step is critical in that an analytical process is only as good as its expositional ease. Finally, the last phase involves updating the analysis over time (Mun, 2002). Real options analysis adds tremendous value to projects with uncertainty, but when uncertainty becomes resolved through the passage of time, old assumptions and forecasts have now become historical facts. Therefore, existing models must be updated to reflect new facts and data. This continual improvement and monitoring is vital in making clear, precise, and definitive decisions over time.

APPENDIX B. THE FIVE PHASES OF SHIPMAIN[23]

There are five phases leading to the completion of an alteration/modification. These five phases are: conceptual, preliminary design, detailed design, implementation and installation.

A. PHASE I—CONCEPTUAL

The purpose of this phase is to identify a need for change, propose a resolution, and gain approval to proceed with development of that resolution into an engineered Ship Change (SC). Products developed during this phase include:

- Requirement and proposed conceptual solution.
- Proposed fielding plan.
- Estimate for Phase II and III design development.
- "Best Guess" estimate for Phase IV and V implementation and execution.

[23] This entire Appendix taken directly from (Seaman, 2007).

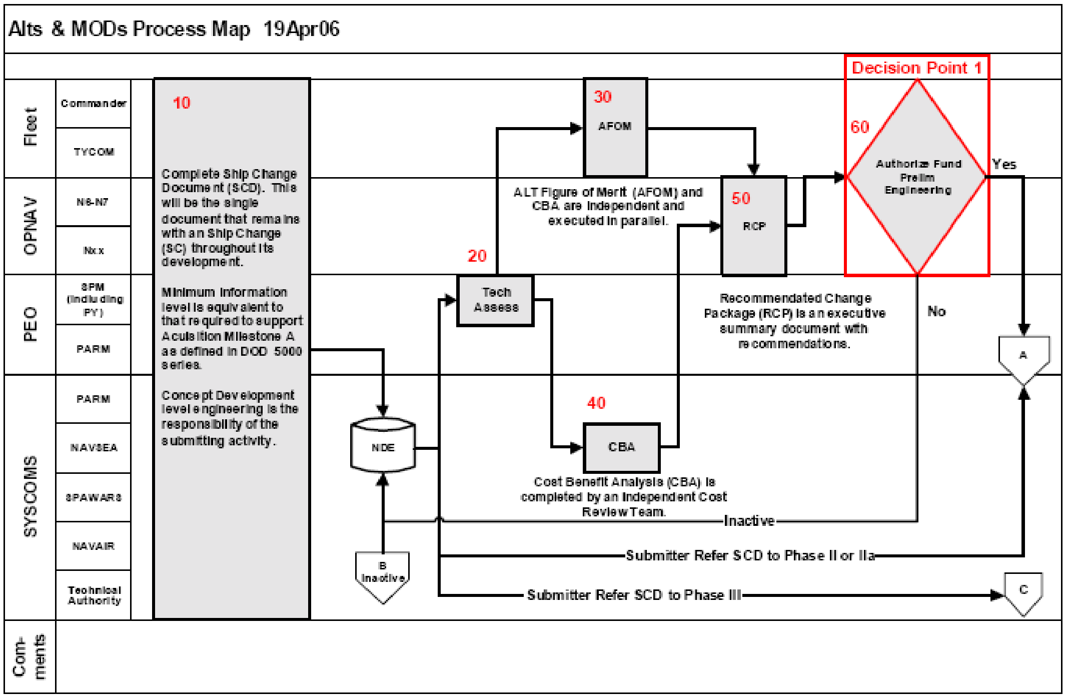

Figure 17. Phase I Top Level Flow Chart
(Commander, Naval Sea Systems Command, 2006)

B. PHASE II—PRELIMINARY DESIGN

The purpose of this phase is to initiate design work for the SC, perform preliminary design development of the SC, and gain approval to continue to detailed design. Preliminary design development can include selection of technologies, establishment of design parameters, and prototype development. Products developed during this phase can include:

- Design parameters.
- Updated fielding plan.
- Refined estimates for Phases III, IV, and V.
- Initiation of Installation Control Drawings (ICDs) and performance specifications.
- Identification of interfaces and distributive system impacts.
- Design Budget Execution Plans.
- Prototype Design.

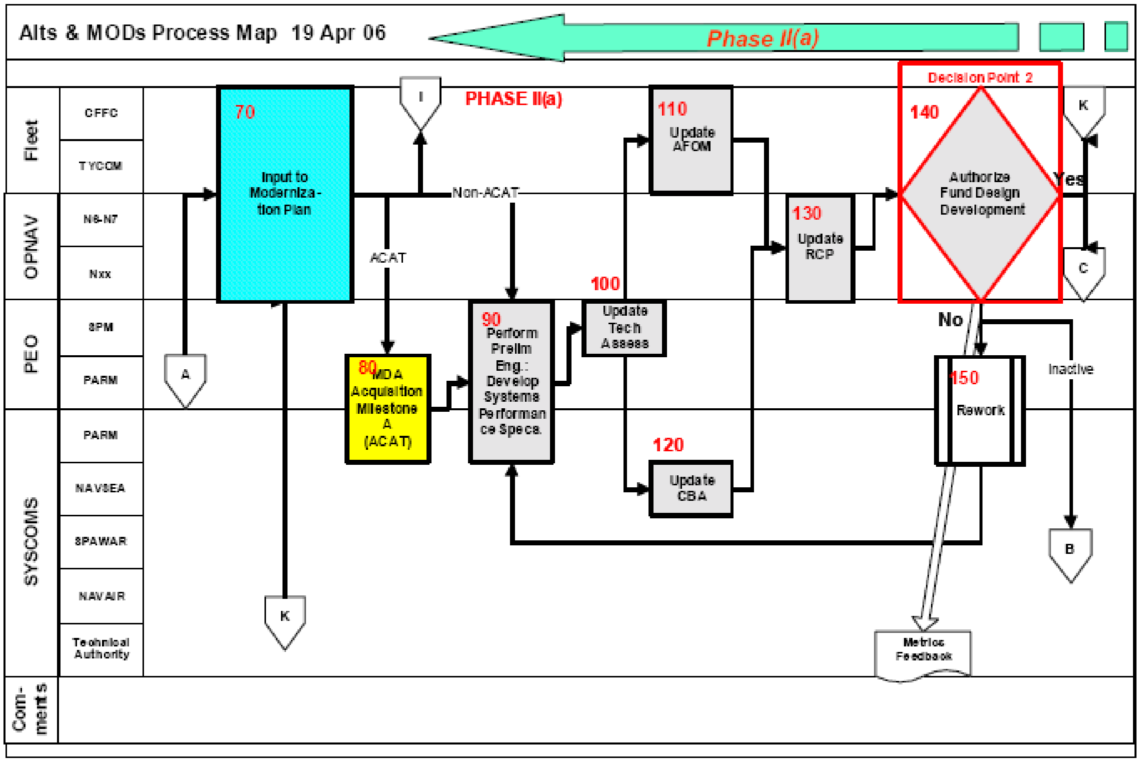

Figure 18. Phase II Top Level Flow Chart
(Commander, Naval Sea Systems Command, 2006)

C. PHASE IIA

Upon approval at Decision Point (DP) 1, the approving authority may determine a SC is eligible to move through Phase IIa. Phase IIa is utilized when a proposed SC design is mature to the point that DP 2 is not required. Phase IIa is a combination of the Phase II and III development and review processes and ends at DP 3. In order to qualify for Phase IIa, the following criteria must be met:

If the scope of the SC is an Internal Equipment Modification, all of the following criteria must be met:

- The SC can be accomplished without changing an interface external to the equipment or system.
- The change is made within the equipment or system.

- The change does not negatively impact Strike Force Interoperability (SFI)
- The change does not impact shipboard distributive systems, Ship Selected Records (SSRs) or interfacing equipment or systems, compartmental arrangement records, or Damage Control records.

If the scope of the SC is a Ship Modification, all of the following requirements must be met:

- The change does not negatively impact SFI.
- The change does not impact ship stability records (weight & moment).
- The change does not impact or alter the 3-dimensional footprint of the equipment being replaced.
- The change does not impact shipboard distributive systems, SSRs or interfacing equipment or systems, compartmental arrangement records, or Damage Control records.
- The change does not impact manning levels.

Installation may not begin until authorized in Phase IV.

D. PHASE III—DETAILED DESIGN

The purpose of this phase is to complete detailed design development of the SC. Once approved at DP 3, SCs are added to the Authorized or Planned but Not Authorized section of the Ship Program Manager (SPM) Letter of Authorization (LOA). Installations may not begin in Phase IV until they have been added to the Authorized Section of the SPM LOA in accordance with the milestones identified. The Technical Data Package (TDP) for a Ship Change Document (SCD) at DP 3 must include the level of detail equivalent to preliminary class-level Ship Installation Drawings (SIDs) or preliminary ICDs. Products developed during this phase can include:

- A Technical Data Package.
- Installation Control Drawings.
- Performance Specifications.

- Quantification of interfaces and distributive system impacts (i.e. parametric data).
- Refined estimates for Phases IV and V.
- Refined fielding plan.
- List of required certifications and Plan of Action and Milestones (POA&M) for completion.
- Alteration Bill of Material (ABOM) including Long Lead Time Material (LLTM), Government Furnished Equipment (GFE), and logistically significant material 3-4.

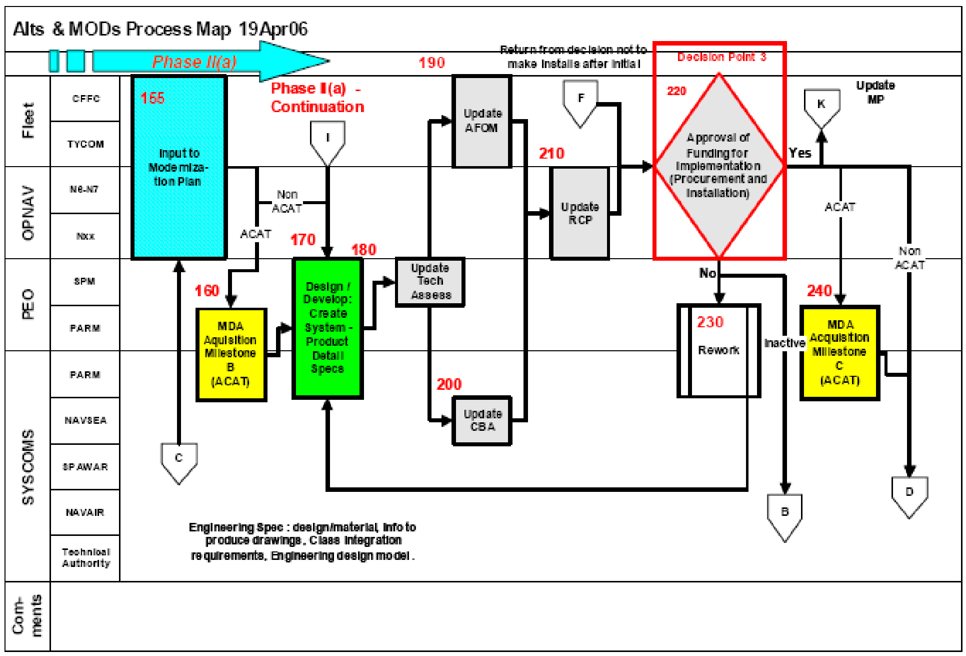

Figure 19. Phase III Top Level Flow Chart
(Commander, Naval Sea Systems Command, 2006)

E. PHASE IV—IMPLEMENTATION

The purpose of Phase IV is to accomplish site-specific advanced planning of the SC. The attention is redirected from overall SC applicability to design for installation on a specific hull or at a specific location. This phase includes finalized design (including Ship Check/site survey, drawings, technical installation instructions, etc.), initiation of procurement, pre-installation certification and testing, installation readiness assessments, and risk assessments. Products developed during Phase IV can include:

- Ships Installation Drawings
- ILS Certification.
- Government Furnished Equipment (GFE) and Industrial Activity Furnished (IAF) material procurement.
- Pre-installation certifications.
- Pre-installation testing.
- Risk assessments.
- Installation documents.
- Alteration Installation Team (AIT) Plan of Action and Milestones (POA&M).

Funding for Phase IV is budgeted as part of the Modernization Plan (MP) after Phase IIa or III approval.

1. SCD Revision

There are currently two reasons to have a SCD revised, post DP 3. The first is capability difference between what was planned for procurement and what was actually procured. This capability difference includes changes inherent through design, provided by the manufacturer, for a multi-year procurement requirement. The second is if SCD actual costs are projected to increase by a factor greater than +/- 10% more than estimated costs, a revised SCD must be resubmitted to DP 3.

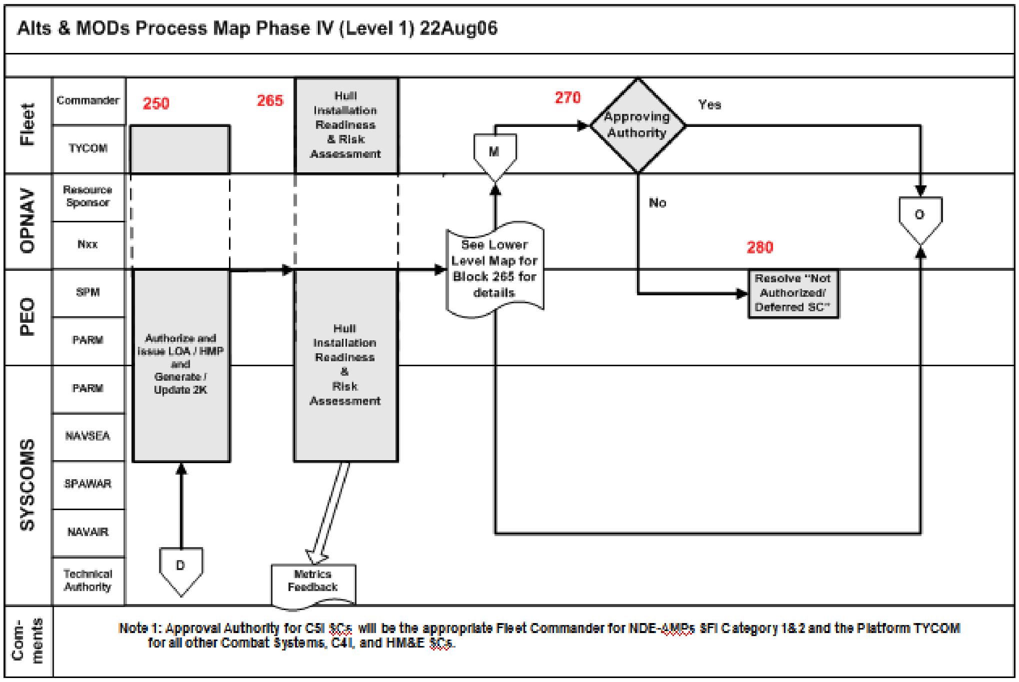

Figure 20. Phase IV Top Level Flow Chart
(Commander, Naval Sea Systems Command, 2006)

F. PHASE V—INSTALLATION

The purpose of Phase V is to execute the SC and provide feedback for future installation decisions. It is possible for a SC to be in Phase IV and V in parallel for different individual installations. Feedback from each individual installation is provided to update and refine technical information and installation cost estimates. Once all planned installations have been completed, this phase and the SC are closed out by providing feedback data reflecting final installation and closeout. Products developed and services performed during Phase V can include:

- Return Cost Reports.
- Liaison Action Requests (LARs).
- Post-installation certification and testing.
- ILS Product delivery.
- Alteration Completion Reports.

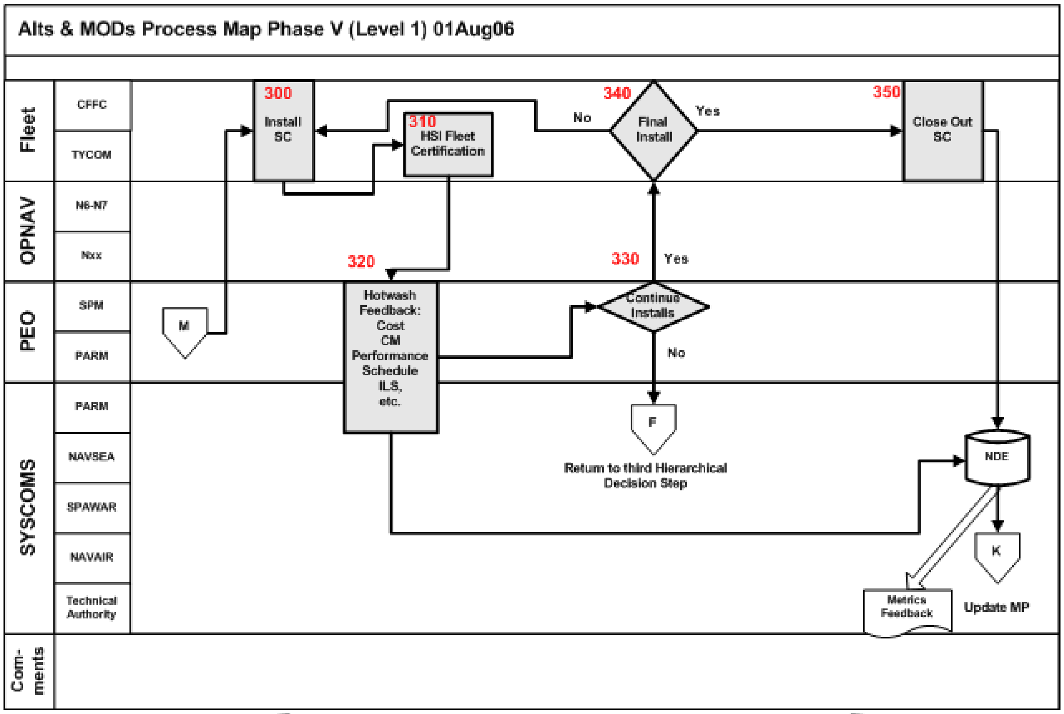

Figure 21. Phase V Top Level Flow Chart
(Commander, Naval Sea Systems Command, 2006)

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