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Ship Maintenance Processes With Collaborative Product Lifecycle Management and 3D Terrestrial Laser Scanning Tools: Reducing Costs and Increasing Productivity

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Preface & Acknowledgements

Welcome to our Ninth Annual Acquisition Research Symposium! This event is the highlight of the year for the Acquisition Research Program (ARP) here at the Naval Postgraduate School (NPS) because it showcases the findings of recently completed research projects—and that research activity has been prolific! Since the ARP's founding in 2003, over 800 original research reports have been added to the acquisition body of knowledge. We continue to add to that library, located online at www.acquisitionresearch.net, at a rate of roughly 140 reports per year. This activity has engaged researchers at over 60 universities and other institutions, greatly enhancing the diversity of thought brought to bear on the business activities of the DoD.

We generate this level of activity in three ways. First, we solicit research topics from academia and other institutions through an annual Broad Agency Announcement, sponsored by the USD(AT&L). Second, we issue an annual internal call for proposals to seek NPS faculty research supporting the interests of our program sponsors. Finally, we serve as a "broker" to market specific research topics identified by our sponsors to NPS graduate students. This three-pronged approach provides for a rich and broad diversity of scholarly rigor mixed with a good blend of practitioner experience in the field of acquisition. We are grateful to those of you who have contributed to our research program in the past and hope this symposium will spark even more participation.

We encourage you to be active participants at the symposium. Indeed, active participation has been the hallmark of previous symposia. We purposely limit attendance to 350 people to encourage just that. In addition, this forum is unique in its effort to bring scholars and practitioners together around acquisition research that is both relevant in application and rigorous in method. Seldom will you get the opportunity to interact with so many top DoD acquisition officials and acquisition researchers. We encourage dialogue both in the formal panel sessions and in the many opportunities we make available at meals, breaks, and the day-ending socials. Many of our researchers use these occasions to establish new teaming arrangements for future research work. In the words of one senior government official, "I would not miss this symposium for the world as it is the best forum I've found for catching up on acquisition issues and learning from the great presenters."

We expect affordability to be a major focus at this year's event. It is a central tenet of the DoD's Better Buying Power initiatives, and budget projections indicate it will continue to be important as the nation works its way out of the recession. This suggests that research with a focus on affordability will be of great interest to the DoD leadership in the year to come. Whether you're a practitioner or scholar, we invite you to participate in that research.

We gratefully acknowledge the ongoing support and leadership of our sponsors, whose foresight and vision have assured the continuing success of the ARP:

- Office of the Under Secretary of Defense (Acquisition, Technology, & Logistics)
- Director, Acquisition Career Management, ASN (RD&A)
- Program Executive Officer, SHIPS
- Commander, Naval Sea Systems Command
- Program Executive Officer, Integrated Warfare Systems
- Army Contracting Command, U.S. Army Materiel Command

- Office of the Assistant Secretary of the Air Force (Acquisition)
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- Director, Office of Acquisition Resources and Analysis (ARA)
- Deputy Assistant Secretary of the Navy, Acquisition & Procurement
- Director of Open Architecture, DASN (RDT&E)
- Program Executive Officer, Littoral Combat Ships

We also thank the Naval Postgraduate School Foundation and acknowledge its generous contributions in support of this symposium.

James B. Greene Jr.	Keith F. Snider, PhD
Rear Admiral, U.S. Navy (Ret.)	Associate Professor

Panel 21. Innovative Approaches to Controlling Costs in Systems Acquisition

Thursday, May 17, 2012	
1:45 p.m. – 3:15 p.m.	**Chair: Rear Admiral David H. Lewis,** USN, Program Executive Officer, Ships ***Ship Maintenance Processes With Collaborative Product Lifecycle Management and 3D Terrestrial Laser Scanning Tools: Reducing Costs and Increasing Productivity*** David Ford, *Texas A&M University* Thomas J. Housel and Johnathan C. Mun, *Naval Postgraduate School* ***Unit Cost as a Contract Requirement*** Jacques Gansler, William Lucyshyn, and David Ziman *University of Maryland* ***An Analysis of TRL-Based Cost and Schedule Models*** C. Robert Kenley and Bernard El-Khoury *Massachusetts Institute of Technology*

David H. Lewis—As a program executive officer, Ships, Rear Admiral Lewis is responsible for Navy shipbuilding for surface combatants, amphibious ships, logistics support ships, support craft, and related foreign military sales.

Born at Misawa Air Force Base, Japan, Lewis was commissioned in 1979 through the Navy ROTC program at the University of Nebraska–Lincoln with a Bachelor of Science degree in computer science.

At sea, Lewis served as a communications officer aboard the USS *Spruance* (DD 963), where he earned his surface warfare qualification; the USS *Biddle* (CG 34) as a fire control officer and missile battery officer; and the USS *Ticonderoga* (CG 47) as a combat systems officer. His major command assignment was as the Aegis Shipbuilding program manager in the program executive office ships, where he helped deliver seven DDG 51 class ships and procured another 10 ships.

Lewis' shore assignments include executive assistant to the assistant secretary of the Navy (research, development, and acquisition), assistant chief of staff for maintenance and engineering, commander, and Naval Surface Forces, where he also served as a charter member of the Surface Warfare Enterprise. Lewis' other ship maintenance and acquisition assignments ashore include the Navy secretariat staff; commander, Naval Sea Systems Command staff; the Aegis Shipbuilding Program Office; supervisor of shipbuilding, Bath; and Readiness Support Group, San Diego. Upon selection to flag rank, Lewis served as vice commander, Naval Sea Systems Command. Lewis earned a Master of Science degree in computer science from the Naval Postgraduate School. He completed the seminar course at the Naval War College Command and Staff School and received his Joint Professional Military Education certification. He is a member of the acquisition professional community with Level III certifications in program management and production quality management, and he has completed his civilian project management professional certification.

Lewis' personal awards include the Legion of Merit, Meritorious Service Medal, Navy and Marine Corps Commendation, Navy and Marine Corps Achievement Medal, and various service and unit awards.

Ship Maintenance Processes With Collaborative Product Lifecycle Management and 3D Terrestrial Laser Scanning Tools: Reducing Costs and Increasing Productivity

David Ford—Ford received his BS and MS degrees from Tulane University and his PhD degree from MIT. He is an associate professor in the Construction Engineering and Management Program, Zachry Department of Civil Engineering, Texas A&M University and the Urban/Beavers Development Professor. He also serves as a research associate professor of acquisition with the Graduate School of Business and Public Policy at the U.S. Naval Postgraduate School in Monterey, CA. Prior to joining Texas A&M he was on the faculty of the Department of Information Science, University of Bergen, Norway. For over 14 years, he designed and managed the development of constructed facilities in industry and government. His current research investigates the dynamics of development supply chains, risk management with real options, and sustainability. [DavidFord@tamu.edu]

Thomas J. Housel—Housel specializes in valuing intellectual capital, knowledge management, telecommunications, information technology, value-based business process reengineering, and knowledge value measurement in profit and non-profit organizations. He is currently a tenured full frofessor for the Information Sciences (Systems) Department. He has conducted over 80 knowledge value added (KVA) projects within the non-profit, Department of Defense (DoD) sector for the Army, Navy, and Marines. He also completed over 100 KVA projects in the private sector. The results of these projects provided substantial performance improvement strategies and tactics for core processes throughout the DoD organizations and the private-sector companies. He has managed a $3million+ portfolio of field studies, educational initiatives, and industry relationships. His current research focuses on the use of KVA and real options models in identifying, valuing, maintaining, and exercising options in military decision-making. [tjhousel@nps.edu]

Johnathan C. Mun—Mun is a research professor at the U.S. Naval Postgraduate School (Monterey, CA) and teaches executive seminars in quantitative risk analysis, decision sciences, real options, simulation, portfolio optimization, and other related concepts. He has also researched and consulted on many Department of Defense and Department of Navy projects and is considered a leading world expert on risk analysis and real options analysis. He has authored 12 books. He is also the founder and CEO of Real Options Valuation Inc., a consulting, training, and software development firm specializing in strategic real options, financial valuation, Monte Carlo simulation, stochastic forecasting, optimization, and risk analysis located in northern California. [jcmun@realoptionsvaluation.com]

Abstract

The current cost-constrained environment within the DoD requires a cogent approach to cost reductions that will not compromise the productivity of core defense support processes such as ship maintenance, a core process. The SHIPMAIN initiative was designed to standardize ship maintenance alternations in order to take advantage of the cost savings from standardizing core processes. However, the normal cost-reduction learning curve for common ship alterations has not materialized. This study uses the knowledge value added (KVA) + systems dynamics (SD) + integrated risk management (IRM) methodology to estimate, analyze, and optimize the potential cost savings and productivity improvements available by moving to a ship maintenance approach that incorporates the 3D terrestrial laser scanning (3D TLS) and collaborative product lifecycle management (collab-PLM) tool suite. Results suggest that when the SHIPMAIN process employs these technologies it will finally obtain the prophesized learning curve benefits. The results indicated that the biggest “bang for buck” is in using the combination of the two technologies. An optimized portfolio controlling for risk using the IRM methodology and tool suite indicates that both rapid and incremental implementation approaches generate significant savings and that other factors should be incorporated into final implementation of the 3D TLS and collab-PLM tools.

Introduction

The current cost-constrained environment within the federal government and Department of Defense (DoD) requires a cogent approach to cost reductions that will not result in compromising the productivity of core defense support processes such as ship maintenance. At the same time, defense leaders must also navigate a complex information technology (IT) acquisition process. The DoD spends over $63 billion annually, or 14% of its total budget, on defense maintenance programs throughout the world (Office of the Deputy Under Secretary of Defense [Logistics and Material Readiness], 2006).

One such core process that is central to naval operations is the ship maintenance process. This process alone accounts for billions of the overall Navy annual budget. There have been a series of initiatives designed to reduce the cost of this core process, including ship maintenance (SHIPMAIN) that was designed to standardize ship maintenance alternations in order to take advantage of the cost savings from standardizing core processes. One purpose of SHIPMAIN was to take advantage of the well documented cost-savings learning curve found in the manufacturing arena. A problem in using the SHIPMAIN approach has been that the normal cost-reduction learning curve for common ship alterations across a series of common ship platforms has not materialized.

SHIPMAIN was created, in part, to address the glaring disparity in ship maintenance performance within the Navy. However, the initial instantiation of SHIPMAIN did not include two recommended technologies, 3D terrestrial laser scanning (3D TLS) and collaborative product lifecycle maintenance (collab-PLM), which were deemed necessary by Bob Stout, the creator of SHIPMAIN, for ensuring the success of the new standardized approach (i.e., normal learning curve cost savings).

These technologies are currently employed in ship building. When they are also incorporated into the maintenance cycle, the results should lead to the benefits projected in this study. The use of the tools in ship building will allow for the reuse of their outputs (i.e., the ability to create, update, and remotely distribute 3D images of the entire ship inside and out; cross-platform sharing of these images; and the capability for cross-platform searches). Using the tools across the entire ship building and maintenance lifecycle should result in substantial cost savings and increased shipyard capacity to accommodate the Secretary of the Navy’s (Honorable Ray Mabus) goal of a large increase in the fleet.

To evaluate and select ship maintenance options (e.g., strategies for the use of the collab-PLM and 3D TLS technologies) that promise the best cost savings and highest returns, measurement methods are essential to define, capture, and measure the cost savings and returns on these technologies. In addition to estimating potential cost savings, these measurement methods also must incorporate and analytically quantify elements of uncertainty and risks inherent in predicting the future value of these technologies for ship maintenance processes. This will allow acquisition professionals to develop ways to mitigate these risks by taking advantage of the most promising strategic ship maintenance options while analytically developing and allocating budgets to optimize project portfolios.

In this study, the IRM framework is used to quantify and project potential process cost savings and the potential benefits of selecting collab-PLM and 3D TLS technology in the ship maintenance program. SHIPMAIN is a large program with many interrelated concepts, instructions, policies, and areas of study. Although the quantitative scope of this research was constrained to Phases IV and V of the SHIPMAIN process, the technologies evaluated in this research are likely to provide additional benefits (e.g., more accurate cost estimation, higher quality, less rework, and more efficient system dynamics) across all phases of ship maintenance.

In this paper a description of the SHIPMAIN program is followed by a description of the collab-PLM and 3D TLS technologies. Following this, the IRM framework is applied to Phase IV of SHIPMAIN to perform a real options analysis, and future research will incorporate portfolio optimization using modern portfolio theory (MPT).

The knowledge value added + systems dynamics + integrated risk management (KVA + SD + IRM) framework measures operating performance, cost-effectiveness, return on investment, risk quantification, strategic real options (capturing strategic flexibility), and analytical portfolio optimization. The use of SD scenario modeling provides a means to estimate the impact of ship maintenance process improvements with collab-PLM and 3D TLS technologies over time. The analysis can be compared with historical static data to assess the fidelity of the SD models. Background on the system dynamics methodology and its application to the current work are provided in Ford, Housel, and Mun (2011).

SHIPMAIN

In August 2006, the *Surface Ship and Carrier Entitled Process for Modernization (SSCEPM) Management and Operations Manual* became the Navy's official document for the modernization of all surface ships and aircraft carriers (Commander, Naval Sea Systems Command, 2006). SSCEPM provides the policy and processes associated with ship maintenance (SHIPMAIN) for planning, budgeting, engineering, and installing timely, effective, and affordable shipboard improvements while maintaining configuration management and supportability. The SHIPMAIN process represents a sweeping change in the modernization of surface ships and carriers. The SHIPMAIN process streamlines and consolidates a number of existing modernization practices, processes, meetings, and supporting documents to provide a single, hierarchical decision-making process for modernizing surface ships and carriers.

The SHIPMAIN process comprises five distinct phases[1] and three decision points (DP)[2] that take a proposed change from concept to completion in a single Ship Change Document (SCD). The SCD is a single lifecycle-management document depicting a modernization change from concept to completion for ships (Commander, Naval Sea Systems Command, 2006, § 3, pp. 3–2). Although SHIPMAIN has a functional governance structure and supporting business rules, it has yet to reach a fully implemented state, especially in Phases IV and V. Business rules for Phases IV and V are in a maturing phase, and the process owners are regularly gathering input from stakeholders to resolve issues and refine the business rules in order to move forward with this initiative.

SHIPMAIN is designed to take advantage of best business practices from industry that lead to cost reductions based on the production learning curve. The Navy implemented the SHIPMAIN process in fiscal year (FY) 2004 in order to increase the efficiency of the maintenance and modernization process without compromising its effectiveness, define a common planning process for surface ship maintenance and alterations, install a disciplined management process with objective measurements, and institutionalize that process and provide continuous improvement methodology (Commander, Naval Sea Systems Command, 2006).

SHIPMAIN seeks to identify and eliminate redundancies in maintenance processes. It provides a single entitled process, assisting the Navy in realizing the maximum cost

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

[2] 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).

savings in maintenance by eliminating time lags, prioritizing ship jobs, and empowering Sailors in their maintenance decisions (Commander, Naval Sea Systems Command, 2006). The five-phase process was originally designed to employ collab-PLM and 3D TLS. However, these technologies were not incorporated in the implementation of the SHIPMAIN program.

3D Terrestrial Laser Scanning, Collaborative Product Lifecycle Management Technology

Terrestrial laser scanning technology is currently used in a variety of industries. According to industry analysts, laser scanner manufacturers and related software and service providers report strong activity across many markets, including shipbuilding, offshore construction and repair, onshore oil and gas, fossil and nuclear power, civil and transportation infrastructure, building, automotive and construction equipment, manufacturing, and forensics (Greaves & Jenkins, 2007). Sales of terrestrial 3D laser scanning hardware, software, and services reached $253 million in 2006—a growth of 43% over 2005 (Greaves & Jenkins, 2007). Most manufacturers' scanners work by scanning a target space with a laser light mounted on a highly articulating mount, enabling data capture in virtually any orientation with minimal operator input. Some also incorporate a digital camera that simultaneously captures a 360° field-of-view color photo image of the target. Once the capture phase is complete, the system automatically executes proprietary point-processing algorithms to process the captured image. The system can generate an accurate[3] 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 them into 2D/3D computer-aided design (CAD) packages.

Collab-PLM technology provides a common platform to electronically integrate 3D TLS images in 3D surface representations to enable collaboration among all parties involved in a given project, regardless of their geographic location. It also provides a means to store the images and all related maintenance work within a common database accessible by all participants in a ship alternation or modernization project. PLM is defined by CIMdata as a strategic business approach applying a consistent set of business solutions in support of the collaborative creation, management, dissemination, and use of product definition information across the extended enterprise, from concept to end of life (CIMdata, 2007).[4] It integrates people, processes, and information. The collab-PLM tools include technologies that support data exchange, portfolio management, digital manufacturing, enterprise application integration, and workflow automation. A range of industries have invested in collab-PLM solutions, including those involved in aerospace and defense, automotive and transportation, utilities, process manufacturing, and high-tech development and manufacturing. The collab-PLM market is poised for further growth, with vendors expanding product offerings as the industry evolves.

SHIPMAIN: Collab-PLM and 3D TLS Technologies

The KVA + SD + IRM valuation framework was used to demonstrate how the integration of these two technologies within Phase IV of SHIPMAIN can result in substantial cost savings and decreased fleet cycle-time via significant productivity improvements. The results also demonstrate the possible increases in shipyard capacity when these tools are used in ship maintenance. This may become a critical benefit for the Navy per the Secretary of Navy's recently articulated goal for a substantial long-term increase in the fleet's size. A

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[3] NSRP's study (2006 & 2007b) requirement was within 3/16 of an inch to actual measurements.

[4] 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, 2007).

prior study of the ship maintenance process (Komoroski, 2005) was used as a basis for the current work. That study identified seven sequential core processes, as well as the subprocesses within each core process, that are utilized to plan for ship maintenance alterations on U.S. Navy surface ships. (See Ford, Housel, and Mun [2011] for details.) The study collected data from the Puget Sound Planning Yard through extensive interviews with subject matter experts. This data was used to quantitatively describe ship maintenance in an “as-is” environment, i.e. without collab-PLM and 3D TLS technologies. The KVA method was applied to model the as-is environment, which is used as baseline cost and productivity data for the current work.

The Komoroski (2005) study estimated baseline costs for these SHIPMAIN Phase IV seven core processes to be $45 million per year. This estimate was based on executing the seven core planning processes 40 times across the four public shipyards. The model was then used to model costs in a “to-be” environment in which 3D TLS had been adopted by the four shipyards. Adding 3D TLS to the planning process cycle lowered expenses a projected 84% (to less than $8 million), as seen in Table 1. Introduction of 3D TLS in the to-be environment could result in projected cost savings of nearly $37 million because Subprocesses 3, 4, and 7 were dramatically reengineered (Komoroski et al., 2006).

The second notional to-be KVA model evaluated the effects of adding both 3D TLS and the collab-PLM suite of software to the as-is baseline. Projections for this scenario (based on increased savings in Core Processes 3, 4, and 7, as well as additional savings realized in Core Processes 2 and 5) included a cost savings of 90%, or approximately $40 million.

Table 1. KVA Results—Analysis of Costs of Seven Core Planning Processes
(Komoroski et al., 2006, p. 36)

Seven Core Processes	Cost
1 Issue Tasking	$173,500
2 Interpret Orders	$520,000
3 Plan For Ship Check	$1,655,000
4 Conduct Ship Check	$2,604,500
5 Report Assembly	$235,000
6 Revise Schedule	$131,000
7 Generate Drawings	$39,386,000
Totals	**$44,705,000**

KVA Results

The cost analysis results were based on the as-is KVA baseline analysis from the previous study. The return on investment (ROI) for each of the seven core processes was calculated (Table 2). The numerator of the ROI calculation was the difference between the surrogate revenue (based on common units of output for each process) per time period for each process and the cost of the process, divided by the cost for the process (ROI = (Revenue per process - Cost for the process)/Cost for the process). These estimates provided baseline relative productivities for each of the core processes. For example, Process 3, Plan for Ship Check, provided the lowest ROI (-99%) even though it was not the most costly. And Process 7, clearly the most costly ($39,386,000 from Table 1), was not the least productive process in terms of its ROI performance (-37%, fifth of the seven core processes). These baseline estimates provide a reference point for comparing relative productivity increases when the technologies are included in the process modeling, which results in substantial increases in the two to-be ROI estimates.

Table 2. KVA Results—Analysis on ROI

Core Process	Process Title	"AS-IS" ROI
1	Issue Tasking	-69%
2	Interpret Orders	518%
3	Plan for Ship Check	-99%
4	Conduct Ship Check	552%
5	Report Assembly	783%
6	Revise Schedule	1375%
7	Generate Drawings	-37%

This baseline model provided the inputs for the current study's SD model. A comparison with the SD model and the static KVA analysis revealed that the SD model was of high fidelity with the previous results and could be used for further analysis and projections for the to-be scenarios. These analyses can describe a variety of environmental conditions, such as different product lifespans, thereby capturing the potential effects of the two technologies on resulting costs and ROIs. While these results of the previous study might be considered relatively positive, the current work reveals that the addition of collab-PLM and 3D TLS technologies promises to return even more significant savings and higher ROIs.

Collab-PLM and 3D TLS Adoption Conditions and Simulation Results and Discussion

SHIPMAIN was simulated with the SD model (see Ford, Housel, & Mun [2011] for model details) by varying four conditions: (1) the number of ship yards that adopt the technology, (2) the cycle-time reduction due to the adoption of the technologies, (3) the life span of the technologies before they were replaced, and (4) the finance plan for adoption. The three simulated numbers of shipyards adopting were zero, which represents the as-is conditions; four, which represents adoption by the Navy yards but not the commercial yards; and seven, which represents adoption by the four Navy yards and the three commercial yards. The three simulated levels of cycle-time reduction were 20%, 40%, and 60%, based on estimates of experience by other industries provided by the product vendor. Three product life spans were simulated: five, 10, and 15 years (researcher estimates). Two financing plans were simulated, based on either adoption of the technologies by the four Navy yards over several years or the simultaneous adoption of those technologies by all four Navy yards. The first plan (adoption over several years) assumed that the Navy paid a total of $6,400,000 based on an estimated $1,600,000 per Navy yard (vendor estimate) for each of the four Navy yards. The second financing plan (simultaneous adoption) assumed that the Navy paid a total cost of $3,200,000 for all four Navy yards. The 36 scenarios generated by the possible combinations of these adoption alternatives (two yard adoption alternatives, three cycle-time reductions, three life spans, two finance plans) were used to estimate ship maintenance cost.

The simulated costs with no yards adopting the technologies (as-is conditions) over the product life spans assuming four or seven yards of production were used as base cases for estimating savings. As an example, the as-is costs for four yards if the product life span is five years is estimated to be $228.15 million (= $45.63 million/year x 5 years). The difference between each simulated cost of an adoption scenario and the base case cost for the same number of yards and product life span is the estimated cost savings for the scenario. The resulting cost savings for each adoption scenario are shown in Table 3. For example, the estimated cost of four yards adopting the technologies for a five-year life span and capturing 20% cycle-time reduction with a cost of $1.6 million for the two technologies per yard is $39.05 million. Therefore the estimated savings are $189.10 million (= $228.2 – 39.05), the value shown in the upper-left estimated savings cell in Table 3.

Net estimated cost savings potential range, by adopting collab-PLM and 3D TLS, is from $161 million to $1.03 billion (in bold and underlined print in Table 4). As expected, cost savings increase with the number of yards adopting collab-PLM and 3D TLS and product life span. Savings reduce with increased cycle-time reduction, a counterintuitive result. The impact of cycle-time reduction on the throughput of ships, described previously in the specification of the model on pages 23-25, explains this behavior because the increased throughputs increase costs, decreasing savings.

Table 3. Simulated SHIPMAIN Cost Savings due to Adoption of Collaborative PLM and 3D TLS

Reduced Total Ownership Costs ($millions)											
Finance Plan: $1.6m for each of 4 yards = $6.4m total											
20% CT reduction	**Product Lifespan**			*40% CT reduction*	**Product Lifespan**			*60% CT reduction*	**Product Lifespan**		
No. Yards Adopting	**5 years**	**10 years**	**15 years**	**No. Yards Adopting**	**5 years**	**10 years**	**15 years**	**No. Yards Adopting**	**5 years**	**10 years**	**15 years**
4	189.10	384.59	580.08	**4**	179.73	365.87	552.01	**4**	**161.04**	328.48	495.92
7	337.96	682.34	1026.68	**7**	321.58	649.57	977.55	**7**	288.86	584.13	879.40
Finance Plan: $3.2m for 4 yards = $3.2m total											
20% CT reduction	**Product Lifespan**			*40% CT reduction*	**Product Lifespan**			*60% CT reduction*	**Product Lifespan**		
No. Yards Adopting	**5 years**	**10 years**	**15 years**	**No. Yards Adopting**	**5 years**	**10 years**	**15 years**	**No. Yards Adopting**	**5 years**	**10 years**	**15 years**
4	192.29	387.79	583.28	**4**	182.93	369.07	555.21	**4**	164.24	331.69	499.10
7	341.16	685.53	**1029.88**	**7**	341.16	652.77	980.75	**7**	324.78	588.94	884.23

For example, for four yards acquiring the two technologies for $1.6 million each (see the top row of Table 3) with a product life span of 10 years, savings dropped from $385 million to $366 million to $328 million as cycle-time reduction increases from 20% to 40% to 60%. The increased throughput capacity of the maintenance yards made available by the adoption of collab-PLM and 3D TLS may prove critical for Navy development. Navy Secretary Mabus recently announced plans to build a 324-warship Navy by 2020 (Howe, 2011). This will require increased ship maintenance capacity. The increased capacity may prove a critical part of growing the fleet without increasing the number of maintenance yards. The modeling described above assumes that the Navy has the demand and other required resources needed to utilize the increased capacity created by reduced cycle-times. This may not be accurate, but describes an extreme condition on a continuum of potential combinations of increased throughput and decreased capacity. The other end of that continuum assumes that the throughput rate remains unchanged. Similar calculations to those above show that the required capacities with reduced cycle-times are proportionate to the cycle-time reduction. Therefore, a 20% cycle-time reduction for the current throughput requires 20% less capacity, and so forth. This scenario could allow the Navy to maximize capacity use at certain yards and idle or close one or more yards that were not needed, depending on the cycle-time reduction actually captured.

Integrated Risk Management

The results for the IRM analysis are built on the quantitative estimates provided by the KVA + SD analysis. The IRM analysis provides defensible quantitative risk analytics and portfolio optimization that suggest the best way to allocate limited resources to ensure the highest possible cost savings over time in ship maintenance processes. The first step in IRM using real options is to generate a strategic map through the process of framing the problem. Generally, problem identification during the initial qualitative management screening process leads to the identification of strategic options for each particular project. Those strategic options can include flexibility to, among other things, expand, contract, abandon, switch, and choose. The current work focuses on the use of real options to expand the adoption of collab-PLM and 3D TLS, including some options to abandon the adoption effort. Through the use of Monte Carlo simulation, the stochastic KVA ROK model that is based on the identified options has a distribution of values for the drivers of project value. Thus, simulation models analyze and quantify the various risks of each project. The product of the simulations is a distribution of the ROKs and the project's volatility. In real options, we assume that the underlying variable is the future benefit minus the cost of the project. An implied volatility can be calculated through the results of a Monte Carlo simulation performed. Usually, the volatility is measured as the annualized standard deviation of the logarithmic relative returns on the free net benefit stream.

Portfolio optimization will be performed in a future phase of the project because, as of now, there is insufficient data to perform an adequate portfolio optimization applying modern portfolio theory. A description of the proposed optimization approach is presented in the appendix. When the analysis is done on multiple projects or processes, decision-makers can view the results as a portfolio of rolled-up projects because the projects are in most cases correlated with one another, and viewing them individually will not present the true picture. As organizations do not have only single projects, portfolio optimization becomes crucial. Given that certain projects are related to others, there are opportunities for hedging and diversifying risks through a portfolio. Because organizations have limited budgets, along with time, people, and resource constraints, and at the same time have requirements for certain overall levels of returns, risk tolerances, and so forth, portfolio optimization would take into account all these conditions to create an optimal portfolio mix. The analysis would provide guidance for identifying the optimal allocation of investments across multiple projects.

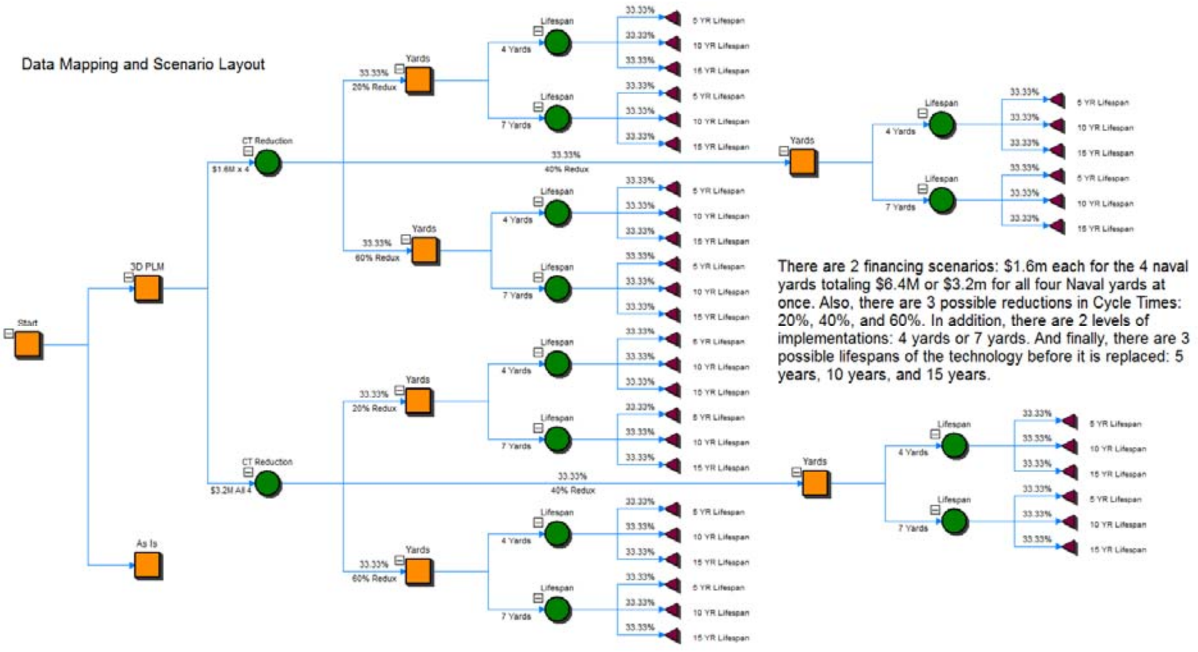
The current work addresses how the Navy can use real options to manage risk. Risk management using real options assumes that the future is uncertain and that decision-makers have the right to make midcourse corrections when these uncertainties become resolved or risks distributions become known. Risk analysis for the design and use of real options is usually done ahead of time and, thus, ahead of actually experiencing such uncertainty and risks. Therefore, when these risks become known and better understood, the analysis should be revisited to incorporate new information into decision-making or to revise any input assumptions. Sometimes, for long-horizon projects, several iterations of the real options analysis should be performed, where future iterations are updated with the latest data and assumptions. Understanding the steps required to undertake an integrated risk analysis is important because it provides insight not only into the methodology itself, but also into how it evolves from traditional analyses, showing where the traditional approach ends and where the new analytics start.

Real options analysis was performed to determine the prospective value of the basic options over a multiyear period using KVA data as a platform. The strategic real options analysis is solved employing various methodologies, including the use of binomial lattices with a market-replicating portfolios approach, and backed up using a modified closed-form sequential compound option model. Risk analysis of the current work requires the modeling of compound options. Compound options occur when managers have an option to use a second option, or when an option is “nested” within a different option. The value of a compound option is based on the value of another option. That is, the underlying variable for the compound option is another option, and the compound option can be either sequential in nature or simultaneous. Solving such a model requires programming capabilities. (See the appendix for examples.) Figure 1 shows the graphical depiction of the scenarios available for this initial 3D TLS and collab-PLM analysis. This figure uses a decision tree to depict the two alternate financing scenarios (Scenario 1 comprises a total of $6.4 million where $1.6 million per shipyard is implemented one at a time for a total of four shipyards, and Scenario 2 where all four shipyards are implemented simultaneously, with a total of $3.2 million); the three possible reductions in cycle-time (20%, 40%, and 60%); the two levels of implementation (four yards or seven yards); and the technology’s life span (five years, 10 years, and 15 years). We chose the decision tree for its simplicity in graphically depicting the various scenarios and conditions. In decision trees square nodes depict investment decisions such as how many yards to implement, circles depict uncertainty events such as cycle-time reduction and life span, and triangles indicate end points of all possible combinations of outcomes. In this case there are 36 possible combinatorial outcomes. The decision tree is only used for showing these various combinatorial outcomes and not used as a computational method due to its many limitations. Instead, we revert to using the Monte Carlo risk simulation and strategic real options methodologies discussed in the following sections.

Figure 2 shows the three investment option paths. The first strategy (Strategy A) is a phased implementation, where the first four yards are implemented sequentially, one at a time, and at the end of the fourth yard (Phase 4), an additional three yards can be implemented at once. The benefit of this first option is that a lower initial investment is at risk, and at any time, the entire project can be abandoned. That is, at the end of Phase 1 or during any of the phases, if significant problems arise during the implementation process, the Navy can decide to abandon the project altogether and not risk the entire investment amount (e.g., only $1.6 million will be expended in Phase 1 instead of risking a total of $3.2 million in implementing all four yards at once, or $7.2 million for all seven yards). The disadvantage of this scenario is that the total ownership cost savings will not be realized as quickly as in Strategy B, where multiple yards are simultaneously implemented.

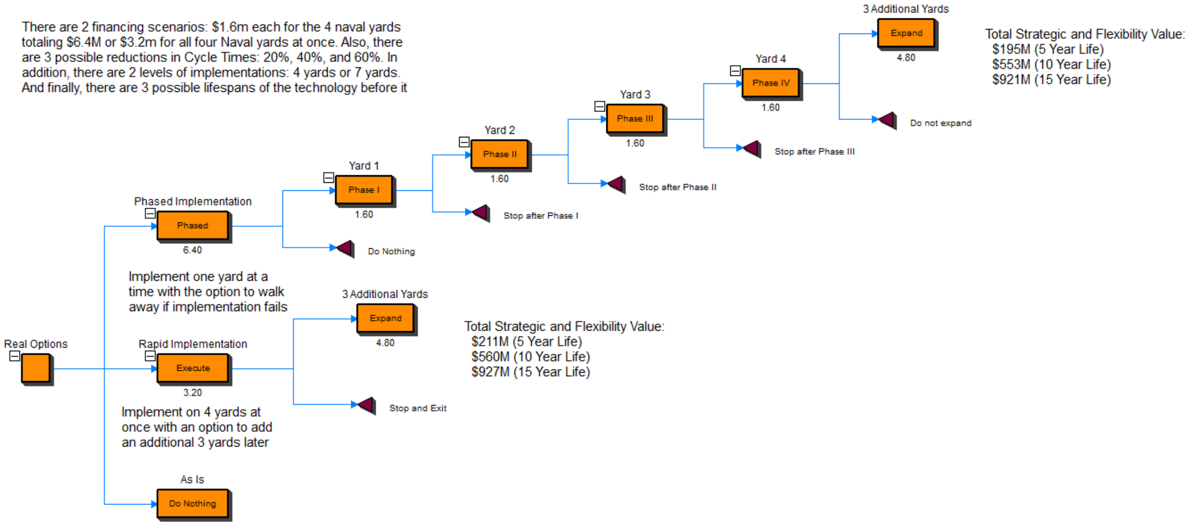
This second option path, or Strategy B, involves rapid implementation by investing in four yards simultaneously, thereby reducing the total investment cost ($3.2 million instead of $6.4 million as in Strategy A), but clearly the investment amount risked is higher. The benefit is that implementation is rapid and the savings can be obtained faster, and if all goes well with the implementation, the additional three yards can be added to the portfolio quickly.

Both Strategies A and B are compared to Strategy C, the as-is or do-nothing-new situation. Therefore, the analysis results from the strategic real options analysis is a relative analysis, where the results indicate reduction in total ownership costs and strategic values relative to Strategy C. Figure 3 shows the various scenarios and the reduction in total ownership cost (TOC) savings. The table also shows the risk-adjusted, inflation-adjusted, and diminishing marginal returns adjusted savings, as well as their relative volatilities. These adjustments are required because the different implementation paths take on different timelines and, hence, have different inflation effects as well as risk-time effects. Further, we assumed some levels of diminishing marginal returns on the reduction in TOC over time, as will be discussed later.



There are 2 financing scenarios: $1.6m each for the 4 naval yards totaling $6.4M or $3.2m for all four Naval yards at once. Also, there are 3 possible reductions in Cycle Times: 20%, 40%, and 60%. In addition, there are 2 levels of implementations: 4 yards or 7 yards. And finally, there are 3 possible lifespans of the technology before it is replaced: 5 years, 10 years, and 15 years.

Figure 1. Representation of Implementation Scenarios and Data Requirements



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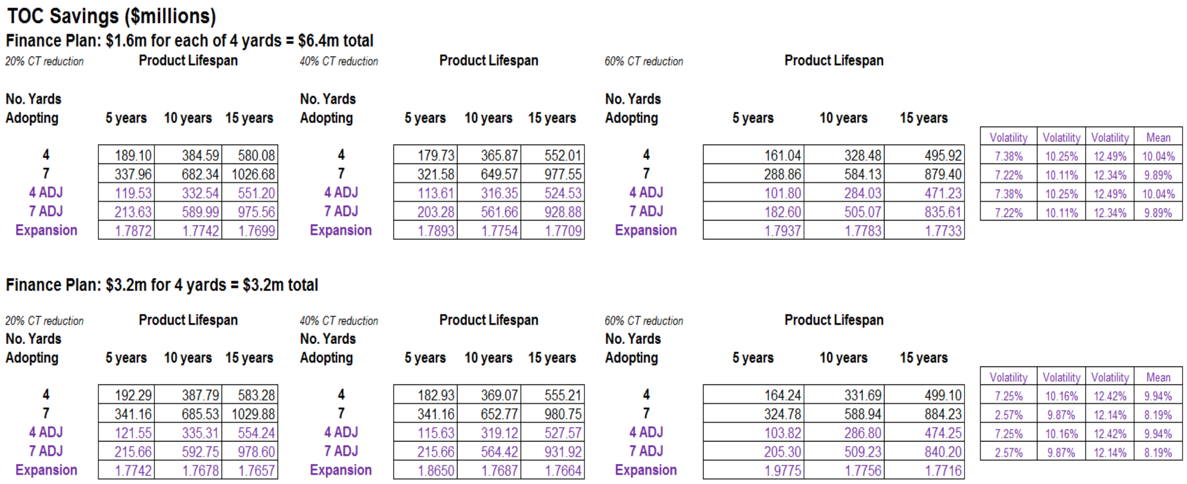
Total Strategic and Flexibility Value:
$195M (5 Year Life)
$553M (10 Year Life)
$921M (15 Year Life)

Implement one yard at a time with the option to walk away if implementation fails

Total Strategic and Flexibility Value:
$211M (5 Year Life)
$560M (10 Year Life)
$927M (15 Year Life)

Implement on 4 yards at once with an option to add an additional 3 yards later

Figure 2. Strategic Real Options of Investment Paths



TOC Savings ($millions)

Finance Plan: $1.6m for each of 4 yards = $6.4m total

20% CT reduction	Product Lifespan			*40% CT reduction*	Product Lifespan			*60% CT reduction*	Product Lifespan		
No. Yards Adopting	5 years	10 years	15 years	No. Yards Adopting	5 years	10 years	15 years	No. Yards Adopting	5 years	10 years	15 years
4	189.10	384.59	580.08	4	179.73	365.87	552.01	4	161.04	328.48	495.92
7	337.96	682.34	1026.68	7	321.58	649.57	977.55	7	288.86	584.13	879.40
4 ADJ	119.53	332.54	551.20	4 ADJ	113.61	316.35	524.53	4 ADJ	101.80	284.03	471.23
7 ADJ	213.63	589.99	975.56	7 ADJ	203.28	561.66	928.88	7 ADJ	182.60	505.07	835.61
Expansion	1.7872	1.7742	1.7699	Expansion	1.7893	1.7754	1.7709	Expansion	1.7937	1.7783	1.7733

Volatility	Volatility	Volatility	Mean
7.38%	10.25%	12.49%	10.04%
7.22%	10.11%	12.34%	9.89%
7.38%	10.25%	12.49%	10.04%
7.22%	10.11%	12.34%	9.89%

Finance Plan: $3.2m for 4 yards = $3.2m total

20% CT reduction	Product Lifespan			*40% CT reduction*	Product Lifespan			*60% CT reduction*	Product Lifespan		
No. Yards Adopting	5 years	10 years	15 years	No. Yards Adopting	5 years	10 years	15 years	No. Yards Adopting	5 years	10 years	15 years
4	192.29	387.79	583.28	4	182.93	369.07	555.21	4	164.24	331.69	499.10
7	341.16	685.53	1029.88	7	341.16	652.77	980.75	7	324.78	588.94	884.23
4 ADJ	121.55	335.31	554.24	4 ADJ	115.63	319.12	527.57	4 ADJ	103.82	286.80	474.25
7 ADJ	215.66	592.75	978.60	7 ADJ	215.66	564.42	931.92	7 ADJ	205.30	509.23	840.20
Expansion	1.7742	1.7678	1.7657	Expansion	1.8650	1.7687	1.7664	Expansion	1.9775	1.7756	1.7716

Volatility	Volatility	Volatility	Mean
7.25%	10.16%	12.42%	9.94%
2.57%	9.87%	12.14%	8.19%
7.25%	10.16%	12.42%	9.94%
2.57%	9.87%	12.14%	8.19%

Figure 3. Reduction in Total Ownership Costs

Figure 4 shows the input assumptions used in the strategic real options analysis, as well as Monte Caro risk simulation analysis for the two implementation strategies. Simulations of 10,000 to 100,000 trials were applied using these values, and the various combinatorial effects were collapsed into probability distributions and then simulated. The results were then used as inputs into the real options analysis. Figure 2 illustrates the two strategies' (Strategy A, phased implementation, and Strategy B, rapid implementation) input into the real options model (e.g., the net reduction in total ownership costs minimum, most likely, and maximum values, implementation costs over time, simulated risk volatility and other assumptions).

Figures 5 and 6 show the results from both strategies. Specifically, Strategy A's phased implementation (sequential compound option) shows a value of $546 million, whereas Strategy B has a value of $557 million. This shows that the rapid implementation has a higher strategic value in that, although the risk is slightly higher with the higher up-front investment amount, the saving received will be faster and the total invested cost is lower (as compared to the higher total investment cost for Strategy A). However, the values of the two strategies are quite close (within 2%). In addition, Figure 6 shows that when simulation was applied to compare the relative values of Strategies A and B, Strategy B, the rapid implementation path, has a 53.20% probability of exceeding Strategy A. In fact, the relative risk measures show that both scenarios have very close relative risks (41.65% versus 41.07%). This further explains why the values of the two strategic real options are so close.

The results of the simulations indicate that both Strategies A and B are valuable and that their values are very similar. This suggests that the choice of one strategy over the other should be up to the decision-maker based on which path makes more sense in an operational environment. Both strategies show a significant reduction in TOC overall, even after considering risk effects and diminishing marginal returns.

Options Assumptions Used (Combined Analysis)

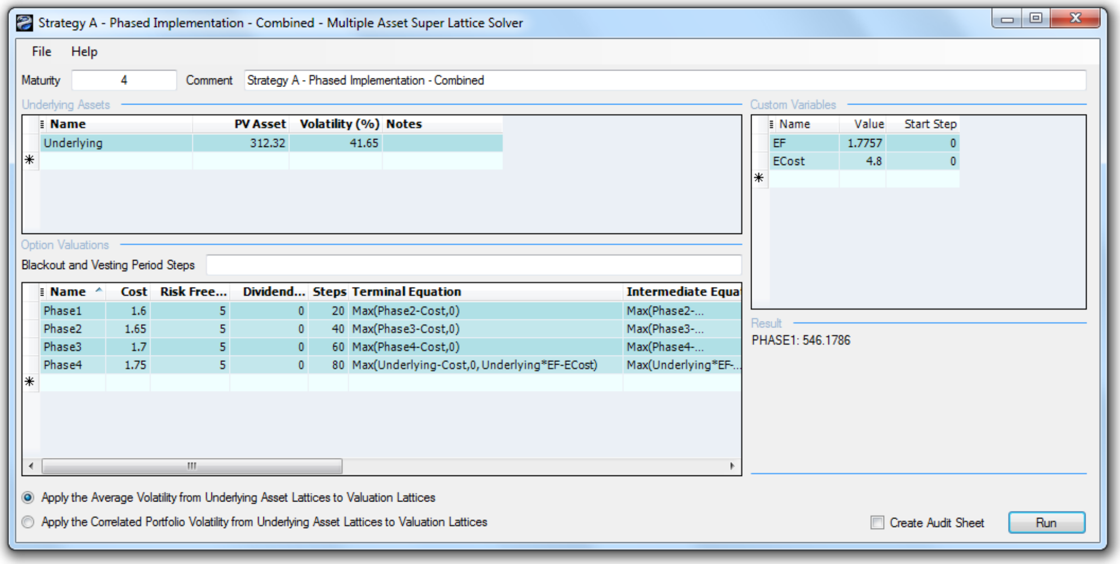
Strategy A: Phased Implementation

Asset (Distribution)	112.14 (Min)	312.32 (Likely)	517.87 (Max)	
Cost	$1.6M	$1.6M	$1.6M	$1.6M
Maturity	1 Year	2 Year	3 Year	4 Year
Risk-free	0.5%			
Volatility	41.65%			
Dividend	0%			
Steps	1000			
Expand Cost	$4.8M			
Economic Life	5 Years	10 Years	15 Years	
Probability	25%	50%	25%	
4 ADJ RAROC	$112.14	$312.32	$517.87	
7 ADJ RAROC	$200.70	$554.59	$917.23	
EF RAROC	1.7897	1.7757	1.7712	
Inflation	3%			
Inflation Adj. Cost	$1.60	$1.65	$1.70	$1.75

Strategy B: Rapid Implementation

Asset (Distribution)	114.16 (Min)	315.09 (Likely)	520.91 (Max)
Cost	$3.2M		
Maturity	4		
Risk-free	0.5%		
Volatility	41.07%		
Dividend	0%		
Steps	1000		
Expand Cost	$4.8M		
Economic Life	5 Years	10 Years	15 Years
Probability	25%	50%	25%
4 ADJ RAROC	$114.16	$315.09	$520.91
7 ADJ RAROC	$213.07	$557.71	$920.66
EF RAROC	1.8664	1.7700	1.7674

Figure 4. Real Options Valuation Input Assumptions



Maturity: 4

Comment: Strategy A - Phased Implementation - Combined

Name	PV Asset	Volatility (%)	Notes
Underlying	312.32	41.65	

Name	Value	Start Step
EF	1.7757	0
ECost	4.8	0

Blackout and Vesting Period Steps:

Name	Cost	Risk Free...	Dividend...	Steps	Terminal Equation	Intermediate Equa
Phase1	1.6	5	0	20	Max(Phase2-Cost,0)	Max(Phase2-...
Phase2	1.65	5	0	40	Max(Phase3-Cost,0)	Max(Phase3-...
Phase3	1.7	5	0	60	Max(Phase4-Cost,0)	Max(Phase4-...
Phase4	1.75	5	0	80	Max(Underlying-Cost,0, Underlying*EF-ECost)	Max(Underlying*EF-...

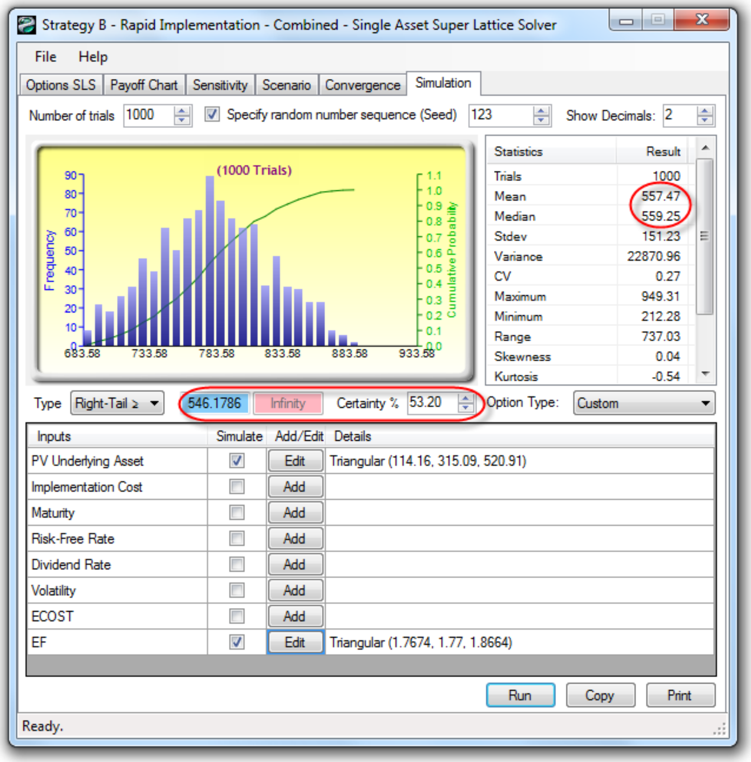
PHASE1: 546.1786

● Apply the Average Volatility from Underlying Asset Lattices to Valuation Lattices

○ Apply the Correlated Portfolio Volatility from Underlying Asset Lattices to Valuation Lattices

☐ Create Audit Sheet

Figure 5. Strategy A’s Real Options Valuation Results



Number of trials 1000 ☑ Specify random number sequence (Seed) 123 Show Decimals: 2

Statistics	Result
Trials	1000
Mean	557.47
Median	559.25
Stdev	151.23
Variance	22870.96
CV	0.27
Maximum	949.31
Minimum	212.28
Range	737.03
Skewness	0.04
Kurtosis	-0.54

Type Right-Tail ≥ 546.1786 Infinity Certainty % 53.20 Option Type: Custom

Inputs	Simulate	Add/Edit	Details
PV Underlying Asset	☑	Edit	Triangular (114.16, 315.09, 520.91)
Implementation Cost	☐	Add	
Maturity	☐	Add	
Risk-Free Rate	☐	Add	
Dividend Rate	☐	Add	
Volatility	☐	Add	
ECOST	☐	Add	
EF	☑	Edit	Triangular (1.7674, 1.77, 1.8664)

Ready.

Figure 6. Strategy B's Real Options Valuation Results

Discussion and Conclusions

The KVA + SD + IRM framework for modeling and evaluating DoD systems was applied to the adoption of collab-PLM and 3D TLS in SHIPMAIN processes. The model extends the previous KVA modeling by including important implementation costs and improvements in performance due to cycle-time reduction and a potential increase in shipyard maintenance capacity. Simulations across a range of values for uncertain conditions describe a defensible range of potential savings. The KVA + SD modeling revealed and quantified an increase in shipyard capacity of 25% to 150% due to reductions in maintenance cycle-times. The results of the KVA + SD model were used in the IRM model to include uncertainties and strategic real options. Results indicate that both a phased implementation (Strategy A) and a rapid implementation (Strategy B) of collab-PLM and 3D TLS in SHIPMAIN processes are very valuable, generating a net total ownership cost savings of about $550 million compared to the current approach to ship maintenance.

Although some modeling assumptions may not become realities in terms of implementation strategies and conditions, the results of the current work provide a means to analyze the potential impacts of the adoption of collab-PLM and 3D TLS in the SHIPMAIN process in terms of cost savings and, thereby, to better guide implementation. In addition to the cost savings potential, there is also the possibility of an increase in shipyard capacity for ship maintenance. If the fleet size grows to the level suggested by the Secretary of the Navy, it is entirely possible that this excess capacity will be consumed quickly. However, it also implies that the Navy will have greater flexibility in adding or reducing capacity using the two technologies. Such flexibility is critical in the coming budget-constrained DoD environment. The results clearly point to the cost savings advantages of using collab-PLM and 3D TLS technologies. There appears to be no logical reason for delaying implementation of these two technologies based on the results of this study and the previous studies with similar cost savings projections.

The current study is the fourth attempt to gauge the impact of these technologies and confirms the general results of the previous three studies: adopting these technologies will result in substantial cost savings and productivity increases. Further, the current study also provides a practical means to track the performance of these technologies over time, allowing a continuous portfolio optimization based on learning about the performance of these technologies in ship maintenance over time. In addition, the current study identified and quantified the increase in shipyard capacity created by the adoption of the technologies and a potentially critical component of the Navy’s expansion strategy.

The primary limitation of the current study is the absence of actual ship maintenance performance data over time. Without this kind of performance information, it becomes very difficult to reassess and restructure maintenance resource portfolio allocations. The use of systems dynamics provides a means to make reasonable estimates based on a model that allows variation in initial conditions. The fact that the current study model mirrored the prior study’s (Komoroski et al., 2005) empirically derived results provides some compelling evidence that the results of the SD modeling provides a defensible forecast of the cost saving impacts of these technologies. However, real historical performance data would provide the best means for forecasting the future cost savings and portfolio optimization impacts of these technologies on ship maintenance. Future research must focus on obtaining historical ship maintenance process performance using the two technologies. Comparative analyses may also be possible with shipyards that have already adopted these technologies.

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