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ACQUISITION RESEARCH

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Product Lifecycle Management:
A Collaborative Tool for Defense Acquisition

30 September 2010

by

Lt. Christopher M. Schindler, USN

Advisors: Dr. Thomas J. Housel, Professor

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Systems Engineering

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ABSTRACT

A 2010 review of 96 defense acquisition programs showed average delivery rates are 22 months behind schedule and the cumulative cost growth exceeded $296 billion. With budget cuts looming, a small window of opportunity exists to enact reforms improving the health and solvency of the defense acquisition portfolio. First, we must leverage the technology investments made into collaborative software suites such as product lifecycle management (PLM) to align the requirements, design, engineering, logistics, maintenance, and operational data environments into one comprehensive activity. Implementing a PLM strategy will present cost-saving opportunities through faster information access, improved data reuse, social networking, and virtual collaboration and testing. PLM systems have the ability to capture and organize vast amounts of data. Because through human interaction data becomes knowledge, lean product design is a philosophy that can change how we think, learn, use, and build up on that knowledge. By going beyond merely attacking waste by finding a balance between waste reduction and value addition, total ownership costs can be reduced drastically. These reforms have the ability to fundamentally change how we design, build, and maintain the fleet, making the defense portfolio solvent and thus continuing to fulfill the needs of the warfighter.

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Disclaimer: The views represented in this report are those of the author and do not reflect the official policy position of the Navy, the Department of Defense, or the Federal Government.

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LIST OF ACRONYMS AND ABBREVIATIONS

CAD	Computer-aided Design
CAE	Computer-aided Engineering
CAM	Computer-aided Manufacturing
CAVE	Computer Automated Virtual Environment
CIM	Computer-integrated Manufacturing
COTS	Commercial Off-the-shelf
DARPA	Defense Advanced Research Projects Agency
DoD	Department of Defense
EDM	Engineering Data Management
EMALS	Electro Magnetic Aircraft Launch System
EVM	Earned Value Management
FY	Fiscal Year
GAO	Government Accountability Office
GDP	Gross Domestic Product
IDE	Integrated Data Exchange
IPDE	Integrated Product Development Environment
IPPD	Integrated Product and Process Development
IT	Information Technology
KPP	Key Performance Parameter
LAN	Local Area Network
LPD	LEAN Product Development
NAVSEA	Naval Sea Systems Command
NDO	National Design Organization
NSRP	National Shipbuilding Research Program
ONR	Office of Naval Research
PDI	Product Data Interoperability
PDM	Product Data Management
PEID	Product Embedded Information Devices

PLM	Product Lifecycle Management
RAM	Reliability, Availability, Maintainability
RFID	Radio Frequency Identification
ROM	Rough Order of Magnitude
RSM	Response Surface Methodology
SIP	Strategic Investment Plan
TOC	Total Ownership Cost
TPS	Total Production System
TSSE	Total Ship Systems Engineering
VPD	Virtual Product Development

ACKNOWLEDGMENTS

At American Society of Naval Engineers (ASNE) Day 2010, a question was asked of a panel: "What should we as young engineers do to aid in our development"? The respondent pointed out that it is up to us to "push the envelope" because we do not know where the boundaries are, and, therefore, do not have to be constrained by the "this-is-how-it-has-always-been" mentality. This research is my contribution to fulfilling this vision of what a young engineer needs to be. I have relied greatly on those with tremendous amounts of experience, who were willing to serve as valuable mentors, acted as my sounding board, provided access and insight that was invaluable to my research, particularly Dan Billingsley, Robert Keane, Patrick Hudson, Ben Kassel, Randy Langmead, Michael Schwind, and Jeff Watson. I also must thank my advisors, Thomas Housel and Bill Solitario, for guiding me through this academic endeavor, keeping me focused and making constant progress. I would also gratefully acknowledge that without the assistance of RADM Jim Greene, Karey Shaffer and the entire Naval Postgraduate Acquisition Research team this effort would not have been possible.

More importantly, I could never be at the station of life that I find myself without the love and support of my wife, Tansy. She has sacrificed so much to allow me to pursue my endeavors, and has more than picked up the slack where I fell short. Thanks, and I will strive to be the husband you deserve.

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I. INTRODUCTION

A. BACKGROUND

The United States has a broad set of national security missions that it must be prepared to complete. To accomplish these missions, an equally broad set of weapon systems must be developed by the acquisition community, providing capabilities to our warfighters and ensuring they hold the advantage regardless of the mission or task. To accomplish its assigned missions, the United States Navy builds and operates the most sophisticated, technologically advanced ships in the world. Since 2002, Congress has appropriated over $74.1 billion for the construction of new aircraft carriers, nuclear submarines, surface combatants, and amphibious transport ships (Government Accountability Office [GAO], 2009b).

Any inefficiency through the acquisition process will consume resources, leaving fewer available to invest in the weapon systems of tomorrow. One indicator that inefficiencies are present in the current process is the unexpected cost growth and schedule delays of recent programs. A 2010 Government Accountability Office (GAO) report (Table 1) reviewed the performance of 96 major defense acquisition programs in 2009 and showed that average delivery rates are 22 months behind schedule and running at a cumulative cost growth of $296 billion (GAO, 2010).

Table 1. Analysis of the DoD Acquisition Portfolio
(GAO, 2010)

Fiscal year 2009 dollars			
	Fiscal year		
	2003	2007	2008
Portfolio size			
Number of programs	77	95	96
Total planned commitments	$1.2 trillion	$1.6 trillion	$1.6 trillion
Commitments outstanding	$724.2 billion	$875.2 billion	$786.3 billion
Portfolio indicators			
Change to total RDT&E[b] costs from first estimate	37 percent	40 percent	42 percent
Change to total acquisition cost from first estimate	19 percent	26 percent	25 percent
Total acquisition cost growth	$183 billion	$301.3 billion[a]	$296.4 billion
Share of programs with 25 percent increase in program acquisition unit cost growth	41 percent	44 percent	42 percent
Average schedule delay in delivering initial capabilities	18 months	21 months	22 months

The Honorable Gene Taylor, congressional representative from Mississippi, speaking on the state of the acquisition portfolio, said "Our ships are simply too expensive. [...] I believe the Navy needs to look very hard at their requirements process to determine if marginal extra capability is worth significant construction or integration costs" (*Opening Statement*, 2009).

Congressman Taylor was speaking to the fact that through fiscal year (FY)09, the Navy has seen cost growth across every major current program, the worst being Littoral Combat Ship, which saw an increase of 208% from the original estimate, as shown in Table 2 (Department of Defense [DoD], 2010). Because of these high costs, Congress or the Navy could decide to kill the troubled program, or pay the additional cost growth either by placing an additional burden on the tax payers or by cutting the funds from other programs. Both of these actions would result in fewer capabilities for warfighters.

Table 2. Program Budget Cost Growth for Ships Under Construction in 2009 (DoD, 2010)

Program Acquisition Cost Summary (Dollars in Millions)
As of December 31, 2009

Program	Baseline Estimate			Current Estimate			% Change to date
	Then Year $	Quantity	$/hull	Then Year $	Quantity	$/hull	Then Year $
CVN 78	$ 36,082	3	$ 12,027	$ 40,546	3	$ 13,515	12.4%
DDG 1000	$ 36,296	10	$ 3,630	$ 19,771	3	$ 6,590	17.4%
DDG 51	$ 20,118	23	$ 875	$ 80,408	71	$ 1,133	21.4%
LCS	$ 1,212	2	$ 606	$ 3,733	2	$ 1,866	208.0%
LPD 17	$ 10,762	12	$ 897	$ 18,659	11	$ 1,696	101.0%
SSN 774	$ 71,081	30	$ 2,369	$ 91,394	30	$ 3,046	28.6%
T-AKE	$ 4,890	12	$ 408	$ 6,889	14	$ 492	16.9%

The expensive nature of ships referred to by Congressman Taylor is not limited to the acquisition costs. Total Ownership Cost (TOC) includes all costs associated with the research, development, procurement, operation, and disposal of an individual weapon system over its full life. Commenting on the high cost of weapon systems, General Joseph W. Ralston, former commander of Air Combat Command, has observed that "The B-1 bomber cost of ownership is more threatening to the aircraft than the enemy" (Reed, 2003).

Traditionally, the cost to procure a system (as shown in Figure 1) is approximately 28% of the total ownership cost, with the remainder representing the cost to operate and maintain the product through its lifecycle and eventual disposal (General Accounting Office [GAO], 2003b).

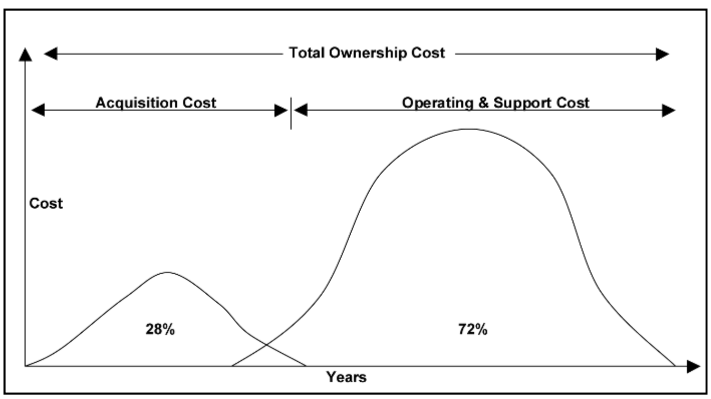


Figure 1. Typical DoD Program Life Cycle Cost, 30-Year Service Life (GAO, 2003b)

While a majority of the TOC will occur during the operations-and-support phase of a program, Figure 2 demonstrates how decisions made while crafting requirements and maturing the design will dictate operating and support expenditures. This is similar to purchases made with a credit card—you can buy anything today, but at the end of the month, the bill will be waiting. Making poor decisions early can leave a program with bills that cannot be paid. Failing to consider TOC in the acquisition strategy is like making an impulse purchase without considering the real cost. The GAO cites studies demonstrating that by the time 10% of lifecycle costs have been spent, about 85% of operating and support costs have been determined by set requirements. By the time the product is ready for production, 90% of TOC is locked in, while only 28% has been expended (GAO, 2003b). Understanding the ramifications early decisions have on the TOC will help to ensure that decisions made are the best in regard to the entire lifecycle.

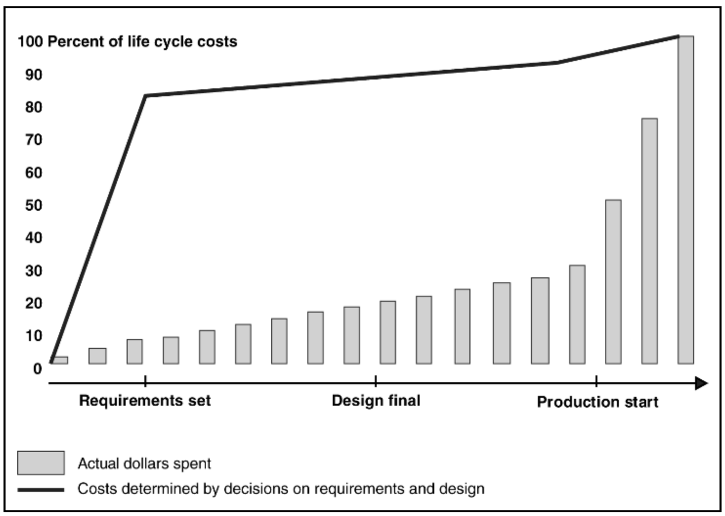


Figure 2. Operating and Support Costs through the Acquisition Process
(GAO, 2003b)

In a 2003 study on ways to reduce the TOC, the GAO identified three primary reasons that weapon systems have experienced costly maintenance problems and low readiness rates. First, during the early stage design, when decisions have the greatest effect, the Department of Defense (DoD) overemphasizes technical performance capabilities at the expense of operating, support, and readiness. Second, the reliance on immature technologies to meet performance goals decreases the ability to design weapon systems with high reliability. As the technology matures, the design evolves to accommodate differences from the original estimate, sometimes the requirements of the technology are not fully understood until after construction has begun. Immature technologies limit the ability to plan for inclusion of various cost-saving manufacturing techniques, such as open systems or parts reduction. Third, the current organizational structure limits collaboration and feedback between departments, creating stovepipes responsible for requirements generation, product development, and maintenance. The current system the DoD uses to capture and analyze currently fielded systems-operation and maintenance data is unreliable, making it difficult to understand the total cost of operations and support. These stovepipes prohibit the proper exchange of information, resulting in inefficient behavior such as ship alterations scheduled immediately upon delivery, versus working with the builder to make the corrections or improvements while in production (GAO, 2003b). By enacting reforms addressing root causes behind the cost escalation and schedule delays during procurement and making conscious decisions that positively influence TOC, the Navy can make more efficient use of the appropriated budget. However, being good stewards of taxpayer dollars is not the only reason to consider changing how the Naval acquisition community operates.

The U.S. government is projected to spend $3.5 trillion in FY10—approximately 20% of gross domestic product (GDP). Of that amount, 38% ($1.37 trillion) is considered “discretionary” spending and funds the 12 major federal government agencies and departments. The largest of those is the Department of Defense (DoD), which consumes nearly half of the discretionary budget, or $663 billion (Office of Management and Budget [OMB], n.d.).

The DoD is a major target for spending reductions because it is 8.5 times larger than the next largest department. Figure 3 shows that based on historic trends, cuts in defense spending should be expected. Connie Bowling, a senior TOC advisor for Naval Sea Systems Command (NAVSEA) and Navy headquarters, points out that after a major war period, defense spending has contracted by 30% and then risen by 30% over the course of the next war (McPherson & Bowling, 2009).

Figure 3 shows that we may already be past the peak of this spending cycle. This conclusion coincides with Secretary of Defense Robert Gates's comments during a speech at Eisenhower Library in Kansas, during which he said, "Given America's difficult economic circumstances and perilous fiscal condition, military spending on things large and small can and should expect closer, harsher scrutiny. […] The gusher has been turned off, and will stay off for a good period of time" (Dreazen, 2010). As public opinion continues to exert tremendous pressure on the government to become more accountable for its spending, the probability increases that the defense budget will be cut. The DoD should prepare for these cuts by ensuring that best practices are implemented now, to maximize the value delivered to the warfighters and avoid the need for hasty decisions as budgets are cut.

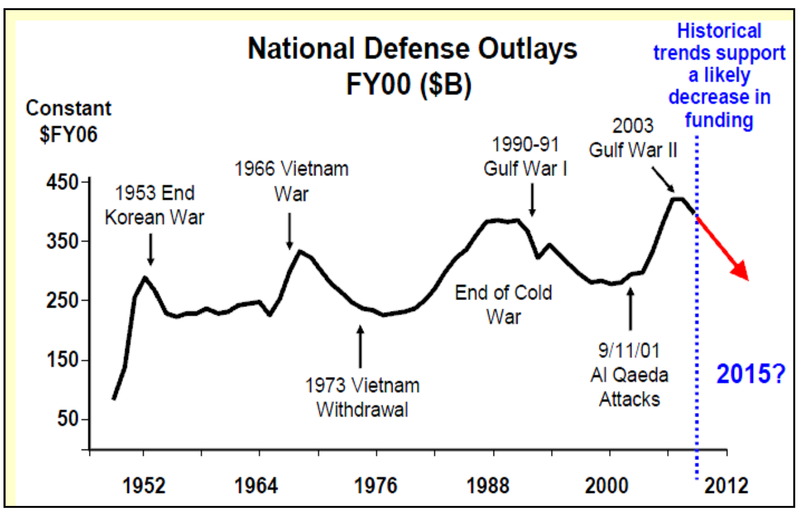


Figure 3. National Defense Outlays FY00 ($B)

(McPherson & Bowling, 2009)

When the hostilities in Iraq and Afghanistan finally end, it is highly probable that cuts to the defense budget will shortly follow to compensate for other areas of national interest that have been financially neglected. These hostilities have put an incredible stress on the military's equipment—not only has the operational environment been brutal, but in order to keep systems operationally available, regular maintenance has been deferred or ignored. For example, helicopters are flying two or three times their planned usage rates. Tank crews are driving more than 4,000 miles a year, five times the normal rate. Truck fleets that convoy supplies down Iraq's bomb-laden roads are running at six times the planned mileage (Tyson, 2006).

An estimated $17 billion-plus worth of military equipment is destroyed or worn out each year, blasted by bombs, ground down by desert sand, or used up to nine times the rate of expenditure compared to times of peace (Hochberg, 2007). This equipment must be repaired or replaced. At the same time, funds are needed to build the systems of tomorrow that will be ready to replace the old or worn-down systems.

To accomplish all of these goals, the acquisition process must be very efficient with the funds appropriated, to develop systems utilizing best practices that strive to find a balance between maximizing capabilities for the warfighter and minimizing the TOC, which causes a strain on budgets.

In order to address the root causes behind the cost volatility and schedule delays, as well as make prudent TOC decisions based on the entire lifecycle, the Navy needs to take action. Investment in the right technologies can provide the workforce capability and features that can lead to an improved knowledge base. Improved knowledge can lead to informed decision making and to building an organizational history that ensures lessons are learned from mistakes instead of repeated, which leads to reforming the practices, processes, and organizations and to making better use of the available resources.

B. RESEARCH QUESTIONS

What is needed is a balance between the design selected to meet the warfighters' needs and the resources (funding, technology, design knowledge, engineering capacity, etc.) available to transform the idea into a functioning product. The following research questions established the framework and served as an underlying guide throughout this research:

1. How can a technology such as collaborative product lifecycle management (PLM) be used to improve the acquisition process?

2. What reforms to the acquisition process are possible, complimenting, or supplementing the capabilities provided by collaborative PLM, helping ensure value is optimized throughout the lifecycle of the product?

II. SCOPE AND METHODOLOGY

A. RESEARCH METHODOLOGY

The research methodology used is non-numerical and descriptive and will apply reasoned arguments supported by external sources. This is an applied, qualitative research methodological approach. The goal of this study is to find a solution to improve the performance of our acquisition programs. Staying inside the applied research approach, the solutions were crafted from well-supported and accepted theories and principles. The research is categorized as qualitative because the focus is on experience, aimed to acquire the implications and opinions describing the situation, as opposed to numerically prove or disprove a hypothesis through experimentation.

Due to the immensity and complexity of ship lifecycle, systems analysis based studies should be conducted to examine and evaluate a variety of issues such as requirements development, technology maturity, construction, operation, and sustainment. This thesis demonstrates how the collaborative PLM tool suite can supplement other reforms of the acquisition process to deliver a product that meets requirements while improving the return on investment.

B. RESEARCH OBJECTIVE AND SCOPE

The research objectives are twofold. The first is to find companies that have had success addressing similar issues plaguing DoD acquisitions and to determine whether these commercial best practices offer opportunities to improve the outcomes in DoD acquisitions and aid its efforts to improve the value-to-cost ratio of its fleet. The second is to determine if a PLM approach could facilitate these practices.

One of the best opportunities to reduce the risk associated with an acquisition program is early in the design phase where the program has the greatest flexibility and a course correction results in minimal disruption and the need for rework. This thesis does not exclude any phase of an acquisition program, but focuses primarily on reforms applicable to the time early in the design phase. The belief is that a solid design is the foundation of a successful program. A helpful attribute of a solid foundation is the integration of each phase of a product lifecycle, in order to capture experience and knowledge unique to that phase, and then use this knowledge to influence positive decisions during design. This research will also show ways this knowledge can assist the design team in optimizing value to the stakeholders across all phases.

C. RESEARCH DATA SAMPLE

A multitude of literature, including government white papers, industry point papers, GAO reports, program lessons learned, books, and journal articles concerning best practices and lessons learned during the product development phase were studied for this thesis. The opinions formed were based on which processes offered the greatest return on investment and how current technologies can act as a facilitator for implementation of the identified processes.

The author was granted access and was provided with internal documents such as lessons learned and whitepapers, as well as met or spoke with representatives from current Navy programs such as LPD 17, DDG 1000, LCS, SSN 774, and CVN 78. Observation of active programs' daily operations provided insight on issues experienced, reasoning behind decisions made, and lessons learned from mistakes, among other general observations. These programs were selected because they are current and offered the best perspective of the state of the acquisition process.

The United Airlines engine maintenance facility in San Francisco also provided data and access that aided my research. They offered meetings with engineers and tours of the facility, to see how United closed the information loop throughout the engine lifecycle. Other private-sector companies provided information, white papers, interviews, and case studies; however, due to proprietary information, my access was limited.

The capabilities of collaborative PLM and the evolution of LEAN product development (LPD) was learned from literature provided and interviews conducted with professionals, including the founder of Huthwaite Innovation Institute and experts from Siemens Product Lifecycle Management Software, Dassault Systems Solutions, John Stark

Associates, SofTech, Ship Constructor Shipbuilding Software, and the Center for Naval Shipbuilding Technology. This helped to develop an understanding of how LPD philosophy was built into and supported by collaborative PLM tools. These experts helped me understand the best practices and lessons they had learned from commercial programs, which have successfully integrated collaborative PLM tools into their processes, and most importantly, how these practices can be applied to naval acquisition programs.

1. Data Collection Process

To compensate for lack of personal experimentation, my research leveraged experiments and projects conducted by both the government and the private industry to address the issues discussed in the paper. The GAO has created extensive case studies examining commercial best practices, and it has explored weaknesses in the DoD acquisition framework. These reports reinforced lessons learned from the programs and companies that made data available, and they introduced new concepts and ideas. Several of these studies were utilized to determine how the best practices identified by GAO could apply to DoD acquisitions and be facilitated by the collaborative PLM approach.

2. Data Analysis

The author obtained an understanding of the government shipbuilding processes, insight into recent lead-ship programs and specific commercial practices while conducting a series of interviews with government subject-matter experts from NAVSEA, the Center for Innovation in Ship Design, Ship System Integration and Design Department, former NAVSEA chief architects, current Naval architects, Supervisors of Shipbuilding, program managers, and Program Executive Office Ships representatives.

In particular, the ASNE Day 2010 conference titled Engineering the Affordable Global Navy through Innovation offered a tremendous opportunity for me to listen to panels of experts representing both the government and private industry discussing the impact of not controlling ship TOC, as well as their thoughts on initiatives that could address current issues. This conference afforded me the ability to broaden my perspective by meeting with representatives from commercial shipyards responsible for developing complex ship solutions: Northrop Grumman, Austal, and General Dynamics. Meeting with individuals from these companies provided the opportunity to hear their opinions on current efforts as well potential solutions that have yet to be attempted. The author was also able to present his own opinions, which led to a discussion of the strengths and weaknesses of the proposals, leading to a more realistic product. One of the most thought provoking events during this conference was the Global Shipbuilding Executive Summit, where global leaders representing both the private and public sectors held a brainstorming session on potential solutions to address the unsustainable trend of poor cost, schedule, and technical performance across the defense portfolio. This data established a foundation of understanding necessary to complete this research.

III. PRODUCT LIFECYCLE MANAGEMENT

A. BACKGROUND

This section provides an introduction to a technology that can assist with implementing the new possible strategy, collaborative PLM, a promising tool that, as its name implies, allows for the management of the product from the earliest stages of the lifecycle, all the way through to disposal.

Follow-on chapters will present practices and processes that can help reform the naval acquisition community. The recommended reforms either take advantage of the capabilities, or they are needed to support the deployment of a collaborative PLM across the naval acquisition enterprise. The reforms are based on lessons learned and best practices from companies that have successfully institutionalized collaborative PLM into their organizations. None of these reforms are groundbreaking; in fact, the proven practices and process have been successfully implemented by several DoD programs. However, on a whole, our corporate knowledge never seems to improve as the successes or lessons learned from the failures are isolated and not effectively communicated across the portfolio. It is not only necessary to improve the practices and processes, thus, improving the organizational productivity, but also a new strategy is necessary to learn and retain corporate knowledge, to prevent taking any steps backwards in order to move forward.

The Navy is constantly looking for initiatives to address weaknesses or correct deficiencies that lead to problems such as cost overruns and schedule delays, among others. However, whether due to size, authority, or some other reason, most of these initiatives have been limited to one functional area or even a subdivision of one functional area, such as design, engineering, manufacturing, sales, or service. For instance, LEAN manufacturing has eliminated a lot of waste from the manufacturing realm, but generally does not attempt to address the waste encountered throughout the entire lifecycle.

However, optimizing performance in one or even a series of functional areas does not necessarily result in the optimization of the entire organization. The problem is that different departments of organizations have become silos of information. Collaborative PLM links the different functional areas through shared product information, breaks down the silos, and gains benefits from a shared base of information. For instance, imagine a car designed to take advantage of the most efficient sequence of construction. The car company could take the savings from construction to undercut the competition and expect this new car to be very successful. However, if this new design overlooked that the only way to change oil was to remove the entire engine block, requiring an expensive overhaul of the car every 3,000 miles, it would not be very appealing to car buyers. The designers could misdiagnose the reason behind the poor sales figures and add additional cup holders to attempt to increase the appeal. A mechanic knows the real reason that the car is unpopular, but if that knowledge is never communicated and captured, this new design, which might overall be a tremendous improvement, will be abandoned as a failed design. Collaborative PLM enables an organization to completely integrate and then leverage everything related to the product, in an attempt to maximize productivity. Collaborative PLM uses information technology and organizational practices and processes to improve efficiencies both within and, more importantly, across the traditional functional divisions.

A common theme during the ASNE Day 2010 conference titled Engineering the Affordable Global Navy through Innovation was the voicing of concern over the cost escalation across the Navy acquisition portfolio. Adding to this concern was the lack of results achieved by various cost-reduction strategies. An advantage of collaborative PLM is that it does not address a problem from solely a cost-reduction perspective. As with the car design example, collaborative PLM offers the ability to facilitate increased innovation, functionality, and quality, by organizing the intellectual capital of an organization. As the old adage goes, “you can’t simply save your way to prosperity” (Grieves, 2006). Building better, more creative, and more useful products with the same or fewer resources can drive productivity; it is a better business model than simply cutting costs.

B. COLLABORATIVE PLM DEFINED

The origins of collaborative PLM lie in the computer-aided design (CAD) market and how it initially generated designs—first 2D and now 3D. As technology progressed, the

CAD programs started incorporating more knowledge capabilities into their drawings (e.g., material characteristics, notes, part numbers). This change accompanied programs that linked other data, not associated directly with the CAD file (engineering data management (EDM) and product data management (PDM)). Computer-integrated manufacturing (CIM) was created, which could use the CAD models for computerized machining, simulation, or testing. While all these steps were useful and had similar goals, not being integrated meant they were islands of automation, creating bottlenecks or errors, as information had to be manually transferred from one tool to the next, if it was transferred at all. This meant that even if individual activities or tasks were efficient, the overall practices and processes used and products created still had room to improve. The success of an organization centers on the ability to remain in control versus being controlled by its products. In other words, think of the difference between laying out a plan and executing it, making calculated decisions and understanding the ramifications, versus constantly moving from one emergency to the next, trying to put out fires, making snap decisions without thinking the problem through. Loss of control during development leads to delayed schedules, unexpected costs, or the creation of a product that does not meet requirements. Loss of control during operations could result in user frustration, unsustainable TOC, or, in the worst cases, injury or death (Stark, 2005).

It is important to note that collaborative PLM is not a definition of a piece (or pieces) of technology (Figure 4). It is a business approach that can align and increase the efficiency and effectiveness of activities by leveraging software applications and process improvements. In this respect, it is more of a strategy than a system. As a strategy, not a system, collaborative PLM can be configured to meet the unique aspects of any organization. A company can invest in as many or as few collaborative PLM components as necessary to meet their unique needs. This eases the hindrance of a large capital investment as well as allows organizations to focus on one area at a time and not become overwhelmed by trying to change too much at once.

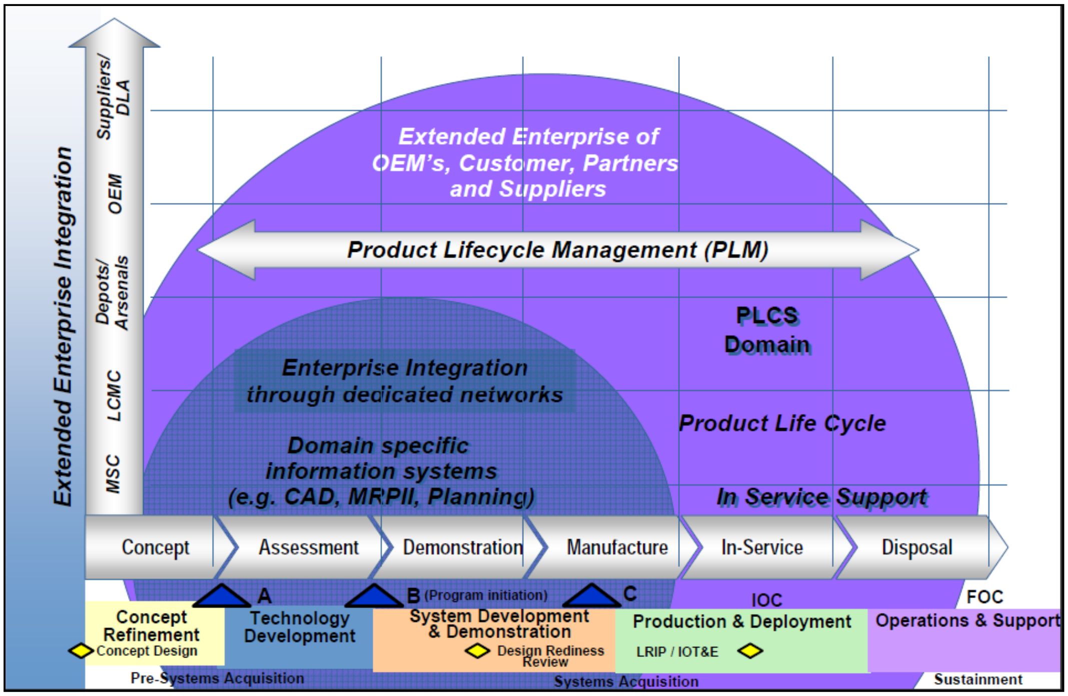


Figure 4. Collaborative PLM Across the Lifecycle

In the following section, we can examine how two technical publications have tried to answer the question "What is collaborative PLM?"

CIMdata ("Product Lifecycle Management," n.d.), an independent PLM consulting firm, defined PLM as,

> A strategic business approach that applies a consistent set of business solutions that support the collaborative creation, management, dissemination, and use of product definition information across the extended enterprise from concept to end of life of a product or plant- integrating people, processes, business systems, and information. (p. 1)

A second definition comes from CIO Magazine, a publication whose mission is to provide technology and business leaders with insight and analysis on information-technology (IT) trends. CIO magazine (2003) stated the following about the evolution of PLM and its role in achieving business goals:

> Product lifecycle management is an integrated, information-driven approach to all aspects of a product's life, from its design through manufacture, deployment, and maintenance, culminating in the product's removal from service and final disposal.

> PLM software suites enable accessing, updating, manipulating, and reasoning about product information that is being produced in a fragmented and distributed environment. Another definition of PLM is the integration of business systems to manage a product's lifecycle. (Stackpole, 2003, p. 1)

There is a common theme between these two definitions: By creating, sharing, and using all forms of product related information, we can trade information for wasted time, energy, and material to ensure the most efficient use of physical resources.

Collaborative PLM can help manage a product better, but the real benefit is that it strives to manage all products better in a fully integrated portfolio. Dan Billingsley has over 30 years of acquisition experience: When asked his view on DoD acquisition, he argued that the structure has become heavily product centric, with too much focus given to the performance of the product, while forgetting how we got to that particular point (D. Billingsley, personal communications, April 5, 2010). He argued that we need to learn from our successes as well as our failures and fix the practices and processes used during the lifecycle, in order to ensure the entire portfolio is successful. Collaborative PLM offers a way to restore the balance because it emphasizes, "how a business works," just as much as, "what is being created" (CIMdata, n.d.).

The following paragraph from *Product Lifecycle Management* by Anitti Saaksvuori and Anselmi Immonen (2008) perfectly answers the question, "What is PLM?":

> PLM is an organized, controlled strategy for developing and then managing products and all their associated information. The central theme of PLM is the creation, preservation, and storage of information relating to the company's products and activities, in order to ensure the fast, easy and trouble-free finding, refining, distribution and reutilization of the data required for daily operations. In other words, work that has been done should remain exploitable, regardless of place, time, or—within prescribed limits, naturally—data ownership. At the same time, the idea is to convert data managed by a company's employees, skilled persons and specialists into company capital in an easily manageable and sharable form. (p. 32)

Collaborative PLM can help improve the productivity across the defense acquisition community by capturing and using data the first time it is created. Time previously wasted searching for or recreating product data can be spent collaborating with other experts on how to improve the product.

C. PRINCIPLES BEHIND THE PLM STRATEGY

1. Focus on the Product

The shipbuilding industry is a product-focused business, meaning the portfolio may contain many variants of a single product line, each with similar specifications, parts, drawings, manufacturing techniques, or operations, as opposed to an assembly line organization that churns out an indefinite quantity of one identical product. These variants could be different building blocks of either the same class, or common components or systems across all classes. The benefits of the collaborative PLM strategy are realized when lessons learned from the first generation are applied to all subsequent generations, in order to decrease their cost and time for development. The second generation may reuse 75% of the parts from the previous generation, decreasing the time and resources spent designing and verifying the second generation design (Stark, 2005).

Co-locating experts with diverse backgrounds as members of the design team has benefits to the program. Teams with representatives from marketing, design, engineering, operations, manufacturing, service, testing, quality, and logistics can make better collective decisions, reducing bottlenecks, rework, and wait times by sharing knowledge. With each iteration, the collective knowledge expands, to the benefit of future projects. The teams' combined knowledge of design, process, material, manufacturing, quality, and customer requirements enables them to deliver first-time quality in a product, a product that has a better fit to customer needs, reduced costs, and a faster to-market time. While collocation is preferred, sometimes it is not feasible to collocate the people that have the authority to make decisions. Collaborative PLM gives organizations the ability to gain some of the same benefits through its collaboration tools.

2. Collaborative PLM Involves Customers by Listening to Feedback

It is important to listen to the customer and ensure that the requirements, expectations, features, and wishes are reflected in the delivered product, but listening to the customer is the minimum. A better solution is to involve the customer directly in the design from the very beginning. With a customer empowered to make decisions as a member of the cross-functional team, problems can be identified sooner, thus avoiding expensive rework or, worse, resolving the problem too late, leading to an unsatisfied customer.

Another way to gain valuable insight from the customer is by receiving feedback on fielded products. Customers may be frustrated that a particular system is not operating as expected, or they may need help completing a particular piece of maintenance. Helping operators with these frustrations can give designers ideas about how to improve the product further. The designers can capture this knowledge and make sure it is reflected in the follow-on design.

Sensors can capture feedback directly from the product. Maintainers will be able to monitor products to trace when a particular system begins operating out of the normal operating range and trouble shoot if its operators need training or if the system needs maintenance. Designers will be able to determine if a particular system was over-engineered or can be optimized for actual operations.

3. Collaborative PLM Offers More than Cost Savings

The unsustainable trend of cost escalation is one of the main drives for undertaking acquisition reform. Money is a finite resource, and the lack of money is forcing program managers to take a hard look at the business model to determine how things can be done better. However, it is important to remember that a goal to solely minimize cost is shortsighted. Programs are not started because they are the cheapest, but because warfighters have needs and new products have the ability to meet their needs.

During an interview, Ron Watson, global product data manager for ITT Industries, commented that by

> Restricting the focus to cost reduction, what you’re essentially doing is sacrificing the needs and the functions needed by the customer. [...] The greatest value is really a function of [delivering] what the customer wants, and cost is just something that you try to drive down. [...]If you use just cost as an arbitrary determining factor, then you're limiting yourself. (Teresko, 2004a, p. 1)

Any changes recommended for the Navy's strategy must be focused on delivering increased value to the warfighter, not endlessly chasing cost reductions.

4. Implementing Processes, Techniques, Methodology

Various techniques have been used successfully to carry out product developments and support more effectively. One of the challenges of collaborative PLM is providing structure to techniques capable of assisting with organizational goals. Table 3 is a list of just a few of the processes that have been implemented by organizations through a collaborative PLM system.

Table 3. Representative Processes Incorporated into PLM

(Stark, 2005)

Concurrent Engineering
Technique to bring together multidisciplinary teams that work from the start of a development project with the aim of getting things right as quickly as possible, and as early as possible.
Configuration Management
The activity of documenting initial product specifications and controlling and documenting changes to these specifications. A formal discipline to help assure the quality and long-term support of complex products through consistent identification and effective monitoring and control of all the information.
Design for Assembly
Techniques aimed at reducing the cost and time of assembly by simplifying the product and process through such means as reducing the number of parts, combining part functions, reducing or eliminating adjustments, simplifying assembly operations, designing for parts handling, and ensuring products are easy to test.
Lifecycle Assessment
Methodology used to understand the main impacts arising in each phase of a product's lifecycle.
Portfolio Management
Technique allowing managers to make tradeoff decisions based on risk/rewards of the product portfolio against an organization's strategic objectives.
Process Mapping
Methodology carried out to understand, design, and analyze business processes.
Quality Function Deployment(QFD)
A step-by-step technique for ensuring that the voice of the customer is heard throughout the

product-development process so that the final product fully meets customer requirements.

5. Integrating Modern Components, Applications, Systems

Collaborative PLM is a new concept that relies on the capability of several complex technologies. Collaborative PLM is not a new tool, nor does it strive to replace the tools you already have. Collaborative PLM is an effort to take those concepts and technologies that have existed on their own, and integrate them together, providing a comprehensive understanding of the product. The manner in which these tools and technologies are integrated allows productivity gains that could not be experienced if you were running all of the same tools independently. One of the challenges of PLM is to identify system components that are aligned with company goals and understand how they fit into a collaborative PLM system. We will explore four of the foundational components of a collaborative PLM system: computer-aided design (CAD), engineering data management (EDM), product data management (PDM), and computer-integrated manufacturing (CIM).

a. Computer-Aided Design

Computer-aided design (CAD) refers to an application that can represent physical products using math-based descriptions to locate and consistently replicate shapes in either two or three dimensions (Figure 5). CAD models have the ability to improve quality and reduce developmental time and costs. Precision is only limited by the capabilities of the CAD application. Each replication will be identical every time, and measurements will be consistent, regardless of who is taking the measurements. Because the object can be rotated and displayed from various angles and zoomed in to see details, users can find errors more quickly and can correct them immediately.

The progression from two-dimensional to three-dimensional drawing makes virtuality and computer-aided engineering (CAE) possible. CAE refers to the extraction of data from the model and performing analyses and simulations, testing things like structural integrity and performance. Simulation delivers insight into the performance of a system's product or process before it has been built. Once the model is developed, it can be inserted into an artificial environment to analyze a system's behavior under various conditions. From this analysis, errors can be corrected, tradeoffs can be evaluated, and designs can be optimized. Simulation allows a continuous stream of "what ifs" to be considered, without the costs and time needed to build physical prototypes.

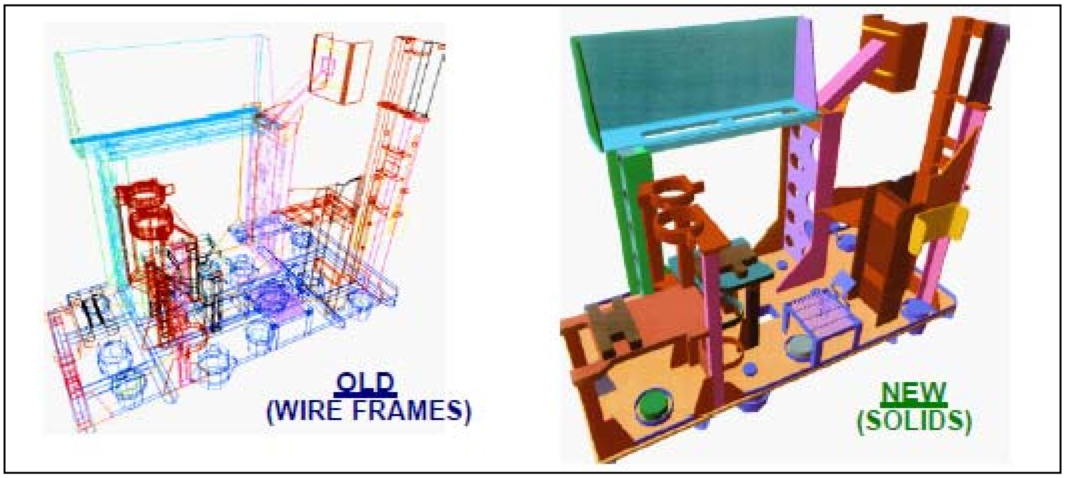


Figure 5. 3D Solid Versus Wireframe CAD Model
(General Dynamics Electric Boat, 2002)

Once built, the component can be reused throughout the design without having to be recreated. Once released, other products can reuse, update, or modify it to fit future needs. Stakeholders can evaluate the model and accept or suggest modifications, improving the design without waiting for a prototype.

b. Engineering Data Management

The models built in CAD applications describe the products geometrically, but for a complete description, they must be augmented by other information or characteristics. These characteristics, to complete the description, could be any kind of information, such as tolerances, tensile strength, weight restrictions, adhesives, conductivity requirements, the process for assembly, the methodology for coating or painting, or testing requirements or procedures, to name a few (Grieves, 2006).

This type of information was the focus behind developing engineering data management (EDM). A positive aspect is that there is one program that is used by the majority of engineers to track this information; thus, distribution and access is easier. A negative aspect is that this program is Microsoft Excel, which has an infinite number of ways it can be customized and presented. While this flexibility has allowed engineers to personalize their files for optimal personal productivity, organizational productivity suffers because each new user has to go through a learning curve every time a new file is used. Extensive reorganization needs to occur, taking the extensive data known by individuals and making it accessible to the entire organization.

c. Product Data Management

Product data management (PDM) is a primary component of a collaborative PLM solution and is designed to provide the right information, at the right time, to the right person. PDM is needed as a means to organize and catalog the CAD and EDM information. Once the data is in the systems, it can be accessed by anyone with the appropriate permission, anytime and anywhere. Data does not get lost, and it will not be damaged. The data in the systems will not be an outdated copy, and it will not be unavailable because someone else has it. Once all the data is linked, if a source document changes, notifications will be made to all those affected so that everyone and everything stay on the same page. Product data is a strategic resource that influences decisions. Therefore, the data must be under control, before the product can be controlled.

The functionality of a PDM system can be grouped into two categories: user functions and utility functions. The user functions provide the functionality for the users to interact with the database and can be grouped in the following subcategories:

1. Data vault and document management,
2. Workflow and process management,
3. Product structure management,
4. Classification management, and
5. Program management (Crnkovic, Dahlqvist, & Asklund, 2003).

The utility functions provide the ability for the data to interface between different operating environments and can be grouped into the following subcategories:

1. Communication and notification,
2. Data transport and translation,
3. Image services,

4. Administration, and
5. Application integration (Crnkovic et al., 2003).

d. Computer-Integrated Manufacturing

Computer-aided manufacturing (CAM) is the idea that CAD files can be used to generate programs to control and sequence automated manufacturing machines. Computer-integrated manufacturing (CIM) goes a step further, and focuses on the advantages of sharing information across function areas of an organization. CIM represents the idea that a computer system could integrate the functions necessary to design, engineer, and manufacture a product.

Rapid prototyping is the construction of a physical prototype directly from the computer model. A physical prototype can be tested to validate the accuracy of the computer models, check interference, and evaluate ease of assembly and maintenance. In the traditional prototyping process, a design is produced and then sent to manufacturing engineers, who then figure out how to build it. The manufacturing department has often had to recreate data that was available in engineering, but was never transferred so that it could modify the design into something buildable. After this process of recreating data, a model was built. With rapid prototyping, the physical model can be produced directly by one of the rapid-prototyping applications, saving time and possible transcription errors or misinterpretations from engineering to manufacturing. Closing the information loop between engineering and manufacturing will help correct one of the most inefficient elements of engineering, the fact that often, a design is "thrown over the wall" to where manufacturing has to figure out if and how to build it.

6. Collaborative PLM Continuously Strives to Increase Value, Quality, and Reduce Cycle-Time and Costs

The organization must be structured in a manner that focuses on always providing its customers with products and services that satisfy their needs. By eliminating defects and reducing waste first-time quality can be achieved.

Cycle-time reduction should be a major focus. The product was created to satisfy a capability gap of the warfighter; thus, the sooner that gap is closed the better. In addition, the sooner the product is in use, the sooner feedback can be applied to a new and improved version. When it comes to rapidly evolving technology, if the cycle-time is too long, what began in the design process as cutting edge could be obsolete by the time it is in operation. Shorter cycle-time not only ensures the technology gets to the warfighter while it is still relevant, but also supports the evolutionary approach in which new technology can be inserted into the latest model. Finally, shorter cycle-times lead to increased flexibility and experience for the design organization. As the threats evolve, having a design team that is not invested in designing the weapon for the previous war will keep the organization agile. In a given time period, a shorter cycle-time results in a greater number of cycles; meaning, the more times a team does something, the better they will become.

D. WHAT IS THE NEED FOR PLM?

This section will look at some of the driving forces behind the need for collaborative PLM, and reasons why the previous technologies and procedures are not sufficient in the current environment. The Navy is not alone in its need to improve its business model. Indeed the same thing drives other companies: the need to create value and improve productivity, the rate of innovation, collaboration, and quality (Grieves, 2006).

1. Maximizing Productivity

Productivity for an organization refers to the ratio of outputs received while expending a given set of inputs or resources. The private sector focuses on striving to improve productivity, which it hopes translates into improved profitability. The government does not turn a profit, per se, but productivity is still critical because there are never enough dollars to fund every need, and the ability for government programs to make the best use of the funds available, frees money to allocate to other needs.

A 1994 Cooper & Lybrand study broke down the typical day of an engineer (Figure 6). The study showed that about 24% of time was spent looking for, distributing, or maintaining information. The engineers also indicated that rather than search for data it was easier and quicker to just redo work that had already been completed previously; redoing work accounted for 21% of the time. Another 14% of the time was spent in meetings, where engineers were either updating or being updated on progress (Saaksvuori & Immonen, 2008). This study indicated that there is a tremendous opportunity to improve the productivity of the typical engineer.

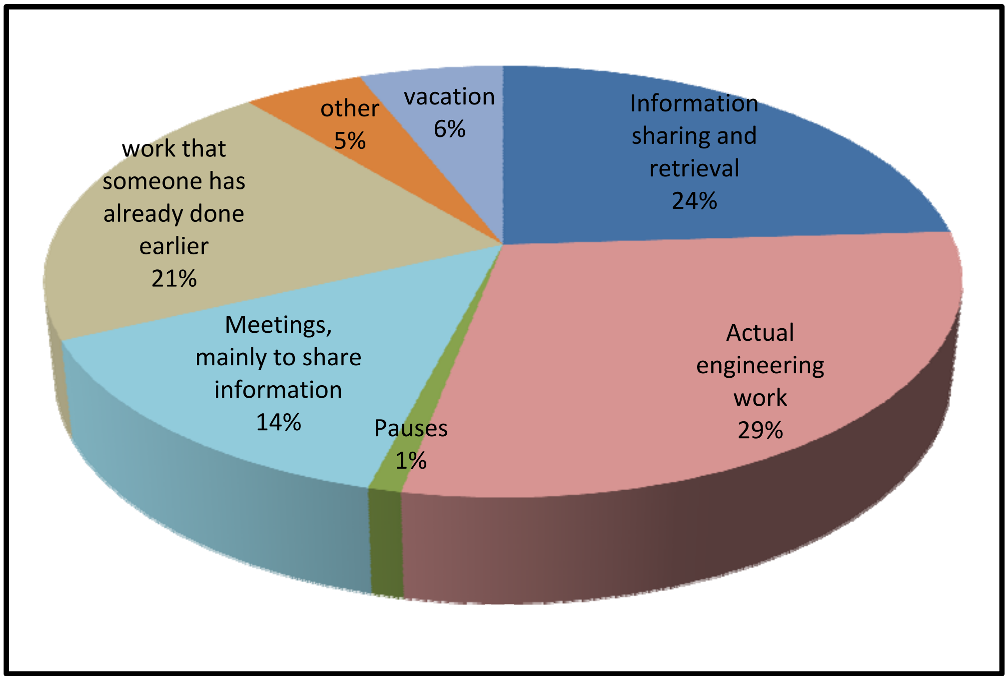


Figure 6. The Engineer's Use of Time

(Saaksvuori & Immonen, 2008)

Collaborative PLM offers the ability to positively impact productivity by leveraging information to eliminate wasted time, especially the time spent searching for data, by utilizing simulations to discover the most efficient workflow, and by facilitating the reuse of designs that would normally be recreated.

2. Cultivate Innovation

Innovation is a change in the thought-process for doing something. It may refer to incremental, emergent, or radical and revolutionary changes in thinking, products, processes, or organizations. These changes could be new inventions, such as the automobile or computer, or they could be new approaches, such as the assembly line or LEAN manufacturing. All these examples have changed the way things are accomplished in their respective disciplines. When Michael Grieves delineated the different goals of productivity and innovation, his position is that while productivity focuses on costs, innovation focuses on adding value for the stakeholder. Taking his point about integration further, he asserted that innovation is another major driver behind collaborative PLM, one that can be subdivided into (1) product innovation and (2) workflow innovation (Grieves, 2006).

The first kind of innovation, i.e., product innovation, refers to improving some characteristic of the product, such as new technology or new features. These things create value for the users by reducing the time, energy, and materials required to perform tasks or by making it possible to perform tasks that were previously impossible. An example of product innovation would be the *USS Nautilus* (SSN 571) the first nuclear submarine, which could remain submerged for up to four months, a feat previously unachievable, this capability made new missions possible and transformed the submarine force (Smithsonian Institution, n.d.). Collaborative PLM cannot deliver any new innovative ideas but can free engineers from menial tasks and allow them to focus innovation. Through collaboration with the stakeholders, PLM helps raise visibility of what the customer values in order to limit product innovation to only the value-added items. The users will determine what is a desire and what is a need to help guide the design effort. For instance, if the Navy "needs" a ship that can go 35 knots, it may not be willing to pay the extra cost to design a ship that can go 50 knots. By failing to listen to the customer, there is a risk of expending resources on non value-added features.

The actual task of innovation does not occur without human skill, talent, and creativity. The collaborative PLM's role is to enhance this effort by ensuring the right information is accessible when and where it is needed. Innovation also requires resources. The ability of collaborative PLM to reduce wasted time, material, and energy through activities such as eliminating redundant activities or decreasing time searching for information will help ensure that more resources are available to focus on value-added innovation tasks.

Workflow innovation is the second kind of innovation, and unlike product innovation, it focuses on finding better methods and technologies to reduce the time, energy, and material needed to produce the product. For instance, Henry Ford created the assembly line to build his automobiles. As a result, his more effective methods created savings, making automobiles much more affordable; this not only changed how automobiles were constructed but also influenced the processes of many other industries. The majority of the recommendations contained in this research deal with workflow innovation. This approach was chosen because an improved workflow has the ability to improve the entire portfolio of programs, while product innovation is more specific to a particular capability. We will be searching for workflow innovation that the Navy can apply to ensure that the most efficient use of resources is being made.

3. Improve Collaboration

Collaboration is where two or more people or organizations work together in an intersection of common goals. For example, an intellectual endeavor is collaborative and creative in nature when numerous people share knowledge, learning, and build consensus. As project teams today are rarely located under one roof, the need to effectively collaborate must be enabled by technologies that connect people across geographical distances, organizational borders, and, more frequently, national borders. The collaborative PLM contribution to collaboration is the ability to co-locate in virtual time and space, people who otherwise would not be able to be together geographically or temporally.

Social networking is a form of collaboration adding new dimensions to the way that people interact within their network of friends. The latest versions of collaborative PLM have embraced these social computing capabilities to take advantage of these collaborative techniques, creating "corporate social networks" that tie together communities around a common business goal (Brown J., 2009).

Features such as instant communication and sharing—including alerts, subscriptions, instant messaging, status updates, and other techniques—help people instantly contribute to the ongoing product development dialogue. Chat and presence detection help bring communities together in real-time to share ideas and solve problems, answering questions that would otherwise be saved for later, forgotten, or ignored. This is particularly important during the early phases of a project when interactions are more frequent and results are less formal.

These new social capabilities go beyond traditional collaboration, which generally occurs between people who already know each other. These social capabilities build on what is referred to as *social discovery*. Social discovery involves finding others in the corporate network that may have relevant expertise, similar to how the Internet-based popular network Facebook recommends friends. Through the network, colleagues who may never have met may contact each other, and can build upon their collective knowledge base. Corporate social networking is a new feature of collaborative PLM applications, and based on how it matures, has potential to facilitate innovation and help enhance collaboration (Brown J., 2009).

The *USS Virginia* (SSN 774) program used teleconferencing (Figure 7) to have long-distance reviews/discussions of the evolving *Virginia Class* design on a regular basis. The teleconferencing system used in the program allows reviewers at a distance and in real time to see engineering models of the design, including the 3D virtual reality model of the ship arrangement. During sessions, the Navy participants in Washington, DC, were able to request changes in the 3D model (being executed in Connecticut), question the location of certain items, and see how certain items could be removed and accessed (General Dynamics Electric Boat, 2002). As this example shows, the ultimate end state of collaborative PLM is to be capable of capturing enough data about a product that the virtual product is indistinguishable from the physical, and the richness of communication makes virtual communication just as effective as face-to-face contact.

Figure 7. Virtual Collaboration on *USS Virginia* During Weekly Teleconference
(General Dynamics Electric Boat, 2002)

4. Need to Develop Quality

There exist two main aspects of quality: first, the product must meet its specifications; second, the product must perform to a particular standard of usage (Grieves, 2006). A product that lacks quality will at best result in wasted time, material, and require energy to repair it, and at worst, it could cause injury or death.

Products that fail to meet their specifications must be scrapped, reworked, or repaired, consuming resources that could otherwise be applied to value-added activities. If the designer or supplier has confusion or misunderstandings concerning the specifications, then there is a greater chance that the product will fail to meet the intended specifications. Collaborative PLM offers a constant and singular view of product data to help remove any uncertainty about product specification, and, as described before, the collaboration allows the building of a consensus while in the virtual world, before any physical delays can be experienced.

When looking at the complexity of the products being created and realizing that the operating environment is equally complex, it is easy to justify extensive testing to ensure products can meet usage requirements. Traditionally, extensive and comprehensive testing in various states under various conditions was required, consuming excessive resources. Collaborative PLM can assist by conducting a majority of tests in the virtual world for substantially less time and money, and because a physical prototype is not required, collaborative PLM can test many more options than physical testing (Grieves, 2006). Dassault Systems collaborative PLM system V6 has the ability to conduct virtual maintenance (Figure 8). This feature not only measures the ergonomics of the workers, in order to verify the task can be accomplished safely, but also enables the worker to see everything that needs to be seen, and shows that all tasks are physically possible (Dassault Systems, 2010). This is an example of how problems can be identified and corrected in the virtual world, where the impact to the program is negligible.

Figure 8. Images Demonstrating Virtual Maintenance

(Dassault Systems, 2010)

5. Current Life Cycle Environment Lacks Control

An aspect of properly managing product data in the product-lifecycle environment means not allowing the data collected to sit in a virtual file cabinet and become a giant repository, collecting dust without providing any benefits. The data being created, collected, integrated, and used during a program, and made available in a virtual library could be as follows: customer requirements, design specifications, process models, drawings, assembly drawings, analytic models, simulation results, parts list, tools and fixture designs, mounting instructions, process plans, bills of material, configuration drawings, CAD geometry, status reports, maintenance history, and requirements, to name a few.

A potential problem with managing the different types of product data is the large number of people who use product data through the lifecycle, including members of various departments inside an organization, suppliers, contractors, maintainers, users, and so on. Each needs access to the data to support the product; however, at the same time, the data also needs to be protected from those who should not have access. As the repository of product data grows, so can wasted efforts; developers may waste time searching through various databases, having to navigate through the mass of existing designs to find a specific piece of data. Studies have shown that design engineers spend up to 80% of their time on administrative and information-retrieval activities (Stark, 2005). If the data found is an outdated version, rework could be required to correct discrepancies. When the existing design cannot be found, the data is usually recreated, resulting in unnecessary costs.

As more and more data is generated, the task of controlling it becomes more overwhelming. CAD drawings are just one piece from the list of product-data types mentioned previously. A submarine's plans can easily exceed 100,000 drawings (Stark, 2005). Think of a single CAD drawing as one piece of a 100,000 piece puzzle: as the designer completes the drawing, it is stored in the project data base with all the other drawings, simply thrown into the box of puzzle pieces. What happens if a particular piece is needed later? How long could it take to sort through the box to find the particular piece? When the file is needed and cannot be found, it must be recreated, usually in a rush, and will likely be less thorough than the original, opening the potential for more errors. Just because the particular file could not be found before making the decision to recreate it does not mean that it is not actually in the system. And now, the puzzle has *two* of the same pieces, causing problems later. Each time this cycle repeats, another version of a file enters the system, and the likelihood that work will be progressed based on data from an out-of-date document is increased. This cycle is how the lack of reliable configuration management introduces more errors and waste.

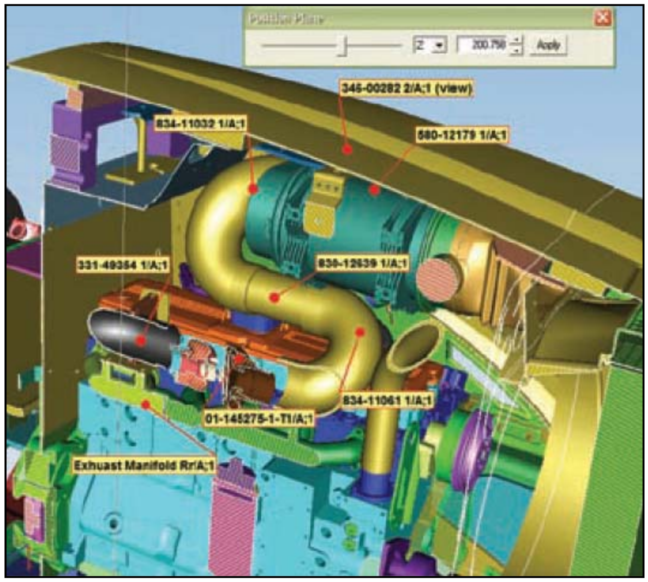


Figure 9. Enhanced 3D Product Model

(Siemens PLM Software (Team Center), 2008)

Collaborative PLM addresses this issue by having integrated all the product data. For instance, through the 3D model (Figure 9), a user can click on a particular component and the data fields will show every piece of product data associated with that component. Additionally, with the appropriate links established, if that part changes, the stakeholders of other affected components are notified. For example, if one of the puzzle pieces is changed, the owners of the surrounding puzzle pieces will be notified in case their pieces must also be changed. This prevents problems that may otherwise go unnoticed until much later in the process.

E. BENEFITS ALONG THE LIFECYCLE

Organizations are often metrics based, and prior to making a major shift in strategy, the metrics must justify the value of that shift. This has justified program managers in making decisions that affect today's bottom line, while disregarding the effect on the lifecycle. Collaborative PLM will make the full impact of these decisions visible sooner to correct this behavior. When decisions are made that consider the entire lifecycle, sometimes the benefits are not easily traced back to a particular decision, and sometimes they will not occur in the same phase. They will often overlap or appear in different forms (i.e., cost, schedule, or functionality). However, when the product is under control, there will be benefits. The following chapters will introduce case studies and specific examples of how the DoD portfolio could benefit by modifying its processes, to correct deficiencies and take full advantage of capabilities possible with a collaborative PLM suite. The following is a list compiled by Softech and John Stark (2007) of potential benefits with collaborative PLM:

- Capturing customer requirements better,
- Creating more innovative products,
- Delivering the required product on schedule, on budget,
- Providing superb support of the product in use,
- Preventing future failures through knowledge of past failures,
- Schedule maintenance effectively based on knowledge of the actual use of the product,
- Reducing over-engineered products based on actual use of products,
- Reducing labor costs by reducing time spent on data retrieval and management, leaving more time for value-added activities,
- Reducing overhead labor by reducing paper shuffling, data re-entry, and data formatting, and
- Reducing engineering cost by reusing designs. (Softech INC and John Stark Associates, 2007)

F. CHAPTER SUMMARY

CIMdata Corporation stated: “PLM is not just a technology, but is an approach in which processes are as important, or more important, than data” (Vasilash, n.d.). According to CIMdata, PLM goes beyond data. It is “a business approach to solving the problem of managing the complete set of product definition information—creating that information, managing it through its life, and disseminating and using it throughout the lifecycle of the product.” In other words, in order to effectively make decisions from the lifecycle perspective, the data must be properly managed; however, managing the data properly does not indicate that all decisions are being made with the lifecycle in mind (Vasilash, n.d.).

Michael Bauer, the executive director of North American Automotive, gave an interview in which he stressed that collaborative PLM is only a tool designed to act as a process multiplier, giving benefits to those with good processes while giving those with bad processes the knowledge to catch up. He said:

> Too often we run into companies that are trying to use technology for competitive advantage, but it is really the process that makes the difference. If you have best practices in your organization, then PLM can help amplify the results. If you don't have best practices in your organization, then PLM—at least the newly developed PLM products that encompass the learning from a multitude companies—can help you get much further ahead than you are. (Vasilash, n. of d.)

Collaborative PLM has an impact on all the functional areas of a company: design, engineering, manufacturing, sales, operation, and service. Collaborative PLM is the next generation of LEAN thinking, in that it actively substitutes information for wasted time, material, and energy. This information helps designers reduce the time spent designing items that already exist, and instead it allows them to apply time to innovation or improvements to make the product better. People can spend time researching ways to improve the process, and increase efficiency and productivity, by figuring out ways to use less material or create products that are more easily produced.

It is possible to design, validate, and test products entirely in the virtual space. This not only creates better products, but also provides confidence that the products will perform at the level expected by the customer. Products that can exceed the expectation of the customer are the real definition and test of quality.

The investment into collaborative PLM is not insignificant. For the Navy to acquire software, hardware, consulting, education and training, the cost could easily surpass several hundred million dollars. However, the collaborative PLM providers foresaw this financial barrier, and the architecture they created helps overcome this hurdle. Collaborative PLM can be phased in on a project-by-project basis. As we will see later, there are already several Navy acquisition programs using collaborative PLM software. Collaborative PLM is a conglomeration of services that build upon each other, producing benefits greater than the individual contributions. Another element of the architecture is the ability to unbundle any of these features, either to stagger the capital investment or to tailor the functionality to the organization or project's particular needs.

With as much as 80% of the costs set early in design, it is logical that the majority of the benefits of collaborative PLM would be delivered as information and decision-making would be improved during this stage. However, one of the biggest benefits is when collaborative PLM initiatives cross functional boundaries and maintain the organization's focus on the total lifecycle. I hope this chapter has demonstrated how collaborative PLM can help an organization think LEAN and decrease the costs of wasted time, energy, and material. However, collaborative PLM is not limited to only a cost-reduction strategy, for it can also lead to decreasing complexity, decreasing cycle-times, aiding collaboration, improving innovation, and therefore quality. In essence, it can ensure that the product is under control, having an impact on all aspects of an organization.

Before moving on, it should be reiterated that the benefits outlined in this chapter would not be realized simply because a new system is bought and installed. A collaborative PLM suite contains some very useful tools to assist with problems in product information and lifecycle management. However, a technological solution rarely solves any problems itself. Collaborative PLM can assist with the organizational changes that are needed for the acquisition community to gain control over its products. The following chapters will look at lessons that the DoD can learn from successful organizations, as well as how those improvements will be facilitated by the capabilities of a collaborative PLM suite.

IV. LEAN PRODUCT DESIGN

"We can't solve problems by using the same kind of thinking that we used when we created them." — Albert Einstein

The preceding chapter introduced collaborative PLM as technology designed to provide structure and efficiency to an organization, as it records, retains, and organizes knowledge throughout the lifecycle. This chapter will discuss how to use this knowledge set to make more informed decisions, which should lead to correcting the inefficient, wasteful processes that have led to the unsustainable cost growth, schedule delays, and unacceptably high TOC that have historically plagued the DoD acquisition programs.

A. BACKGROUND

The essence of the LEAN philosophy is rather simplistic: It is the pursuit of the perfect product, through the elimination of all waste, while adding value as defined by the needs of the customer. The majority of the research and applications of LEAN principles, attempting to eliminate waste or non value-added tasks, has focused on production and manufacturing processes, overlooking the potential benefits during the design process (Spear, 2004).

There are differences between manufacturing and design techniques, which means that the same techniques can't be directly applied to both processes. Manufacturing processes are usually serial and visible, making it easier for a person examining the processes to identify and remove waste. However, the design process is usually not serial, and waste is much harder to eliminate, because it may not appear until much later in the process. For instance, if two different systems call for a valve to be installed in the same physical location, the mistake might go unnoticed until construction, when the problem becomes visually apparent.

The version of LEAN product design presented in this research was developed by Bart Huthwaite, Sr., the founder of the Huthwaite Innovation Institute and the thought leader in the emerging business process known as "Systematic Corporate Innovation." This is a method for giving managers the knowledge to make corporate innovation understandable, repeatable, and very importantly, measurable. Huthwaite has mentored managers and teams in corporate innovation worldwide at more than 1000 companies over the past 30 years. Huthwaite used the following analogy to get to the heart of the issue: "What is needed is more fire prevention and less firefighting" (Huthwaite, n.d. a, p.1). Huthwaite described that just as firefighters are portrayed as heroes on the front pages of newspapers, organizations have their own heroes, who are constantly called upon to put out fires and save the company or project. Underappreciated is the fire inspector who saves far more homes by ensuring that a fire never breaks out in the first place and accomplishes this feat for a fraction of what it cost to put out the fire. The LPD is the fire inspector in his analogy. Huthwaite's philosophy is essentially the principle that a more productive way to eliminate the waste in the process is to ensure that it will not happen in the first place.

B. WHAT IS LEAN PRODUCT DESIGN?

Huthwaite would answer the question "What is Lean Product Design?" by saying "it is a verb and a noun." As a noun, it is a product that has been created to deliver high value with low waste. As a verb, it describes the design process to create such a product (Huthwaite, 2007a). The method presented in this paper goes beyond the traditional approach of elimination of the production waste on the factory floor by extending the efforts to the eliminating waste experienced by the supplier and customer as well. Another reason for this methods section is the comprehensive approach to balancing the need for waste reduction and value addition across the entire lifecycle. This particular application of LEAN design also pairs nicely with the capabilities of a collaborative PLM suite, and its goal of integrating knowledge across all domains of the lifecycle.

Huthwaite evolved the following LEAN Design Equation while working with hundreds of design teams as a consultant (Huthwaite, 2007a).

Strategic Ilities - Evil Ings = LEAN Product Success

Huthwaite defines the strategic "Ilities" as the values and attributes that both the producing organization as well as the ones customers seek from a product such as "manufacturab-ility," "maintainab-ility," "durabil-ity," and so on. The evil "Ings" are the processes or tasks that create the potential for quality loss, high costs, and slow time to market. The term describes no-value processes such as "inspect-ing," "fix-ing," "repair-ing," and other non-productive tasks throughout the lifecycle (Huthwaite, 2007b, p. 139). The LEAN approach helps design teams find a design solution that maintains a balance between values as opposed to trying to maximize one at the expense of all others. For example, the LEAN approach would prevent the design of the most technically capable ship ever created only to discover all that technology made it unaffordable. Instead, the LEAN philosophy finds a balance between all the customer values; using this big picture approach produces an optimal solution.

C. "LAWS" OF LEAN DESIGN

The following section will discuss four of the five factors Bart Huthwaite calls his "laws" of LEAN design. An additional law, the law of marketplace pull, would be relevant to the requirement generation process, but it is outside the scope of this research and as a result was eliminated. Huthwaite described his laws as "the most direct route to product value and simplicity, giving you the 'true north' of what LPD is all about. They will guide you so the 'how to' of making LEAN design will really work for you" (Huthwaite, n.d. b, p. 43).

1. Law of Strategic Value

Projects are initiated to satisfy particular primary values of customers, and are balanced against values held by an organization. These values are the guiding principles used to develop the requirements. Understanding the customer values will help designers understand the "why" that is driving a particular requirement and will lead to a more complete design.

Actively managing the product across all four of the lifecycle domains (design, supply, manufacturing, and customer) will result in a better understanding of what the product needs to be. To help design teams, Mr. Huthwaite has developed a list of questions that help designers identify stakeholders' strategic values (Table 4). He stressed that "good designs always begin with problem seeking not problem solving" (Huthwaite, 2007a, p. 64).

Table 4. Customer and Company Primary Values

(Huthwaite, 2007a)

Primary Customer Values	
Performability	Will the product perform as expected?
Affordability	What will it cost?
Featureability	Will it provide added benefits?
Deliverability	When will it be ready?
Useability	Can I quickly and easily install it and learn to use it?
Maintainability	How easy will it be to keep in service?
Durability	Can it withstand abuse?
Imageability	Will it convey an image of quality and prestige?
Primary Company Values	
Profitability	Will it deliver profit at an acceptable level?
Investability	Does the product make sense in terms of payback?
Riskability	Are the risks we must take prudent?
Produceability	Can the factory and supply chain deliver this product?
Marketability	Do we have the means to sell this product?
Growability	Does this product offer growth and market expansion?
Leverageabilty	Does this product build on our core competencies?
Respectability	Will this product strengthen our reputation?

By "problem seeking" and exploring each of the values found in Table 4 with the stakeholders, the designers will understand the priorities and what the stakeholders want from the product. Each of these value categories has opportunities for the program to conduct tradeoffs, to create the optimal design solution for the particular stakeholder. For instance, when designing the *Virginia* (SSN 774) class submarine, the Navy valued affordability above all other attributes except stealth. During each trade, the deciding factor was affordability unless it dealt with stealth (General Dynamics Electric Boat, 2002). Thus, without understanding what the customer values, the design team will be unable to deliver an optimal solution.

2. Law of Waste Prevention

In Huthwaite's model of LEAN Product Development, every decision made should be to either enhance one of the values discussed in the previous section or to minimize the potential for waste. The seven types of waste identified in Table 5 are responsible for the majority of waste found in programs (Huthwaite, 2007a). A general rule is the sooner waste is identified, the cheaper it will be to resolve. Once the concept becomes a prototype, or takes root in the mind of your team members, the flexibility and receptivity to change shrinks drastically (Huthwaite, 2007b).

Table 5. Product Life Cycle Waste

(Huthwaite, 2007a)

Seven Worst Solutions	
Name	Description
Complex	Many different processes, high quality required to deliver product's value both on factory floor and in customer use. Each process or step takes time, costs money, and, if performed wrong, can result in a quality flaw that must be corrected.
Precise	Solution requiring precision at the outer limits of manufacturer's ability to produce the product or the customer's ability to use it.
Variable	Processes that are not "mistake proof" or are applied inconsistently.
Sensitive	Products that are easily flawed, not robust.
Immature	Solutions not previously validated for specific application. Difficult to accurately predict cost, schedule, and testing needed for development.
Dangerous	Solutions with dangerous impact on humans or environment.
Skill Intensive	Solutions requiring high degree of training or experience.

3. Law of Innovation Flow

"There is always a way to do it better . . . find it!"

—Thomas Edison

According to Huthwaite (2007a), The Law of Innovation Flow states, "we must provide the means for all members of the design team to contribute to the innovation process. Only by seeing the design challenge from many different perspectives will we ever be able to solve it" (p. 87).

Developing a good design requires systematically working through the design space, exploring all possibilities prior to selecting a particular solution. In *The Lean Design Solution,* Huthwaite recommends that design teams should work the problem from the system, through the subsystems, down to the parts levels, looking to capitalize on the five targets of opportunity: functions, parts, processes, materials, and people (Huthwaite, 2007a, p. 99). Ship designers have an endless set of opportunities to improve the design. When looking at functions, the idea for interchangeable mission modules on LCS was created. By analyzing unique part counts, a common parts catalog was identified as a way to reduce the strain on the logistics system. Through examining processes, the question was raised of why ships cannot be built upside down to make it easier on the welders. Scrutinizing the use of materials led to aluminum superstructures, replacing steel, saving weight and painting costs. Focusing on reducing personnel cost and improving safety led to the idea that watch standers could be removed as systems were automated and capable of being controlled remotely. The first design is never the best, and the second and third are only a step in the journey to success (Huthwaite, 2007a, p. 99).

Collaborative PLM applications offer the designer a powerful tool, the ability to store and organize data so no idea has to be thrown away. Every attempt to solve a particular problem has merit, a good idea could be iterated to become great, a failure today could be tomorrow’s answer, a dead end may serve as a warning not to repeat the same mistakes (Huthwaite, 2007b).

4. Law of fast feedback

Metrics provide a sense of direction to a program. That direction, be it right or wrong, depends on the quality of the metric. DoD programs rely on earned-value metrics and status reports to measure a program’s health. Earned Value Management (EVM) is a method for integrating the scope, schedule, and resources for measuring project performance. It compares the amount of work or effort that was planned with what was actually earned and spent to determine if cost and schedule performance were as planned. A limitation of these metrics is that they only indicate when a problem already exists. During the 2010 NPS Defense Acquisition Symposium, an analogy compared the limitation of these metrics to driving your car by only looking at the rear-view mirror. No matter how successful metrics and testing are at uncovering waste, a better strategy is to look out the windshield and ensure that waste was never there to begin with. Being over budget or behind schedule is only a symptom of a problem. To address the root cause, additional research must be conducted. Because earned value is not a real-time metric, by the time the issue is actually resolved, a program may have been traveling in the wrong direction for some time.

Earned-value measurements are still valuable and need to be maintained. They fall into a category of metrics called “performance metrics” (M. Brown, 2006). A performance metric lets you know if you are tracking toward your goal and if corrective action is needed. A second category called “predictive metrics” is potentially more valuable to managers (M. Brown, 2006). These metrics will tell us the likelihood that our decisions will have the desired results. Huthwaite (2007a) recommended using predictive metrics to achieve three important benefits:

1. By providing focus and direction, they help ensure all stakeholders’ visions for product goals are aligned.
2. They provide a better understanding of the cause-and-effect relationship between design actions and results, providing decision-makers the knowledge needed to make good decisions.
3. Once you have buy in on the vision, implementation becomes easier. Predictive metrics are developed looking towards the end state. (p.106)

Over his years of consulting experience, Huthwaite identified seven rules quoted as follows that he contended make for effective measurement and feedback (Huthwaite, 2007a, pp. 107–111).

“Rule one: Measure what is most important to your customers, not just what is easiest to measure.” A project may be on schedule, under budget, and meet all of the technical-performance metrics, but if it fails to deliver on the customer values, it cannot be considered a success. Finding an accurate metric to forecast designs TOC is very difficult, but if designs cannot be evaluated based on this metric operation and sustainment costs might eventually exceed the budget.

"Rule two: Be cautious with metrics, as the wrong metric can lead to the wrong conclusion." For instance, DoD program managers have measured and been held accountable for the acquisition cost of their programs. Is it wise to trade one dollar of savings during acquisition for ten dollars during sustainment? Acquisition costs could be the wrong metric for determining program success.

"Rule three: Use both hard and soft metrics." In his book, *Keeping Score: Using the Right Metrics to Drive World Class Performance*, Mark Brown emphasized the importance of soft metrics: "Soft measures are measures of customer opinions, perceptions and feelings. These are leading edge indicators that should be used to try and predict customer behavior. The opinions and feelings of customers are extremely important" (M. Brown, 2006, p. 116). For instance, measuring how many targets a new radar can track and engage simultaneously is an important metric and should be recorded. The human operator must also be able to interact with the new radar, and the evaluation must ask: "Has the operator's satisfaction been measured?" Virtual reality tools such as computer automated virtual environment (CAVE) have been designed to allow sailors to walk around inside and interact with a design years before it becomes a reality (Briggs et al., 2009). As those tools are integrated into the collaborative PLM suite, the feeling and observations concerning the design can be embedded in the model, giving designers another form of feedback. However important soft metrics are, they should be supplemented by hard measures of customer satisfaction to track what the customer actually does.

"Rule four: Measure for direction first and precision later." During the very early stages of design—for instance, when the design team is looking at concepts for hull design—there are no hydrostatic details to be measured with any degree of accuracy. To compensate for the lack of specifics, consensus measurements such as Delphi can capture experts' gut feelings, and this type of measurement will let designers know if they are on the right track. Precision can be worked out later, once a project is heading in the right direction.

"Rule five: Get information concurrently on the "ilities," or the values and attributes that both the producing organization as well as the customer seek from a product, and the "ings," or processes or tasks that create the potential for quality loss, and high costs." Many

DoD programs focus on one area at a time, and lose sight of the total picture. Section D will show how radar charts can be used to capture the entire design solution.

"Rule six: Make sure everyone is on the same feedback system." The measurement creation process helps form consensus on what problems must be solved and how they will be evaluated. It is hard to win, if everyone is playing by different rules.

Finally, "rule seven: Enable those who will be measured to have input into the creation of the measurement system." Ownership is a powerful way to assure a feedback system will be used.

Collaborative PLM has capabilities that compliment each of these seven rules and can assist in the development of an appropriate set of metrics. As the design is progressing, collaborative PLM can store various data points. After enough data is captured, statistical analysis can reveal which of the captured data points correlate to the factor that dictates success or failure. For example, a collaborative PLM analysis might show schedule delays are related to design stability, which can be measured, by the number of change orders, and the number of change orders is correlated to the percentage of drawings complete by a particular milestone.

D. LEAN DESIGN SCORECARDS

> "Measure the right things and get the right results. Measure the wrong things and get the wrong results."
>
> —Proverb (Huthwaite, 2007a)

Several previous sections have discussed the value of metrics and called for the development of more predictive metrics to ensure that programs are heading in the right direction. This section is going to describe one process that can help create these predictive metrics.

According to *Product Development for the LEAN Enterprise*, some of Toyota's success was attributed to its knowledge-based product design. This approach encourages sharing and applying collective knowledge to improve the probability of product development success (Kennedy, 2003). The following method is a technique to capture knowledge and assess the leanness of the total design solution. This example comes from Bart Huthwaite's book *The Lean Design Solution*, in which he stresses that the greatest value comes from working with the stakeholders to develop the criteria for how the program will be evaluated, where the byproduct of that process is referred to as the scorecard. This process is valuable, as it forces communication between stakeholders, gives the design team insight into stakeholder priorities and encourages the exploration of many different solutions across the entire lifecycle (Huthwaite, 2007a).

The best way to develop project scorecards is through a dialogue between the stakeholders and the design team. The process begins by asking the stakeholder to develop criteria for the rating scale (Table 6), making sure to capture the rationale by asking "why."

Table 6. Example of Scorecard Rating Scale

(Huthwaite, 2007a)

Rating	Value Level	Description
9-10	Extremely High Value	Sets the standard for the industry.
7-8	High Value	Superior to most competitors.
5-6	Acceptable	Meets expectations most of the time.
3-4	Low value	Frequently does not meet expectations.
1-2	Extremely Low Value	Well below competition.

Once consensus between the design team and key stakeholders is reached concerning scale, the baseline is scored along with any alternatives that need to be compared (Figure 10). Once again, it is important to capture the "why" behind each rating; this will give true insight to the values behind the decisions. For instance, when evaluating two designs based on maximum speed, a faster ship will be more desirable because it offers operational flexibility. However, knowing how much speed is enough is important for the designers, as a ship may be able to go 30 knots on 4 engines, but to reach 35 knots it would need 6. Those additional 5 knots have a cost associated with them: either it could be money for the additional engines, or it could be removing 2 missiles to decrease the weight. Understanding the values attributed by the stakeholders will be important for the design team to deliver an optimized solution. These scorecards must be created for each phase of the lifecycle to fully understand the impact of the design. Recall the car design built to optimize manufacturing with dire repercussions to maintenance: Complexity in manufacturing may result in simplicity for the user. Unless both of these environments are explored, it is impossible to make informed tradeoffs. Scorecards can also be applied at all levels of the design from the component, to sub-system, to system, to system of systems. This technique is an effective way to share high-level information and knowledge among those involved in the process, ensuring alignment to the strategic goals and facilitating quick management reviews.

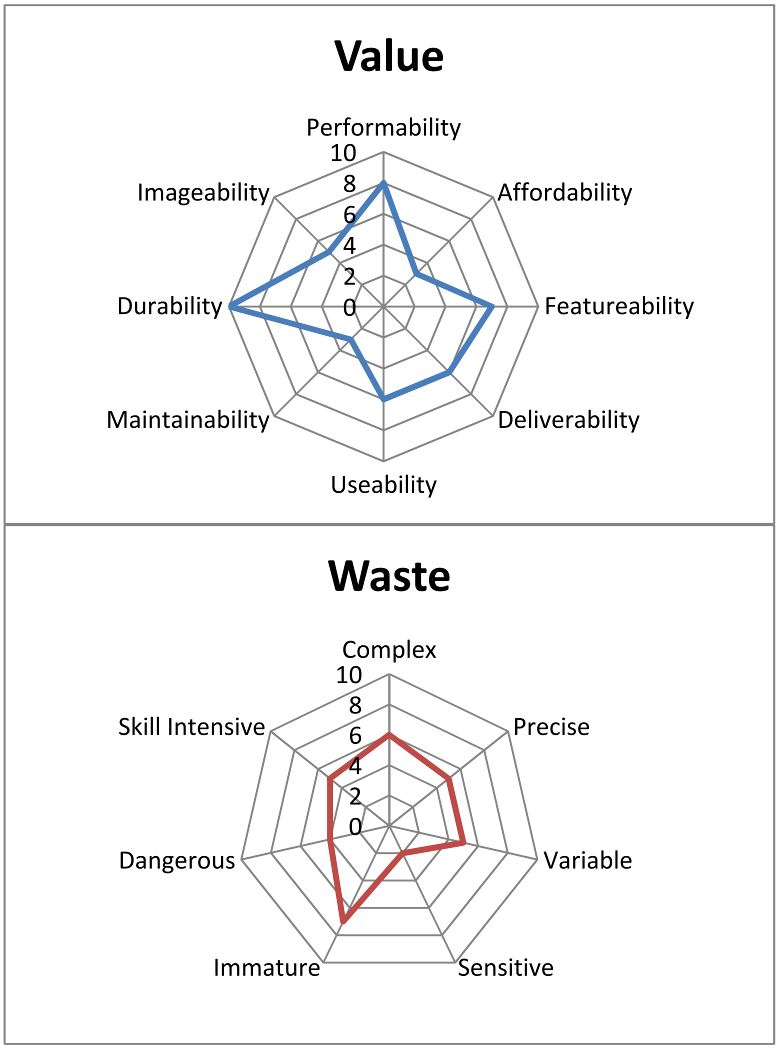


Figure 10. Examples of Value and Waste Scorecards

(Huthwaite, 2007a)

E. ACHIEVING LEAN DESIGN WITH COLLABORATIVE PLM

Collaborative PLM was created to manage a product and its associated data throughout the lifecycle, from the cradle to the grave. So to speak, LEAN is a strategy to remove waste throughout processes, saving the resources expended on wasteful activities, in order to ideally use them more profitably. The data collected and organized inside the collaborative PLM environment will be used to accomplish the LEAN analysis to identify wasteful processes. Studies have documented cases in which applying LEAN principles to product development has reduced product development cycle-times by 60-70% (Fiore, 2004). Once the more efficient process is identified, collaborative PLM has the capability to automate the workflow and institutionalize the efficient process, making both data and processes accessible to users throughout the lifecycle to eliminate repetition, redundancy, errors, and other forms of waste.

Peter Schmitt, vice president of marketing communications for Dassault System in the Americas, explained:

> If you drive the concepts and principles of LEAN up the chain of product development, you're coming to manufacturing planning, and from there to the product design. The further up the product lifecycle, the bigger the benefits you get. It's that old saw: A mistake detected in design costs \$1; in manufacturing planning, \$100; in production, \$1,000. (Gould, n.d., para. 4)

To show how collaborative PLM can facilitate LEAN, I will dissect the following explanation by David Van Horn, director of Archstone Consulting:

> LEAN is all about designing and developing products that meet or exceed customer needs, that can be effectively and efficiently produced and serviced, and that do not involve excessive development investment. . . . LEAN “works on” physical product and information flow, while LPD “works on” engineering product and information flow–virtual products, if you will. (Dassault Systems, 2007, p. 2)

Van Horn states that products must meet or exceed customer needs. Collaborative PLM cannot determine a customer’s needs or wants, but it can store the information about market needs and wants so that those qualified to separate the good ideas from the bad can access it. Howie Distel, a solution architect for Dassault Systems, explained, “In defining a product that has category killer potential, it is important to eliminate bad concepts quickly. The ability to create rapid design candidates and interrogate those designs through simulation and validation of virtual product data is at the heart of PLM" (Dassault Systems, 2007, p. 2).

Van Horn also referred to how designing products with manufacturability and maintainability requires interactions between the manufacturing and maintenance departments early in the design. He argued that early in the design process, making an informed decision is key to program success by citing that "70–80% of the final unit cost of a product is driven by research- and development-based decisions, often without conscious awareness of the repercussions of those decisions" (Jaruzelski, Dehoff, & Bordia, n.d.). If a problem does not emerge until after the design is complete and the product is in production or operation and sustainment, there may not be enough time or resources to go back and fix it. Collaborative PLM helps produce fast feedback, by integrating all parties involved, and allowing each member's specialized expertise to be incorporated. Helping bring those unconscious decisions to light and manage them with processes designed to eliminate waste is a key capability of collaborative PLM.

Excess development investment should be minimized by collaborative PLM, enabling broad visibility into the product data and keeping everyone informed on progress, regardless of their role or location. Allowing everyone to access, create, modify, and manage information concurrently from a single source eliminates the traditional data silos that lead to errors from working with outdated data. Powerful search capability makes it easier to find existing designs that meet or could be adapted to fit the current project needs, eliminating rework and reinvention. Employing the use of relational design templates enables a part to be designed once and automatically adjusted to fit new parameters when required. Using templates to standardize processes will help create the consistency that will improve the manufacturability of the product. These examples demonstrate how the structure and workflow can be built inside collaborative PLM, reducing resources spent on wasteful activities.

Collaborative PLM operates with a knowledge-based engineering method that can be used to capture corporate know-how and standards and can improve quality and consistency across the portfolio of programs. As Distel stated, "Over time, collaborative PLM properly used will become a repository for everything the company knows and what they have learned from past projects. Because you have so much time on the back end, collaborative PLM makes it possible to spend more time in the early stages of development, investigating design alternatives that lead to new innovations" (Dassault Systems, 2007, p. 3).

Products can be mocked up in a virtual 3D environment to determine if project goals will be met. This can usually be done for lower cost and in less time than building a physical model. These savings can be applied to compare several different alternative designs to determine the clear winner. Boeing, for example, rolled out the virtual design of its new 787 Dreamliner in 2006. This presentation included a 3D model, virtual simulations, video of production start up, and the final assembly production flow. Being able to correct deficiencies in the process while in the virtual environment led to efficiencies that allowed the actual first-time assemblies to be constructed in hours, not the days originally scheduled. Those same efficiencies resulted in calculations that show that an overall operating cost has been improved an additional 20% from the original projections (Gates, 2006).

These are just a few examples of how collaborative PLM can facilitate the application of LEAN best practices during the product-development cycle. By eliminating routine work, streamlining processes, exploring alternatives, supporting concurrent design, eliminating data inconsistencies, and improving communication between team members, collaborative PLM can lead to an LPD process in which results surpass those experienced in the manufacturing sector.

V. FRAMEWORK BEHIND DEVELOPMENT OF FUTURE STATE

A. FOUNDATIONS OF SUCCESSFUL ORGANIZATIONS

This chapter discusses how the synergy between organizations, people, information, technology, processes and practices can create a successful organization. This grouping will also be the structure behind how the recommendations are presented in the following chapters.

When first being introduced to collaborative PLM, it is easy to think of it only as a new software technology, allowing tasks previously impossible or at least improbable, to be accomplished. Assuming that improvements to our organization are only possible when a new technology delivers some missing capability makes the assumption that everything about our people, organizations, and processes was perfect and that the lack of capability delivered by the new technology was the root cause behind the particular problem. Collaborative PLM as a software suite could be considered a new technology, it can deliver capabilities that our programs currently do not have, but implementing a collaborative PLM suite is only the first step toward organizing and improving the information available, enabling people and organizations to perform their practice and processes most efficiently.

In his book *Product Lifecycle Management Driving the Next Generation of LEAN Thinking,* Michael Grieves described the relationship between technology, process, and people. The book has a good discussion of the three main areas of an organization that must work together in order to be successful. Figure 11 demonstrates how Grieves visually captured the interaction between technology and processes in effecting outcomes (Grieves, 2006). The first quadrant combines low technology and poor processes. This usually produces undesirable outcomes because of the tremendous waste of time, material, and energy. In this quadrant, even routine tasks are not standardized. There is a lot of trial and error, as people are trying to figure out how to accomplish tasks, and little or no information is learned, resulting in rework and other non-value added activities.

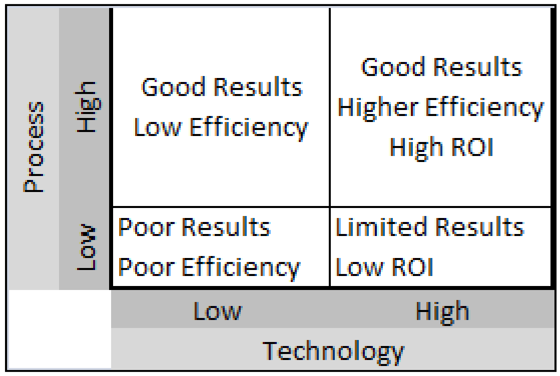


Figure 11. Interactions Between Process and Technology
(Grieves, 2006)

Improving the technology without addressing the process will move an organization into the second quadrant. The high technology and poor process quadrant produces outcomes that may be more consistent, but not necessarily favorable for the organization. An example would be if a new technology such as collaborative PLM automated an organization's processes, without addressing the poor processes. In this scenario, the control over the process offered by collaborative PLM actually becomes a burden to employees, because they are forced to comply with the poor process. This will result in employees finding ways to work around the system or simply putting the least amount of effort possible to move through the bad process. Both results eliminate most of the benefits discussed in the previous chapters. This behavior negatively impacts the return on investment for the system. Lack of understanding as to why outcomes are not improved is usually the justification for the next new technology that shows promise.

The third quadrant of Figure 11 represents low technology but good processes. An actual example of this quadrant would be Toyota and their total production system (TPS). Toyota spends a lot of effort training its employees on how to analyze, improve, and document its processes. They utilize low tech solutions such as Kanban cards. While Kanban cards are common in manufacturing processes, they are in effect, the message that signals depletion of product, parts or inventory that when received will trigger the replenishment of that product, part, or inventory. Toyota has also been successful in using them in the design realm, shaving years off their design and engineering cycle (Spear, 2004).

The final quadrant in the figure is the goal of each organization: high technology and good processes. In this quadrant, the technology is organized and structured to enable the people to accomplish tasks more efficiently and more reliably than they could otherwise. There is structure that not only ensures processes and practices are followed, but that they are continuously analyzed and improved to capture the knowledge needed to prevent repeated mistakes. In this quadrant, the processes and practices are so well understood that they can be simulated in the virtual space, saving time, material, and energy (Grieves, 2006). This is the quadrant where collaborative PLM can deliver the benefits needed to address the DoD acquisition portfolio's woes.

Absent from the four quadrants discussed above was the role of people. All the interactions between process and technology are dependent on the people in the organization. When people operate with good intentions and are motivated and competent, they can figure out a way to improvise and will make even poor processes and low technology work for them. However, if people set out with willful malice, they will use the same ingenuity and find ways to ensure that even the best processes fail. Before presenting the case studies, lessons learned, and recommendation for the DoD shipbuilding-acquisition portfolio, it will be helpful to explore the impact of characteristics of practice, processes, organizations, people, information, and technology more thoroughly.

1. Practices and Processes

A ship design program manager should understand the differentiation between a process and practice in order to understand what and how adjustments need to be made and to know what a software vendor is promising with new technologies. Michael Grieves explained this differentiation in his book, *Project Lifecycle Management*. Grieves pointed out that when, "thinking of organizations in a systems view, everything starts with given inputs. Processes then transform those inputs into a well-specified, predictable, consistent set of outputs" (Grieves, 2006). However, when looking at the Navy portfolio, while you can argue that lately outputs have been consistent and predictable, it would be hard to argue that those outputs are the desired results. Perhaps more attention needs to be paid to the so-called processes that transform the resources.

When looking across the spectrum of ways to accomplish this transformation, there are multiple approaches to reaching the organizational objectives. Collaborative PLM groups these approaches into three categories: "process," "practice" or "art" (Grieves, 2006). The most defined approach is a process; for example, a machine that takes a set quantity of material and runs at a set speed for a determined duration, producing a consistent output. On the other end of the spectrum is the least defined approach: art. Art begins with unclear inputs that are transformed through unorthodox applications fully understood only by the artist. Art has the ability to produce a variety of outputs, to be selected based on how well they match requirements. The results are subjective, and consensus may never be reached: for example, when deciding "What is the best hull shape for a new class of warship?" In between the art and process is practice. In practice, inputs and outputs are fairly well defined, but how they are transformed is not. Practices rely on judgment and experience and often do not occur in the controlled environment, for instance, determining how to minimize the number of change orders to control the cost escalation of a program (Grieves, 2006).

Pointing out the differences between these concepts is important for a few reasons. First, it could provide an explanation as to why our programs struggle with inconsistent performance. If the organization is executing processes, like the machine described previously, it is rational to eliminate unnecessary information and extra communications in order to LEAN the process. However, if the organization is in fact using practices, this approach could eliminate necessary information needed by the decision makers to make an informed decision. Second, the differences are important in order to understand what a vendor is offering. Before making the substantial investment in collaborative PLM, it would be necessary to be sure it is structured in a manner to enable operations with practices as well as processes. For instance, a process is very structured and the goal is to move through the steps as efficiently as possible. Practices lack the same structure as processes so the goal is to collect enough data and information during each step to assist decision-makers to identify the patterns (Grieves, 2006). For collaborative PLM to be helpful, it must have the ability to operate organization activities, whether practices or processes. Collaborative PLM should help an organization categorize its tasks and evolve practices into processes wherever possible. Processes lend themselves to automation, thus freeing resources to concentrate on practices where perception and judgment are important.

2. Organizations and People

As mentioned above, the characteristics of the people will have a dramatic influence on the success of an organization. The capabilities of people within any organization are varied. Some of those characteristics contributing to an employee's capability can be enhanced and will be discussed below. They are experience, education, training, and support (Grieves, 2006).

a. Experience

One definition of experience is active involvement in an activity or exposure to events or people over a period of time, which leads to an increase in knowledge or skill—basically, to keep the same theme in this paper, knowing how to use information to reduce wasted time, material, and energy. Experience helps reduce the search time to find the information needed to predict the outcomes of situations with a higher probability of success.

A problem with experience is that it is predominantly an individual characteristic, meaning when you lose the employee, you lose the experience. The experience of the DoD's workforce is one of the issues that will cause problems if not addressed. Due to the downsizing and hiring freezes of the 1990s, a significant amount of the workforce is eligible to retire, and there is a gap between them and the large number of new hires waiting to take over. This leaves a small window in which to transfer the requisite knowledge to those new workers. We will explore specific recommendations later, but collaborative PLM can help in at least two general ways: First, it can embed the information into the processes, and second, it can allow new operators to gain experience in the virtual world.

b. Education and Training

Real-world situations that present opportunities for employees to gain necessary experience cannot be scheduled. Unlike the real world, the virtual world can be used to simulate any situation, rather than waiting for the desired opportunity to present itself, and the virtual world to be scheduled. This simulation is a method of education and training. Education teaches people why things are done, while training focuses on what to do. Recall from earlier the differences between processes and practices. Education is suited to practices in which an understanding of how inputs affect outputs is needed in order to determine what is relevant versus what is irrelevant before deciding on a course of action. Training is better applied to processes in which the actions required are standardized and produce consistent results. The accuracy of these virtual simulations is dependent on information captured by collaborative PLM during real-world events.

c. Support

Even if a person learns something during education and training, this does not guarantee that they will be able to remember it when that information is actually needed. Support functions to supplement education and training by providing a network of people who can assist in searching, recalling, or relearning the information when required.

John Seeley Brown, the former director of Xerox PARC, provided an interesting analogy concerning the support function. While investigating how copier repair technicians solved complicated problems, he concluded that “when the going gets tough, the tough get coffee” (Brown & Duguid, 2002). When looking at morning coffee breaks from a LEAN perspective, a logical conclusion is that coffee breaks were non value-added activities and technicians should seek to eliminate them to improve efficiency. However, these coffee breaks were not wasted time. Instead, they were a support activity in which all the technicians gathered and discussed and collectively diagnosed solutions to their individual problems. Thus, eliminating the coffee breaks would have had a negative effect on efficiency.

Collaborative PLM needs to have support functions that provide assistance for product information as well as control how the supporting technology will interact with the collaborative PLM suite in order to prevent people from becoming inefficient or frustrated.

3. Information/Technology

The success and capability of any particular collaborative PLM application is dependent on the capability and availability of the underlying technology. Availability refers to the infrastructure required at an organization. Obviously, all infrastructure costs money to establish. However, establishing the proper balance is necessary to get a good return on investment. Excess infrastructure does not deliver any benefits, so the investment is wasted. Meanwhile, missing infrastructure will restrict access, limiting the potential benefits. People will find workarounds or simply avoid the system if it lacks, for example, adequate computing power, communications bandwidth, and storage capacity. Therefore, proper infrastructure does not determine collaborative PLM success, but improper infrastructure could dictate failure. The recommendations contained in the following chapters do not try to determine the scale of proper infrastructure as this is dependent on the extent to which these recommendations are applied.

a. Applications

It is unlikely that one of the relatively few collaborative PLM providers is capable of developing, providing, and updating the entire collaborative PLM software suite (as well as all the applications necessary to design, build, and maintain the shipbuilding portfolio). By selecting a one-company solution, a tremendous amount of risk is assumed because success is entirely dependent on the products, quality, and evolution of that one company. A better strategy is to develop interoperability standards so that applications are compatible and have the ability to transfer and use data amongst themselves.

Software should be developed to reflect how people do their jobs versus people changing how their jobs are done to accommodate the easiest way to program the software. The collaborative PLM software and applications should be embedded into the practices and processes so that they work as a seamless unit. For collaborative PLM to be fully embedded into practices and processes and adopted by the workforce, it must be completely reliable when capturing, retrieving, and using product data.

b. The virtualization of physical objects

Technology development has experienced an unbelievable trajectory, constantly redefining what is possible, which projects very well for the future. Briefly looking at this progression, we can begin with storytelling, as an example. Storytelling would be error-prone due to its reliance on the accuracy of the teller, as well as the comprehension of the receiver. As storytelling progressed, people supplemented the oral description with pictures, eventually mastering the ability to create physical drawings showing length, width, and depth. When accompanied by other data, this opened up the ability to create physical mockups with complete accuracy. However, these advancements still had limitations. For instance, as the richness of information increased from descriptions to drawings to mockups, the time needed to create these mockups increased, as did the resources required to transport them across the geographically expanding organizations. With computers and the Internet, the resources required for transportation have decreased substantially. However, these drawings and models were still just a snapshot of the design at a moment in time. Today, it is possible to operate in a full virtual environment. Designers can pick up, move, make changes to, and interact with the design as if it was a real object, all in real time.

One of the values of collaborative PLM comes from the ability to access and leverage product information wherever it resides. One example is the simulation software that supports virtual product development (VPD) in a collaborative PLM strategy, notes Bob Ryan, executive vice president, of MSC Software Corporation (Teresko, 2004b). According to Ryan, the VPD facilitates the innovation process, "how to design products for form, fit, function and manufacturability. As part of an optimal collaborative PLM strategy VPD can easily and effectively relate to other aspects of a product's lifecycle, such as inventory, maintenance and related considerations" (Teresko, 2004b, p. 1).

With an optimized collaborative PLM/VPD strategy, in other words, improving the integration of physical and virtual building and testing of the product, the result is accelerated innovation and greatly reduced risk at a lower cost. To maximize the benefits of virtual product development, Ryan recommended viewing physical "build-and-test" as a complement to virtual "build-and-test." An example of Ryan's recommendation is the Boeing 777. As the first digital aircraft, it went beyond the traditional use of CAD by checking form and fit with a digital mockup. Boeing then virtually flew the aircraft, checking the landing gear and other systems functionality (Teresko, 2004a).

Ryan stressed that VPD's goal should be to integrate testing automation into the mainstream collaborative PLM environment. His advice: Start by studying how VPD automation can solve existing design problems. The second step: Research the benefits VPD automation can bring to new design initiatives. The final level is to achieve the ability to do design signoffs by using simulation instead of physical tests. The end point arrives when simulation can drive all of the product definition throughout the supply chain (Teresko, 2004a, p. 1).

B. CHAPTER SUMMARY

This chapter discussed the synergy between organization, people, information, technology, processes, and practices and the impact it has in creating a successful organization. A program manager should understand the differentiation between a process and practice in order to understand what and how adjustments need to be made and to know what a software vendor is promising with new technologies. A process transforms those inputs into a well-specified, predictable, consistent set of outputs, versus a practice where inputs and outputs are fairly well defined, but how they are transformed is not. Practices rely on judgment and experience and often do not occur in the controlled environment.

When people within our organization operate with good intentions and are motivated and competent, they can figure out a way to improvise and will make even poor processes and low technology work for them. Some of the characteristics contributing to an employee’s capability can be enhanced by improving their experience, education, training, and support.

The success and capability of any particular collaborative PLM application is dependent on the capability and availability of the underlying technology. Software should be developed to reflect how people do their jobs, versus people changing how their jobs are done to accommodate the easiest way to program the software. The collaborative PLM software and applications should be embedded into the practices and processes so that they work as a seamless unit. For collaborative PLM to be fully embedded into practices and processes and adopted by the workforce, it must be completely reliable when capturing, retrieving, and using product data. The selected collaborative PLM application needs to fully take advantage of the benefits gained by operating in the virtual environment; the upfront effort it takes to build a rich environment will be worthwhile, as correcting errors or making modifications are substantially cheaper and faster than performing the same modification to a physical product.

VI. FUTURE STATE OF DEFENSE ACQUISITION: ESTABLISHING A HEALTHY FOUNDATION

This chapter focuses on reforms that will create a healthier organization in terms of DoD acquisition processes, ensuring that the workers have the knowledge and flexibility to adjust course when the plan begins to go awry. The recommendations contained below are not explicitly tied to the deployment of collaborative PLM, but collaborative PLM offers capabilities magnifying the expected benefits of these reforms and these reforms will help institutionalize collaborative PLM applications, which can reduce acquisition costs and TOC.

A. CREATING A NATIONAL DESIGN ORGANIZATION (NDO)

In 1936, Theodore Paul Wright described the effect of learning on labor productivity in the aircraft industry and proposed a mathematical model of the learning curve, Figure 12 (Wright, 1936).

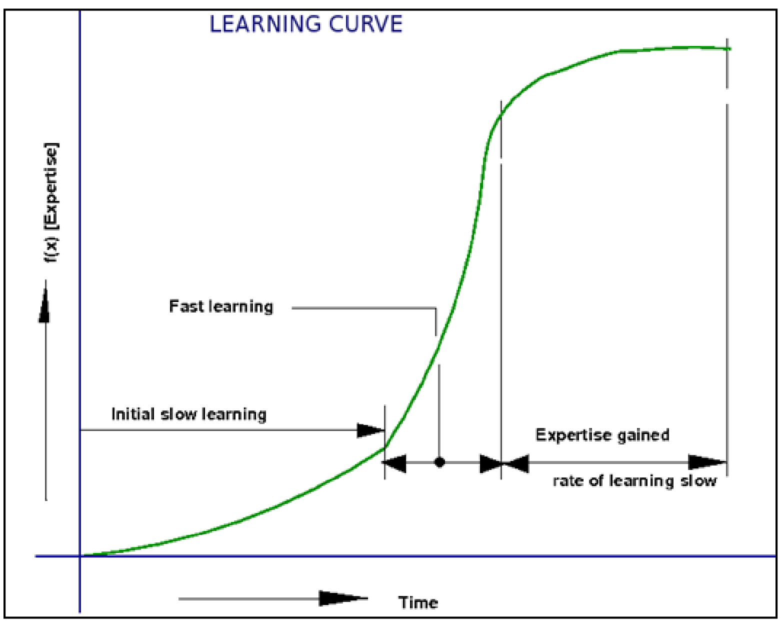


Figure 12. Representation of the Learning Curve
(Wright, 1936)

The theory estimates the changing rate of learning during a set activity or tool. Typically, the increase in retention of information is highest during the initial attempts, and then gradually evens out, meaning that less and less new information is retained after each repetition. However, today each new acquisition design program begins at the bottom of the learning curve, because each program is initiated by forming a new team with many members, who may have never completed a ship design or at least never worked together previously.

Dan Billingsley would like to change this practice of beginning each new ship design program with a new team, and when we discussed this inefficient practice, he stressed the need for an organization to provide sound designs in response to the emerging and ever-changing needs of the entire acquisition portfolio (D. Billingsley, personal communications, April 5, 2010). His 30 plus years of experience in the acquisition community has led him to believe that a single design organization initiating each new design would have a series of positive benefits. The main function of a national design organization (NDO) would be to provide structure and leadership during the early design phases and deliver trusted products (cost, performance, schedule, and risk estimates). This organization should be comprised of representatives from each phase of the lifecycle: design, production, maintenance, and operation domains. Applying the learning-curve concept, by having one team handle all the designs, this team will have the opportunity to learn from previous mistakes and provide a design to serve as a solid foundation for each new program. The NDO would also serve as the custodian for each of the reforms contained in this research.

The NDO would also be charged with grooming new engineers, establishing and maintaining design and engineering standards, providing a focal point for fleet feedback, developing and maturing analytic tools required during design and certification, and ensuring that product data interoperability standards evolve and are followed. Billingsley contended the foundation of a successful program would be established by having every design begin under the same roof, ensuring that the up to 80% of TOC set by those early decisions are made by the most experienced team possible (D. Billingsley, personal communications, April

5, 2010). It will also benefit institutionalizing collaborative PLM as the design team will become very familiar and comfortable operating in its virtual environment.

During a meeting with the DDG-1000 program office a comment was made that the Navy is still performing a majority of its functions, such as reviewing drawings or collaborating on documents, outside the collaborative PLM environment simply because their workers were unfamiliar and unconfident completing tasks within collaborative PLM (J. Watson, personal communication, April 5, 2010). This hurdle of training an organization as large as NAVSEA and the Program Offices will still need to be addressed and will actually be magnified, as eventually that list will be expanded to include sailors, vendors, and contractors that will be involved with the ship throughout the lifecycle. The time needed to train individuals until they are comfortable within the collaborative PLM environment will not only take away time from actual ship design tasks, but also, until they are proficient within collaborative PLM, the quality of those tasks could also be compromised. The NDO should be responsible for conducting the preliminary ship design for every new program, as the decisions made during this portion of the program have dramatic impact. The design should be conducted by a team that, through repetition, is already familiar with the intricacies of collaborative PLM and can focus solely on the quality of the design. The NDO can build a solid foundation for a new ship program so that when transferred into the program office's responsibility, the majority of the critical decisions have already been made to reflect the best interest of the program from the total lifecycle perspective. The program office will be responsible for overseeing the contractor conducting the detail design and construction.

Lastly, the NDO will be charged with supporting the process during follow-on stages of design and construction, providing continuity to the new ship program, and, most importantly, witnessing the ramifications of early decisions in learning and improving the process (D. Billingsley, personal communications, April 5, 2010). Billingsley's position is: "our organizations have become very product centric." By this, he means that large investments will be made in order to gain any amount of value when it concerns the product: for instance, the large investments required to develop a new technology such as the rail gun. Operating the organization as described above would assign the same emphasis on improving the processes. The NDO would have the repetitions necessary to travel up the collaborative PLM and ship design learning curves; they would be familiar with the collaborative PLM environment, and would be able to leverage the capabilities of the new technology to improve the ship design process. Once the ship design process is improved it will pay dividends across all product lines, present and future (D. Billingsley, personal communications, April 5, 2010). Calling for a design organization does not require disestablishment of the program offices that currently handle new acquisition projects. The current structure of program offices is held accountable mainly to the acquisition unit cost of their programs. Once the preliminary design is complete, it can be transferred to the program office and contractors for complete detail design and construction. Mission funding the NDO as a standalone organization would allow the focus to be placed on producing the best design for the Navy across the entire lifecycle, as opposed to the current funding structure, which incentivizes program managers to prioritize staying below acquisition unit cost thresholds.

B. GROOMING AN EXPERIENCED DESIGN WORKFORCE

The experience of a design team can be an influential factor of project success. Experience can overcome many shortfalls and seize opportunity when it presents itself. Figure 13 is from a study demonstrating how an experienced design team building one-of-a-kind oil platforms resulted in a 20–25% cost savings, as compared to an inexperienced design team (Keane, Fireman, Hough, Helgerson, & Whitcomb, 2008). Secretary of the Navy Winter understood this concept. He emphasized the importance of experience:

> Hiring top quality people who have experience with large shipbuilding programs is essential. The ability to assign an experienced and capable team must be a precondition to a program's initiation. Finding and developing the people we need is easier said than done, and it will take time to rectify this problem, but we cannot ignore the leverage that can be obtained by putting the right, experienced and prepared people, in the right positions. (Winter, 2007)

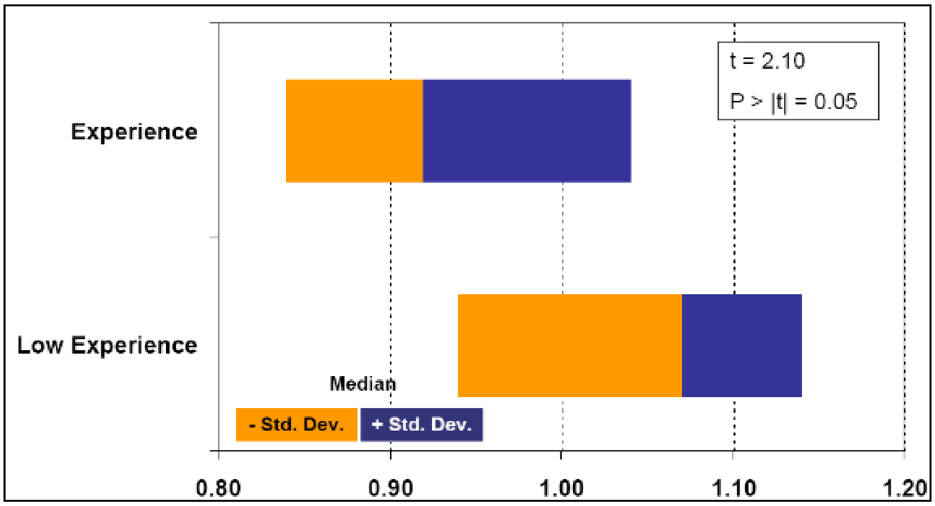


Figure 13. Experience of Design Team Drives Cost Performance
(Keane, Fireman, Hough, et al., 2008)

NAVSEA has successfully maintained a core of highly skilled, experienced ship-design leaders. However, this experienced core has continued to age since the hiring freezes in the '90s, and these ship-design leaders are beginning to retire in rather significant numbers.

In FY2008, 15% of the acquisition workforce was eligible for retirement. In ten years, this will climb to 54% among current employees (Federal Acquisition Institute, 2009). Ben Kassel, currently with Naval Surface Warfare Center Carderock, commented that during a significant portion of the 1990s, NAVSEA accomplished its downsizing mandate by limiting new hires, a decision that today is the cause of another problem. This hiring policy created a gap of experienced workers who today would be capable of assuming all the duties as older workers retire (B. Kassel, personal communication, April 6, 2010). The response has been hiring a large number of entry-level engineers. While this strategy will meet the full-time equivalent quota, it still leaves the monumental task of ensuring that the accumulated knowledge of the older workforce is transferred to these new hires. Dan Billingsley estimates that it takes five years of experience before an engineer truly understands the complexity of ships and can contribute to the design effort (Billingsley, 2010). Compounding this problem is the fact that today's programs currently take at least 10–15 years to work through the design phase (GAO, 2008b). This means a new hire at best will be trained by an experienced worker through one cycle, but more than likely, a new hire will only experience a partial cycle before assuming the reins. The urgent challenge is how to effectively transfer the design experience to this new workforce.

However, what these new hires lack in experience, they have the ability to compensate for by being comfortable with software and other high-tech tools coming into the marketplace. The Navy has implemented simulators into its warfighter-training plans. Ship drivers, pilots, and shooters all receive simulator training as a cheap, reliable, controlled way of gaining experience. The acquisition community does not have a comparable set of tools to train workers in the virtual environment.

Training is part of daily life in the Navy and should be part of the NDO's life as well. Effective training has the ability to improve on the estimated five years needed to gain experience. During times when the NDO has either no active program or the active program does not require the entire organization, training could occur. A team could be assigned to design a major project to near production-level detail, and then evaluate the design. "Engineering a Solution to Ship Acquisition Woes," presented the following benefits that can be expected by conducting of this type of exercise:

- The exercises serve as individual and organizational training.
- The exercises help ensure familiarity with the analytical tool kit as well as areas of weakness.
- Being able to experiment with new design processes and really push the envelope would be possible without adding risk to a particular program. Often, more is learned from failure than from success. In a training scenario, not being concerned with failure could lead to unexpected breakthroughs.
- Since schedule is not an issue, several iterations of a design could be accomplished to fully explore the trade and determine optimal solutions.
- It would provide the opportunity to mature design products, and as designs are completed, they can be stored as a digital library. Once archived, the design can be reinitiated and modified in response to an emerging threat or need (Billingsley, 2010).

The military conducts war games constantly, trying to forecast the future and make sure that we are never caught off guard. Yet today the acquisition community is conditioned to hop from one active program to the next, without the opportunity to plan, prepare, and train adequately. Implementing design exercises can correct that deficiency.

A second benefit of these design exercises is that true innovation cannot be forced. The best ideas rarely come on cue, and when a program is constrained by a schedule, the entire design space is rarely explored, before having to moving on. These design exercises serve to capture and preserve ideas when they do come. A collaborative PLM suite would incorporate this "idea bank" to capture all the inspiration, be it needs, products, services, processes, policies, or insights that people come up with, but are not directly related to the current efforts.

Collaborative PLM has extensive vaulting, search, and organizational capabilities that would be ideal to contain this knowledge bank and ensure that it is easy to use, protected, accessible, and captures the right information so that the ideas can be searched later. Collaborative PLM also can store several configurations of the same project. For instance, if during one of the design exercises, a decision must be made concerning a tradeoff between two technologies that will take the project in different directions, collaborative PLM offers the designers a unique way of addressing the decision. Inside the collaborative PLM architecture, both alternatives can be worked simultaneously by creating a snapshot of the project at that point in time, duplicating it, and then exploring both alternatives. This will help ensure that the entire trade space is explored and prevents delays if one of the alternatives turns out to be a dead end.

Each design exercise does not have to start as a clean sheet design. Rather, they can offer the opportunity to iterate through designs, leveraging the contents of the idea bank, evaluating and evolving ideas to either match current threats, integrate new technologies, or correct deficiencies. The idea is that when an actual design is needed, a majority of the work has already been accomplished, thereby shortening time elapsed before it can be delivered to the warfighter. Or, by making the best use of the schedule to explore the entire trade space, the design would be optimized to ensure that it is the best design capable.

At the Naval Postgraduate School (NPS), students volunteer to participate in a design exercise referred to as the total ship systems engineering (TSSE) project. It is a design exercise as described above. The intention is to give experience to students who will, upon leaving NPS, work in the acquisition community on active programs. The students are provided a project that addresses a need of the Navy; they then attempt to work through the entire design process, from a clean sheet to a presentable design. With proper structure, this program could be improved, to not only expand the student experience, but also to deliver something valuable to the Navy. The previous student design team commented that the exercise lacked sufficient mentorship from the acquisition community. They made an assumption because they did not have access to the appropriate data, then discovered during their final presentation that the assumption was incorrect, invalidating their design proposal. My group is having a similar experience as we are halfway through our design exercise, and we have not interacted with the stakeholders of our design concept. Once the NDO is formulated, part of their task should be to mentor this and other TSSE programs across the country. One of the strengths of collaborative PLM is that since it is web based, NPS could purchase a seat on the NAVSEA Integrated Data Exchange (IDE) and use the same idea bank, design tools, common parts catalogue, social networking, and support that actual NAVSEA engineers are using. These would not only improve the TSSE program with regards to student education, but perhaps the students could accomplish something of actual value for NAVSEA.

C. PRODUCT DATA INTEROPERABILITY (PDI)

The last two sections recommended reforms such as creating the NDO and used design exercises to groom inexperienced workers through training exercises. Next, we will move into ways to assist the people and design organization in their direct efforts on executing value-added tasks of the ship-development process. Daniel Billingsley has defined these value-added tasks as "knowledge-work and analysis, decision-making, and problem solving associated with development, construction, and support during the service life" (Billingsley, 2006). In several white papers and most recently at the ASNE symposium, he estimated that in NAVSEA, this knowledge work accounts for approximately one-third of their total obligation authority, or $7.2 billion each year (D. Billingsley, personal communications, April 5, 2010). This is a significant portion of the budget and is a prime area to look for improvements.

Studies have shown that 50–90% of a knowledge worker's time is spent on non-value-added preparatory tasks (locating, retrieving, verifying, transforming, and recreating) and then follow-on tasks (recording, distributing, and storing) (Keane, 2007). By eliminating or reducing these non value-added activities, either cycle-time can be reduced or more time can be allocated to improving the product; either scenario is beneficial.

The amount of preparatory and follow-on tasks stems from the organization necessary to handle the immense and overwhelming amount of data involved in a warship design. One of the challenges is efficiently getting the right data to the right person when needed so that it can be used productively. Programs recently have begun to design integrated product development environments (IPDE) to support integrated information processing to address this challenge. IPDEs are systems that have both 3D product data and management capabilities, in addition to document-management capabilities. Figure 14 shows the IPDE created for the LPD 17 program (Murphy, 1997).

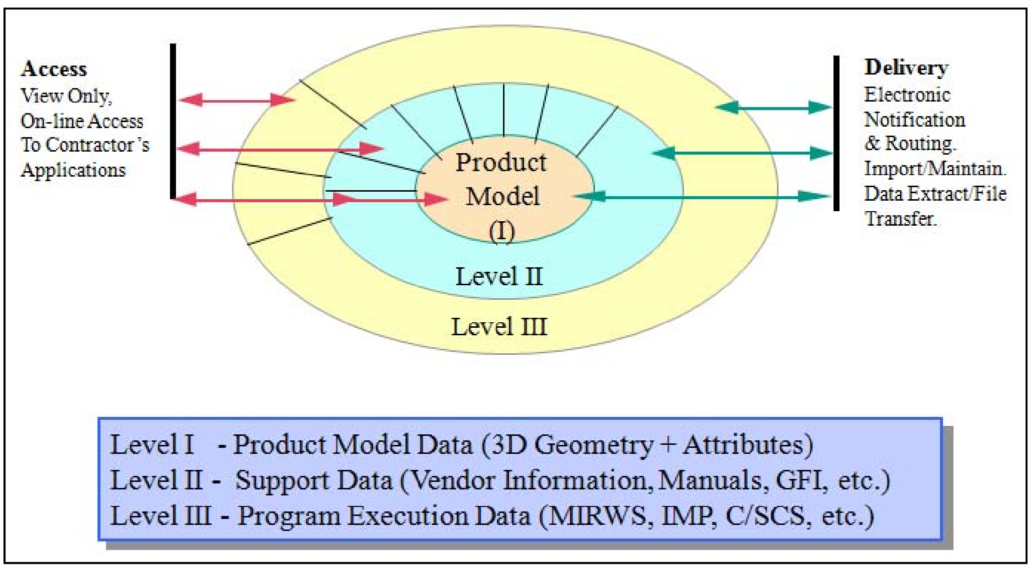


Figure 14. LPD 17 IPDE

(Murphy, 1997)

These environments are very similar to the collaborative PLM suites discussed in Chapter II, but seem to lack the total lifecycle perspective that was common in the collaborative PLM suites evaluated. The IPDE's were created and used during the design and manufacturing phases of a program, but were not designed to be transferred and used during the operation and sustainment phases. For instance, the designers did not design the IPDEs to capture and leverage the knowledge learned or the problems experienced by the ship operators or maintainers, nor were 3D product models available to the operators or maintainers (P. Hudson, personal communication, April 6, 2010).

1. Program-specific IPDEs are less than ideal

Whether integrated into a collaborative PLM suite or as a stand-alone unit, IPDEs have promising upsides. However, significant software developmental and integration challenges are also present. There are several Commercial Off-the-shelf (COTS) IPDEs and collaborative PLM options. However, due to the complexity of information being processed and the limited market, none of them are specifically tailored to support naval ship programs. This means that shipbuilders and programs independently work with the vendors to build IPDEs from COTS components and custom interfaces. For a major shipbuilding program, the IPDE could total $150–200 million, of which 45–55% is integration planning, information engineering, and interface software development (Keane, Fireman, & Billingsley, 2007). With each program office paying to custom build its IPDE to meet its requirements, processes, relationships, and to take advantage of the latest hardware and software developments, there are no incentives to build interoperability or lifecycle features. In "Ready to design a Naval ship? Prove it!" Keane, Fireman, Hough, Helgerson and Whitcomb outlined various problems associated with this ad hoc process:

- Duplication of development effort across many programs,
- Multiple partially integrated systems that are not interoperable with others,
- Annual integration expenses of $10–30 million for each major program,
- Multiple incompatible systems at each shipyard, and
- Numerous inconsistent sources of product information for Navy engineering and support during the service life. (Keane, Fireman, Hough, et al., 2008)

An assumption can be made, that because many of the recent acquisition programs have taken on the expense to create individual IPDEs, they assessed the capabilities and determined the benefits were greater. However, these tools would be even more powerful if they had the ability to leverage knowledge and effort across the entire enterprise, versus being limited to their own programs. Creating a Navy enterprise IPDE would eliminate each of the problems discussed above.

2. The Need for Standards, not Selection

The enterprise-wide solution could be accomplished in several different ways. The Navy could pick a particular vendor to create the entire enterprise-wide solution. Another way could be for various vendors to operate under the same PDI standards. The first option is unadvisable, because it puts a tremendous amount of pressure on selecting the appropriate vendor, as once that vendor has a monopoly on the market, there is less incentive to improve its product to meet evolving needs or shortcomings. The more advisable solution is to spend the time and effort to ensure that all of our data, regardless of what particular software vendor is being used, is transferable between platforms.

Investment in PDI from 1986 through 2004 totaled approximately $61.3 million, $26.3 million of which was used directly by the Navy. The original focus was on transferring CAD data between shipyards to support the "lead-yard," "follow-yard" business model (Keane, Fireman, Hough, et al., 2008). Billingsley (2006) argued that an enterprise-wide strategy for product interoperability has certain benefits over individual IPDEs, including:

- Enable introduction of improved and third-party capability in specific areas, including discipline-focused software developed by ABS, Office of Naval Research (ONR), Defense Advanced Research Projects Agency (DARPA), academia, and industry.
- Reduce or eliminate the need for multiple IPDEs within a single yard.
- Enable acquisition programs to re-use engineering tools and data-management components developed by preceding programs.
- More flexibility in teaming and second-sourcing.
- Expedited review of shipbuilder designs by government engineering agents.
- Enabling common methods of handling product data for support during the service life.
- Ability to utilize archived data in current-generation systems (Billingsley, 2006).

3. Impact of product data interoperability (PDI)

The benefits to the shipbuilding enterprise and timing of pay back can be hard to quantify. Three attempts have been made to quantify the savings once PDI is achieved; the results vary between $150–450 million (Billingsley, 2006).

Achieving product data interoperability will:

- Make cross-program collaboration possible,
- Allow the Navy to control policies and contract terms for product data for acquisition and support during the service life,
- Format data to be useful during each phase of lifecycle,
- Enable communication of shipbuilder designs to NAVSEA for design review and certification,
- Enable NAVSEA to give guidance focusing on software development by ABS, ONR, DARPA, universities, and industry,
- Enable acquisition programs to re-use engineering tools and data management components developed by preceding programs,
- Enable common methods of handling product data for support during the service life. (Keane, Fireman, Hough, et al., 2008)

PDI will not itself solve any of the issues that are leading to the unsustainable cost growth or the unrealized TOC being experienced today because it deals only with the transferability of data. However, all of the solutions depend on the efficient flow of quality information throughout the enterprise. Program risk will be reduced by cost savings associated with eliminating the need for expensive translators that must be updated frequently to account for software updates. Technical risk will be reduced because technical warrant holders will not have to waste time transferring and translating data before analyzing it (R. Keane, personal communication, April 8, 2010). Programs will be able to re-use designs, eliminating the need to start with a blank sheet of paper each time. Managers will have an easier time approving data because it will always be in the same format.

The *Virginia Class* program should serve as a model for how to achieve PDI. Congress decided that two submarine yards are required for national strategic reasons. In

February 1997, Electric Boat and Newport News Shipbuilding entered into an unusual co-production team arrangement (see Figure 15). The construction is split evenly between the two yards with each alternating as the lead integrator. Each yard is operating a collaborative PLM system and have successfully shared data and collaborated between the two yards during execution of this program. Collaborative PLM allowed them to work from one design even though they were geographically separated. Their efforts ensured no surprises occurred as they constructed components in one yard, put them on a barge, and shipped them to the other yard for assembly (General Dynamics Electric Boat, 2002).

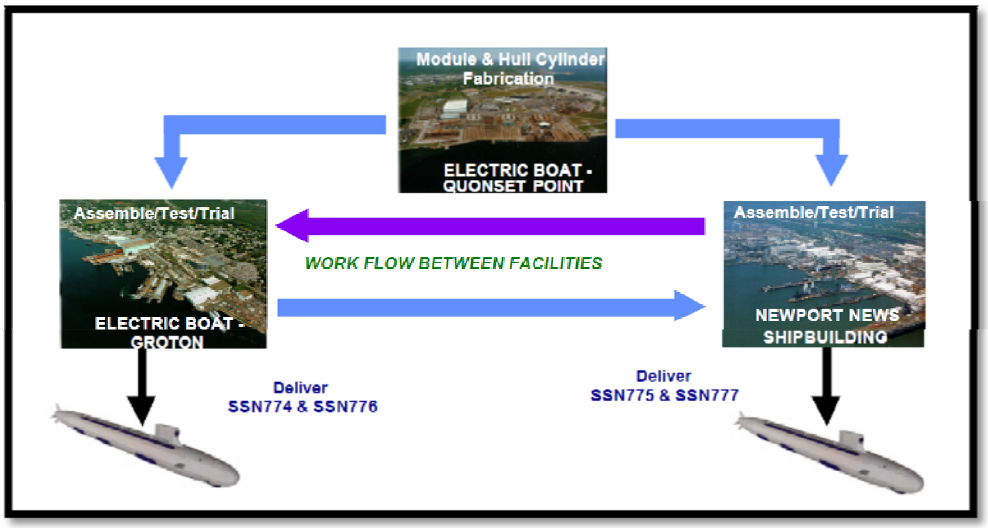


Figure 15. Workflow between Electric Boat and Newport News
(General Dynamics Electric Boat, 2002)

While PDI will not solve any problems, the lack of it is a barrier that could prevent other reforms from being successful. The Navy will not realize all the benefits of collaborative PLM if the data is not interoperable and knowledge can be leveraged across the entire portfolio.

D. DESIGN AND CERTIFICATION TOOLS

Just as the small, specialized shipbuilding market makes necessary the development of a customized collaborative PLM suite, it also means the industry cannot expect the associated tools and applications needed to support the design and technical warrant holders to be developed without the guidance and investment of the Navy. This is yet another reason to support data standards and interoperability, as it would allow myriad sources (public, private, and academic) to develop tools in a fashion that would ensure they are capable of being integrated into the collaborative PLM suite while eliminating the translators and the recoding traditionally required to ensure compatibility. Independent of the design source, a mature tool kit is critical, because by the end of the design phase, 80% of TOC is set, so those early decisions can offer the greatest potential or dire consequences (Briggs et al., 2009). Collaborative PLM is going to be able to capture and organize data that our programs have never had before. Real world data collected from operational ships can be statistically analyzed to determine what are the most important predictive metrics to track.

Keane, McIntire, Fireman, and Maher (2009) argue that operational architecture tools such as those being developed by the NAVSEA Future Concepts and Surface Ship Design Group could address the shortcomings of the ship synthesis models that existed at the time of the LPD-17 cost and operational effectiveness analysis (p. 49).

When comparing ship options, a better understanding of what options are optimal is needed. Tools (algorithms) exist that optimize the design parameters of a ship concept. Keane, McIntire, et al. discuss two of these tools. Georgia Tech’s Unified Trade Environment method thoroughly searches the entire design solution space better, calculating differences between various ship options. Virginia Tech’s Overall Measure of Effectiveness enables the prioritizing and quantifying operational requirements to drive the design optimization computations. Prioritization of requirements was achieved by a pair-wise comparison hierarchy with experienced operators, ship designers, and program managers from a wide range of disciplines (Keane, McIntire, et al., 2009, p. 49).

Numerous options need to be studied prior to settling on a new ship concept. The quicker each of these options can be created and evaluated, the more iterations can occur, creating the potential for a better product. The tools that project a particular concept’s technical, risk, and cost characteristics must produce consistent, trusted results or decision-makers cannot possibly make a sound evaluation based on merits.

1. Current tools need development

NAVSEA can improve the design and engineering tools and applications available to assist its engineers in making sound decisions, while evaluating the multiple options of a particular design. Ship design concepts are an accumulation of decisions evaluating particular systems or components against a set of requirements and assumptions. Each criteria used to make a decision is another axis, that when combined, forms a point in multi dimensional design space. Each iteration of the design provides the opportunity to change one of the variables, creating a new point forming the field showing what is possible (Billingsley, 2006). This is a good method to validate certain assumptions and to decide which point estimate is best. There is minimal risk while extrapolating between the point estimates. However, as demonstrated by Figure 16, there is no guarantee that the point estimates calculated contain the optimal solution, and extrapolation beyond the points introduces a tremendous amount of risk.

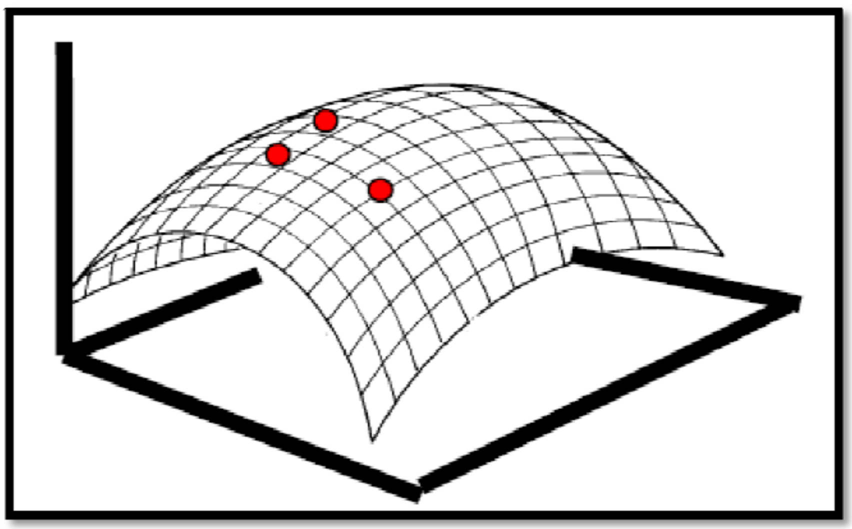


Figure 16. Conventional Approach for Design Space Exploration
(Billingsley, 2010)

Current early stage ship-design tools have the following deficiencies for rough order of magnitude (ROM) and feasibility level studies:

- Inability to conduct real-time cost assessments,
- Inability to assess total ship survivability at the concept level,

- Inability to conduct topside design assessments at the concept level,
- Inability to conduct weapon systems-effectiveness assessments,
- Inability to conduct preliminary ship-manning analysis,
- Inability to analyze a wide range of unconventional hull-form alternatives,
- Inability to conduct preliminary maneuverability assessments,
- Inability to conduct rapid design space exploration in order to narrow down the range of acceptable ship concept alternatives, and
- No flexibility, transparency, or scalability (Billingsley, 2006)

2. Impact once completed

Over the past several years, the Navy has been attempting to address these shortcomings, but it needs to continue to fund the efforts into design space exploration using response surface methodology (RSM) (Billingsley, 2006). This new approach leverages the power of computers to automate the systematic exploration of the design space, once enough data is entered into the system, the computer can cycle through various combinations, testing them virtually. It would be cost prohibitive to build a mock up and test physically the number of combinations that a computer can cycle through; however, a computer's virtual modeling could enable the decision-makers to decide which combinations would be valuable to test physically and which options should be eliminated from consideration. This increased information decreases the risk of interpolation and allows for the selection of the truly optimized solution, meeting competing objectives (Figure 17). Continuing to mature these technologies is critical, but it is only half of what is needed. Collecting data throughout a ship's lifecycle is a necessity so that these models can be validated and trusted.

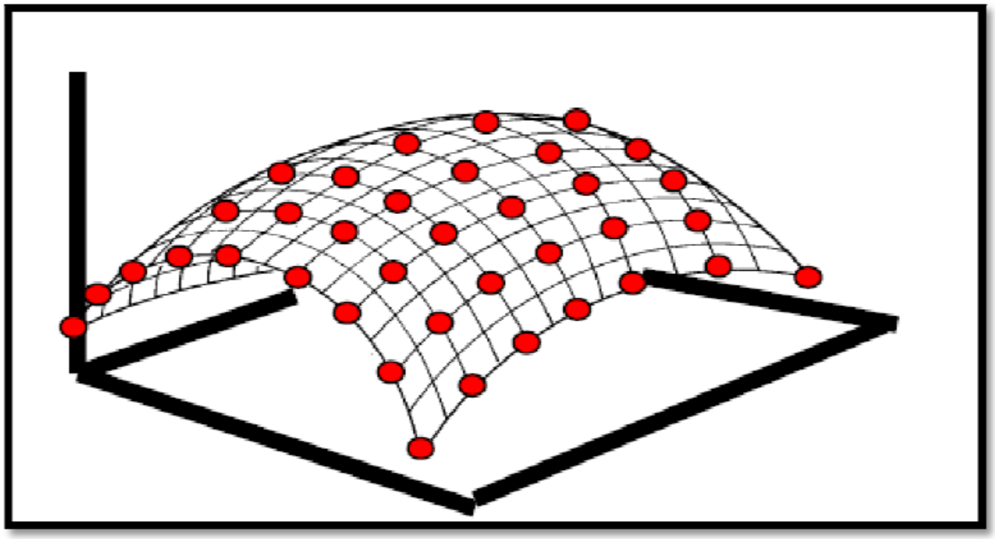


Figure 17. New Approach for Design Space Exploration
(Billingsley, 2010)

The designers and technical warrant holders must respond to all program requests, regardless of the stored format of the data. If each program collects different information and stores it in a different format, (i.e. the data lacks interoperability), the process becomes more difficult. This scenario would require the retrieval of the data, and then the translation of data so that it can be evaluated in the format required for the particular tool being used. Then, after the analysis, the data must be converted back into its original form and assimilated back into the original program, so that it can be used. Those are all wasted steps that require time and effort. PDI will eliminate these wasted efforts to allow the time to be spent either conducting a more thorough analysis or the elimination of an option, thus reducing cycle-time, both of which are beneficial.

Once these tools are integrated into the collaborative PLM suite, they will have the access to the lifecycle data needed as the suite is populated, providing the ability to refine and evolve these tools, making them accurate and reliable. Quantifying direct cost savings from a more comprehensive set of design and certification tools is difficult, but it is possible to see how the effort would lead to savings. During the lifecycle, savings could come from providing tools where none currently exist in order to allow the evaluation of failures that have not been analyzed before. Lifecycle savings would also come from uncovering and correcting design issues before they ever reach the fleet. The investment required to develop good software is insignificant compared to the cost of a failed system once in service.

E. SECTION SUMMARY

This chapter focused on reforms of the organization and the tools and people that comprise it. Recreating a National Design Organization will be the lynchpin for any lasting reforms of the acquisition process. An NDO would provide the focus and authority necessary to make meaningful changes and address many of the weaknesses. It makes sense then that the most experienced well-trained individuals can make appropriate decisions, essentially locking in success, before transferring the project into the larger program offices of current operations. Once this organization is in place, many of the other reforms outlined begin to fall into place with minimal effort. For instance, the next wave of engineers can be mentored through various design exercises by the experienced engineers, building not only the digital idea bank, but their own experience and knowledge. PDI will be easier to resolve, because all product data will originate inside the same organization, ensuring consistency. This consistency will facilitate data transfer between programs and throughout the lifecycle, as well as provide standards for private or public development of the next generation of collaborative PLM or design tools.

VII. FUTURE STATE OF DEFENSE ACQUISITION: ESTABLISHING SOUND PRACTICES AND PROCESSES

This chapter will focus on some reforms that could have a dramatic effect on the ship acquisition process. These reforms look at the practices and processes of the ship design and acquisition process and how they can be modified to leverage the capabilities of collaborative PLM applications. Many of these incorporate lessons learned that have proven effective in other industries and can be adapted to shipbuilding.

A. RECTIFY LACK OF EARLY SYSTEMS ENGINEERING: DECISIONS MADE BEFORE MILESTONE B

The proper business case of a ship design program should stress the application of LEAN design principles as early as possible. During these early stages, the flexibility to change design is highest, because as a design progresses into more detailed phases, the cost to make changes increases. The National Shipbuilding Research Program (NSRP) developed a strategic investment plan (SIP) outlining a business case with two main objectives: 1) focus on the application of LEAN concepts to the preproduction areas of design, thereby reducing cycle-time, non value-added activities, and the cost of ships; and 2) focus leadership on process improvement, which is needed due to the multi-organization efforts required to change design practices that are deeply embedded in the enterprise culture (Keane, Fireman, Hough, et al., 2008).

In 2006, the DoD established a mandatory sustainment key performance parameter (KPP) requirement for acquisition systems. The KPP has three main factors: system availability, reliability, and ownership costs. The Defense Science Board gave the following recommendation in its May 2008 report:

> The single most important step necessary to correct high suitability failure rate is to ensure programs are formulated to execute a viable system engineering strategy from the beginning, including a robust reliability, availability, maintainability (RAM) program, as an integral part of design and development. No amount of testing will compensate for deficiencies in RAM program formulation (Under Secretary of Defense (AT&L), 2008).

However, the current practice lacks focus, and many programs pass through milestone B (entry into the engineering and manufacturing development phase), without a true understanding of the technical risk and projected TOC of the design, which can lead to cost and schedule growth during acquisition and higher than anticipated operating and maintenance costs, once transferred to the fleet.

Several characteristics of the current acquisition structure drive this behavior. First, the unnecessarily long cycle-time (15 plus years for some programs). To compensate for the long developmental time, programs must forecast technology that will be innovative 15 years from now. This incorporates a high degree of technical risks. Second, because a program must be fully funded, managers underestimate costs and risk in order to sell the program and be established. This competition for funds has led program managers to trade off lifecycle cost or capabilities to keep acquisition costs down. Lastly, even when overruns and delays come to light, the program keeps going fueled by optimistic “fix-as-you-go” strategies, preventing the fiscal and political fallout associated with killing a program (R. Keane, personal communication, April 8, 2010). Pushing forward programs containing so much risk forces the government into cost-plus contracts, because no company can estimate a firm price on a design that is still evolving.

All three of these issues can be addressed by limiting the developmental time to no longer than six years from milestone A, which signifies the start of technology development to low-rate initial production as recommended by the Deputy Secretary of Defense (“Assessment Panel of the Defense Acquisition Performance Assesement Project,” 2006).

The *Virginia Class* (SSN 774 class) program has demonstrated that this cycle-time is achievable, due to the effects of electronic design technology and integrated product and process development (IPPD) implementation. Electric Boat reports that *USS Ohio* took more than 13 years and used 2,100 designers. *USS Seawolf* took about 13.5 years and 1,850 designers. *USS Virginia* will have taken about 9 years and 1,150 designers. The Electric Boat Virginia Class IPPD program manager suggested that future advances that incorporate more knowledge-base-driven design might further revolutionize the design process, cutting it to 4.5 years at 50% the current manpower (General Dynamics Electric Boat, 2002).

With the shorter cycle-time, the program requirements will more accurately reflect what the warfighter needs because there is less time for trends, missions, and threats to change. The shorter cycle will force immature technologies out of consideration because programs no longer would have the schedule to allow these technologies to mature.

Some other reforms are necessary in order to make this five-year timeline realistic. First, it will be best to leave the technology development as the responsibility of the research labs, such as the ONR and DARPA. The time spent maturing immature technology can be eliminated from the schedule. Because all designs begin in the NDO, relationships can be established, fostering not only a smooth transfer of technology but also a focus point for the warfighter, feeding needs and desires into the design. Once the NDO has its tasking, it can reach into collaborative PLM's virtual idea bank and pull either a similar design or components from many designs to incorporate into the new program. Because the NDO handles all new design, its engineers will be intimately familiar, from all the previous designs and exercises that they have completed, with both what is available in terms of the common component catalog, as well as what works and what does not. This experience will help them turn out a better design, while setting the pace to meet the five-year goal. Finally, as long as the funding stream for the NDO is established intelligently, they can be held accountable based on the quality of the design and avoid the pressure today's program managers experience when meeting spending limits. This pressure is understood and even drove the previous reform, separating the technical warrant holders responsible mainly for safety of ships and the program managers held accountable for cost and schedule.

B. USING STANDARD COMPONENTS AND PRODUCT STANDARDS

I referred to the common parts catalog earlier and will discuss it further in this section. Today, the Navy has to design, buy, and support thousands of different pump valves for surface ships and hundreds of different electrical controllers. Leveraging previous designs and components needs to become a standard process during early stage design. The "Affordability Through Commonality" Program highlighted the benefit of reducing the proliferation of similar parts in the fleet (Billingsley, 2010). When each of our programs is operating in a fully integrated collaborative PLM environment with a common parts list, designer A can drag and drop a part or even an entire system created by designer B for a different program and save all the engineering cost to redesign, retest, and revalidate an identical part from scratch. Perhaps some of the savings can be spent upgrading or optimizing the part or system to increase value. This improved part now becomes the new common part that designer C will use in a future project. Savings will cascade throughout the lifecycle as use is made of a common parts catalogue. The program manager will have risk reduced (cost, schedule, and performance) as the design matures and a real history is created. Manufacturing will have one assembly line that it must keep open. Supply will have fewer spare parts to purchase, store, inventory, and ship. Operators will have fewer systems to learn how to operate and maintain. Maintainers will have fewer systems that they must repair.

Strictly controlling the introduction of new parts into the design is effective if established at the start. For example, Electric Boat noted that *USS Seawolf* had over 100,000 unique parts that required separate purchase actions, storage control, and consideration for spare parts support. The Virginia Class program had a policy that new parts could only be introduced into the design with the approval of a single individual, and the result was a limited number of unique parts. For the Virginia Class, Electric Boat built a standard, approved parts library inside its collaborative PLM system. Of the 105,400 parts available for review from the *USS Seawolf* (SSN-21) design, Virginia's team reviewed about 98,000 of them and selected about 15,000 as *USS Virginia* standard parts. The final design will have fewer than one fifth the unique parts compared to *USS Seawolf*. This parts reduction strategy has a direct effect on administrative costs for purchasing and storage for ship construction, and will reduce the amount of spares required for life cycle support (General Dynamics Electric Boat, 2002).

To get the most of a common catalog, the engineers must know what is in it. Each of the collaborative PLM suites evaluated contained a method to search and recall information based on a variety of parameters. Because all designs will be initiated under one roof (the NDO), it will be easy to ensure the processes remain consistent, regardless of platform. This means, basically, that data is data and will become interchangeable. Yesterday, the task may have been designing a pump for LPD 17 and today, for LCS. The function of the pump did not change, so why should the design? The constant design exercises will not only keep the idea bank full with ready-to-go designs, but it will also keep the engineers up to date with what has already been done before, constantly updating design, making improvements, and creating the new standards. This helps give a reason that past efforts have not been complete successes. A second disadvantage of any commonality program is the potential to limit competitiveness, as only those products conforming to the standard are eligible for consideration, regardless of the quality of the product. A technology, such as collaborative PLM, capable of storing, sorting, and using huge amounts of data is only half of the solution. It must be paired with a healthy organization that understands not only which data is available for incorporation into the design, but also how to interact with a database such as collaborative PLM efficiently so that it is easier to find current design, as opposed to simply doing it over again.

C. MANAGING RISK TO IMPROVE OUTCOMES

1. Private-sector retire risk prior to contract signing

As budgets shrink, decision-makers will have to determine what programs are to receive the reduced funds. However, the volatility of the cost estimates is one thing that gets managers called before Congress. In 2009, 96 programs evaluated by the GAO were a cumulative $296 billion over budget. Overruns of this magnitude will make any planning ineffective, and will cripple the acquisition programs if not addressed as the funds dry up (GAO, 2010).

Removing programmatic risk as early as possible is a proven method to reduce the volatility currently plaguing the naval acquisition portfolio. Analysis provides an opportunity to not only gain a full understanding of the potential risks associated with a particular project, but also to determine if those risks can be mitigated prior to bidding on the ship. If the shipbuilder fails to mitigate the risks, it could encounter problems later in the construction process that will require additional unplanned resources. It would be difficult for shipbuilders to stay competitive with extra capacity available; thus, these unplanned resources would likely be pulled from other projects, potentially cascading through the entire organization, delaying multiple ships, and damaging the organization's reputation and ability to acquire new work. Figure 18 shows the desired process, emphasizing early risk mitigation in commercial shipbuilding programs (GAO, 2009b). While the naval acquisition community doesn't have the same luxury of deciding to pass on a particular class of ships if it appears too risky, the process of early risk mitigation still offers benefits, leaving a program more capable of delivering performance on cost and schedule.

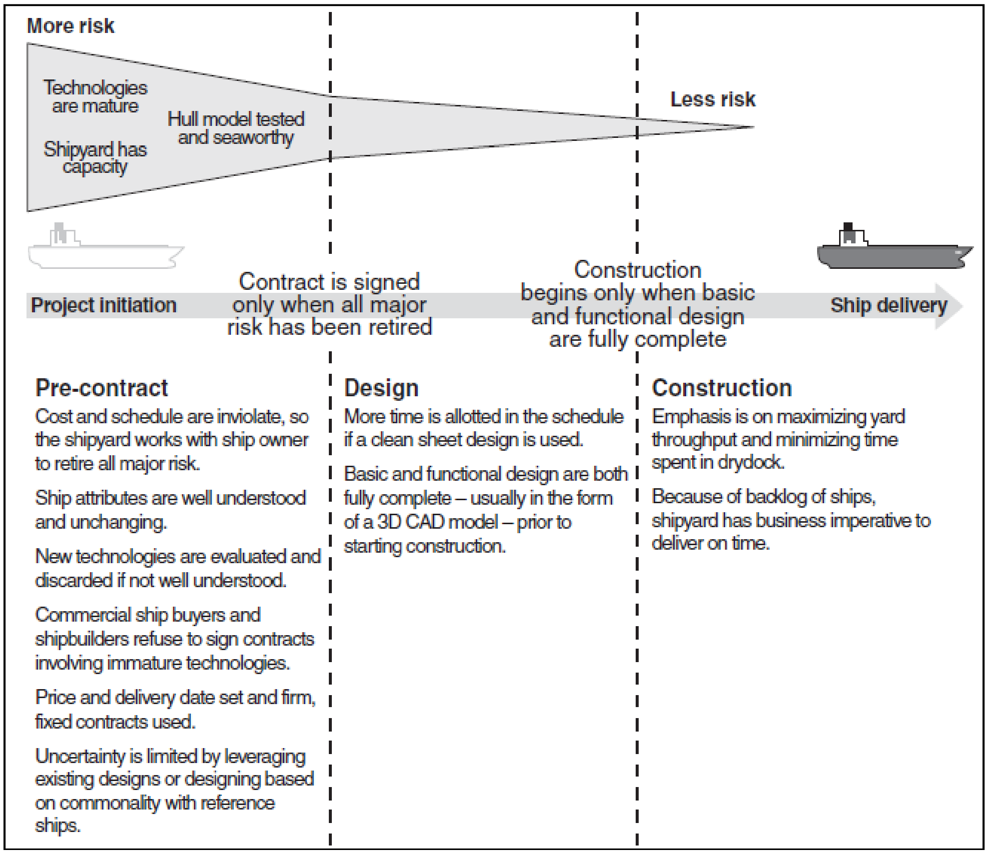
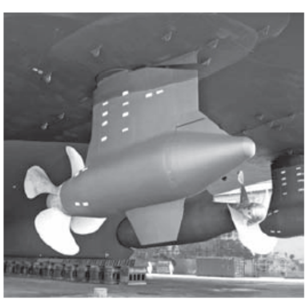


Figure 18. Commercial Practices: Risk Minimized Pre-Contract

(GAO, 2009b)

The commercial sector relies on several strategies to ensure that risks are minimized as early as possible. One option is to reuse an existing design, rather than requiring a new design be created from scratch. Using an existing design saves on the amount of design work that must be done, and historical data provides assurance to the customer that the design can be built and that the particular shipyard can build it for cost and on schedule. This approach tailors nicely with collaborative PLM because all the data from previous designs are already in the system, so efforts can be spent updating and modernizing the design to meet current objectives.

The GAO reported that Korean shipyards utilize this tactic as they maintain several standard designs for different classes of ships and allow customers to select and modify a design as necessary (GAO, 2009b). The cruise ship industry has a similar tactic that may be more suited for defense programs. The Royal Caribbean's Freedom Class drew heavily off the design of its predecessor, the Voyager Class. Even though the *Freedom* has a different hull and is 47 feet longer, it uses the propulsion system, power lines, and several other basic features designed for the *Voyager*. The cruise industry also understands that the ships will undergo extensive revitalization and designs them accordingly. These revitalizations have been as intensive as cutting the Royal Caribbean ship *Enchantment of the Seas* in half to add a new middle section of cabins, but they are more commonly used to introduce new features that were not mature enough to be included in the initial build. An example would be hydro-dynamically efficient ducktails to improve fuel efficiency (GAO, 2009b). It is easier to resist the urge to insert immature technology when planned modernizations will ensure the ships will remain state of the art.



In the 1990s, Royal Caribbean wanted to change the propulsion system on its cruise ships from standard fixed propellers driven by propeller shafts to a rotating, podded propulsion system called Azipod. These pods carry the propeller and motor outside of the ship and have the capability to rotate 360 degrees, allowing for the ship to be pulled through the water as well as pushed. This technology, developed by a company called ABB, offered the potential of improved fuel efficiency and greatly enhanced maneuverability—affording Royal Caribbean the ability to construct significantly larger cruise ships capable of accessing major ports. At the time Royal Caribbean wanted to move from conventional propulsion to Azipod, the technology had only been installed on smaller ships, including tug boats and icebreakers. Royal Caribbean approached ABB about the possibility of scaling Azipod up to the size required for a cruise ship and brought the shipyard it planned on using for the project on board. The three parties worked together to extensively prove the technology and built close-to-scale versions of Azipod before Royal Caribbean and the shipbuilder both became comfortable enough to move forward with the project. Further, despite its growing confidence in Azipod, Royal Caribbean decided that it was prudent to maintain some redundancy through installation of fixed pods that could provide propulsion in the event that the new Azipods failed. After overcoming some initial maintenance issues, the Azipods project proved successful for Royal Caribbean. The enhanced maneuverability offered by the Azipods enabled the company to initiate development of the new 220,000-ton *Oasis of the Seas*, which is currently under construction and planned to be the largest cruise ship ever built.

Figure 19. Royal Caribbean Cruises, Ltd., Employment of Azipod Propulsion
(GAO, 2009b)

The cost and schedule volatility experienced in DoD programs could be significantly reduced if we had the same discipline regarding technology insertion as commercial firms. By *discipline* I mean that new technology would have to undergo modeling, testing, and simulations, to prove that it offers significant benefits to performance, or operational, and maintenance costs, before it would be included in designs.

Figure 19 is the result of a case study conducted by the GAO, demonstrating how Royal Caribbean worked through the risks of integrating new azipods into its design (GAO, 2009b). A collaborative PLM suite has several features that help the designers ensure that the appropriate level of risk is communicated about particular components. For instance, particular components in the 3D model can be color coded to ensure that high-risk items are highly visible. Figure 20 shows how documents and data can be integrated directly into the model. For instance, if the designer saw the azipods were color coded red, they could click on the component and bring up amplifying data such as the mitigation plan and schedule, the testing schedule, or any other data necessary to communicate the situation of that particular component. The designer could also attach a question directly to the component that would be answered by the particular point of contact for that component. By integrating all the applicable data into the 3D model, it helps ensure warnings or red flags are not overlooked because they are spread out through a series of emails, reports, etc. (R. Langmead, personal communication, April 4, 2010). If the technology cannot be matured to a point where both the buyer and the builder are confident that it will perform as expected and not delay delivery, then it will be discarded from consideration for the sake of program success.

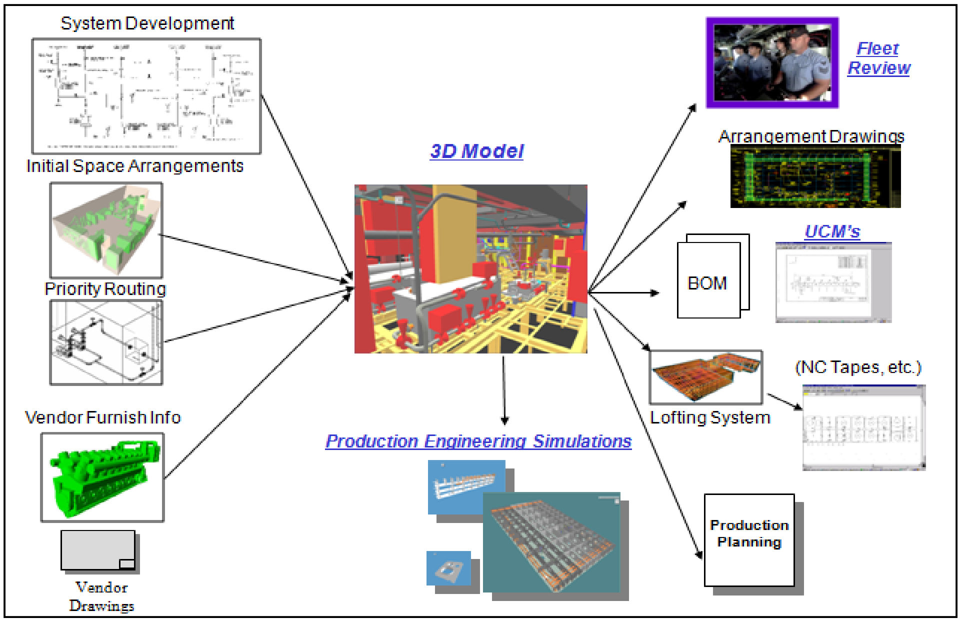


Figure 20. Information Can Be Imbedded Directly into 3D Model
(Murphy, 1997)

2. Navy shipbuilding programs don't prioritize the early mitigation of risk

The Navy approaches technology development differently than the commercial approach described in the previous section. To ensure that our sailors always have the advantage in a fight, the Navy needs to deliver ships that have outpaced and overmatched all future threats. To gain this advantage, naval acquisition programs are generally not restricted to proven technologies. Instead, they invest considerable resources developing and integrating cutting edge technologies that can meet mission requirements. Unlike commercial shipbuilding counterparts, the Navy has been willing to assume the risk and enter contracts without fully functional prototypes, demonstrating technologies are mature enough to validate performance expectations. This means that in situations where the commercial buyer and builder have full understanding of the requirements to design and build a particular ship and are confident enough to enter into a firm fixed-price contract, the Navy has traditionally used a cost-plus contract, assuming the majority of the risks. The GAO was able to capture this point in Figure 21, which highlights the differences between the assumptions of risk in naval versus commercial shipbuilding programs (GAO, 2009b).

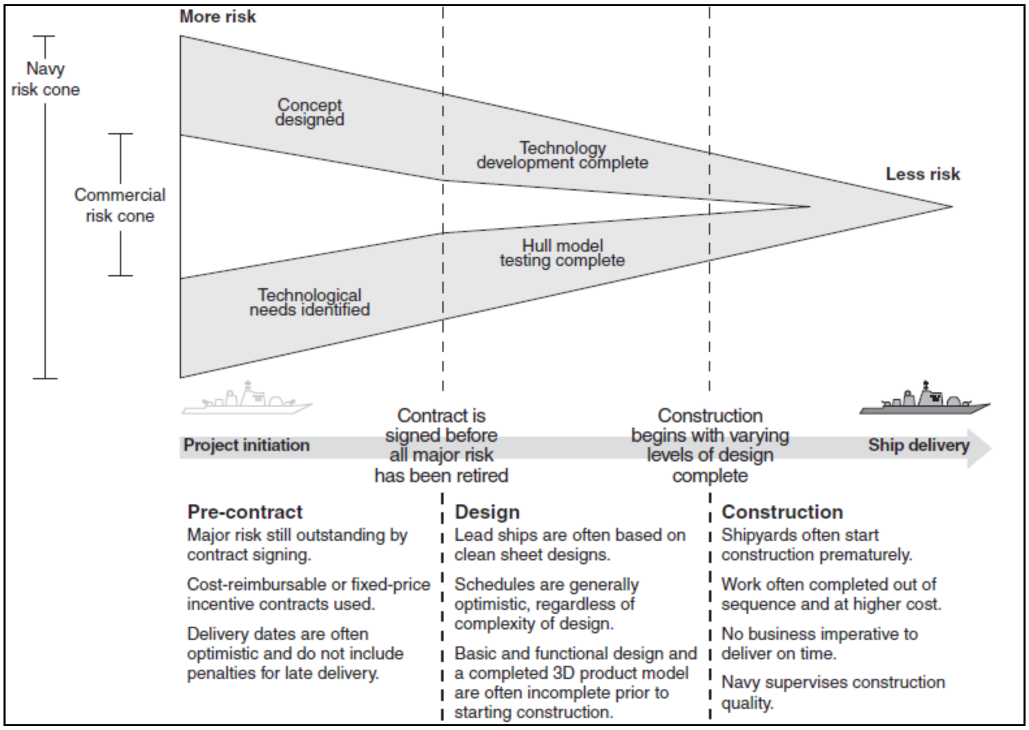


Figure 21. Navy Practices: Significant Risks Remain Unresolved at Contract Award (GAO, 2009b)

Once the schedule starts slipping, certain risky practices are employed to try and recover lost time. Examples of risky practices could be trying to design and develop technology concurrently and starting construction before achieving a stable design. For example, when designing around immature technology in order to keep the design progressing on schedule, shipbuilders must make assumptions about systems and equipment when actual information is not available, for instance a component's size, weight, the heat generated by it, its vibration profile, and so on. If the technology does not mature according to those assumptions, then the shipbuilder has to redesign entire aspects of the ship, rework portions already completed, and most likely conduct that work in an inefficient sequence. These types of practices are what preclude the Navy from finding a partner willing to agree to a fixed-price contract.

In its current state, the Navy does not allocate sufficient time to engage all stakeholders in a manner similar to the commercial sector (P. Hudson, personal communication, April 6, 2010). Instead, there is a race to understate costs and risks and become a program of record by rushing decisions on requirements and specifications. If the LCS program, as illustrated in Figure 22, had taken the opportunity to engage in open dialog between stakeholders, it could have alleviated a lot of its headaches by realizing from the start that its $220-million and two-year build time was unachievable (GAO, 2009b). Inside a collaborative PLM environment, all of the stakeholders are integrated together through social networking tools, thus creating a culture where open communication is easier and problems become more transparent, helping to prevent designers and engineers from making incorrect assumptions during the design.

Mission: LCS is designed to perform mine countermeasures, anti-submarine warfare, and surface warfare missions in littoral (coastal) regions.

Issues: From the outset, the Navy sought to concurrently design and construct two lead ships in the LCS program in an effort to rapidly meet pressing mission needs. Implementation of the new Naval Vessel Rules (design standards) further complicated the Navy's concurrent design-build strategy for LCS. According to Navy officials, these rules required program officials to redesign major elements of each LCS design to meet enhanced survivability requirements, even after construction had begun on the first ship. While these changes improved the robustness of the LCS designs, they contributed to out-of-sequence work and rework on the lead ships. The Navy failed to fully account for these changes when establishing its $220 million cost target and 2-year construction cycle for the lead ships. When design standards were clarified with the issuance of Naval Vessel Rules and major equipment deliveries were delayed (e.g., main reduction gears), adjustments to the schedule were not made. Instead, with the first LCS, the Navy and the shipbuilder continued to focus on achieving the planned schedule, accepting the higher costs associated with out-of-sequence work and rework. This approach enabled the Navy to achieve its planned launch date for the first LCS, but required it to sacrifice its desired level of outfitting—a practice that further increased costs later in construction.

Figure 22. LCS Program Capsule

(GAO, 2009b)

The Ford aircraft carrier (CVN 78), seen in Figure 23, is another example showing how the lack of early risk mitigation could jeopardize the success of a program. One of the foundational technologies on CVN-78 is the electromagnetic aircraft launch system (EMALS), a catapult that uses an electrically generated magnetic field, instead of steam, to accelerate aircraft to launch speeds. The EMALS offers several advantages over steam, including improved sortie rate, less stress on the airframes due to more controlled acceleration, and a reduced demand for fresh water. It also weighs less, requires less space, requires less maintenance and manpower, and is more reliable. The downside is that it is an immature technology that has not been proven by an operational prototype. Because work did not stop to wait to see how EMALS would evolve if the assumptions needed to be modified, it could result in major amounts of rework. Collaborative PLM would have given the design teams the ability to create a mirror of the CVN-78 design and progress one with EMALS and one with the traditional steam. This would have eliminated a portion of the risk: if EMALS fails and a plan B is needed, then an alternative to EMALS would be on the shelf, ready to go.

Mission: The Navy's CVN 21 program is developing a new class of nuclear-powered aircraft carriers that will replace USS *Enterprise* and the Nimitz-class as the centerpiece of the carrier strike group. The new carriers are to include advanced technologies in propulsion, weapons handling, aircraft launch and recovery, and survivability designed to improve operational efficiency and enable higher sortie rates while reducing required manpower.

Issues: CVN 21 technologies, including EMALS, the dual band radar, and the advanced arresting gear, have all experienced schedule delays that could disrupt construction of the lead ship in the Ford-class, CVN 78. EMALS was initially designed and tested in a configuration that minimized the system's weight. However, after the Navy defined the ship's survivability requirements, the system was reconfigured and its weight increased above its margin, resulting in reallocation of weight elsewhere on the ship and the redesign of a subsystem. Further, the contractor for EMALS designed one subsystem component—the power conversion system—to generic shock and vibration requirements while waiting for the Navy's final determination of shipboard requirements. At present, the subsystem may need to be reconfigured during production in order to meet final requirements—an outcome the contractor attributes to delays arising from limited coordination with the shipyard on requirements issues. Dual band radar testing has been delayed as a result of technical difficulties in developing the volume search radar. Upcoming land-based tests will be conducted at a lower voltage than needed to meet requirements and without the radar's composite shield. Full power output will not be tested on a complete system until 2012, and carrier-specific functionalities will be demonstrated shortly before shipyard delivery in 2013—an approach that leaves little time to resolve problems ahead of ship installation. In addition, the advanced arresting gear has encountered delays resulting from difficulties meeting the Navy's requirements for the system. Specifically, the Navy and the contractor disagreed on the necessary format of design drawings, drawings were delivered late, and changes in Navy requirements for shock and vibration led to a redesign of a major subsystem.

Figure 23. CVN-78 Program Capsule

(GAO, 2009b)

The AEGIS project is an example of how the Navy has successfully reduced the risks of a new program. Deputy Secretary of Defense David Packard directed a number of actions when the contract was awarded, including the completion of a simplification effort to reduce complexity and costs. The AEGIS program required the use of engineering development models. Engineering development models are versions of the system that are used to demonstrate the system performance. Once demonstrated, a second engineering development model could further the design moving on to the next, more complex version. This testing program was referred to as, "Build a little, Test a little, Learn a lot." And was based on incremental testing of function and components as the system was built. Hood argued, that the escalation of functionality and complexity was built upon a solid base of performance, and was a key element in reducing integration problems, increasing the chances of success (Hood, 2009).

Technological development requires a different skill set than program management. We are asking too much of our managers to try to maintain cost and schedule benchmarks based on a new technology that does not exist yet (P. Hudson, personal communication, April 6, 2010). All of our programs would be better served by taking a lesson from the commercial sector; leave the technology development in the research labs. Instead, we should produce designs based on proven technologies and plan for upgrades, once the technology becomes available. Until this happens, collaborative PLM offers the capability to ensure that the data is organized in a fashion that increases the visibility of the risk so the appropriate attention can be assigned, as a portion of the risk can be mitigated by progressing two designs simultaneously, just in case one fails.

D. SMART PRODUCTS CAN CLOSE THE DATA LOOP

Smart products are products that can sense and communicate information about their condition and environment. The idea is that information becomes knowledge on how to support existing products or create new and better ones. *Promise* is an innovative project that has demonstrated how to use smart products to build on the capabilities of collaborative PLM, offering companies a new business model and new ways of creating value (Stark, 2010). Most of the systems that the Navy operates already offer some degree of smart functionality, meaning that we have sensors in just about all of our equipment to monitor operating conditions and transmit it over networks to operators in, for instance, the control room or bridge. However, the *Promise* program demonstrates that there are other potential benefits, and smart products with collaborative PLM can reform the acquisition portfolio, by converting a constant stream of data directly from the products into knowledge usable by the designers.

1. *Promise* project concept

The core concept of *Promise* (Figure 24) is that information captured by smart products can be transformed into knowledge that can be used to better support existing products, create new products, as well as service value (Kiritsis, Moseng, Rolstadås, & Røstad, 2008). One of the greatest weaknesses in the current product lifecycle is the barrier that prevents the flow of information between phases. For instance, once a product leaves their area designers rarely get data on actual product use. An attempt to address this weakness is the practice of hiring previous operators to design the new systems or involving current operators in the process to capitalize on the experience they each have. The *Promise* project demonstrates that there is a much better way to close the information loop.

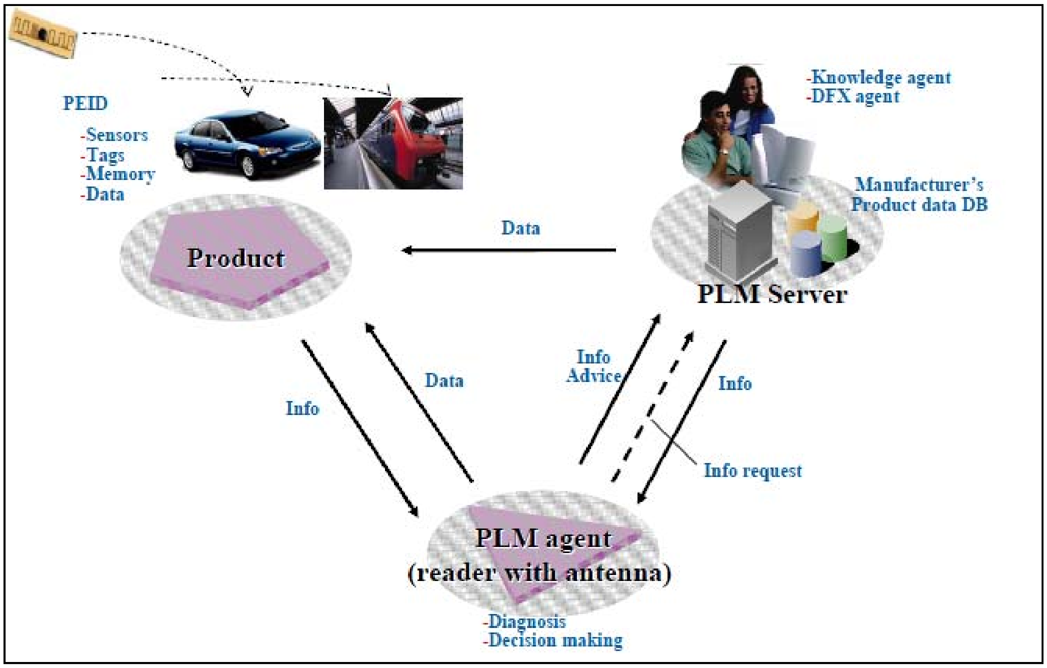


Figure 24. *Promise* Concept

(Kiritsis et al., 2008)

The *Promise* project extends existing smart product and collaborative PLM technologies by using product embedded information devices (PEIDs) based on a combination of existing technologies, such as bar code, radio frequency identification (RFID) transponders, and short- and long-range wireless communication technologies. *Promise* technologies are being tested in 11 demonstrations in the automotive, railway, heavy vehicle, electronics, and white-goods sectors (Stark, 2010). The advantages and improvements identified by the *Promise* project demonstrate how the Navy could leverage these efforts.

Closing the information loop creates benefits for many participants in the product lifecycle:

- Customers get better products and services.
- Manufacturers get more information about the conditions and modes of product use and disposal.
- Service engineers get up-to-date information about the status of the product and its parts.
- Product developers use real-life experience with previous products to improve future products, reduce over-engineering, and achieve lifecycle quality goals.
- Recyclers get complete information about the EOL value of products, parts, and materials. (Stark, 2010).

New services and improvements made possible with *Promise* include

- Innovative products and services that go far beyond competitor offerings and are difficult for less-skilled competitors to copy.
- Improved customer-relationship management based on up-to-date real-life product data.
- Simplified product authentication and enhancement of product and user security and safety.
- New types of product leasing and insurance services.
- Improved maintenance and service at reduced cost. (Stark, 2010)

2. *Promise* project demonstrations

The *Promise* project completed 11 demonstrations proving the benefits and capabilities of these smart technologies. All 11 showed unique ways that smart products could improve a company's business model. A summary of one of the demonstrations from the *Promise* final report as well as a hypothetical naval application follow.

a. Predictive Maintenance for Trucks

The overall objective of this demonstrator is to support the maintenance of a fleet of cargo carrying semi trucks, optimizing the maintenance plan and increasing the overall availability of the trucks. The fleet of trucks worked under normal conditions, installed sensors, and collected and continuously updated operational data. The data was transmitted via a wireless GPS link to a ground station, where the data was stored and processed through diagnostic algorithms to develop predictive information. After analyzing the data, the ground station computer sends a maintenance schedule to each vehicle, garage, design department, production department, and supplier (Kiritsis et al., 2008).

(1) Objectives

The overall objective of the demonstrator is to support the maintenance of a fleet of trucks, optimizing the maintenance plan and increasing the overall availability of the trucks. Closing the information loop for predictive maintenance will improve the knowledge of the customer, as well as the actual use profile of the vehicle, making it possible to:

- Reduce the number of vehicle stops for maintenance,
- Minimize the overall lifecycle costs of the components,
- Avoid component breakdowns,
- Take into account vehicle availability while planning maintenance interventions, and
- Take into account maintenance crew availability for performing maintenance. (Kiritsis et al., 2008)

(2) Naval Application

The theory behind this demonstration is that the trends in performance can offer a variety of benefits throughout the lifecycle. The Navy already understands the benefits of preventive maintenance and has a detailed maintenance schedule that is followed on each piece of equipment it owns. However, these schedules are developed by the contractor based on lab-testing data. Each of our ships operates in a different manner in entirely different environments. It is unreasonable to expect the wear of a piece of equipment operating in the blowing sand of the Persian Gulf to mimic the results obtained in the lab. To account for these differences, safety margins are built into the schedule. For instance, a part that is expected to fail at 36 months will be replaced at 30 months. Using smart technologies and collaborative PLM to capture the data, the ships will get a maintenance schedule based on actual performance, helping eliminate waste associated with replacing perfectly good parts, just because of what month it is. The maintainers will have a tool that can identify other problems based on a particular part wearing out faster on one ship versus another. The suppliers can accurately forecast the part lifespan and increase operational availability by decreasing the normal downtime, during which they had to wait for a part to fail before they could order a replacement.

A second naval example corrects the process of designers basing decisions on the sporadic and inaccurate information provided from the operators. Smart products allow the designer to pull actual data from the product. For instance, if a particular pump is designed to move 200 gallons per minute, from the operator's perspective the pump might be perfect, as it has always performed as designed, and there have been no issues. But the data directly from the pump may tell a different story. For instance, it may show during the entire operational life that the highest quantity ever moved was 100 gallons per minute, and this would indicate that the original pump was over-engineered. Thus, future design can more accurately reflect the expected operations.

Designers can obtain data on the actual mission profile to assist in developing better products. They can also eliminate waste by noticing that a particular part has been over- or under- engineered. All this can be accomplished automatically, inside a collaborative PLM environment, eliminating the time and errors typically associated with completing the tremendous amount of paperwork that currently is necessary in today's process.

E. GAINING CONTROL OVER TOTAL OWNERSHIP COSTS

1. Commercial companies offer a model on how to address TOC

Select commercial companies have experienced a competitive edge by deliberately managing and controlling TOC as a part of their acquisition-development process. They strive to attain knowledge about their products as early in the developmental process as possible, they make sure the design is mature and stable prior to starting production, and they have the production processes under control before production begins. Companies such as United Airlines, FedEx Express, and Polar Tanker strive to maintain the readiness of their fleets at as low an operational cost as possible—a strategy to increase profits and gain a market advantage. As customers, they rate operational and support costs, product readiness, procurement costs, and performance requirements equally. For example, United Airlines penalizes a supplier for lost revenue if the aircraft fails to maintain a readiness rate of 98.5%. Polar Tanker drove trades during design, sometimes increasing development costs to achieve lower operating costs by making a requirement that its Endeavor Class tanker operate at least

330 days a year at a reduced operating cost per tanker. FedEx Express required the design of its new delivery truck to be able to operate for 300,000 miles at a specific cost per mile (GAO, 2003b).

a. Polar Tanker

Figure 25. Polar Tanker
(GAO, 2003b)

Polar Tanker (see Figure 25) is a commercial oil-transportation company that designed a new tanker for its run between Puget Sound and Prince William Sound. The company had two requirements it deemed critical to its ability to reduce the cost of delivering oil: (1) it required less expensive operations and maintenance over a 30-year lifecycle, thus increasing the industry standard lifecycle by 10 years; and (2) the tanker had to be operationally available for at least 330 days per year (GAO, 2003b).

To design their new double-hulled tankers, the procurement team relied on the knowledge and experience of its maintenance engineers, along with archived maintenance data from other Alaskan operations. The design team was able to make tradeoffs that reflected the low maintenance, high availability strategy for this tanker. For instance, the previous data collected revealed ballast-tank maintenance as one of the most significant cost maintenance burdens. Based on this knowledge, the Polar shipbuilder made the decision to use the most expensive epoxy coatings and specialized paints to protect the tanks from corrosion. This is an example of how integrating the knowledge gained during sustainment can benefit the design. Integrating knowledge throughout the lifecycle is the cornerstone of collaborative PLM applications.

Another lesson to take away from this program was its use of the modeling and simulation tools to improve the design. Polar Tanker assessed the fatigue cracking in the hulls of its fielded fleet and used this data in modeling tools to determine what structural changes would result in the optimal structure. These are just two examples of Polar Tanker trading higher design costs (about $25 million) for lower TOC (GAO, 2003b).

b. United Airlines/Boeing

Figure 26. United Airlines

(GAO, 2003b)

United Airlines (see Figure 26) established strict requirements regarding readiness and operation cost for the new Boeing 777, ensuring reliability was an important design element. United specified that the new plane had to be capable of flying extended ranges from any U.S. airport, that it not exceed current operational and supports costs, and that it be available at the gate within 15 minutes of departure 98.5% of the time. If Boeing fell short, they agreed to compensate United for lost revenue. Reliability was highly valued by United in its new plane (GAO, 2003b).

Boeing approached the design for its new aircraft, just as Polar approached the tanker, by merging the experience of experts and the operations and maintenance histories of its current planes. They assigned engineers to shadow the planes' maintenance crews to collect data. The data history led them to the root causes behind maintenance failures, and the experienced experts gave insight into how to resolve the issues. The result was a team focused on delivering the strategic value held by its customer: an easy-to-repair aircraft (GAO, 2003b).

The previous section introduced smart products, which can communicate directly with the collaborative PLM systems, preventing the need for engineers to shadow the design team. The products themselves will create the data history, and depending how automated the analysis tools are, collaborative PLM could use the data to perform analysis and recommend a solution for engineer approval.

c. FedEx Express

Figure 27. FedEx Express
(GAO, 2003b)

The FedEx Express's mission (see Figure 27) is to provide global air and ground transportation of high-priority goods and documents that require rapid, time-certain delivery. It is easy to understand why high availability, high reliability, and low operating cost would be very valuable in the fleet of vehicles operated to accomplish this mission. When designing the new fleet of trucks, FedEx, just as the other examples, created an integrated team consisting of design engineers, suppliers, a logistics expert, maintainers, as well as their own representatives. The result was a new 700 cubic-foot truck that averages 70,000 miles between breakdowns, while operating below FedEx's established cost-per-mile threshold (GAO, 2003b). FedEx created manually an integrated team that spanned the entire lifecycle to ensure that one phase or feature was not maximized at the expense of another. This is the same approach collaborative PLM takes as data and knowledge are integrated across the lifecycle. Social networking tools built into the collaborative PLM system can create virtual teams to produce an integrated design, without physically dislocating the team members from their primary functions.

2. Use of feedback to better understand customers' needs

The examples from Polar, Boeing and FedEx show that leading commercial companies consider it essential to collect and analyze data from fielded systems. Tracking the actual operating cost, reliability of parts, and readiness of systems offers the ability to validate the processes and estimates created during design. A collaborative process between the customer and developer seems to be able to positively influence the design of new products by drawing extensively from past and current operations. Boeing has personnel residing with the airlines to assist as problems arise. They also feed all relevant information back to the designers to improve the next product.

United conducts a quarterly meeting with representatives from across the lifecycle to discuss open issues with operational aircraft and develop short- and long-term solutions. United also monitors flight movements on a computer system that records each aircraft by tail number. This monitoring is much more than a record of the maintenance history of each aircraft. It can report problems requiring corrective actions on a current flight so that ground crews can be prepared upon landing. It tracks statistics and operational parameters, and recommends preventive maintenance based on the actual performance instead of an estimated calendar approach. Completing this preventive maintenance not only decreases the probability of a catastrophic failure, but also offers the ability to schedule the maintenance to be completed at a time and location that is both convenient and cost effective, for instance, at the maintenance hub rather than a remote field that lacks the necessary mechanics, parts, and tools.

This data has several useful applications for Boeing: it lets them know how it can improve future iterations of the product, develop better preventive maintenance schedules, provide better estimates of the operating and support costs, and refine reliability requirements for future products (GAO, 2003b). All of these are examples of possibilities, once our organization is operating inside a collaborative PLM environment.

The Navy shipbuilding acquisition community could apply collaborative PLM in a similar fashion with similar results. The Navy could use collaborative PLM to capture actual data during the operation and sustainment phases as a method to improve the knowledge available to designers during the design phase. Analysis of system failures or maintenance data, or sailor inputs could be used to improve the design, or justify higher acquisition costs to purchase systems with reduced TOC.

3. TOC Hard to Control in Current Linear Acquisition Strategy

The current DoD strategy employs a linear approach to setting requirements, developing, and fielding a system (Figure 28) (GAO, 2003b). Three key groups are involved during this process. First, there is a warfighter service based requirements community that establishes what the requirements will be for the new system. Second, there are acquisition organizations tasked to design and produce a product to meet the established requirements. During this phase, the majority of effort is spent on developing revolutionary performance technologies while keeping acquisition costs as low as possible. Finally, once the product is delivered, it is turned over to the warfighter for operations and maintenance. One of the problems with this current process is that there is not much communication between the three groups. Decisions made when establishing the requirements have a dramatic effect on the overall system. Tradeoffs made during design usually are to maximize the performance capabilities identified in the requirements. By the time the operators and maintainers are brought into the process they can have very little influence and have no alternative but to pay the support bills and try and figure out workarounds to maintain readiness (GAO, 2003b).

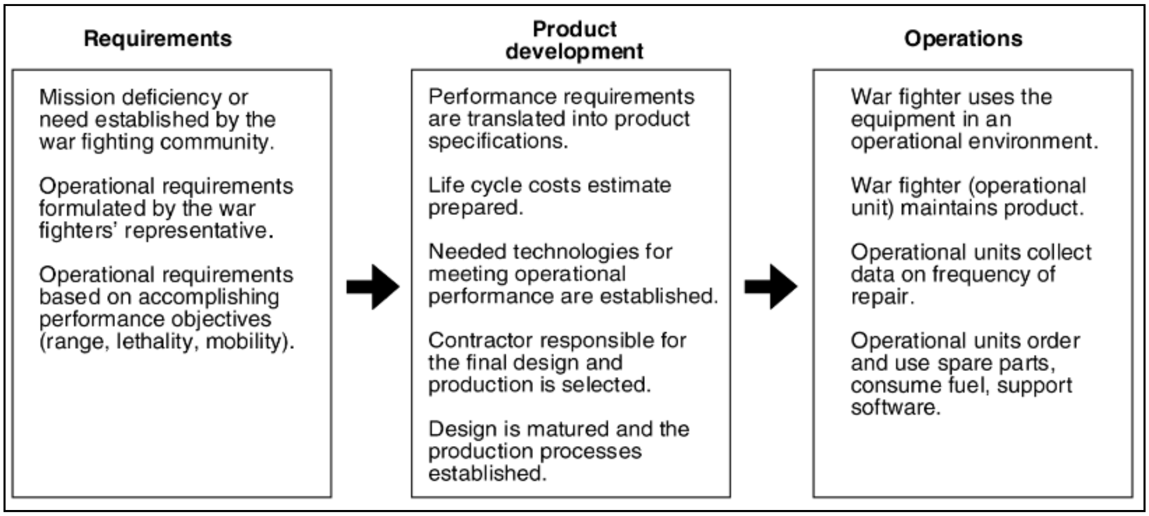


Figure 28. DoD Linear Acquisition Process

(GAO, 2003b)

4. How the Navy Can Reduce TOC

The DoD has similar policy goals as the commercial firm's best practices, and the DoD desires to deliver products that will not only meet performance requirements, but also do so at the lowest possible cost to build and operate. Where DoD and commercial firms diverge is the manner in which each implements these policy goals. The private sector operates in an integrated, collaborative manner from requirement definition through design, production, operations, and support. The current DoD process encompasses several separate organizations with different objectives and little communication between them. For instance, Naval Shipyards are responsible for conducting maintenance on aircraft carriers. A shipyard has a knowledge base built on seeing components that have failed, an understanding why they fail and knowing how they must be repaired. This would be valuable knowledge for ship designers.

While both understand the integrated lifecycle, commercial firms have made TOC a priority from the outset. Until very recently, the DoD has been focused mainly on technical performance. Several possible reasons exist for this behavior. Responsibility for TOC is spread across many organizations, and, as a result, no one is held accountable. The metric used to justify killing a program is acquisition costs, so managers will do anything necessary to keep that as low as possible. The private firms discussed earlier (United, Polar Tanker, and FedEx Express) must manage TOC to remain profitable to survive. The DoD does not have the same incentive. Table 7 shows a GAO comparison of practices between commercial firms and the DoD. If more operation and maintenance money is needed, the next budget request simply requests the additional funds to keep the systems online (GAO, 2003b).

Table 7. DoD and Commercial Practices for Controlling Operating and Support Costs

(GAO, 2003b)

Commercial prevailing practice	DOD prevailing practice
Practices used to set initial product requirements	
Operating and support cost goals as a key requirement.	Operating and support cost goals are not established as key parameters.
Readiness a key requirement.	Readiness is not a key parameter.
Trade performance for reduced operating and support costs, if appropriate; sometimes results in increased costs.	Technical performance is sometimes traded using cost as an independent variable, but cost is usually production cost or development cost, and the trades occur during the design phase.
Direct relationship during requirements-setting between the user and the product developer.	User and product developer separated by user representative and government program office.
Practices used during product development	
Provide detailed operating and support cost estimates early in product development.	Operating and support cost estimates not required until product development launch.
User and developer focus on ways to reduce product parts and standardize parts across product lines.	Product developer has responsibility of focusing on ways to reduce parts counts or use standardized parts with little input from the user (operators or maintainers).
Use open systems architecture approach to improve the cost effectiveness and installation efficiency of future upgrades to the product.	Open systems approach is mandated but implementation is limited.
Set realistic reliability growth goals for the product.	Reliability goals set, but they are tradable or not met.
Conduct reliability testing early.	Reliability testing sporadically performed.
Practices used during operations	
Collect and analyze operations and support data.	Data is often incomplete or unreliable.
Manage operations and support costs to targets.	Do not manage to operations and support targets.
Identify areas for continuous improvement.	Lack of complete and reliable data makes identifying areas for improvement difficult; some areas that are identified are not funded for improvement.
Feedback to developer on product performance.	Limited feedback to the developer. The maintainer does not have a direct relationship with the product developer.

a.

b. Change the Requirements to More Specifically Address TOC

The GAO cited the lack of accountability and responsibility as one of the primary reasons for the out of control TOC (GAO, 2003b). Cited in a previous recommendation, the NDO should be held accountable for the quality of design, as TOC falls under his or her responsibility. To evaluate the completeness of the design, the NDO should use a tool such as the LEAN design scorecard spider charts from Chapter IV.D. This change should help ensure that the DoD and the Navy understand the total picture and do not get too focused on a particular aspect, such as performance, basically making the Navy a smart buyer. The Navy must also use the data collected by collaborative PLM to develop other predictive metrics. For instance, do 90% of drawings released by a particular milestone demonstrate design stability and correctly forecast a program's probability for success?

c. Use Evolutionary as Opposed to Revolutionary Technology

In several different sections, the characteristic of commercial firms eliminating immature technologies from consideration has been touted as a major contributor to their success. While collaborative PLM technologies do not necessarily help with the physical technology maturity, they can play a dramatic role in the execution of evolutionary acquisition. Figure 29 is a graphic from a GAO report on the F-22 program. It illustrates the difference between the two approaches (GAO, 2003a). *Revolutionary* development would be a program that attempts to develop immature technology in the program. In the GAO's example, the warfighter had a requirement for a new aircraft but had to wait 15 years before anything was delivered. All too often, the product delivered has morphed and fails to satisfy the original need or the need has changed during the multiple years of development.

The preferred approach is *evolutionary* product development, in which the requirements are met over several generations of the product. In the GAO example, the first generation incorporates the needs of the warfighter and the available technology from the research labs. The warfighter is delivered the first generation platform at the five-year point. This is when a collaborative PLM can offer substantial benefits to the process. Once the warfighter has the first generation, they can begin to offer feedback to the designers who are working on the second generation. Feedback could be likes, dislikes, correcting misinterpretations of the requirements, changes to the need, or others. The smart products themselves are communicating with the designer about how they are performing or leading to improvements. Additionally, the research labs may have new technology that is now mature enough for integration into the second-generation platform. This process repeats, and each successive generation of product evolves into exactly what the warfighter needs, while never accepting undue risk from immature technologies.

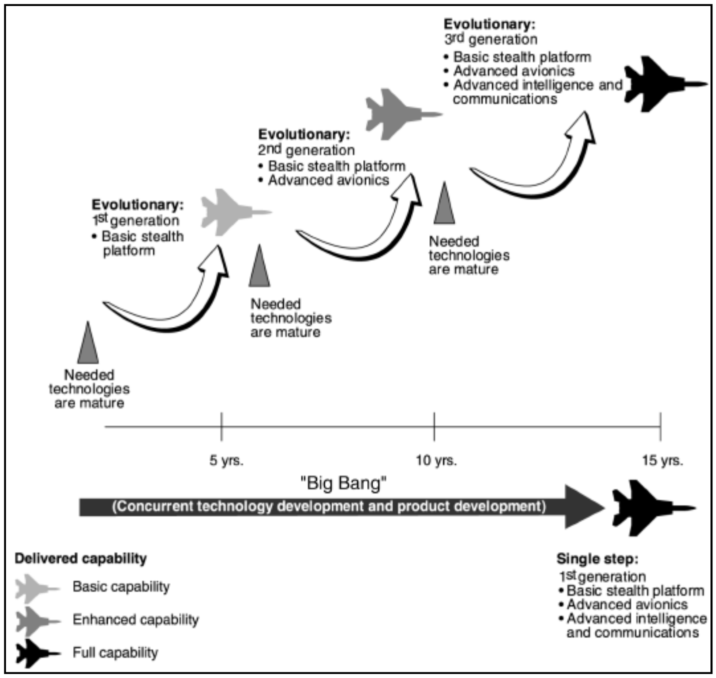


Figure 29. Evolutionary Versus Revolutionary Development Comparison

(GAO, 2003a)

Virginia class submarine is an example of a design with planned technology insertion over the life of the ship. For example, the structurally integrated enclosures are designed with shockproof supports and necessary services to allow for change out of COTS electronic units; the universal modular masts can easily accept new sensors in the sail; and the baseline ship design has a high reserve buoyancy to accommodate future weight growth. In addition, the modular construction method used on *USS Virginia* facilitates technology insertion, since equipment can be removed and replaced as individual packages (General Dynamics Electric Boat, 2002).

Electric Boat continues to plan upgrades to the Virginia class to reach visions captured in the Submarine Futures Studies Group report of July 2000. The Navy has proposed an upgrade path to reach the 2020 vision with specific upgrades proposed for later ships of the class (see Figure 30). For example, technologies that have almost reached a level of maturity that eliminate the risk that prohibited prior insertion include: an advanced sail, improved payloads and sensors, and a large-aperture conformal array. By 2020, the submarine would be all-electric with fully modular payloads, external weapons, a "smart skin," high-rate communications at depth and speed, and increased automation (General Dynamics Electric Boat, 2002). The Virginia class program has been designed inside a collaborative PLM application, making the technology insertion easier as well as maintaining several configurations of the class of ships to reflect the *as designed*, *as constructed*, and *as maintained* of each hull.

Figure 30. Virginia Class Program Planned Technology Insertion

(General Dynamics Electric Boat, 2002)

d. Close the feedback loop

While discussing smart products in the section "Smart Products Can Close the Data Loop," some of the benefits of closing the information loop were explored. Having good communications between each phase of the lifecycle will also help control TOC, and the tools to foster solid communications are built into every collaborative PLM. Each collaborative PLM platform is different, but they all deliver similar capabilities. Some of the various options are standard email points of contact built into the design files. For instance, if a sailor has a question about troubleshooting a particular component, he can access the 3D model, click on the particular part, and access any point of contact built into the system, from designers to maintainers to an engineer or supplier. There are more advanced options, such as video collaboration, in which several people can chat while working together in the system. Some of the platforms are even developing Facebook-like social-networking capabilities that allow people from specialized areas to congregate and troubleshoot. The section on smart products demonstrated how communication is not limited to people, but the products themselves can communicate, inputting knowledge into the system that can be used to create improved systems.

F. DESIGN MATURITY

1. Design stability of the private sector

Commercial shipbuilding typically defines a design as stable when both the basic and functional designs are complete (see Table 8). Until this stability is achieved, they will not move into the construction phase. Usually the product is a complete 3D product model, demonstrating a clear understanding of both the structure, as well as every system and how those systems integrate into the building blocks of the ship (GAO, 2008a). Integrating suppliers into the process is very important to design stability, as they not only provide a complete set of data for their respective systems, but also are the experts in their fields and can offer valuable insight to the integration into the total ship.

Table 8. Description of Design Phases

Design Phase	Tasks involved and parties responsible
Basic design	•Fix ship steel structure and set hydrodynamics •Design safety systems and get approvals from applicable authorities •Route all major distributive systems, including electricity, water, and other utilities •Ensure that the ship will meet the performance specification •Complete (shipbuilder) and review (buyer)
Functional design	• Provide further iteration of the basic design; generally equates to 3D modeling • Provide information on exact position of piping and other outfitting in each block • Complete (shipbuilder) and review (buyer)

Bringing the vendors on board and not relying on immature technology are the best ways to quickly progress the design and lock in system requirements such as power, water, and other utilities. The ability to gain this high level of knowledge early reduces the possibility of very costly design changes after spaces have been closed out.

During the LPD-17 program Avondale Industries, Bath Iron Works, Ingalls Shipbuilding, National Steel and Shipbuilding, and Newport News Shipbuilding were contracted to provide technical services during concept design. These shipyards provided significant inputs on subjects such as metrication, less reliance on military specifications and standards, corrosion control, materials, and producibility. Nevertheless, Keane, McIntire, et al. (2009) argue that a greater investment at this stage of design could have paid big dividends. However, since this level of involvement was not factored into the initial planning for the program it was not adequately funded (p. 29).

Involving the shipbuilder in the early design allows for the selected vendors to be brought into the design process much earlier. During the detail design, the design team benefits greatly from early access to the vendor furnished information. For example, for communication between electric plant devices the vendor selected by the shipbuilder for LPD-17 Class power distribution management used a proprietary Local Area Network (LAN) that was very difficult to integrate. This LAN was not addressed in the shipbuilding specifications because it was not anticipated; if it had, an effort would have been made to either avoid its use or, make the necessary accommodations (Keane, McIntire, et al., 2009). Having to constantly go back and fix seemingly harmless changes wreaks havoc on a schedule, with cascading effects throughout the design.

The previous sections have discussed the design team's advantages by working with the buyers and the vendors. They must also work with members of their own yard to ensure that the design is highly producible. This producibility concept is achieved when the design is successfully matched to the capabilities and production techniques of the particular shipyard, so the ship can be efficiently constructed. Activities associated with design for producibility could be collaboration between the construction and design teams or using common parts, components, and processes that support multiple ships, in order to take advantage of the learning curve (GAO, 2010). The capabilities of collaborative PLM technologies have assisted commercial companies with both of these activities through collaboration capabilities, as well as improving the visibility into the design to help identify trouble before it ever becomes critical.

2. Design volatility of the public sector

The lack of early systems engineering and risk mitigation has led to the volatility plaguing Navy programs. Starting construction before the design is stable, a common occurrence for Navy programs, increases the probability of costly out-of-sequence work and rework. For example, maturing a particular technology concurrently with design and construction opens the possibility to a considerable amount of volatility to the design process. As the technology matures, the initial assumptions about size, shape, weight, as well as energy requirements and byproducts may change significantly.

For example, the Seawolf class attack submarine (see Figure 31) relied on a new computer-aided detection, classification, and tracking combat system, the AN/BSY-2, to complete its mission requirements. The design progressed with a space and weight reserved for the system. However, the system did not mature as the Navy expected, and it turned out to be bigger and heavier than expected. This caused the need for a considerable redesign of the submarine and ultimately led to the delivery of a platform 45% over budget (GAO, 2009b).

Mission: The Navy's SSN 21 nuclear-powered submarines are designed to track and engage enemy targets with greater depth, speed, and stealth capabilities than predecessors.

Issues: The timely development of AN/BSY-2—a computer-aided detection, classification, and tracking combat system—was critical to the submarine meeting its mission requirements. Even though this technology was a modified successor to the AN/BSY-1 system found on earlier Los Angeles-class submarines, the technology did not mature as quickly as the Navy expected. Changes to the AN/BSY-2 system's design caused a portion of the submarine to be redesigned at an additional cost. The Navy originally provided Newport News with general space and weight information for the AN/BSY-2 that the shipyard used to begin designing its portion of the Seawolf. The Navy later provided the shipyard with more specific information that caused considerable redesign of the submarine and increased design costs, according to Newport News. The lead submarine ultimately experienced cost growth on the order of 45 percent above initial budget estimates.

Figure 31. SSN-21 Program Capsule

(GAO, 2009b)

Each new design is in response to a new mission requirement that will likely use a new technology, making it easier to start a design from scratch rather than modify anything already in existence. The Virginia class (SSN-774 class) submarine was a positive example of how a collaborative PLM application offers improved capabilities, for instance, how a new design could leverage off past efforts by reusing a number of components and systems tested on previous submarines.

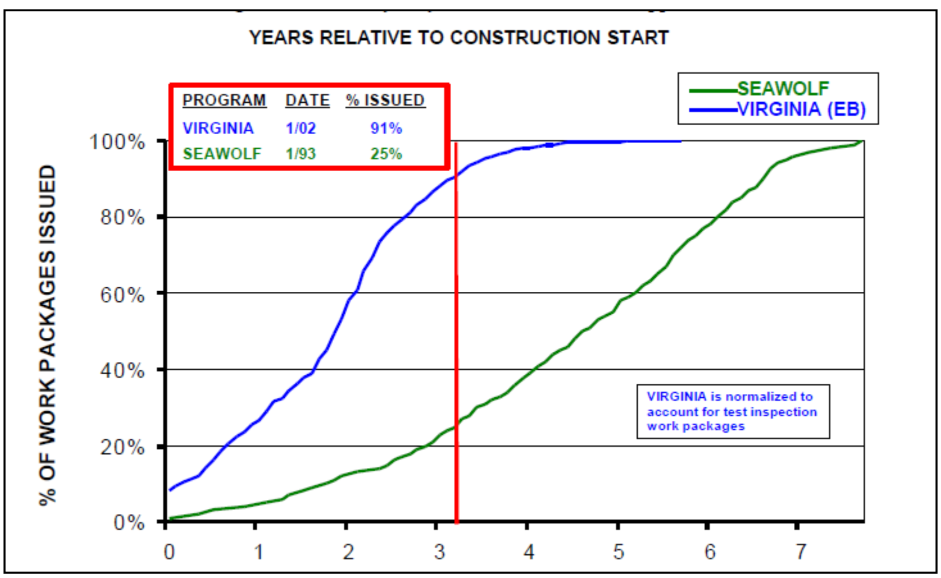


Figure 32. Percentage of Work Package Issued, Comparison Between *Virginia*, *Seawolf*

(General Dynamics Electric Boat, 2002)

Figure 32 shows the drawing release history for the *USS Virginia* compared with the *USS Seawolf*. The x = 0 point is the construction-start date for each program, October 1989 for *Seawolf*, and October 1998 for *Virginia*. The date of this chart is February 2002 (the vertical line); thus, all *Virginia* data to the right of x = +3.3 are projections, whereas all *Seawolf* data are actual. *Virginia* had released 99.1% of all drawings by February 2002, about 3.5 years earlier than *Seawolf*.

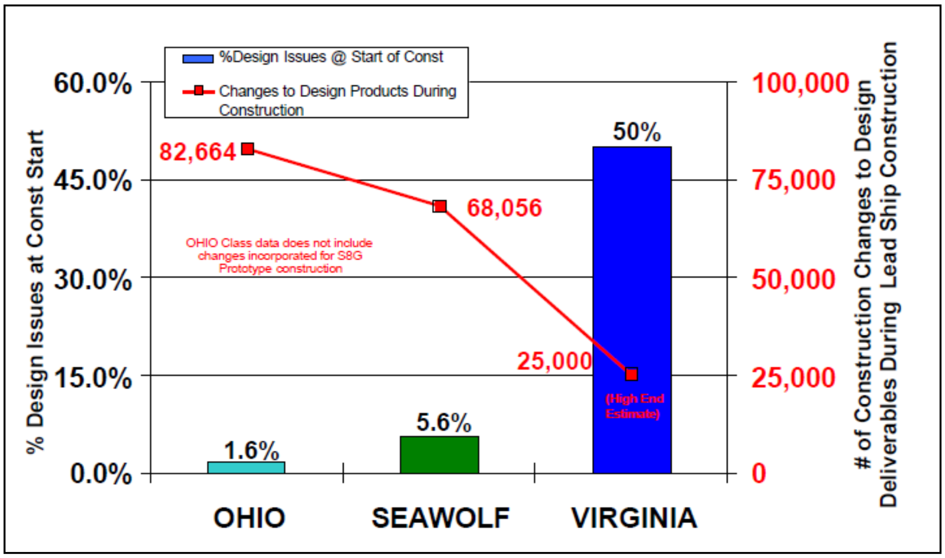


Figure 33. Mature Virginia (SSN-774) Design Results in Fewer Changes During Construction

(General Dynamics Electric Boat, 2002)

The Virginia IPPD team and process created a more mature design to support construction. Figure 33 shows that 50% of the Virginia design had been issued prior to construction start, compared to 5.6% for *USS Seawolf* (SSN 21) and 1.6% for *USS Ohio* (SSBN 726). The Electric Boat team had a disciplined strategy to keep contracts and requirements stable, and Figure 34 shows the pay off. The figure shows the projection for contract changes are about 12% of Seawolf's and 0.46% of Ohio's (General Dynamics Electric Boat, 2002).

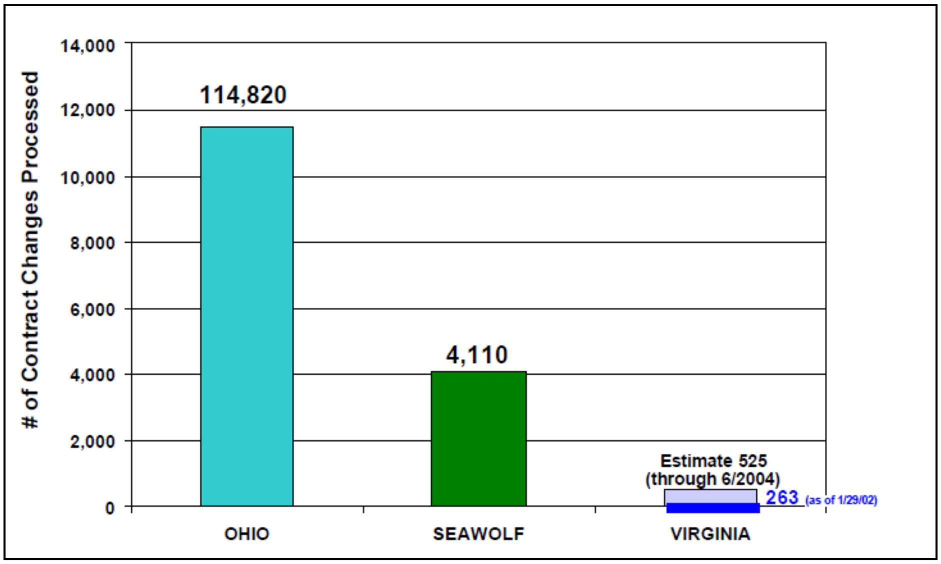


Figure 34. Virginia (SSN-774) Contract Changes (1/29/02)

(General Dynamics Electric Boat, 2002)

Not having to spend time designing everything from scratch was a contributing factor to the ability to have a complete 3D model prior to construction start. This model was a contributing factor to the small number of design change orders (GAO, 2009a). This design volatility has been a major root cause behind the cost escalation in Navy programs. The cost escalation is the byproduct of the risk that was never removed and precluded the use of more advantageous contract vehicles, such as firm-fixed price.

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VIII. SUMMARY OF RECOMMENDATIONS AND CONCLUSIONS

The defense acquisition community is responsible to design, build, and deliver some of the most technologically advanced machines in existence. Since 2002, Congress has appropriated over $74.1 billion for the construction of new aircraft carriers, nuclear submarines, surface combatants, and amphibious transport ships (GAO, 2009b). However, a 2010 review of 96 defense acquisition programs showed the average delivery rates are 22 months behind schedule, with a cumulative cost growth that exceeded $296 billion. These are indications that the acquisition community has room to improve the execution of its programs. Compounding the current inefficient use of funds is the high probability of defense budget cuts. Unless budget cuts are accompanied by a corresponding cut in missions, the Navy will need a more efficient utilization of dollars to fulfill all tasking. This leaves a small window of opportunity to enact reforms improving the health and solvency of the defense acquisition portfolio.

Sean J. Stackley (*Prepared Testimony*, 2009), Under Secretary of the Navy, said:

> Inarguably the underlying challenge, the pressing requirement, before us today in shipbuilding is affordability.
>
> The reality is that there is no single fix to turn around this trend, but rather a large number of initiatives, practices, and standards that we need to attack across the board.
>
> We need to ensure that our requirements are balanced by our resources. .... The key here is to inform the process with realistic cost estimates and realistic risk assessments at the front end. This drives the difficult decisions early, where there are true choices, and true opportunities.

The Navy has the opportunity to fundamentally transform the acquisition community by enacting reforms addressing some of the root causes behind the cost escalation and schedule delays during procurement and by making conscious decisions that will reduce TOC. The Navy can make more efficient use of the appropriated budget by addressing these root causes.

This research was a search for answers to the following two research questions:

1. How can a technology such as collaborative product lifecycle management (PLM) be used to improve the acquisition process?

2. What reforms to the acquisition process are possible, complimenting or supplementing the capabilities provided by collaborative PLM, helping ensure value is optimized throughout the lifecycle of the product?

Collaborative PLM can offer the acquisition community features and capabilities that can be used to positively reform the acquisition process. Being able to record, organize, then leverage the tremendous amount of data generated in a new ship design program is paramount to the decision makers making quality choices from the total lifecycle perspective. PLM also offers the ability to integrate data across the entire acquisition portfolio, a feature when coupled with the social networking capability can eliminate redundant efforts and increase the reuse and commonality between programs.

Answering those questions led to the reforms recommended throughout the paper and reiterated in the Summary of Recommendations for Action section below. Together, they show a path that the acquisition community can follow to improve as an organization and move the portfolio of programs toward solvency. The reforms will affect the three main elements of the community: its organization, people, information, technology, processes, and practices. The synergy between each of these elements means that reforms collectively working together will produce a result not obtainable by anyone acting independently.

A. SUMMARY OF RECOMMENDATIONS FOR ACTION

- **Invest in a collaborative PLM suite that can be utilized by the entire Navy acquisition enterprise.** Product lifecycle management is an integrated, information-driven approach to all aspects of a product’s life, from its design through manufacture, deployment, and maintenance, culminating in the product’s removal from service and final disposal. Collaborative PLM software suites such as Siemen's Teamcenter, PTC's Windchill, or Dassault's Enovia, each enable accessing, updating, manipulating, and reasoning about product information that is otherwise being produced in a fragmented and distributed environment.

Collaborative PLM applications will allow team members to link data from various sources, to all other program structures to ensure that the relationships and interdependencies are understood. This understanding will lead to participants having a real time knowledge or a program status, requirements, issues, changes, reviews, operations, and so on. The collaborative PLM environment can effectively manage data, more effectively manage configurations, improve collaboration and networking, and integrate applications and tools across the entire lifecycle. These benefits are just a few of the ways collaborative PLM can deliver efficiencies that have the potential to dramatically reduce TOC.

- **Apply the LEAN Product Design philosophy to the design process.** Collaborative PLM was created to manage a product and its associated data throughout the lifecycle, from cradle to grave. LEAN is a strategy to remove waste throughout processes, saving the resources expended on wasteful activities. The data collected and organized inside the collaborative PLM environment will be used to accomplish the LEAN analysis identifying wasteful processes. Once the more efficient process is identified, collaborative PLM has the capability to automate the workflow and institutionalize the efficient processes, making both data and processes accessible to users throughout the lifecycle, which will eliminate repetition, redundancy, errors, and other forms of waste.
- **Create a National Design Organization.** This design organization would be responsible to conduct the preliminary design of every new shipbuilding program. The repetitions through the design process would create a very experienced design team that was intimately familiar with the collaborative PLM tools and how to translate requirements and knowledge into a good ship design. The NDO would also be responsible for grooming new engineers, provide a focal point for fleet feedback and conduct design exercises to populate the collaborative PLM idea bank, improve standby designs and integrate new technology into current designs. They will establish and maintain design

and engineering standards used during naval shipbuilding programs, and manage the development of mature analytic tools required during design and certification.

- **Establish and maintain product data interoperability standards.** PDI will make cross-program collaboration possible. PDI will provide a consistent format for data, establishing standards required for the development of applications to be integrated into the collaborative PLM suite. PDI will format data to ensure it is useful during each phase of the lifecycle, which will enable collaboration between phases of the lifecycle, thus allowing designers to focus on improving the product.
- **Develop and integrate design and certification applications inside the collaborative PLM suite.** NAVSEA can improve the design and engineering tools and applications available to assist its engineers in making sound decisions while evaluating the multiple options of a particular design. These new tools could be developed in academia or in the public or private sector by ensuring that they conform to the data interoperability standards maintained by the NDO. Thus, they will be easily integrated into the collaborative PLM suite, making utilization across the acquisition portfolio easier.
- **Institute requirements to use common parts catalog.** Once a part or component is entered into the collaborative PLM system, any designer with access can use it. During a design, the common catalog can be accessed and the part can by dragged and dropped into the current design, saving the cost and time designing and testing a new part. Decreasing the number of unique parts across the Navy will reduce the strain on the logistics pipeline, will decrease the number of parts sailors must learn to operate and maintainers must learn to fix.
- **Retire risk as early in the process as possible, to decrease the volatility of our programs.** Every part in the collaborative PLM system has product data captured and stored; this data could be everything related to its design, testing, and actual operational performance. As more knowledge is captured inside the collaborative PLM system, the risk of an unexpected event occurring decreases. As the percentage of reused components in a design is increased, the risk of the entire system decreases.

- **Employ smart products to automate the communication of information throughout the lifecycle into the collaborative PLM suite.** Smart products are products that can sense and communicate information about their condition and environment. For instance as an engine communicates its performance data, trend lines develop, and these trend lines can be used to plan maintenance prior to any part failing. Scheduling preventive maintenance based on actual performance will reduce TOC. Thus, parts will only be replaced when failing, instead of on the date recommended by the vendor.

- **Change program requirement to more specifically address TOC.** Establishing operating and support costs and readiness is a key parameter during the design. Using the capability of collaborative PLM to reduce part counts will decrease the number of unique parts and standardize parts across the acquisition portfolio.

  Ensure the collaborative PLM data is transferred and utilized throughout the lifecycle; for instance, the 3D model can be used during the initial build as well as during future ship alterations.

- **Use the *evolutionary* versus *revolutionary* approach concerning technology insertion.** Evolutionary product development, in which the requirements are met over several generations of the product, offers advantages over revolutionary technology insertion. This method decreases the risk associated with maturing technology concurrently with the design and construction of a new ship.

  Once the warfighter is delivered the first generation platform, collaborative PLM can help designers improve the second generation by facilitating collaboration between the operators and the designers. Feedback could be likes, dislikes, correcting misinterpretations of the requirements, and changes to the need or others. The smart products themselves can communicate with the designer leading to improvements based on how the parts are performing, or determining if they were over- or under -engineered. Additionally, the research labs may have new technology that is now mature enough for integration into the second-generation platform. This process repeats, and each successive generation of product evolves into exactly what the warfighter needs, while never accepting undue risk from immature technologies.

- **Reduce design volatility to decrease overall program risk.** Design stability is usually achieved when the 3D model is complete, demonstrating a clear understanding of both the structure as well as every system and how those systems integrate into the building blocks of the ship. Collaborative PLM can assist the design team with integrating the applicable data and ensure that elements are not overlooked or omitted, efforts necessary to achieve design stability. PLM collaboration tools can help integrate suppliers into the process, which is very important to design stability, as they not only provide a complete set of data for their respective systems, but also are the experts in their fields and can offer valuable insight to the integration into the total ship.

B. CLOSING REMARKS

The reforms recommended in this research are not revolutionary; in fact, if you look back at one of the most successful programs in DoD history you will see that most of the principles have already been successfully implemented. With the AEGIS program, the Navy for the first time embarked on a total "systems" development. Systems engineering became the basis for the entire program, from initial weapon system development, through design and construction of the ship, to development of the operation and the support infrastructure. Rear Admiral Hood who served as the Combat Systems Engineer, Technical Director, and Program Manager during the AEGIS program, recalled that the systems engineering process for AEGIS was guided by the firm hand of "the father of AEGIS," RADM Wayne Meyer (Hood, 2009, p. 187). Hood outlines some of the processes and beliefs that led to the success of the program, such as:

- **Early and constant involvement of sailors, as well as frequently sending industry engineers to sea, was required.** This process "closed the information loop," engineers understood what it meant to go to sea and sailors were intimately involved in designing the warship they needed.
- **No one was allowed to work in isolation—teamwork was mandatory.** Naval engineers, laboratory scientists, contractors, and sailors were brought together to collaborate. Each person's different skill set created a synergy that inspired true innovation.

- **Field Activities were enlisted to work on the right problem.** AEGIS was cutting edge technology and the smartest people were employed to work through problems. Various Navy activities were recruited to solve problems in their specialized area. Even those that were not directly assigned to the AEGIS program became "AEGIS people."
- **Contracts were structured to achieve flexibility and facilitate communications.** The contractor and government worked together to ensure that immediate corrective actions were taken when necessary, providing near real time guidance and feedback. Meyer made it clear the principle involved was "do what's right, we'll sort out the contracts and payments later."
- **Only what could be proved at sea was taken to sea.** Technology was proven with a series of engineering development model prior to being included in the design. This helped eliminate setbacks caused by immature technology (Hood, 2009, p. 187–190).

The Navy has the opportunity to institutionalize the principles RADM Meyer and the AEGIS program. A comprehensive collaborative PLM suite, accompanied by these reforms, has the ability to fundamentally change how we design, build, and maintain the fleet, making the defense portfolio solvent. Both of the major defense contractors, General Dynamics (DDG 1000, SSN 774) and Northrop Grumman (LPD 17, CVN 78, SSN 774), already employ collaborative PLM applications during their phase of the ship design process. Like them, the Navy has the opportunity to build on their efforts to create an enterprise-wide collaborative PLM solution capable of supporting the entire shipbuilding portfolio throughout the entire lifecycle. Without collaborative PLM and drastic reforms to the acquisition community, the systems and platforms the Navy needs to meet its national strategic missions might never be delivered.

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