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**Benchmarking Dutch and U.S. Naval Shipbuilding:
Reducing U.S. Naval Shipbuilding Costs Using Collaborative
PLM and 3D Imaging**

2 November 2012

by

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Abstract

U. S. Navy shipbuilding contractors need to find a way to reduce costs while not sacrificing current reliability and quality requirements. 3D Laser Scanning Technology (3D LST) and Collaborative Product Lifecycle Management (CPLM) are two technologies that are currently being leveraged by international ship construction organizations to achieve significant cost savings. 3D LST dramatically reduces the time required to scan ship surfaces as opposed to the traditional photogrammetry techniques currently used, but accuracy is not up to the Navy's standards. Once the technology progresses to a level of accuracy deemed acceptable by the U.S. Navy, dramatic cost savings can be gained by implementing it. CPLM technologies, on the other hand, improve the engineering and design process to the point that they may reduce detailed engineering times by up to 22%.

In order to achieve the cost-saving benefits of these new technologies, U.S. Navy shipbuilding contractors must restructure their organizations to achieve the most productive manufacturing capabilities possible. This report details the answers to a series of research questions that result in a framework for these companies to use to improve manufacturing capabilities from a structural, human resource, and technical perspective. U.S. Navy shipbuilding contractors can use this framework to determine how to best implement these new manufacturing technologies.

Keywords: shipbuilding, ROI, cost savings, CPLM, 3D LST



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His current research focuses on the use of KVA and “Real Options” models in identifying, valuing, maintaining, and exercising options in military decision-making. Prior to joining NPS, he was a research fellow for the Center for Telecommunications Management and an associate professor at the Marshall School of Business at the University of Southern California. Housel has been the chief business process engineer for Pacific Bell, where he completed numerous reengineering projects and developed a KVA methodology that objectively measures the value added by process reengineering. His last assignment in the corporate world was as the chief of consumer market research for Telecom Italia in Venice, Italy, where he developed new methods for predicting the adoption rates for new interactive multimedia broadband applications. He is managing partner for Business Process Auditors, a firm that specializes in training Big Six consultants and large manufacturing and service companies in the KVA methodology for objectively measuring the return generated by corporate knowledge assets/intellectual capital.

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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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Executive Summary

Current shipbuilding costs are rising well beyond the rate of inflation and are unsustainable in today's cost-constrained defense acquisition environment. The real growth in Navy ship costs means that ships are becoming more expensive and outstripping the Navy's ability to pay for them. "Given current budget constraints, the Navy is unlikely to see an increase in its shipbuilding budget" (Arena, Blickstein, Younossi, & Grammich, 2006). If the Navy is to maintain its current capabilities, then shipbuilders and the DoD must find a way to reduce these escalating costs. The challenge of effective cost reduction include the following:

- Understanding the factors that are leading to cost growth,
- Identifying which factors can be addressed without sacrificing capability while adhering to current military standards, and
- Modernizing shipyards without drops in productivity or sharp increases in costs.

The first task is relatively straightforward; there have been numerous studies addressing the issues of rising ship costs. According to the GAO, labor and material increases are responsible for over 70% of cost growth in ships, as seen in Figure 1.



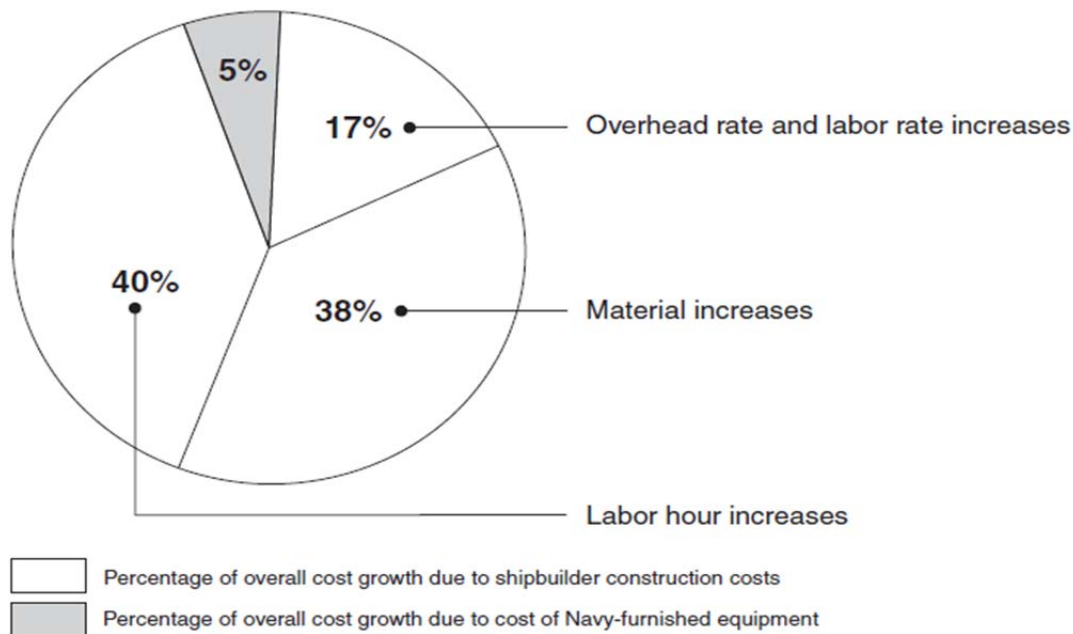


Figure 1. Components of U.S. Navy Shipbuilding Cost Growth
(Government Accountability Office [GAO], 2005)

Deciding on the best ways to reduce these cost increases is more problematic, due to the performance and capability requirements U.S. Navy ships must meet. For example, 3D laser scanning and tracking technologies could offer enormous reductions in labor hours during construction. The Center for Naval Shipbuilding Technology (CNST) awarded the 3D laser scanning technology (3D LST) project to General Dynamics Electric Boat (GDEB) to evaluate the 3D LST capabilities during the measurement, layout, and installation of ship components. The current state of 3D laser scanning technology does not meet the accuracy requirements, 0.030" accuracy minimum, for naval shipbuilding. The report delivered to the CSNT shows that if the accuracy of 3D LST could meet the requirements, the cost savings would be substantial, as shown in Table 1 that was based on an extrapolation of the time-cost savings from this GDBE report, which is provided in Appendix A. There is a high likelihood that this technology would reduce costs and schedule, but, until the accuracy minimums can be met, this technology will not be used during new construction in shipbuilding.

In addition to 3D LST, other technologies have the potential to reduce shipbuilding costs. Appendix A contains the complete final report and findings that GDEB provided to CNST.

Table 1. Maximum Cost Savings per Hull With Implementation of 3D Laser Scanning

Max hrs saved	Cost of personnel per hour ¹	# of parts per ship ²	# of ships	Total	Savings per hull
10	\$42.50	1,000	10	\$4,250,000	\$425,000
10	\$42.50	10,000	43 ³	\$182,750,000	\$4,250,000
10	\$42.50	100,000	5	\$212,500,000	\$42,500,000
SUM				\$470,000,000	

Collaborative Product Life Management (CPLM) technology shows more promise than 3D LST alone in reducing construction costs while not sacrificing capability or accuracy requirements. Interviews we conducted with shipbuilding subject-matter experts revealed that CPLM implementation can reduce engineering and design times in the shipbuilding industry by up to 22%. Construction times and attendant costs would likely be similarly reduced, but that data are not available yet because even the most advanced ship manufacturers are not using the full potential of this technology. Their counterparts in the automobile and aerospace industry have already demonstrated dramatic cost savings using CPLM technology.

However, despite these possible benefits, CPLM technologies come with their own inherent set of implementation challenges. Interviews with subject-matter experts in both the ship construction and CPLM sectors reveal that this kind of

¹ This is the average salary retrieved from the Payscale website (<http://www.payscale.com/>) in 2012. Salary was then converted to an hourly rate using a conversion calculator (Calcxml, 2012).

² The number of parts per ship is estimated because each shipyard would consider total number of parts per ship differently.

³ According to ADM. James A. Lyons (2012), the Navy is currently looking at procuring 43 additional Arleigh Burke (DDG-51) platforms.



technology adoption requires a redesign of traditional shipyards and ship construction processes, and of the enabling organizational design and human resource practices.

The primary focus of the current report is to assess the potential benefits of CPLM implementation in U.S. shipyards as well as provide a framework that companies can use to determine their technology readiness level for the introduction of CPLM. The current research found that CPLM technologies are being used in a variety of industries as a way of reducing the costs of engineering and manufacturing, and that some shipyards are beginning to use this technology in a limited way. However, prior research and interviews of subject-matter experts for the current study show that shipyard management needs to have a thorough understanding of how to adjust their company's people, processes, and technical capabilities in order to successfully implement CPLM.

Fundamentally, the manufacturing capability of these new “digital shipyards” is dependent on both the technical capability of the shipyard information infrastructure to insert CPLM technology and the ability to redesign processes, as well as on the amount of collaboration among company employees and with vendors. Figure 2 is a notional representation of the five elements that must be taken into account in successfully implementing CPLM within a shipbuilding organization. It is a visual representation of the intersection between critical functional areas of a shipyard that leverage organizational design and CPLM technology to achieve greater manufacturing capability through collaboration.



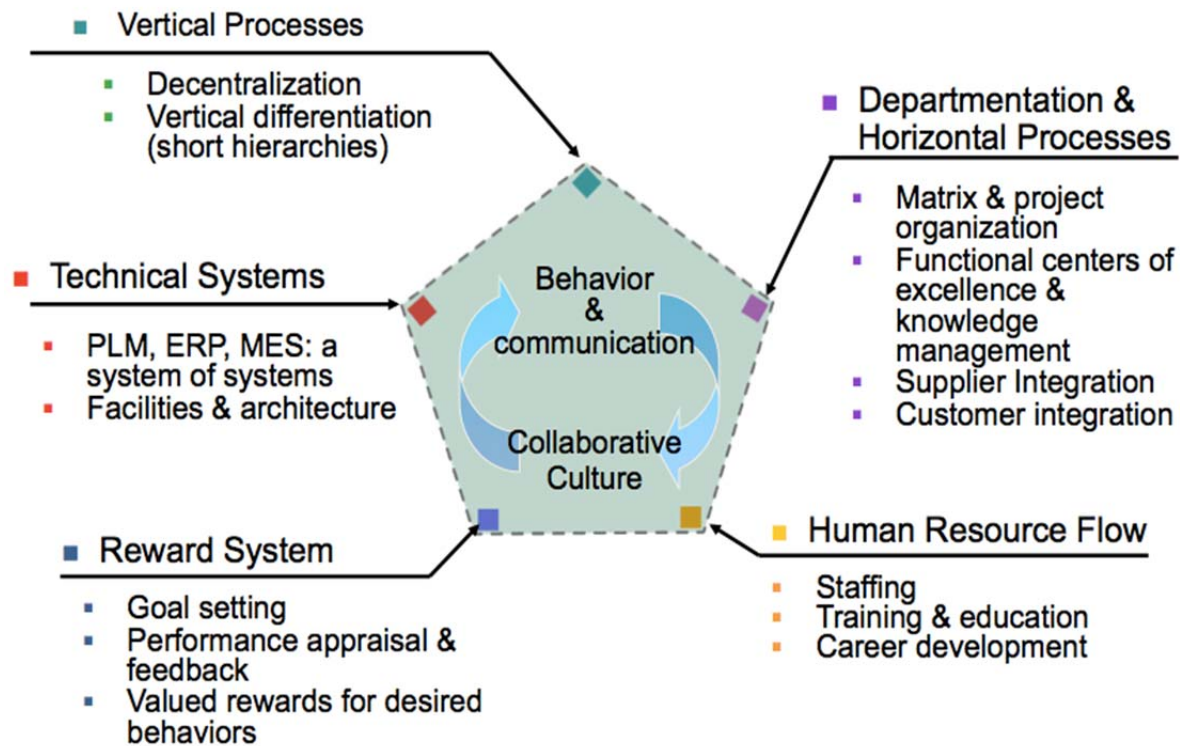


Figure 2. Collaborative Capacity and the Digital Shipyard of the Future

In Figure 2, the interconnectedness of an organization's structure, human resource practices, and technical capability is demonstrated. Taken together, attention to these design factors and their coherence in forming an integrated system of systems can contribute to generating collaborative behaviors, work processes, and a collaborative culture facilitated by CPLM technology that will enable the innovation in manufacturing needed to reduce the costs of U.S. Navy ships.

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I. Introduction

This study found that CPLM showed great promise for reducing shipbuilding design costs. The percentage cost savings ranged conservatively from 9–22%. The results pointed to the need to first align people, processes, and technical capabilities to take advantage of CPLM technology to reduce shipbuilding costs. This research offers a way to assess the manufacturing capability and technology readiness level of shipbuilding organizations to determine their current state. Dutch and U.S. shipbuilding organizations were compared because Dutch shipbuilding (i.e., Damen) has been able to take advantage of CPLM technology to reduce cycle times and costs. It is held up as one of the most advanced shipbuilding companies in the world. Even though there are scale and requirements complexity differences between the two comparison entities, Damen's experiences offer lessons for the U.S. Navy's shipbuilding organizations.

The current study offers a framework for aligning organizational design, human resource practices, core processes, and technology to achieve greater shipbuilding efficiency in the current resource-constrained DoD environment. As a result of using this framework, U.S. Navy shipbuilding organizations should be able to assess their current state and apply lessons learned from best of breed manufacturing organizations to take advantage of the CPLM technology and achieve greater cost savings.

A. 3D Laser Scanning Technology⁴

The first technology reviewed in this report, as a possible way to reduce costs in U.S. Navy shipbuilding, is 3D LST. General Dynamics Electric Boat previously reported, to the Center for Naval Shipbuilding (CNST), the strengths

⁴ This section was abstracted from Kevin Shannon's thesis, *A Comparative Case Study of Dutch and U.S. Naval Shipbuilding Approaches: Reducing U.S. Naval Shipbuilding Costs Using PLM and 3D Imaging* (pp. 15–16).



and weaknesses of this new technology.⁵ This report details the data for the x, y, and z coordinate data (i.e., three-dimensional point cloud generated by the 3D LST technology) received from the scanners and compares the received data against that which was taken using the currently accepted standard of photogrammetry, an accuracy standard of 0.030 inches (in.). The project shows that the two laser system evaluated was unable to meet this known exacting standard. Because of this inability to meet the accuracy standard of 0.030 in., there is no current implementation of this technology in U.S. Navy shipbuilding.

Although the laser scanners currently do not meet the accuracy required by the shipbuilding industry, there was evidence of a significant potential reduction in hours required to survey each part tested. This evidence showed a possible reduction in time from three to 10 hours per part over the current method. A part is defined by each shipyard differently and varies from platform to platform, depending on which shipyard would consider the use of a 3D scanner valuable during the time of installation of a specific part. If 3D scanners were to be implemented in the installation of new ship parts, Table 2 illustrates the possible cost savings that could be achieved by reducing setup/scan time alone.

⁵ The entire project report presented by GDEB to CNST is attached in Appendix A.



Table 2. Average Cost Savings per Hull With Implementation of 3D Laser Scanning

Avg hrs saved	Cost of personnel per hour ⁶	# of parts per ship ⁷	# of ships	Total	Savings per hull
6.5	\$42.50	1,000	10	\$1,950,000	\$325,000
6.5	\$42.50	10,000	43 ⁸	\$139,750,000	\$3,250,000
6.5	\$42.50	100,000	5	\$162,500,000	\$32,500,000
			SUM	\$304,200,000	

Additionally, if the maximum savings were experienced per part, the result would have a significantly more positive effect on the possible cost savings, as shown in Table 3.

⁶ The average salary was retrieved from the Payscale website (<http://www.payscale.com/>) in 2012. Salary was then converted to an hourly rate using a conversion calculator (Calcxml, 2012).

⁷ The number of parts per ship is estimated because each shipyard would consider the total number of parts per ship differently.

⁸ According to ADM. James A. Lyons (2012), the Navy is currently looking at procuring 43 additional Arleigh Burke (DDG-51) platforms.



Table 3. Maximum Cost Savings per Hull With Implementation of 3D Laser Scanning⁹

Max hrs saved	Cost of personnel per hour	# of parts per ship	# of ships	Total	Savings per hull
10	\$42.50	1,000	10	\$4,250,000	\$425,000
10	\$42.50	10,000	43	\$182,750,000	\$4,250,000
10	\$42.50	100,000	5	\$212,500,000	\$42,500,000
SUM				\$470,000,000	

While 3D laser scanning technology is not currently up to the standards specified by the U.S. Navy, it is almost a certainty that with advances in technology, it will soon match, or even overtake photogrammetry in terms of accuracy. The U.S. Navy stands to reap an enormous cost saving when this technology meets the required standards.

⁹ The calculation used for average projected cost savings with the implementation of 3D laser scanning uses the average of the possible reduction in personnel hours as a result of the project conducted by Electric Boat, the average cost per hour of a marine engineer/naval architect, an estimation of the number of parts per ship (this is just an estimation because each shipyard defines a part differently: 1,000 parts = small [i.e., patrol craft (PC)], 10,000 parts = medium [i.e., guided missile destroyer (DDG)], 100,000 parts = large [i.e., carrier aircraft nuclear (CVN)]), an estimation of the number of ships that will be contracted in the future, and the results of the following equation:

$(\text{Avg hours saved}) \times (\text{Cost per hour}) \times (\text{\# of parts}) \times (\text{\# of ships}) = \text{Total}.$

The last column in Table 3 represents the total cost savings divided by the number of ships in order to represent cost savings per hull.

The calculation used for maximum projected cost savings with the implementation of 3D LST uses the maximum of the possible reduction in personnel hours as a result of the project conducted by Electric Boat, the average cost per hour of a marine engineer/naval architect, an estimation of the number of parts per ship, an estimation of the number of ships that will be contracted in the future, and the results of the following equation:

$(\text{Max hours saved}) \times (\text{Cost per hour}) \times (\text{\# of parts}) \times (\text{\# of ships}) = \text{Total}.$



B. Product Life-Cycle Management¹⁰

The second technology the current study viewed as a potential method of increasing the capabilities of U.S. ship manufacturers, while reducing costs, was collaborative product-lifecycle-management (CPLM). CIMdata, an independent global consulting firm that has established itself as a world-leading source of information and guidance to both industrial organizations and suppliers of CPLM technologies and services (CIMdata, 2011a), defines CPLM 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, spanning from concept to end of life of a product, integrating people, processes, business systems, and information. (CIMdata, 2011b)

Siemens (2011) defines CPLM as a tool that “allows companies to manage the entire life cycle of a product efficiently and cost-effectively, from ideation, design and manufacture, through service and disposal.”

There are valuable lessons learned from other industries about the problems associated with the failure to collaborate in core productive processes. For example, many shop-level IT implementations are completed without collaboration, which, most often, results in the inability to maintain a continuous flow of information between different shops along the product life cycle. It also leads to a failure to integrate information flow across sub-organizational levels, as well as additional rework and attendant costs for a company. CPLM allows businesses to make enhanced decisions throughout the product life cycle, optimizes relationships across organizational levels, maximizes the lifetime value of a business’s product portfolio, and sets up a single source of record to support diverse data needs (Siemens, 2011). The value added from an enterprise-level CPLM allows for continuous flow of information from the idea of the design to the disposal of the

¹⁰ This information was abstracted from Kevin Shannon’s thesis, *A Comparative Case Study of Dutch and U.S. Naval Shipbuilding Approaches: Reducing U.S. Naval Shipbuilding Costs Using PLM and 3D Imaging* (pp. 5–14).



product. Some specific benefits of utilizing CPLM technology in other industries include the following:

- an approximate 40% improvement in product change cycle-times,
- a 15–30% reduction in prototypes,
- a 40% reduction in lead-time,
- a 25% productivity increase in design engineering,
- a 75% reduction in development time for a household product,
- a reduced time to cost a product from five days to five minutes, and
- an 83% reduction in the engineering review process. (CIMdata, 2002, p. 9)

These benefits should also accrue to the shipbuilding organizations supporting the U.S. Navy. Clearly, other industries have had tremendous cost-cutting and other benefits from using this technology and the growth in the acquisition and use of this technology is a clear indicator of its potential benefits across the industrial spectrum.

CPLM's exceptional market growth can be seen in Figure 3. As more companies realize the benefits of managing the entire product life cycle from design to disposal, this growth is forecast to continue. The CIMdata research predicts that by 2014, the overall CPLM market will be approximately \$37 billion, as shown in Figure 3. This reveals that the private sector, across a number of industries, must be realizing tangible benefits from the implementations of these CPLM systems, and indicates that U.S. Navy ship suppliers should be able to do the same.



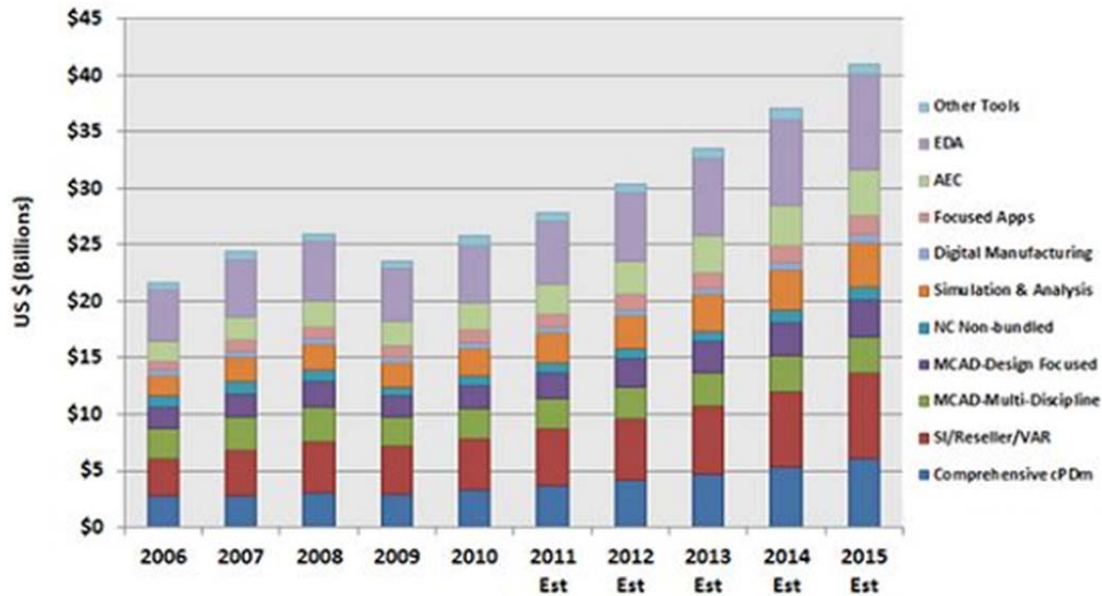


Figure 3. Mainstream CPLM Market Growth History and Forecast
(Malukh, 2011)

CPLM also has a beneficial impact on internal, supplier-facing, and customer-facing operational efficiencies. This makes it even more attractive to the vendors supporting U.S. Navy shipbuilding, leading to a higher likelihood of its adoption. These efficiencies are shown in Table 4.

Table 4. Internal, Supplier-Facing, and Customer-Facing Operational Efficiencies
(PLM Info., 2011)

Internal Operational Efficiencies	Application
Engineering change order (ECO) cycle-time reduced by 50%; ECO admin expense reduced by 60%	Personal computers
Cut box assembly from three hours to two hours 15 minutes; ECO cycle-time improved 40%	Storage
Time to market (TTM) improved 40%	Farm equipment
Reduced design errors and rework by 25%	Transport temperature control
TTM reduced by 5%; design errors and development costs reduced by 5%	Semiconductors
Reduced TTM from 48 months to 18 months between 1997 and 2002; engineering	Automotive

productivity increased 10% per year from 1997 to 2002; 35% reduction in global product development budget	
7–14% improvement in engineering non-value-added time; reduction in ECO cycle-time by 10%	Defense programs
90% faster Federal Drug Administration (FDA) document generation cycle-time	Medical devices
Design cycle-time reduced by 25%	Weapons systems
Overall engineering administrative activity showed an 80% improvement	Storage
ECO cycle-time reduced from 33 days to five days	Electronics
Supplier-Facing Operational Efficiencies	
Reuse improved from less than 2% to 59%. Total savings: \$500 million over three years on direct materials	Computers
Internal supply chain organization found 2% savings on direct materials purchase; \$640 million in materials acquisition savings potential across all groups	Industrial products
10–20% reduction in costs for packaging; reduction of 5–10% on direct materials spending	Consumer goods
Target savings of \$3.9 million in 2002; \$8.5 million in 2003	Seatbelts for auto
By providing suppliers with access to its computer-aided design (CAD) files, lead-time in developing tooling was reduced by 80%	Semiconductor equipment
Material cost reductions were approximately 2–3%	Electronic manufacturing services
2% reduction in direct materials costs	Defense programs
50% increase in component reuse, resulting in 5–15% decrease in prices for standard parts	Aircraft
Customer-Facing Operational Efficiencies	
Order to manufacture cycle-time reduced from four weeks to one day; errors essentially eliminated	Wireless transmissions
Significant savings on allowances for warranty and returns	Farm equipment
Order errors reduced by 50%	Elevators



Request for quotation (RFQ) response time reduction from two weeks to 24 hours	Electronic manufacturing services
30% reduction in cycle-time for complex custom order taking	Custom electrical switch gear
Reduced order lead-time by 50% (from 8–12 weeks to four weeks) using what-if scenarios on screen and direct feedback from distributor customers	Custom aftermarket wheels
Order volume increased 40% while order errors decreased 75%	Semiconductor
Eliminated almost 100% of customer order errors; cut down purchasing order cycle-time by 30 minutes per transaction; completely eliminated sending out-of-date product records to customers	Electromechanical machinery
Reduced order errors by 60–90%, and reduced design spec time by 35–90%	Furniture
50–70% reduction in project (order to quote) cycle-time	Specialty chemicals
50% customer RFQ to prototype cycle-time reduction	Bearings and motion control
Customer RFQ cycle-time reduced by 75%	Electronic manufacturing services

An evolution of the earlier immature version of CPLM was the combination of product data management (PDM) and computer-aided design (CAD) applications used by Chrysler. CPLM suites now enable complete global collaboration and data integration within the company. The evolution of CPLM is illustrated in Figure 4.



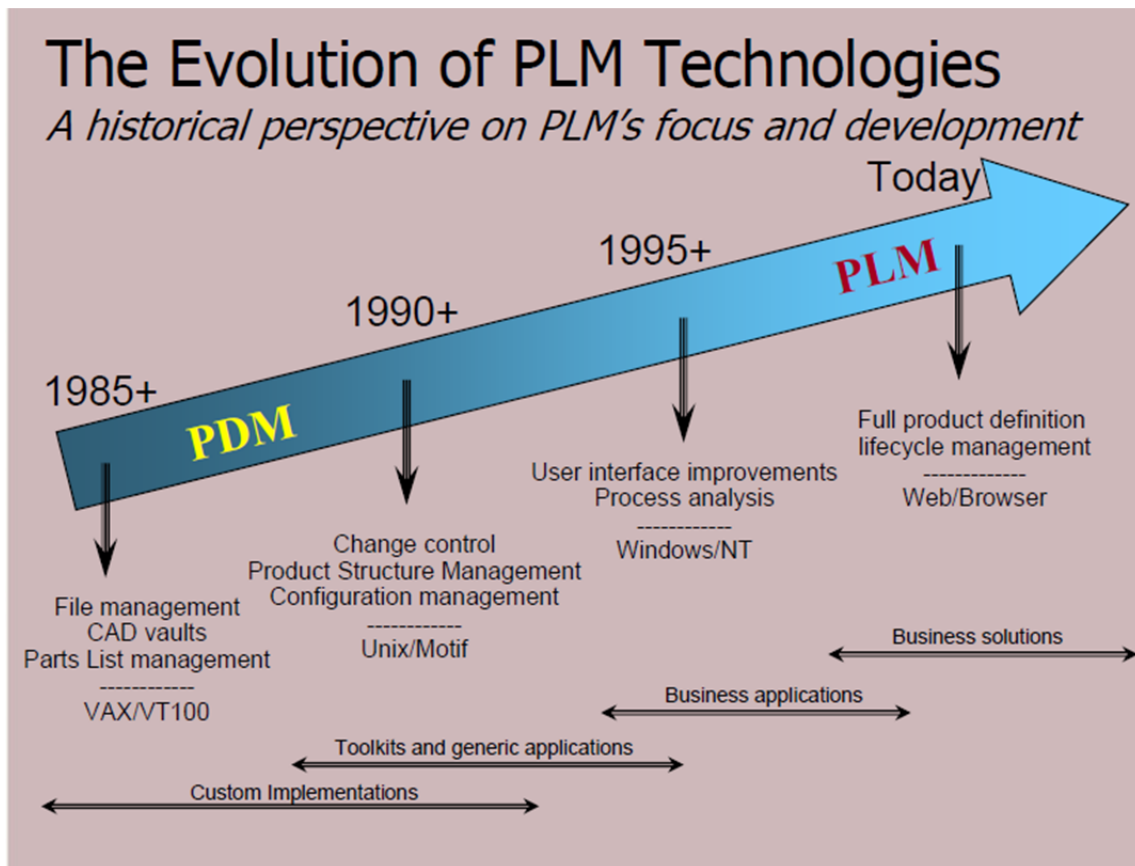


Figure 4. Evolution of PLM Technologies
(Aman, 2006)

As CPLM has evolved, the capabilities of the software have increased. Table 5 lists the capabilities of each software version as it has evolved. In the early 1980s, many organizations started realizing a need for a collaborative system that would integrate the various software suites that were being employed. This led to the development of a home-grown system called production automated design process (PADP). Following PADP was PDM (it had initially evolved in the automobile industry). The software that is now available from one of the leading makers takes the capabilities of the previous systems and adds additional capabilities to allow for product management from design to disposal. Today this is known as CPLM.

Table 5. Comparison of Product Management Software

	PADP	PDM	CPLM (Product A)	CPLM (Product B)
Empower cross-functional design and build teams	✓		✓	✓
Use parallel product and process development	✓			✓
Integrate all scheduling	✓		✓	✓
Involve customers and suppliers early	✓			✓
Minimize life-cycle costs	✓		✓	✓
Develop a life-cycle flow chart	✓			✓
Develop a risk-management plan	✓		✓	✓
Use shared databases to the maximum	✓			✓
Establish, collect, and evaluate metrics	✓		✓	✓
Data vault and document management		✓	✓	✓
Workflow and process management		✓	✓	✓
Product structure management		✓	✓	✓
Classification management		✓	✓	✓
Program management		✓	✓	✓
Communications and notification		✓		✓
Data transport and translation		✓		✓
Image services		✓ (CAD integration needed)	✓ (CAD integration needed)	✓ (CAD solution provided)
Administration		✓		✓
Application integration		✓		✓
Innovation management			✓	✓
Systems engineering and requirements management			✓	✓

Portfolio, program, and project management				✓
Engineering process management				✓
Bill of materials management				✓
Compliance management				✓
Content and document management			✓	✓
Formula, package, and brand management			✓	✓
Supplier relationship management			✓	✓
Mechatronics process management				✓
Manufacturing process management			✓	✓
Simulation process management				✓
Maintenance, repair, and overhaul			✓	✓
Reporting and analytics			✓	✓
Community collaboration			✓	✓
Life-cycle visualization				✓
Platform extensibility services				✓
Enterprise knowledge foundation				✓

Given the relatively slow adoption rate of CPLM technology in U.S. Navy shipbuilding, there is additional evidence from auto and aerospace manufacturing industries that CPLM suites can improve the engineering and design times in U.S. Navy shipbuilding, while at the same time reducing rework.

In recent years, CPLM has become ubiquitous in the automotive manufacturing world. Every major car company uses a CPLM application to manage its global supply chain and manufacturing requirements. Automakers have taken advantage of the collaborative effects of CPLM suites. Because modern automakers source parts and manufacture vehicles from all over the world, CPLM provides a significant benefit by having a standard format to share project data



across all levels of the design and manufacturing process. Whereas more primitive versions of CPLM applications relied on a “silo” approach to sharing data (meaning that the data was shared seamlessly throughout an individual factory rather than across factories), newer applications are extending that collaborative capability across multiple facilities (Pope, 2008).

Another industry that has derived enormous benefit from CPLM tools is the aerospace industry. Because of the strict engineering requirements and slim margins for error in designing and manufacturing aircraft, the ability to precisely model multiple design changes in a software application has yielded excellent results for a number of aerospace companies. Figure 5 shows the value of a CPLM implementation in the aerospace industry as offered by a subject-matter expert from Northrop Grumman.



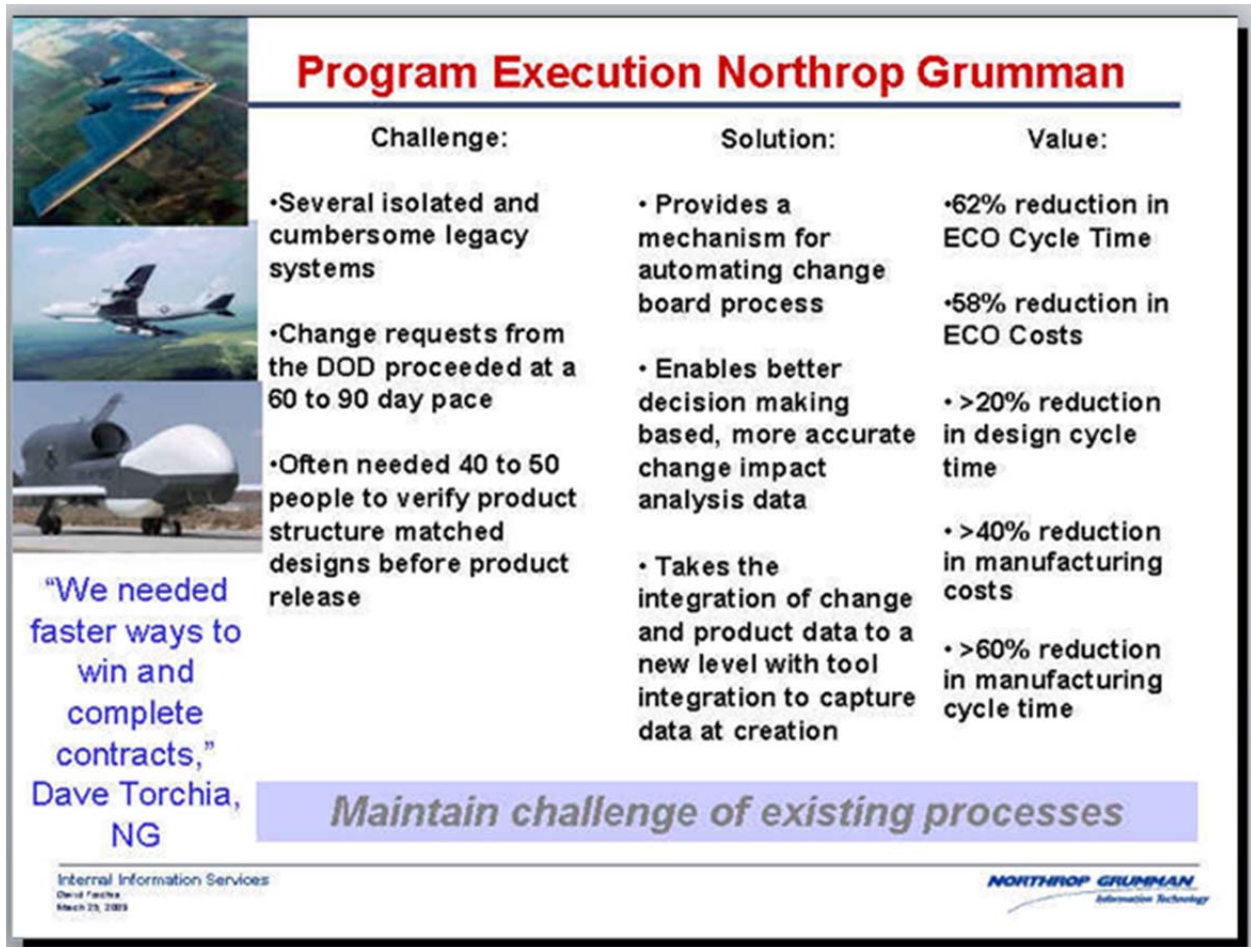


Figure 5. Northrop Grumman Engineering Change Order Cycle-Time Reductions
(R. Langmead, personal communication, 2012)

It is apparent that CPLM technology also has the ability to produce some of the results that the shipbuilding industry desires in terms of reduced cycle-time, rework, and increased collaboration. The relevant question that arises when looking at the success CPLM has provided other industries is this: How will CPLM implementation affect the costs and capabilities of U.S. Navy ships?

C. United States Navy Shipbuilding and CPLM¹¹

To understand the answer to the question of how CPLM will affect the shipbuilding industry, it is beneficial to put it into the context of the problems that rising ship costs are presenting to the Navy.

Over the past four decades, the growth of U.S. Navy ship costs has exceeded the rate of inflation. This cost escalation concerns many in the Navy and the government. The real growth in Navy ship costs means that ships are becoming more expensive and outstripping the Navy's ability to pay for them. Given current budget constraints, the Navy is unlikely to see an increase in its shipbuilding budget. (Arena et al., 2006)

In 2006, the Office of the Chief of Naval Operations asked the RAND Corporation to investigate the causes of the rise in cost of Navy ships. The investigation focused on two factors that have an effect on naval ship costs: economy-driven and customer-driven factors. The report concluded that the

cost escalation for naval ships is nearly double the rate of consumer inflation. The growth in cost is nearly evenly split between economy-driven and customer-driven factors. The factors over which the Navy has the most control are those related to the complexity and features it desires in its ships. While the nation and the Navy understandably desire technology and capability that is continuously ahead of actual and potential competitors, this comes at a cost. We do not evaluate whether the cost is too high or low, but note only that it exists. Nevertheless, given that the pressures on shipbuilding funds will continue in the foreseeable future, the Navy may need to continue seeking ways to reduce the costs of its ships—and this will likely need to come from, in part, a limiting of the growth in requirements and features of ships. The shipbuilders can also help to reduce the cost escalation of ships through improvements in efficiency and reductions in indirect costs. (Arena et al., 2006)

The U.S. Government Accountability Office (GAO) released a report in February of 2005, investigating the causes for the cost growth of U.S. Navy ships. Figure 6 illustrates the components of the cost growth.

¹¹ This information was abstracted from Kevin Shannon's thesis, *A Comparative Case Study of Dutch and U.S. Naval Shipbuilding Approaches: Reducing U.S. Naval Shipbuilding Costs Using PLM and 3D Imaging* (pp. 29–33).



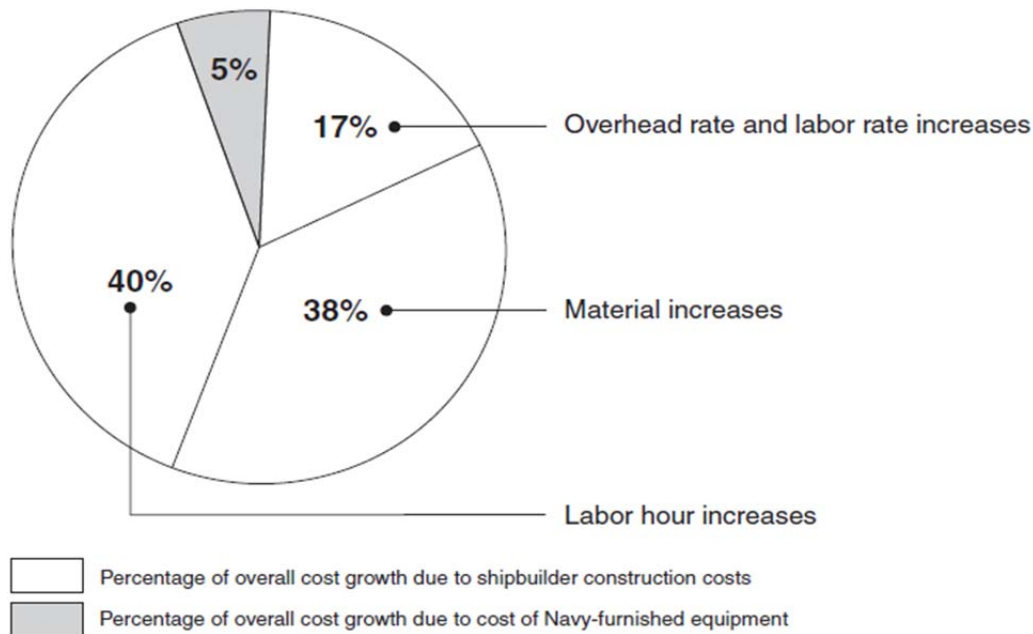


Figure 6. Components of U.S. Navy Shipbuilding Cost Growth
(GAO, 2005)

The rise in ship costs and the decrease in allocated funds for the U.S. Navy to spend on future ship contracts force the Navy to seek new ways to reduce future ship costs. It is evident that one of the largest factors in the rising costs is the increase in labor hours required to complete a naval vessel. The implementation of a CPLM software solution would significantly decrease the number of labor hours required to complete a vessel. There are possible dramatic advantages to the reduction in labor hours from the use of this technology. One of the largest contributors to the increase in labor hour growth, as illustrated in Table 6, is design changes or issues that lead to rework. A CPLM solution would allow for collaboration to take place during the design changes or upgrades and lead to less rework.

Table 6. Reasons Given by Shipbuilders for Labor Hours Cost Growth
(GAO, 2005)

Case study ship	Reasons for increase
DDG 91	• Inexperienced laborers • Design upgrades that result in rework
DDG 92	• Introduction of a new construction facility, setting workers back on the learning curve • Design upgrades that result in rework and workarounds • Strike increased number of hours needed to construct ship
CVN 76	• Less-skilled workers due to demands for labor on other programs at shipyard • Extensive use of overtime • Design changes resulting in rework
CVN 77	• Late material delivery results in delays and workarounds • Design changes resulting in rework
LPD 17	• Inexperienced subcontracted labor • Design difficulties led to doing work out of sequence and rework • Schedule delays • Bused workers to meet labor shortages
LPD 18	• Increases in LPD 17 translated into more hours for LPD 18
SSN 774	• Late material delivery • First in class design issues
SSN 775	• Quality problems and design changes • Inclusion of non-recurring labor hours

As a concrete example, a real-world notional scenario of rework caused by a lack of collaboration and communication is presented here. The absence of a CPLM solution in designing compartments aboard a ship lead to a number of problems that could have been avoided if a CPLM system had been in place. Two different designers were responsible for their respective zones: Zone 1 and Zone 2, as depicted in Figures 7 and 8. The Zone 1 designer knew that he had to get the piping that entered the trash compactor room in his zone to cross to the opposite side of the room; he designed his space as seen in Figure 7. The Zone 2 designer had the same instructions for the piping system: to get the piping that entered his space from one side to the other side of his compartment, so that it exited on the opposite side. Unfortunately, the collaborative system that was being employed at the time did not



allow the Zone 1 designer to view the area of responsibility of the Zone 2 designer. As a result, this situation would have gone unnoticed and the extra piping would have incurred unnecessary costs.

The Zone 2 designer had a more elaborate space to design. The Zone 2 designer's space was the trash compactor room; it included two trash compactors, stairs leading up to the compactors, a lighting fixture, and the piping. The Zone 2 designer was able to meet all the requirements for his space until, during one of the design review meetings, someone asked whether the sailor using the trash compactor room would have sufficient overhead space to lift a trash can and dump its contents into the trash compactor while positioned directly below the designed light fixture. The consensus was that there would not be enough room for the sailor to ascend the stairs to dump the contents of a trash receptacle because of the position of the light fixture. As Figure 7 illustrates, the position of the light fixture was required because of the routing of the pipe. Many meetings were held after this discovery to try to find a solution to this problem. After many wasted man hours trying to figure out a design solution, the Zone 1 designer happened to attend one of the meetings and realized the flaw in the piping design. Figure 8 shows the solution to the trash compactor problem once the Zone 1 designer noticed the piping design flaw. If a CPLM software solution had been implemented, the Zone 1 and 2 designers would have had access to each other's areas of responsibilities (zones) and would have been able to collaborate and save the wasted piping and man hours it took to try to resolve the design problem created in the trash compactor room.



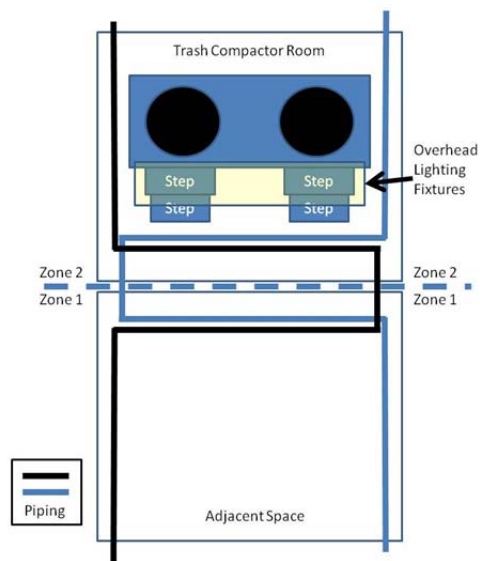


Figure 7. Compartment Piping Design Flaw

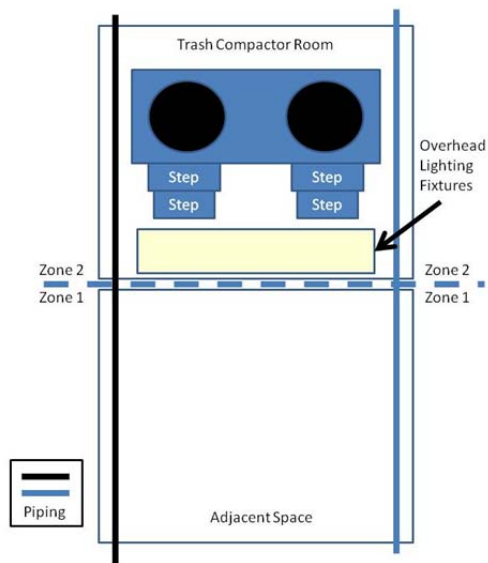


Figure 8. Compartment Piping Design Solution

It is clear that the cost of Navy ships is a serious problem in the current cost-constrained DoD environment, and that CPLM offers some opportunities for manufacturers to offset these costs. The challenge for U.S. shipbuilders is how to

achieve the benefits that other industries are seeing without a clear framework of how to implement the technology as well as the structural changes required by it.

The purpose of the following discussion is to provide shipbuilders with some guidelines for how to assess their capacity for taking advantage of CPLM manufacturing capability and their potential for implementing the technology from a structural, human resources, and technical perspective. The discussion includes examples of real-world scenarios where these technologies were leveraged successfully, and where they fell short, to provide further insights for shipbuilders from the lessons learned from other industries.

D. Damen Naval Shipbuilding¹²

One case study that can serve as an incentive for CPLM implementation is the Damen shipyard group. Damen Schelde Naval Shipbuilding (DSNS) was established in 1875 as Royal Schelde and became part of the Damen Shipyards Group in 2000. The Damen Shipyards Group employs over 8,500 employees in 30 different shipyards around the world. DSNS provides the Royal Netherlands Navy with military vessels, including frigates, amphibious vessels, and auxiliary vessels. In late 2000, Hein van Ameijden joined the Damen Shipyards Group as the director of Naval Export. Prior to the takeover by Damen Shipyards, Royal Schelde had never exported any of its naval vessels. Within three and a half years after his appointment, DSNS was exporting 50–80% of its naval vessels. After experiencing so much success under the direction of Hein van Ameijden, DSNS appointed Ameijden to managing director of Damen Schelde Naval Shipbuilding in 2004.

On February 9, 2011, Ameijden spoke at the American Society for Naval Engineers (ASNE) President's Lunch in Arlington, Virginia. Ameijden's speech covered history and an introduction of DSNS, and discussed how he believed that

¹² This section was adapted from Kevin Shannon's thesis, *A Comparative Case Study of Dutch and U.S. Naval Shipbuilding Approaches: Reducing U.S. Naval Shipbuilding Costs Using PLM and 3D Imaging* (pp. 27–28).



the U.S. Navy has been paying too much for its ships—nearly three times the amount that the Royal Netherlands Navy pays for comparable platforms, as illustrated in Figures 9 and 10.



Figure 9. Cost Comparison of DDG versus LCF
(Ameijden, 2011)

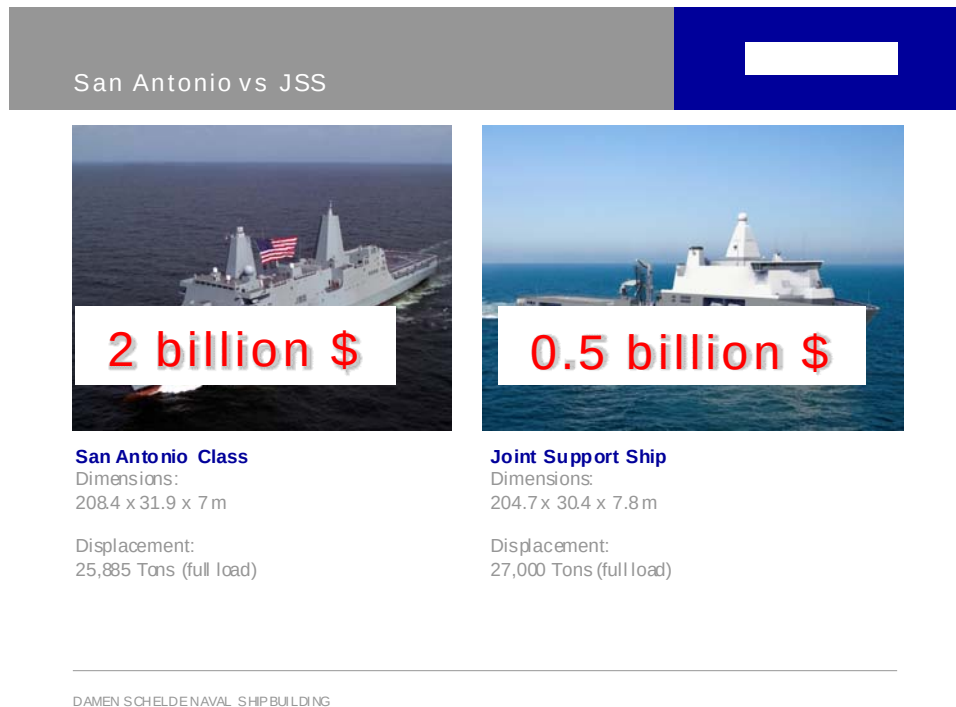


Figure 10. Cost Comparison of Landing Platform Dock Versus Joint Support Ship
(Ameijden, 2011)

DSNS has begun the implementation of one of the industry-leading CPLM solutions and is currently still in the implementation phase. Because of this, hard cost-savings data as a result of partial implementation of the CPLM suite of tools was unavailable; nevertheless, Ameijden stated, “The cost of material is so high that savings through error reduction [assumed as a result of CPLM implementation] will lead to a short payback time and make the investment worthwhile” (Siemens, 2011).

One particular case study within Damen itself that can be used to illustrate just some of the potential benefits of CPLM applications in shipbuilding is the reduction in design times on the 2000-ton corvette designed by Damen. According to our Damen subject-matter expert, the total engineering process is comprised of 6–9 months of system engineering, followed by 12–14 months of detail engineering. With the current CPLM application in use, detail engineering can be started a month earlier, and, ultimately, reduce the time spent on it by 1–3 months. Those estimates indicate that the CPLM offers a reduction of between 9% and 22% on the total time

of the engineering process. When we consider that Damen is working with a total of 300–320 engineers in Holland and Romania, the subsequent cost savings are considerable.

Conversations with a high-ranking member of the Engineering Department at Damen revealed some hard lessons learned that would be applicable to U.S. shipbuilders considering an implementation of a CPLM suite. The first lesson is that there is a 12–18 month implementation time for such a complex technology. This indicates that it is important that U.S. Navy shipbuilders have a well-thought-out plan to customize the software to their unique needs.

Damen began installation and training and integration into their existing systems of the CPLM tool in 2009 and were able to get it implemented in mid-2010. They found that the initial partial implementation of the CPLM suite did not fully meet their needs. The Damen subject-matter expert explained that more training time was needed for engineers working with the software, and that customization of the software for their unique needs was required upfront. The subject-matter expert suggested that each company will probably have to upgrade some dimensions of the CPLM solution for their individual needs. In addition, there is a learning curve and required training time for engineers and team members to become competent in use of the software, which can result in an initial decrement in productivity in the beginning use of the technology. This is the normal learning curve that any organization goes through in adopting a new technology as fundamental as the CPLM system. The subject-matter expert noted that if Damen could re-do the entire implementation process, it would take more time upfront to get its employees up to speed.

Damen's success can be explained by having a highly educated and motivated workforce, being on the forefront of CPLM use in the shipbuilding industry, and having an organizational structure that allows the technology and people in the company to operate as seamlessly as possible. Clearly, Damen represents a model for other ship-construction organizations to follow, and was, in large part, the



inspiration for the checklist for assessing manufacturing capability that follows later in this report.

E. Airbus¹³

Although the benefits of CPLM are lauded by companies implementing CPLM practices, implementing CPLM comes with its own set of challenges that must be faced and understood to ensure success. Like any new, broad software implementation, fully utilizing CPLM software requires a learning curve that, if ignored, can have negative consequences. One particular case of a failure to understand the socio-organizational requirements of implementing CPLM software led to a set of costly negative consequences in the design and manufacture of the Airbus A380 Superjumbo Jetliner.

In 2005, Airbus announced that the production of its much-anticipated A380 Superjumbo would be pushed back by a minimum of two years, a blunder that would cost Airbus “up to 6 billion dollars in lost profits” (Duvall & Bartholomew, 2007, p. 36). The culprit for this enormous setback was a critical error in the cross-coordination of two CATIA CPLM systems. When initial production of the fuselage of the aircraft began at a plant in Toulouse, France, workers noticed that large bundles of wiring and connectors were not fitting as they were supposed to in the aircraft. The scope of this problem was enormous; each plane required over 300 miles of wire and 40,000 connectors (Duvall & Bartholomew, 2007). To fix this problem by hand would have been practically impossible.

The root cause of this calamitous error can be traced to a breakdown in collaborative communications between the two plants that were using different versions of the CATIA CAD program to manufacture different parts of the A380. The newest version of CATIA (Version 5) automated some of the design processes that

¹³ This section was abstracted from Kevin Shannon's thesis, *A Comparative Case Study of Dutch and U.S. Naval Shipbuilding Approaches: Reducing U.S. Naval Shipbuilding Costs Using PLM and 3D Imaging* (p. 14).



had to be manually completed with the older Version 4 software (Duvall & Bartholomew, 2007). This mistake could, and should, have been rectified before manufacturing began, but was overlooked due to the vast scope of the manufacturing project. An unforeseen downside of cross-plant collaboration turned out to be a multi-billion-dollar delay in delivery.

The lesson that can be gleaned from this example is that when implementing a CPLM solution, companies must make a concerted effort to ensure that their organization's structure can handle the capabilities and, resulting efficiencies, offered by this new technology. Time and money spent standardizing software, training employees, and evaluating how the company is organized can have significant downstream benefits and help avoid catastrophic mistakes. In the Department of Defense (DoD) setting, setbacks like these can mean not only substantial cost overruns, but also potentially critical gaps in warfighting capability from a failure to produce new platforms on time.

In order to achieve the benefits of collaborative CPLM technology, as Damen has, while avoiding the pitfalls, the current study presents a set of questions that a company should answer to determine their manufacturing capability readiness. This readiness should also translate into a readiness to adopt CPLM tools. The following sections outline the relationship between an organization's manufacturing capability readiness, its structure, its human resource management, and its general technical readiness capability.



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II. The Organizational Design of Digital Shipyards¹⁴

A. Socio-Technical Systems and Organizational Design

The research on innovation and manufacturing technologies supports the core insight and design principal of the socio-technical¹⁵ systems approach to organizational design, captured in the concept of “joint optimization.” Joint optimization argues that focusing on the social or organizational side of manufacturing without attending to the physical technologies or technical systems¹⁶ results in sub-optimization, as does focusing on technology without attending to the organizational side of the organization. Optimizing organizational processes requires simultaneously using two lenses: one for the social/organizational subsystems and one for the technological or technical subsystems (Badham, Clegg, & Wall, 2001; Cummings & Srivastva, 1977). The failure of Airbus to successfully utilize the two versions of the CPLM suites is one example of what can happen when these two critical factors are not taken into account. To avoid the same kind of mistakes, U.S. Navy “digital shipyards” must ensure that the organizational design and human resource management as well as technological readiness levels be assessed to ensure maximal utilization of the CPLM tools.

¹⁴ The term “digital shipyard” has come up a number of times from subject-matter experts, but is clearly articulated in Siemens CPLM Software (2012).

¹⁵ The socio-technical approach has been developed into a socio-technical systems approach. The importance of people and social relationships is here expanded to include the open systems view of organizational structure (e.g., how departments are organized; the degree to which decision-making is decentralized; what horizontal processes are employed). Socio-technical systems are here subsumed under a broader framework of organizational design.

¹⁶ “Technical systems” traditionally refers to what most people mean by technology, and includes the following: architecture and facilities; equipment and tools; and, communication and information systems, including hardware and software. In our paper, technology or technical systems are synonymous and are viewed as the platforms, physical technologies, and tools that enable people, groups, and organizations to transform inputs into outputs.



The recent and continuing advance of information technologies, especially in the CPLM arena, have contributed greatly to improvements in ensuring world-class manufacturing capabilities. Collaborative information and communication technologies are enhancing the productivity of organizations throughout the larger company manufacturing sector. These new CPLM tools are enabling horizontal communication and collaboration among traditional functions and processes that was cumbersome or nearly impossible in mature manufacturing organizations. CPLM can integrate across the manufacturing domains of initial design, detailed design, product development, planning, and testing prior to deployment. More recent efforts are ideas attempting to apply these operational concepts and supporting tools to the entire life cycle of ships, integrating information to better manage shipbuilding as well as ship maintenance with the goals of reducing life-cycle costs and enhancing warfighting readiness.

Our analysis expands the general socio-technical systems perspective to an organizational design perspective, viewing joint optimization, enabled by tools such as CPLM, as requiring at least three lenses for assessing the diagnosis and adoption of CPLM tools in shipbuilding. These lenses are also critical because they encompass policy domains: They are perspectives for aligning shipbuilding policy in order to effectively integrate organizations, people, and technology. In other words, joint optimization requires optimizing and aligning (1) the organization from a structural perspective; (2) human contributions from a human resources perspective; and, (3) technology through a technical systems perspective. Culture largely emerges in response to ongoing work processes that operate in the contexts created by design decisions—including policy decisions—resulting from insights provided by an understanding of the structural, human resources, and technical perspectives in facilitating the rapid adoption of CPLM tools to reduce costs and enhance warfighting readiness.

Underlying the design requirements of the digital shipyard is the increasing complexity of the business of modern shipbuilding and of the ships themselves. This complexity carries risks of generating non-linear, chaotic work dynamics and



accompanying escalation of costs. Even without losing control over complex, potentially chaotic processes, shipyards that fail to innovate and integrate new technologies, such as CPLM, risk falling behind their competition in terms of costs, efficiencies, quality, and, ultimately, warfighting readiness.

New technologies, such as CPLM, clearly hold the promise for innovation in shipbuilding design, manufacturing, and maintenance, generating major savings throughout a ship's life cycle. However, consensus among practitioners and scholars is that learning and implementing appropriate structural and human resource design changes will be necessary to take full advantage of the promises technical systems offer.

B. Innovation in Manufacturing

Since the industrial revolution, organizing people and their work according to the images of the industrial machine has generated productivity cost-saving efficiencies and wealth. As in other industries, skilled craftsmen capable of performing all or nearly all of the tasks necessary for building ships had to yield to the design requirements of standardization and specialization. Generalists were relegated to niche markets as ships advanced exponentially in size, sophistication, and complexity.¹⁷ Throughout the late 19th and 20th centuries, the machine image of bureaucracy, rationality, and scientific management advanced. This has produced efficiencies and productivity advances responsible for much of the wealth in the modern world.

However, as products—and the manufacturing processes that build them—have increased in scale, sophistication, and complexity, the emphasis on specialization and standardization has generated inefficiencies, due in large part to failures of coordination, and results in motivational problems among the workforce. To overcome these problems and increase competitiveness, alternative engineering

¹⁷ The design principles of Taylorism, associated with the emergence of Weber's bureaucracy, are generally associated with the design metaphor of organizations as machines.



and manufacturing approaches have emerged that have been integrated into a new organizational design perspective. The on-going transformations associated with globalization, information networks, innovative organizational structures, and high involvement of human resource practices have lagged in some industries, but have left few untouched. Given competitive pressures and socio-technical innovations, it appears that shipbuilding is positioned to be able to increase quality standards and decrease life-cycle costs.

Collaborative product management (CPM) technologies,¹⁸ such as CPLM and concurrent engineering (CE), have been emerging for some time. CPM uses CPLM and CE technologies to create a system-of-systems. Some manufacturing organizations and industries (e.g., automobiles) have been at it longer and are, thus, leaders in development and use of collaborative socio-technical systems designs. Other industries, such as shipbuilding, are learning from these experiences, but adapting them to the special circumstances of building ships (e.g., low volume and fewer opportunities for standardization, relative to automobile manufacturing). Lessons in how to assess and develop capabilities are thus emerging as shipyards and CPLM vendors collaborate and pursue more customized paths to developing IT solutions. Insights into how to assess and develop collaborative manufacturing capabilities are informed by subject-matter experts who understand multiple industries in cooperation with those vendors and businesses that focus on shipbuilding.

We now turn to the three design and policy domains of (1) organizational structure and processes, (2) human resources, and (3) technical systems to see what key questions must be answered (or, as the digital shipyard is emerging, may be found to relate) to ensure the effective design of the digital shipyard enabled by CPLM. Lessons regarding human resource policies, practices, and perspectives are

¹⁸ CPM is a strategy that seeks to leverage technology to increase collaboration. This stated goal is very similar to the application of CPLM technologies, so, for simplicity's sake, we refer to both as CPLM.



a lagging domain in terms of current knowledge of how best to use CPLM tools in shipbuilding. We expect “high involvement” human resource practices to be important, but the details of this approach have not been well articulated or researched to date. The first section, covering the structural perspective, is a leading domain in terms of current knowledge that would be useful in applying best practices to the shipbuilding arena. The structural perspective is the heart of organization design. It is rich with lessons learned from multiple industries, lessons already reiterated by subject-matter experts in shipbuilding. We turn first to the domain of “getting organized,” within the structural perspective, to provide insights as to how to assess a shipbuilding organization’s readiness to adopt CPLM.

C. Assessing and Developing Manufacturing Capability From a Structural Perspective

Manufacturing capability is more and more wedded to the criticality of knowledge management that is one of the primary functions of a CPLM tool suite. As ships, like automobiles, become more complicated, the management of knowledge enables greater cost efficiencies as well as stimulating innovative practices.

The structural perspective largely assumes norms of rationality, that the design of the organization is undertaken with the aim of maximizing the efficiencies and effectiveness of the organization as a whole. (The human resource perspective deals with the realities that individuals and groups may have their own motives, interests, inertia, fear of change, and points of view that conflict with optimizing the total organizational system through the use of a CPLM system.) It assumes that effective organizational designs are structured so that information does not overload actors, flows collaboratively to where it is needed, and fits the realities of the workflow and the needs of decision-makers. Failure to consider these impediments to full utilization of CPLM tools is likely to result in problems of cognitive overload, lack of information and knowledge sharing, functional fixity of thought processes, and, as a consequence, wasteful failures to collaborate, integrate, and execute.



CPLM tools facilitate the flow of information across the different functional groups within an organization; however, the structural design that can take advantage of these new capabilities needs to be considered so that CPLM can operate as efficiently as possible.

Table 7 presents a set of questions related to structural success factors for manufacturing capability. They may be viewed as a high-level, strategic checklist. The questions address organizational design considerations critical to the implementation of intra- and inter-organizational collaboration via CPLM, and concurrent engineering. The questions are informed not only by the needs for improvements in productivity in the shipbuilding industry, but also from the experiences of organizations in other industries. Because some organizations have been earlier adopters of CPLM, and CE, they are further along in the maturity curve of developing coherent organizational designs. However, because different industries comprise different contexts,¹⁹ their designs and supporting cultures may eventually differ somewhat from what will eventually emerge in the shipbuilding sector.

From a structural perspective, the emerging digital shipyard is a response to increasing market competition, technological innovation, product complexity, and globalization. All of these forces serve to generate complexity and demands for speed, quality, and cost effectiveness, demands which can be met by a properly implemented CPLM system. The socio-technical design of the digital shipyard, enabled through CPLM, represents a solution to these problems, and especially to the problem of managing information complexity. As environmental and work complexity increase, decision-making and coordination via vertical hierarchies risks degradation due to information overload. The adaptive response is to decentralize decision-making lower in the hierarchy while standardizing and rationalizing

¹⁹ Different industries operate in different regulatory and economic contexts. For example, in the construction industry, functional disciplines are owned by different sub-contractors; thus, creating cross-functional design team is more problematic.



horizontal work flows and their supportive horizontal information processes and systems. CPLM is a system with the requisite complexity for standardizing and rationalizing information flows to support more efficient work flows. Table 7's questions, thus, persistently reveal the theme of creating capabilities for collaboration via restructuring functional organizations and increasing horizontal collaboration to support the hierarchy and deliver products faster, cheaper, and better.

Design is a value-laden activity: nothing can be designed without design values, including the organizational structures and processes that support CPLM and concurrent engineering. The design processes must acknowledge the key role of leadership and leadership's design visions and values. The CPLM-enabled shipbuilding processes must balance the design values of efficiency and innovation. The demand for efficiency requires standardization and formalization and discipline that CPLM can enable when successfully implemented. The increasing demand for innovation in products and processes requires decentralization and horizontal collaboration and structures as well as flexible, informal, mutual adjustment among functional areas. Managing the dynamic tensions created by these somewhat contradictory design pressures requires a leadership team that can fully utilize the capabilities offered by CPLM tools.

The questions in Table 7 address issues of how to re-organize the major departmental architecture of the organization so as to create a greater emphasis on horizontal work processes that have a clear line of sight to the customer by taking advantage of CPLM capabilities. The second set of questions focus on the vertical processes of the organization, including the design factors of decentralization and standardization, which may represent unique challenges to be able to fully utilize the CPLM tools. Finally, the micro-structure of job design is discussed because jobs must be redesigned to take advantage of the new capabilities offered by CPLM tools.



Table 7. Questions for Assessing Manufacturing Capability From a Structural Perspective to Utilize CPLM

Departmentation and Horizontal Integrating Processes	1. Has the organization formalized horizontal product or project units, typically through a matrixed organizational structure? 2. Does the organization have cross-discipline (or cross-functional) integration within product teams? 3. Are the design and manufacturing functions and engineers integrated, taking advantage of concurrent engineering? 4. Are the functional departments or disciplines developed, maintained and deployed as centers of excellence? 5. Are functional centers of excellence deployed so their knowledge of best practices flows into projects? 6. Are suppliers integrated into meetings and teams? 7. Are customers integrated into meetings and teams?
Vertical Processes	1. How tall is the organizational hierarchy? 2. Is vertical differentiation creating a context for responsibility and empowerment? 3. Have employees clearly been given appropriate decision-making authority to match their tasks and responsibilities? ▪ In particular, are integrated process teams appropriately empowered to make decisions?
Work and Job Design (Generating a Sense of Empowerment)	1. Is the work that individuals do—either in jobs or teams—structured so as to enhance intrinsic task motivation? ▪ More specifically, is the work characterized by significance of the work, variety in the skills required, task identity, autonomy, and feedback?

III. Departmentation and Horizontal Processes

The departmentation of the organization refers to the grouping of individuals into larger units. It is the template for the organization's formal vertical and horizontal relationships. Indeed, when people think of organization structure, the organization chart comes to mind. Departmentation in the new digital shipyards must be undertaken with the specific capabilities of CPLM in mind, so as to optimize the efficiency and collaborative benefits of the technology. Because departmentation in emerging digital shipyards formalizes horizontal reporting relationships and units into the structure, we discuss it at the same time that we discuss horizontal structures and processes. Our first questions (see Table 7) are about departmentation and horizontal processes.

A. Departmentation: Matrix and Project Structures

Referring to Table 7, these questions address the horizontal structure of the organization:

1. Has the organization formalized horizontal product or project units, typically through a matrixed organizational structure?
2. Does the organization have cross-discipline (or cross-functional) integration within product teams?

At the highest level of formal organization, state-of-the-art shipbuilding firms may use different terms to describe their departmental structure (e.g., product divisions, integrated product teams), but they are transforming so that traditional functional structures are integrated and coordinated with overlying horizontal structures. It appears that they most generally are and will be matrixed. Horizontal teams and project managers serve as a corrective to the “silos” and “smoke stacks” that block information exchanges and transparency in functional structures; CPLM serves the purpose of providing the technical system through which data can be exchanged freely and transparently across departmental units. Thus, a subject-matter expert in the shipbuilding industry currently using a CPLM suite said,



We have product groups. Those product groups are responsible for each specific product that we make. We have a product group in tugs; we have a product group in workboats; also in offshore and transport, ... and for frigates and corvettes. ...They try to get better in that product range.

The horizontal processes facilitated by CPLM technologies shift the traditional upward focus on the functional hierarchy to the work processes, the final product, and, ultimately, the customer.

The horizontal structures are particularly effective because their organization is congruent with the value-adding business processes of the organizations. As we will see, CPLM has a great impact on the design process as supplier and customer inputs and membership can be integrated into the structure to prioritize design criteria with respect to costs, and to identify process inefficiencies and domains of improvement. This would not be possible if design was conducted within the structure of organized silos lacking a fully functioning CPLM system. One of the more dramatic cases of a CPLM-enabled horizontal structure leading to immense cost and efficiency benefits, discussed in the next section, is the Virginia-class submarine.

1. Virginia-Class Submarine:²⁰

The Virginia-class submarine program is possibly the clearest example of the effectiveness of CPLM and 3D collaboration software on a defense acquisition platform. Designed as a replacement of the aging Los Angeles-class submarines, the Virginia-class vessels took advantage of open architecture and modular design techniques to achieve cost savings while increasing the flexibility and performance of the platform (Johnson & Muniz, 2007).

²⁰ This section was abstracted from Kevin Shannon's thesis *A Comparative Case Study of Dutch and U.S. Naval Shipbuilding Approaches: Reducing U.S. Naval Shipbuilding Costs Using PLM and 3D Imaging* (pp. 17–20).



In the early 1990s, as the Cold War was ending, the Navy went through a bottom-up review to set the necessary standards and fleet numbers according to what the Clinton administration felt was appropriate for the shifting threats of the times (O'Rourke, 2004). The contemporary naval experts agreed that around 50 was the appropriate number of submarines needed in order for the Navy to sustain a 310-ship fleet (Johnson & Muniz, 2007). In addition to the new quota, a decision was made to end production of the expensive and large Seawolf-class submarines after only three vessels because of the shifting threats facing the U.S. Navy, namely operating quietly in littoral combat zones (Federation of American Scientists, 2011).

Ending the production of the Seawolf submarines left the Navy in a predicament, because the Los Angeles-class submarines were slated to be decommissioned "at the rate of three per year" (Johnson & Muniz, 2007, para. 2). The Seawolf was originally designed to replace the Los Angeles class in its traditional deep-sea and arctic roles, but the Navy had different plans for the Virginia-class submarines. The missions that the new, smaller submarines were to fill included the following:

- covert strike by launching land-attack missiles from vertical launchers and torpedo tubes;
- anti-submarine warfare with an advanced combat system and a flexible payload of torpedoes;
- anti-ship warfare, again, using the advanced combat system and torpedoes;
- battle group support with advanced electronic sensors and communications equipment;
- covert intelligence, surveillance, and reconnaissance, using sensors to collect critical intelligence and locate radar sites, missile batteries, and command sites, as well as to monitor communications and track ship movements;
- covert mine-laying against enemy shipping; and



- special operations, including search and rescue, reconnaissance, sabotage, diversionary attacks, and direction of fire support and strikes. (Federation of American Scientists, 2011)

These requirements necessitated a flexible platform, and the contract for the submarines was awarded to General Electric's Electric Boat and Northrop Grumman's Newport News shipyards. Initially the Navy intended to produce these submarines at a rate of one submarine per year, but soon realized that the rate of production would need to be doubled in order to meet the Navy's quota as the Los Angeles subs were decommissioned. To meet this demand, however, the Navy understood that costs of the submarines would have to be dramatically reduced by 2012, from \$2.5 billion to \$2 billion per submarine. This goal was known as Two for Four in Twelve (Johnson & Muniz, 2007).

Electric Boat and Newport News began working on cost-cutting measures that would maintain the submarines' capabilities for their seven aforementioned missions while simultaneously reducing the cost of the submarines to \$2 billion. The tool that was used to design and implement these improvements was a home-grown CPLM and 3D CAD system. With this system, Electric Boat was able to quickly and efficiently make significant changes to the submarines' bow design and launch tubes that would prove critical in reducing the cost per submarine while having the added benefit of increased flexibility and performance.

The two most important design changes that added flexibility and reduced cost were the large-aperture bow (LAB) array and payload integration module (PIM) (Johnson & Muniz, 2007). These changes are representative of prioritizing design criteria with respect to costs, one of the main benefits of a horizontal organizational structure.

The LAB array achieves its initial cost savings by taking the sonar system out of the pressurized hull of the sub (Johnson & Muniz, 2007).

The LAB Array has 2 primary components: the passive array, which will provide improved performance, and a medium-frequency active array. It



utilizes transducers from the SSN-21 Seawolf Class that are designed to last the life of the hull. This is rather par for the course, as the Virginia Class was created in the 1990s to incorporate key elements of the \$4 billion Seawolf Class submarine technologies into a cheaper boat. (“Virginia Block III,” 2008)

In addition to \$11 million in immediate cost savings, the LAB array also relies on cheaper internal components that further reduce costs by being cheaper to replace, maintain, and install (Johnson & Muniz, 2007). The savings resulting from these changes have not yet been quantified.

The PIM is another dramatic design change that has had the most noticeable impact on achieving cost savings and increasing the flexibility of the system while still maintaining the original operational goals of the platform.

The submarine is equipped with 12 vertical missile launch tubes and four 533mm torpedo tubes. The vertical launching system has the capacity to launch 16 Tomahawk submarine-launched cruise missiles (SLCM) in a single salvo. There is capacity for up to 26 mk48 ADCAP mod 6 heavyweight torpedoes and sub harpoon anti-ship missiles to be fired from the 21in torpedo tubes. Mk60 CAPTOR mines may also be fitted. An integral lock-out / lock-in chamber is incorporated into the hull for special operations. The chamber can host a mini-submarine, such as Northrop Grumman's Oceanic and Naval Systems advanced SEAL delivery system (ASDS), to deliver special warfare forces such as Navy sea air land (SEAL) teams or Marine reconnaissance units for counter-terrorism or localized conflict operations. (“NSSN Virginia,” 2011)

Currently, the Virginia-class program has achieved the goals specified by Two for Four in Twelve, as well as won the prestigious David Packard Excellence in Acquisitions Award for “reducing life-cycle costs; making the acquisition system more efficient, responsive, and timely; integrating defense with the commercial base and practices; and promoting continuous improvement of the acquisition process” (“Virginia Class Sub,” 2008). These two drastic design changes and the subsequent rewards that resulted from them were brought about using CPLM and CAD technology, according to a source within the CPLM technology sector.

We don't know how much of the Virginia-class sub program's success to attribute to the structure of the shipyards responsible for building the platforms.



However, the horizontal structure and efficient collaboration are in line with the benefits of CPLM implementation reported by shipbuilders using the collaborative technologies.

Moving away from the traditional silo approach with CPLM technology does not imply that the functional groups disappear; rather, functional groups or disciplines are still critical as they are necessary and central to the work of building ships, but they now are embedded in a context of horizontal structures and work flows.²¹ The shipbuilding subject-matter expert says, “They [the product group] do the proposal work for potential customers, and they do the initial engineering work. As soon as it becomes a contract it goes to the engineering department.” Each organization must determine the points at which disciplinary or functional teams are appropriately used, but critical design and planning phases are multi-disciplinary. On the surface, this move away from functional structures may seem difficult as it appears to sacrifice economies of scale, but the efficiencies gained through CPLM and concurrent engineering’s processes more than make up for this apparent structural inefficiency. As discussed elsewhere in this report, because knowledge is being shared by the CPLM systems in the initial designs, cost savings are generated because more and more costly problems are solved on the digital drawing boards.

Figure 11 illustrates the matrix structure. Note that it is quite possible for most mutual adjustment and horizontal communication to occur at the middle level, with lower level workers, although still organized as teams, following guidance from higher levels. The structured dissemination of relevant information through a CPLM system facilitates and promotes this horizontal communication. A subject-matter expert’s words relate well to the image in Figure 9:

²¹ In the language of Thompson’s theory of inter-departmental interdependence, reciprocal work processes coordinated through mutual adjustment and horizontal processes, are added to traditional pooled and sequential interdependence, coordinated respectively through rules and plans. This allows for interdisciplinary knowledge to be deployed to prevent or solve problems earlier and to respond to product changes more effectively and efficiently.



If you talk about how we keep each other informed, we have, each year, on the various levels, various meetings where the product group directs and sales people, and management meet each other for a number of days. We exchange information by a more or less structured agenda; and that also goes for the procurement department, the engineering department, the production department.

Again, the functions remain critical in the structure, but horizontal mechanisms work to prevent them from becoming stovepipes. CPLM technologies, in this way, can contribute to building an organizational structure that promotes horizontal mechanisms and collaboration. CPLM technology provides the avenue for instant knowledge sharing between and among departments.

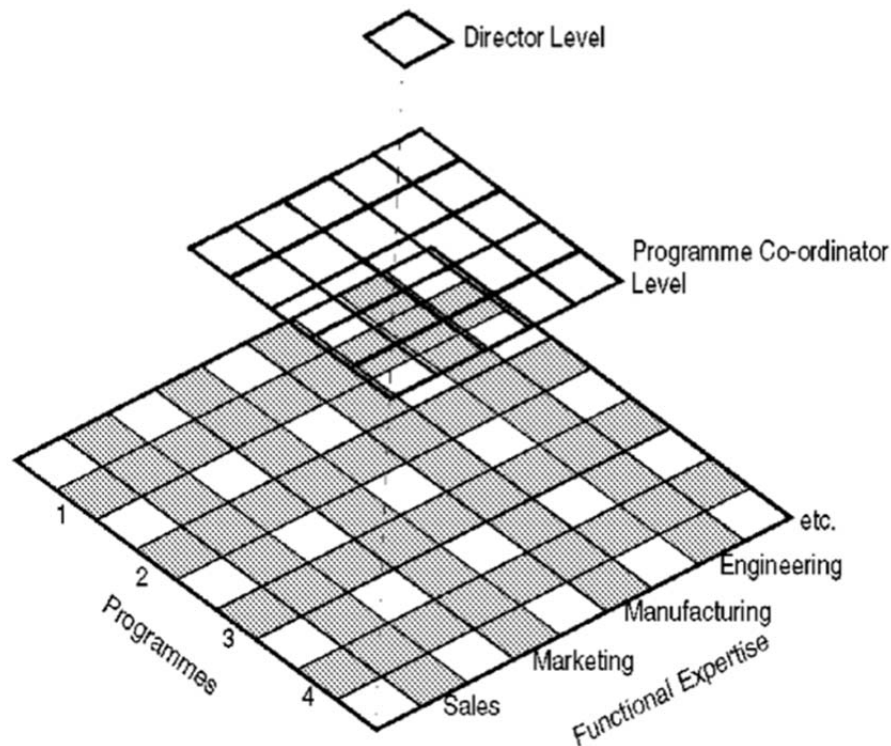


Figure 11. Matrix Structure of Manufacturing Organizations Using CPLM and Matrix Structures
(Tookey, Bowen, Hardcastle, & Murray, 2005)

B. Integration of Design and Manufacturing

Taken from Table 7, this question addresses the horizontal structure of the organization:

3. Are the design and manufacturing functions, processes, and engineers integrated, taking advantage of concurrent engineering?

The cost benefits of structural horizontal integration in manufacturing have nowhere been as thoroughly studied as in the integration of the design and manufacturing functions (i.e., in new product design and development). The matrix design in Figure 11 is especially important in CE and CPLM approaches that create teams of design and manufacturing engineers. In the figure, the program or product teams are further divided into teams that focus on different subsystems or subassemblies. These low-level teams are organized to include personnel with design, engineering, and manufacturing knowledge. Most critically, they develop and require the ability to appreciate the values, assumptions, and perspectives of those from other functions or disciplines. From a human resource perspective, the use of CPLM to create a matrix structure can enrich jobs, giving people a sense of ownership and identification with tasks.

The nature of integration depends on the maturity of the organization's development toward concurrent engineering. More is known about industries that have been early adopters and developers of CE and CPLM (e.g., the auto industry). It also is clear that the structure of some industries (e.g., the construction industry; cf. Tookey, et al., 2005) presents greater barriers to adoption.²² According to an expert in the auto industry, cross-functional launch teams have progressed to the point that they involve "hourly plant employees who sit alongside manufacturing and product engineers, quality experts and plant level managers to resolve

²² Shipbuilding, like construction, is a low-volume industry that resists standardization. A systematic study of its structure with respect to barriers and enablers has not yet been written. However, one of the prime barriers for construction, functional subcontractors in the hands of different owners, does not characterize the shipbuilding industry.



manufacturing and quality issues.” A subject-matter expert notes that low-level employees bring pragmatic, “real-world” tests to the teams:

They look at user friendliness. ... How easy is it to service? How easy is it to maintain? ... An engineer ... only looks at it maybe from a functional perspective, and does not really have the forward vision of anticipating maintenance-ability, serviceability, those kind of things. (Haddad, 1996, pp. 127–128)

CE platform teams in the auto industry may thus be composed of more than 700 people. To the extent decision-making requires consensus, this clearly empowers production and trade employees. It remains unclear to what degree participation and empowerment will reach these levels in shipbuilding as a result of CPLM and concurrent engineering. Although our sample was small, given the size of the shipbuilding industry, managers at shipbuilding firms and CPLM vendors have not seen these changes yet. However, they fully expect that such positive changes will occur in time with proper implementation of CPLM tools.

C. Functions as Centers of Excellence

These questions (see Table 7) also address the horizontal structure of the organization:

4. Are the functional departments or disciplines developed, maintained, and deployed as centers of excellence?
5. Are functional centers of excellence deployed so their knowledge of best practices flows into projects?

The emphasis on product or matrix structures needs to be supported by functions that maintain standards of excellence for their disciplines. For example, engineering can use CPLM systems to maintain the state of the art knowledge and manages knowledge flows: sharing knowledge learned by people across projects. Tookey et al. (2005) give evidence that effectiveness is increased when functional departments share expertise and problem-solving experience by working with product groups on a “sub-contracting consultancy basis” (p. 45); such teams are



“staffed by acknowledged experts in their field who could ‘troubleshoot’ bad practice and promote best practice” (p. 46).

Collaborating functional managers begin to resemble communities of practice, or communities of best practices. Recall the manager who noted the meetings held each year by “the procurement department, the engineering department, and the production department.” These meetings are critical to knowledge flows and are exemplars of sound knowledge management practice that can be enabled through the use of CPLM tools. This may be an especially critical requirement for the Information Technology Departments in charge of overseeing a CPLM implementation. A subject-matter expert said,

Our respective IT departments in our various companies are talking on a very regular basis, and we have a subsidiary company whose IT people have meetings with the main office in order to streamline as much as possible the procurement of IT or software. They share experiences, so that there are meetings at that level as well as trying to harmonize, as much as possible, the software that is being used across the company.

D. Integration of Suppliers Into the Horizontal Structures and Processes

Question 6 from Table 7 also addresses the horizontal structure of the organization:

6. Are suppliers effectively integrated into meetings and teams?

Shipyards are following other industries in increasingly including suppliers into operations. As shipbuilding complexity and knowledge requirements increase, it becomes necessary to leverage the special knowledge of suppliers. This can range from relatively simple components and parts to complex systems. This is a form of specialization that results in costs savings: The shipyard concentrates on developing its own core business processes in collaboration with suppliers who share their unique knowledge. The suppliers need to be included in the design stage when attempting to implement CPLM tools. As one shipbuilding subject-matter expert puts



it, “To get information out of the tools (CPLM), you need technical information from a vendor. You have to store the information properly.”

In addition, if life-cycle management is valued, then suppliers, those providing complex, relatively complete systems, need to be involved; their components need to be monitored and assessed; and this assessment needs to include how they work in terms of the overall system performance. Suppliers might thus have an incentive to become involved in integration of design activities. Note that suppliers, by sharing critical competitive information, become vulnerable, and so trust must be built up over time.

Subject-matter experts refer to the common best practice of building relationships with a few core suppliers (Lindquist, Berglund, & Johannesson, 2008). Formal pre-source agreements may facilitate this. The spirit of this commitment is captured in the promise made by a manufacturer to its suppliers: “As long as you are competitive and as long as you are improving, you will have this business on this vehicle” (Haddad, 1996). Increasing communication and collaboration with suppliers through a CPLM system should help solidify these important relationships.

With trust, it also may be possible to rationally determine outsourcing strategies and practices. Of course, collaborative relationships are longer term alternatives to making short-term purchases in the market place. There is general acceptance of the assumption that investing in relationship building can provide superior performance and cost benefits over the long term (Krause, Handfield, & Tyler, 2006). Subject-matter experts express this when they say that early involvement of suppliers using CPLM can facilitate the development of trust and the avoidance of costly change orders. However, getting suppliers to invest in resources (e.g., personnel or equipment) specific to a particular customer requires long-term involvement.

The primary threat to successful supplier integration is anything (e.g., incentives, culture, resources) that creates pressures for short-term, temporary



relationships. Supplier coaching is viewed as a best practice and a high priority for reducing costs and quality defects; including suppliers in communities of practice and knowledge sharing benefits suppliers and buyers (Mentzer, 2004; Tookey et al., 2005). CPLM technologies can allow this inclusion by storing and distributing data much more easily than traditional manufacturing systems, thus allowing a more effective means of coaching as well as monitoring the performance of suppliers over time.

E. Integration of Customers Into the Horizontal Structures and Processes

The final question from Table 7 that addresses the horizontal structure of the organization is as follows:

7. Are external customers effectively integrated into meetings and teams?

The importance of customer involvement has by now become an accepted design value if customers are defined as the next “downstream” user from developing a system or subsystem. It has become commonplace—although not universal—for representatives of external customers and end users to be involved in defining performance standards. This goes a long way toward eliminating ambiguity in understanding what the customer wants. However, some organizations may view customer involvement less than enthusiastically, as a necessary evil required for reducing dead-ends and clarifying expectations, but at the risk of design creep and cost overruns. The major threat to effective customer involvement may be an organization’s lack of customer knowledge about the products and processes. In naval shipbuilding, where the customer has knowledge of product requirements, design trade-offs, and construction processes, it is foolish not to collaborate (cf. Tookey et al., 2005); this seems well recognized. However, these phenomena indicate that CPLM systems should include performance-monitoring tools that make progress, or lack thereof, transparent to all parties involved in the shipbuilding enterprise.



IV. Vertical Processes

A. Vertical Differentiation

Referring to Table 7, these questions address the vertical processes of an organization:

1. How tall or how short is the organizational hierarchy?
2. Is vertical differentiation creating a context for responsibility and empowerment?

Vertical differentiation refers to the number of layers or levels in the hierarchy; it is the same thing as vertical specialization. Decreasing the number of layers and making the organization shorter creates pressures to push responsibility down the hierarchy that provides the added benefit of faster decision-making and fewer layers of management along with reductions in the overhead costs of an organization.

Tall structures typically correspond to narrow spans of control. (Spans of control refer to the number of subordinates directly reporting to a supervisor or manager.) Wide spans of control make it more difficult to manage subordinates and, thus, can create inefficiencies.

Excessive vertical structure also appears to be incongruent with the promises of increased speed and increased productivity through effective use of CPLM, especially as organizational processes and products become increasingly complex. This has been observed in practice and is explained by the principle that increased complexity eventually will overload the hierarchy, resulting in rework and waste. Teams are critical because they are able to effectively process more information than individuals, especially if they have appropriate tools such as a well-managed CPLM suite. Individual information-processing capacity is relatively slow, and tall hierarchies overtax this limited capacity, slowing down the vertical coordinating processes and decision-making of the hierarchy. This leads to the issue of decentralization.



B. Decentralization

The following question and subquestion (see Table 7) also address the vertical processes of an organization:

3. Have employees clearly been given appropriate decision-making authority to match their tasks and responsibilities?
 - In particular, are integrated process teams appropriately empowered to make decisions?

Decentralization refers to the degree to which authority is moved down from the organization's strategic apex to its mid-level and lower level employees. It has long been known that size tends to generate more vertical differentiation, greater standardization, and limited decentralization. Put differently, as organizations increase in size, they bureaucratize, and bureaucratization is accompanied by *limited* decentralization. In such bureaucracies, low-level employees must follow standard operating procedures, and the hierarchy deals with exceptions.

Similarly, although there is a necessary decentralization in the matrix structure, particularly to team leaders, decentralization to lower levels may be limited, depending on the design values of management and the nature of the work. While the importance of decentralization in manufacturing is accepted in design and concurrent engineering, it is not at all clear that decentralized authority is required for lower level craftsmen and craftswomen. Subject-matter experts indicated that there currently is little change in decentralizing authority to construction of the ship in the shipyard as a result of CPLM. However, CPLM, combined with other technologies (e.g., 3D PDFs) are improving communication and generating a greater sense of certainty for workers about the work they are expected to do.

The sub-question to question 3 above refers to decentralization to integrated process teams. At the micro-structural level of job design, one alternative is to do away with jobs altogether. The socio-technical design school noted that the focus could shift away from individuals doing jobs to teams doing the work. Such "autonomous work groups" are self-managing, but need the support of systems,



such as CPLM, that will provide them with the information they need to coordinate and collaborate with other self-managing teams. This has the potential for more deeply involving people in the work by tapping into processes of intrinsic task motivation (Thomas, 2002), leading to potentially higher levels of job satisfaction and the motivation that accompanies it.

CPLM requires standardization of databases and can make work more transparent. This creates the potential for micro-management, but also for more autonomous teams. Indeed, the context of standardization and formalization demanded by CPLM may create a dynamic tension within these structures, requiring more managerial talent and leadership skills than are required in the traditional, single-line hierarchies of traditional functional organizations. So far we have not been able to find cases where CPLM has been integrated into HRM performance appraisal processes. However, it is a relatively simple first step to provide employees with the performance feedback data derived from a fully implemented CPLM tool suite. This is an additional function that CPLM tools should include in the near term.



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V. Work and Job Design: Generating a Sense of Empowerment

Referring to Table 7, this question and subquestion address work and job design in an organization:

1. Is the work that individuals do—either in jobs or teams—structured so as to enhance intrinsic task motivation?
 - More specifically, is the work characterized by significance of the work, variety in the skills required, task identity, autonomy, and feedback?

Whether the focus is on individuals performing in jobs or on teams doing work in processes, the micro level of organizational structuring and design is where the structural perspective intersects the human resources perspective. To the degree that CPLM empowers teams so that they are able to complete meaningful units of work (versus perform highly specialized, repetitive tasks), set and monitor work goals, and receive feedback about work progress, then the resulting intrinsic task motivation is likely to be activated (Thomas & Velthouse, 1990, 2002). Because concurrency, cross-functional teams, decentralization, and distributed information systems are congruent with the encouragement of intrinsic task motivation, this has positive implications for performance and retention of knowledgeable high-performance workers.

These issues are discussed in the next section in the human resource perspective. The literature on micro-structural work and job design makes clear that gains in product quality and employee retention are affected by job enrichment, such as the potential that CPLM tools have to empower workers to take greater control of their own productivity (Deci & Flaste, 1995; Deci & Ryan, 1987; Hackman & Oldham, 1980).



A. Consequences and Trade-Offs of Design Decisions and Structural Policies

The design decisions and policies in the organizing and structuring of the organization generate synergies to the extent that they support and are congruent with human resource policies and the CPLM systems discussed in the next section. Failures to move in these directions can result in failure to deliver on the standardization required by the databases and information-coding requirements of the CPLM as well as on enabling the autonomy and intrinsic task motivation that can come from decentralization and working with teams. The structural context can contribute to trust and high involvement of personnel, suppliers, and customers. Thus, negative answers to questions in the human resource frame discussed next may be traced to poor implementation and execution of structural policies.²³

We now turn our attention to the optimization required from a human resources perspective and how this perspective is influenced by the implementation of a CPLM system. If the organization's management of its human resources is inadequate, then the organization is at high risk that their structural roles will be dysfunctional or inadequately filled.

²³ Again, there are dynamic tensions that capable leadership must manage in terms of maintaining project and disciplinary perspectives in the matrix structure. The design values of the matrix structure—maintaining a focus that is vertical, hierarchical, and disciplinary focused while also focusing on horizontal processes, teamwork, and the customer—requires continuous adjustment and balance. This places more demands on people skills than traditional functional structures. For example, matrix organizations sometimes frustrate people by the amount of time spent attending meetings versus “doing the work.” In some cases, ambiguity can result over authority, leading, in worst-case scenarios to, “we make decisions and then we see who gets mad.” And the process of moving from functional to more horizontal structures is likely to generate some of these dynamics.



VI. Assessing and Developing Manufacturing Capability From a Human Resources Perspective

The structural frame focuses on roles, jobs, and work more than people and the human side of teams. Organization charts, for example, focus on roles; they are designed with the assumption that people in those roles will effectively inhabit the roles specified. The human resource perspective focuses on the human and personal realities—limited rationality, self-interest, and differences in talent and ability—of individuals and groups who inhabit those roles and teams. To perform effectively as expected, individuals must have appropriate skills and motivations as well as access to ongoing feedback on their performance. CPLM tools can be adapted to provide this kind of required performance feedback.

Although the literatures on concurrent engineering and CPLM have built up a rather substantial literature of practice and research focusing on structures and processes, the literature on the impact of their movements on the human resource policies, practices, and procedures that support these is fairly thin. The importance of HR has been recognized for many years (e.g., Anderson, 1993), but the research literature on the impacts of CPLM systems on human resource practices doesn't reflect this. In shipyards, issues of human resource design and policy choices are less frequently and less systematically articulated.²⁴

This is not to say that top leadership and lower levels of management are not well aware of the importance of—as they often put it—“processes, *people* and technology,” but there is much less understanding of the options and constraints involving HR policies and practices than for structural design options. Given the

²⁴ One expects that there is considerable knowledge in the auto industry, which is far more developed in CE and CPLM, but the systematic presentations and research on HR practices are thin, although many authors discuss the emerging culture that arises because of policy changes to HR and structure.



much better understanding of the structural design issues and the literature on high-involvement organizations, we would expect that recruitment, selection, placement, performance appraisal, incentives, job design or work design, and career paths should be considered when planning to implement a CPLM system. But systemic perspectives on HR design choices, in the context of a new enabling CPLM system for work, are virtually absent, and subject-matter experts are less articulate and reflective on HR issues than on how to reorganize the organization's basic structure to take advantage of CPLM system capabilities. The questions in Table 8 focus on human resource factors relevant to developing competitive advantage using human resource best practices. They are based largely on empirical results across a variety of organizations and industries that suggest the kind of HR practices that are likely to emerge in the digital shipyards of the future when CPLM systems are fully implemented. But much more research is needed on how to adapt these best practices to take advantage of CPLM system capabilities.

From a human resource perspective, the success of the emerging digital shipyard will depend on craftsmen becoming knowledge workers or, perhaps more practically expressed, it will depend on a competency-based approach. Organizational strategy and organization design create the context for defining the requisite human resource competencies. The HR system, to support CPLM, must (1) generate competencies through staffing, training and development; and (2) reinforce competencies through the reward system (cf. Ulrich & Lake, 1990).²⁵

²⁵ See Von Glinow, Driver, Brousseau, and Prince (1983) for a more thorough discussion of the components and conceptual issues involved in an integrated human resource system, and Ulrich and Lake (1990) for other issues related to the competency-based approach.



Table 8. Questions for Assessing Manufacturing Capability From a Human Resource Perspective

Staffing, Training and Development	1. Is the organization recruiting, assessing, and assigning personnel to fit positions and the technology? 2. Is training designed and implemented to develop collaborative individual and team skills including collaborative mind-sets and attitudes? 3. Is training designed and implemented to develop technical individual and team skills with the CPLM system and its larger system of systems? 4. Do employees have the requisite knowledge to make decisions?
Reward System	1. Are individual and team performance appraisals appropriately integrated <i>or</i> appropriately separated from CPLM information? 2. Are individual and team goals set and integrated with CPLM information? 3. Are rewards and incentives appropriately designed to reinforce collaboration, information sharing, and horizontal processes? 4. Are rewards and incentives designed to support vertical structures and disciplinary/functional knowledge <i>and</i> horizontal structures and product/project knowledge? 5. Are long-term motives and skills being managed through career development to maintain skilled employees?



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VII. Staffing, Training, and Development

A. Staffing the Work

Referring to Table 8, this question addresses staffing in an organization:

1. Is the organization recruiting, assessing, and assigning personnel to fit positions and the technology?

In terms of recruitment and placement, an experienced subject-matter expert noted that the digital shipyard of the future will tie these collaborative tools and information technologies to mobile computing. This is especially useful where workers are separated, as they are in shipbuilding, from inventories, parts, and everyday workstations, and where the number of pages workers must access to properly do the work is so high. One subject-matter expert sees a tremendous opportunity from the “new generation of workers who have I-everythings” and can be expected to welcome and be much less resistant to adopting these new tools. This, of course, will depend on the extent to which interfaces for users are cumbersome versus friendly. Subject-matter experts in the shipbuilding industry have lamented the interface designs, even those from sophisticated vendors. Indeed, some have built their own interfaces for these systems. A well-designed CPLM system can have interfaces customized to the various needs of each individual shipyard.

B. Training and Development

The following questions from Table 8 address training and development in an organization:

2. Is training designed and implemented to develop collaborative individual and team skills, including collaborative mind-sets and attitudes?
3. Is training designed and implemented to develop technical individual and team skills with the CPLM system and its larger system of systems?



An HR area where subject-matter experts are articulate and clear is training. A manager of engineering at John Deere's Harvester Works long ago expressed the lesson learned:

At first, the training focused on the technical area. But then we realized "soft skills" [such as team building and problem solving] were more important. Soft-skills training was the corner-stone of making the process work. (Anderson, 1993, p. 50)

And on the technical side, it is apparent that software and other technologies afford and enable people to be more effective and efficient only if people are competent in using them. The two questions above focus on training for collaborative and technical competencies, which also presumes including CPLM tools when assessing training needs. Note that these competencies are not only intra-organizational, between employees and departments, but include working with—and perhaps extending training opportunities to—valued suppliers and customers.

Question 4 from Table 8 also addresses training and development in an organization:

4. Do employees—especially functional leaders, project leaders and executives—have the requisite knowledge to make decisions?

The CPLM tools distribute information, enabling decentralization and participation in problem solving and decision-making, and facilitating continuous quality improvement. The structural perspective creates demands for competencies in working in teams and across boundaries. Training and education support these changes by developing individuals' professional knowledge base and technical expertise. Thought must be given to the best modes of training for use of CPLM tools: classroom, on-the-job, or even self-paced computer-aided instruction from vendors. In addition, various means of knowledge management—conferences, communities of practice, expert systems—should be considered in order to develop and sustain requisite competencies for use of CPLM tool suites.



VIII. Reward Systems

A. Goal Setting and Performance Appraisal

Taken from Table 8, these questions address goal setting and performance appraisal in an organization:

1. Are individual and team goals set and integrated with CPLM information?
2. Are individual and team performance appraisals appropriately integrated or appropriately separated from CPLM information?

Subject-matter experts have indicated that it is important to integrate goal setting for individuals and teams using CPLM tools. Goal setting can be important in clarifying expectations and confronting conflict, which can be especially challenging in the complexity of matrixed organizations.

Because CPLM tools offer the potential for monitoring and appraising performance, one subject-matter expert notes that some initial resistance is to be expected when introducing CPLM technologies:

You are able to better understand how long it took somebody to do something. ... If I routed a task for you to do, and you haven't opened it for a week, I know it as a manager that you haven't opened it for a week. So it gives management better visibility and traceability of the work. I don't think any worker is really happy...feeling like they are being micro managed, and they don't really want management looking over their shoulder. I think in the long term it is a benefit and everybody is ok with it. In the short term there is always a little push back.

One possible long-term payoff for the employees is greater job security due to their increased productivity and knowledge bases. The subject-matter expert quoted here argued that the short-term push back is likely to be overcome because greater efficiency and quality of work will allow more ships to be built, resulting in lower costs, growth in the business, and a steady supply of work. It also may be less frustrating in that workers using CPLM tools will better know what is expected of



them and won't have to do as much difficult and frustrating (and costly) rework. The alternative may be to lose out to global competitors, and to personal unemployment.

We should note that the use of goal setting in performance appraisals is an area needing research. Deming (cf. Elmuti, Kathawala, & Wayland, 1992; Soltani, Van der Meer, & Pei-chun, 2006) has famously argued against traditional performance appraisals as leading to sub-optimization as one individual or group seeks to optimize their local indicators above everything else, including the goals of the overall organization. Indeed, in the next section, a subject-matter expert describes problems resulting from tracking and assessing individuals on meeting individual goals rather than their collaborative behaviors. Design options that might be considered include redesigning the structure to empower team members and partners in other departments to contribute to the individual performance appraisal by indicating how frequently they are appropriately notified, which will allow HR to track how often individuals notify other departments.

B. Rewarding Desired Behaviors

The following questions from Table 8 address the reward systems used in an organization:

3. Are rewards and incentives appropriately designed to reinforce collaboration, information sharing, and horizontal processes?
4. Are rewards and incentives designed to support vertical structures and disciplinary/functional knowledge and horizontal structures and product/project knowledge?

The reward system should reward desired behaviors and thus align individual and organizational goals (Kerr, 1995; Lawler, 1986). The structural requirements of CPLM systems require collaboration, information sharing, and the ability to manage and navigate horizontal processes. However, reward systems may actually punish collaboration and information sharing, because taking time to inform others and work with them to solve problems is time taken away from generating personal metrics



that the system does attend to. A subject-matter expert familiar with shipyards describes how this can occur even “at the top floor”:

Each department has to maintain some key performance indicator matrices. They have to make sure that they are within some kind of a cost and budget analysis or whatever it is, the timing analysis. So if you tool around these yards, wherever it is, they do everything in their power to get the material away from their desk as quickly as they can, to give it to the next guy, and then if a change happens, get it off their desk as quick as they can. But it is not that they want to make sure they are educating somebody else, they are doing it so that their numbers look good. ... The collaboration has to come from that relationship, so that when design sees a change, not only is he able to address the change, but the other organizations are notified if the change affects them up front so that they can make the necessary adjustment to hold off or stop workages before they cause new work or before they order unnecessary material or things like that. So ... all of the silos have to be removed. That is such a difficulty, but the technology is there to support it.

Again, this quote describes people meeting their individual goals to look good, but sub-optimizing the overall system. The reward system is not incentivizing collaboration, but reinforcing the hierarchical structure. The CPLM technology may be there to support collaboration, but it will not happen if structure and incentives are not aligned with technology. Management might profitably diagnose their reward system by asking their people if they would be rewarded, ignored, or punished if they took time to share information versus focus on getting work through their work station as quickly as possible (Kerr, 1995).

The vertical processes and hierarchies in organizations also need to be supported by the reward system. Decentralization of authority needs to be accompanied by accountability, and reward systems also are accountability systems. Individuals who, despite training and learning opportunities, fail to perform to standard may need to be placed in different positions, and sometimes let go. Individual stars who fail to collaborate represent a test of the reward system—and of the *culture*—of organizations. Indeed, the pattern of behaviors that are rewarded and approved, versus those that are ignored, versus those that are punished and disapproved may well be the primary driver of culture and the incentive to use the capabilities of CPLM tools.



C. Career Development

The final question from Table 8 is as follows:

5. Are long-term motives and skills being managed through career development to maintain skilled employees?

As complexity and technological sophistication increase, the importance of knowledge increases, and the value of retaining valued knowledge workers becomes higher. Individuals vary considerably in what rewards they value and in what they expect from their careers. For example, some may want to deepen their technical and functional skills and would consider promotion outside of these areas of expertise more punishing than rewarding. Others measure success by promotions and level of responsibility, as well as their interpersonal and managerial competencies (Schein, 2006). The career is where the individual's long-term interests, motives, values, knowledge, and skills interface with the pattern of work experiences, projects, and positions they will have. Successfully managing careers serves the interests of the organizational member (of whatever rank) and the organization. Although there are limited studies of the careers of design engineers (Petroni, 1998), considering the needs of the organization and of individuals around CPLM and careers (i.e., taking a long-term perspective on motivation, talent, and organizational roles) is not addressed in any depth in the literature. The organization has an opportunity to develop trust with employees to the extent that relationships with management and HR management are based on development as well as assessment.



IX. Consequences and Trade-offs of Design Decisions and Human Resources Policies

Human resources policies, practices, and procedures generate synergies to the extent that they support and are congruent with organizational structures and CPLM systems. People perform when they have the competencies; when they have the motivation; when they have the resources, and when they are clear about expectations. Structure is a major part of the context within which people work. The human resource perspective focuses on the human resource context that selects and trains, sets goals and rewards, and offers a relevant career path.

The need for collaborative mindsets and trust in the digital shipyard points to the importance of rewarding collaboration and information sharing, and of recruiting and selecting people with talents that include communication skills as well as the disciplines required of highly formalized, standardized technologies. How this is best done and will be best done remains a fairly uninvestigated domain. Again, if the organization's management of its human resources is inadequate, then the organization is at high risk that their structural roles will be dysfunctional or inadequately filled, and their CPLM tools will not be used to the fullest extent.

In the previous section, we noted that concurrency, cross-functional teams, decentralization, and distributed information systems are congruent with intrinsic task motivation, and this has positive implications for intrinsically motivating the performance and retention of knowledgeable workers. Job design is as much an HR issue as a structural issue, and a hypothesis that needs investigation is the following: Organization design, enabled by CPLM tools, should include multiple functions in the organizational processes.



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X. Assessing and Developing Manufacturing Capability from a Technical Perspective

Shipbuilding firms and their vendors are working—appropriately, often in collaboration—to develop better designed software packages with innovative features. The list of features in Table 5, shown earlier, illustrates this, and it can be reframed as a set of questions for organizations to consider. As customers incorporate various CPLM modules and functionalities, they must consider their integration with structure and human resources.

An initial intention of this part of the report was to develop a sense of how organizations mature and develop collaborative capacity with these technologies. Previous research already indicated that there is no one path to developing collaborative capacities with organizational partners. The starting point is strategic commitment and strategic communication by top leadership. After this, a systemic approach must be taken, but there is no one path or recipe for success. Perhaps one organization will begin by developing metrics while another will focus on training and rehearsals. It appears that the description of how one develops capability and maturity with CPLM has a parallel lesson: although there may be a common starting point, there are multiple paths toward reaching maturity that are organization specific. The starting point focuses on organizing the increasing complexities of design and technical publications that traditionally have been “housed in disparate and discrete authoring systems and organizational domains” (Siemens PLM Software, 2011, p. 3). Similarly, one subject-matter expert indicated the following, when asked about a life stage model:

It becomes customer specific for us. We always think of foundationally, let's get our data managed. Once we have our data configuration controlled and managed, then we can start using some of the other capabilities, the functionalities, whether we are managing a relationship with our suppliers, or understanding KPI's (key performance indicators) through reporting and analytics, or leveraging the collaborative data environment for requirements management systems engineering, engineering, digital manufacturing, or electronic accumulation of shop floor work. We primarily think of starting out



with that foundation—managing that data, managing the business workflow for people to collaborate and communicate. However, sometimes we do have customers that say, but our initial pain right now is really just understanding the yard, the production. So all we really want to do is model our facility and understand what is our throughput and capacity. If that is the case, we start there. We start where we see the most value for our customers.

Table 9. Questions for Assessing Manufacturing Capability From a Technical or Technological Perspective
(cf. Siemens CPLM Software, 2012; Haddad, 1996)

▪ CPLM in a system of systems	1. Are the CPLM and Enterprise Requirements Planning (ERP) systems appropriately integrated? ▪ Is the master data created in CPLM effectively uploaded into the ERP system? ▪ Are orders generated in ERP effectively downloaded for execution? ▪ When production orders are completed, does feedback to CPLM effectively enable revised process plans for production orders? 2. Are the CPLM and Manufacturing Execution System (MES) appropriately integrated? ▪ Is order data and master data effectively downloaded from CPLM to MES for all orders? 3. Are MES and ERP appropriately integrated? ▪ Are completed production orders effectively backflushed from MES to the ERP?
▪ Facilities	1. Are there specially constructed areas and facilities that provide for teams, units, and task forces to temporarily or permanently work together?

Note. One perspective on the digital shipyard (Siemens PLM Software, 2012) that is especially useful raises questions on its use as an Engineer to Order System of Systems; of course, CPLM is part of a system of systems, and this raises many questions, only a few of which are presented, as illustrative, in Table 9. In addition, the architecture and facilities may also prove to be important enablers of collaboration.

A. The Engineer to Order System of Systems

The following questions are illustrative of the required integration of the system of systems within which CPLM functions (Siemens PLM Software, 2012).

Siemens' report argues for the criticality of collaboration and culture for success with



CPLM systems, but they also describe a system of systems within which CPLM should be integrated.

1. Are the CPLM and Enterprise Requirements Planning (ERP) systems appropriately integrated?
 - Is the master data created in CPLM effectively uploaded into the ERP system?
 - Are orders generated in ERP effectively downloaded for execution?
 - When production orders are completed, does feedback to CPLM effectively enable revised process plans for production orders?
2. Are the CPLM and Manufacturing Execution System (MES) appropriately integrated?
 - Is order data and master data effectively downloaded from CPLM to MES for all orders?
3. Are MES and ERP appropriately integrated?
 - Are completed production orders effectively backflushed from MES to the ERP?

This system of systems results in information that is more easily shared with a payoff of visibility and traceability for business processes (Siemens PLM Software, 2012). Other sections of this report have provided more depth on questions relevant to CPLM itself.

B. Facilities

4. Are there specially constructed areas and facilities to facilitate for teams, units, and task forces to temporarily or permanently work together?

The literature on design (Heragu, 2008; Kunz, Luiten, Fischer, Jin, & Levitt, 1996; Martin, 2006) indicates that the design of facilities is likely to be an important factor affecting human interactions and creativity. Subject-matter experts proudly described new buildings and facilities as being important for facilitating effective



communication, creativity and teambuilding. (Some also describe the importance of co-locating design teams in the earliest stages of design.) While CPLM tools allow virtual communication and information sharing, being able to co-locate, permanently or temporarily, members of design teams and other functions may make employees more likely to share information, build trust, and understand each other's strengths and weaknesses. Misunderstandings involving tacit knowledge or communication styles and differences in terminology may be cleared up more effectively. Future virtual interactions may build on trust and understanding built in face-to-face interactions. CPLM tool designers must take into account this important aspect of collaboration for teams that are in different geographical locations. This is a potential future enhancement to the capabilities of CPLM systems that should be included in future version releases of the tool suites available to practitioners in shipbuilding organizations.

C. Collaborative Capacity

Figure 12 presents an organizational design image of the suggestions for CPLM shipbuilding organizational users in the foregoing discussion. Successful design of the digital shipyard requires the systemic integration of a number of design factors (e.g., decentralization) within five policy domains (e.g., Vertical Processes). Taken together, attention to these design factors and their coherence in forming an integrated system of systems can contribute to generating collaborative behaviors, work processes, and a collaborative culture. The five domains comprise Vertical Processes, Departmentation and Horizontal Processes, Human Resource Flow, Reward Systems, and Technical Systems. Human Resource Flow is concerned with the flow of competencies, embodied in human resources, into the positions and processes of the structure. In order for an organization to get the most out of its CPLM technology, all of these factors must be addressed. This is clearly not an exhaustive list, but the factors provide a reminder of the factors specified in the previous sections (cf. Hocevar, Thomas, & Jansen, 2006; Jansen, Hocevar, Rendon, & Thomas, 2008).



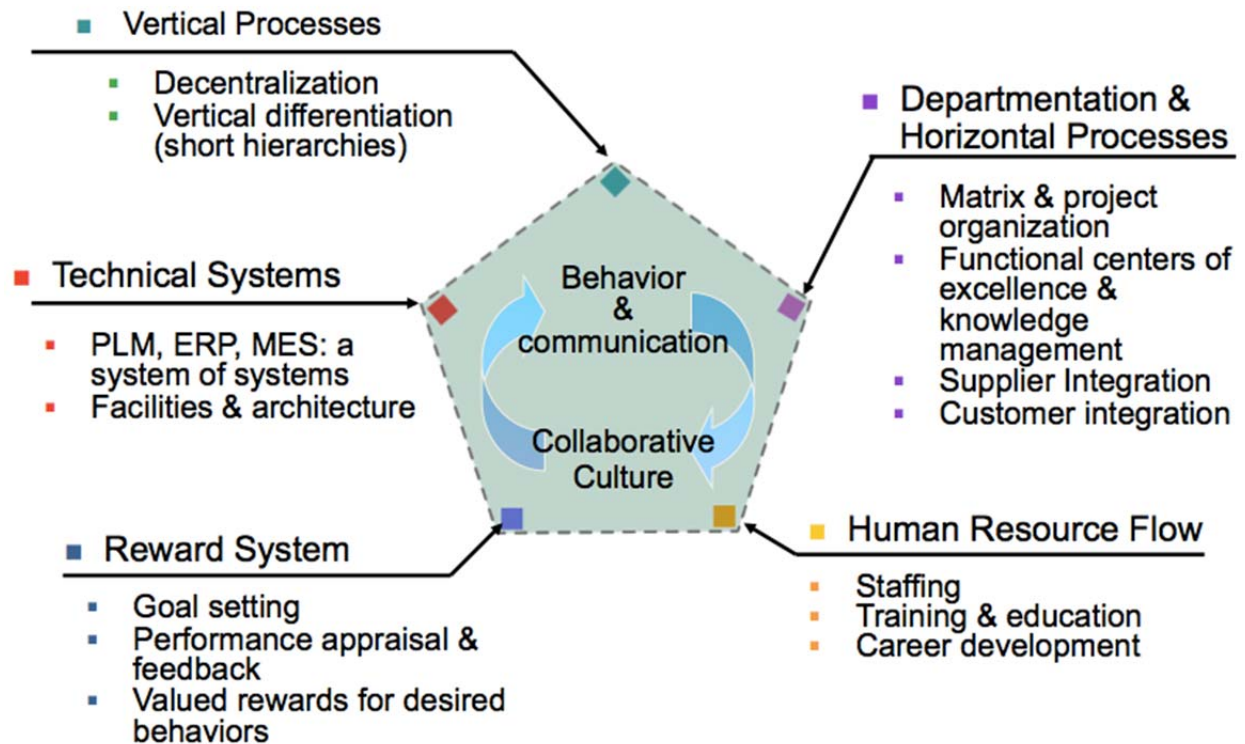


Figure 12. Collaborative Capacity and the Digital Shipyard of the Future

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XI. Summary

Research has shown that U.S. Navy ship costs are rising out of control and far outstripping inflation. A large majority of the increases in these costs is due to labor as well as rework in construction.

CPLM technology has provided tremendous cost savings to a variety of manufacturing industries through reduced engineering times and lower labor costs from rework. To date, there have been only some slight inroads in the use of this promising technology in the shipbuilding industry. For example, one large ship builder found that, by using this technology, there was up to a 22% reduction in design engineering times. Leadership from this shipbuilding company also is planning to exploit the potential for using this tool set to enable faster and more accurate design engineering processes with its geographically dispersed partners around the globe.

Because CPLM integrates manufacturing processes while also supporting data-sharing and collaboration, it has great promise for reducing costs in the U.S. Navy shipbuilding processes

Some technologies, such as 3D LST, also have the potential to offer cost and material savings to U.S. Navy shipbuilders, but studies have shown that the technology does not currently meet the accuracy requirements set by the U.S. Navy. However, it is only a matter of time before these standards are met by the producers of this technology. So, it is important that the U.S. Navy continually monitors this technology, so that when accuracy is up to standards, the Navy can realize the cost savings as early as possible when this technology is implemented in the digital shipyard.

In order to implement this technology and receive the maximum cost-benefit ratio from it, shipbuilding companies must attempt to modernize their businesses in



their structural, human resource, and technology utilization practices. The CPLM technology relies on, and at the same time fosters, an environment of collaboration within organizations using it. As such, this research proposed a framework for evaluating the readiness of shipbuilding organizations to implement the technology. Successful implementation requires an assessment and adjustment of the U.S. Navy shipbuilding organizational structure, human resource practices, and technology integration policies. Taking these critical factors into account will ensure a higher probability of successful implementation of the technology, fostering the cost savings it promises. Implementing this technology should be a high priority in U.S. Navy shipbuilding organizations to enable them to join other prominent manufacturing industries in reaping the rewards of effective collaboration.



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