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Total Ship Design Process Modeling

David A. Helgerson, CSC Advanced Marine Center
Seth Cooper, NAVSEA05C
Gilbert Goddin, Naval Surface Warfare Center, Dahlgren
Gene Allen, Naval Surface Warfare Center, Carderock Division
Daniel Billingsley, Grey Ghost, LLC
Sean Gallagher, Naval Surface Warfare Center, Carderock Division

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NPS Acquisition Research Program
Attn: James B. Greene, RADM, USN, (Ret.)
Acquisition Chair
Graduate School of Business and Public Policy
Naval Postgraduate School
Monterey, CA 93943-5103
Tel: (831) 656-2092
Fax: (831) 656-2253
E-mail: jbgreene@nps.edu

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Preface & Acknowledgements

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

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

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

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

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

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- Program Executive Officer, Littoral Combat Ships

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

James B. Greene Jr.
Rear Admiral, U.S. Navy (Ret.)

Keith F. Snider, PhD
Associate Professor

Panel 12. Revitalizing the Ship Design and Shipbuilding Process

Wednesday, May 16, 2012	
3:30 p.m. – 5:00 p.m.	**Chair: Robert "Bob" G. Keane Jr.,** President, Ship Design USA, Inc. ***International Naval Technology Transfer: Lessons Learned from the Spanish and Chilean Shipbuilding Experience*** Larrie Ferreiro, *Defense Acquisition University* ***Total Ship Design Process Modeling*** David A. Helgerson, *CSC Advanced Marine Center* Seth Cooper, *NAVSEA05C* Gilbert Goddin, *Naval Surface Warfare Center, Dahlgren* Gene Allen, *Naval Surface Warfare Center, Carderock Division* Daniel Billingsley, *Grey Ghost, LLC* Sean Gallagher, *Naval Surface Warfare Center, Carderock Division* ***Revitalization of Naval Surface Warfare Center Excellence in Early Stage Combat System Engineering*** Ashby Hall, Terence Sheehan, and Mark Williams *Naval Surface Warfare Center, Dahlgren*

Robert "Bob" G. Keane Jr.—Mr. Keane is the president of Ship Design USA, Inc. Prior to starting his own consulting firm, Mr. Keane worked at the Advanced Marine Center of CSC and at the Naval Sea Systems Command (NAVSEA) for 35 years. Mr. Keane was a member of the Senior Executive Service (SES) for 21 years. He last served as executive director of the Surface Ship Design and Systems Engineering Group in NAVSEA. He also served as director of the Total Ship Systems Directorate (Code 20) at the Naval Surface Warfare Center Carderock Division (NSWCCD). Mr. Keane previously held senior leadership positions in NAVSEA as chief naval architect and deputy director, Surface Ship Design and Systems Engineering Group; technical director, Ship Design Group; director, Ship Survivability Sub-Group; director, Naval Architecture Sub-Group; director, Hull Form Design, Stability and Hydrodynamics Division; head, Hull Equipment Branch; and as a ship arrangements design specialist.

Mr. Keane is widely recognized as an expert in naval ship design, is a plank holder in the Navy's Center for Innovation in Ship Design at NSWCCD, and has fostered the professional development of engineers and scientists in government and industry. He received his Bachelor of Engineering Science in mechanical engineering from Johns Hopkins University, his Master of Science in Engineering in ship hydrodynamics from Stevens Institute of Technology, and his Master of Science in Engineering in naval architecture and marine engineering from the University of Michigan.

Mr. Keane is currently serving as chair of the American Society of Naval Engineers (ASNE) and Society of Naval Architects and Marine Engineers (SNAME) Joint Ship Design Committee, as a member of the ASNE-SNAME Joint Education Committee, as a member of the SNAME Technical & Research Steering Committee, and ex-officio member of the ASNE-SNAME Strategic Alliance Committee and he is a current member of the ASNE National Council. He recently served as chair of the highly successful ASNE-SNAME International Electric Ship Design Symposium (ESDS) in February 2009, and has served as chair of the ASNE Flagship Section, chair of the SNAME Chesapeake Section, president of the Association of Scientists and Engineers (ASE) of NAVSEA, regional vice president of SNAME, and president of the D.C. Council of Engineering and Architectural

Societies. He has held numerous other leadership positions in these societies, and has published frequently in the *Naval Engineers Journal* and *Journal of Ship Production*.

Mr. Keane has received many honorary awards including the Secretary of the Navy Distinguished Civilian Service Award, Department of the Navy Superior and Meritorious Civilian Service Awards, SNAME David W. Taylor Medal, ASE Silver Medal, ASE Professional Achievement Award, SNAME Distinguished Service Award, two SNAME Elmer Hann Awards for Best Paper, ASE John Niedermair Award for Best Paper, and election as a Fellow of SNAME. Mr. Keane and his wife, Judy, have three sons and four grandchildren. [keanerg@comcast.net]

Total Ship Design Process Modeling

David A. Helgerson—Mr. Helgerson is the technical director for CSC Advanced Marine Center. He obtained his degree in naval architecture and marine engineering from Webb Institute of Naval Architecture in 1977 and is a licensed professional engineer (VA). His 34 years of experience include naval and commercial ship and craft design, construction, testing, maintenance, and repair. He has performed and managed a wide range of tasks in support of ship and ship systems design. He is an active participant in professional society activities, and serves as Chair of the Society of Naval Architects and Marine Engineers Technical & Research Committee. Helgerson has participated in all of the ONR-NAVSEA-HPC sponsored Ship Design Process Workshops. He has served as workshop facilitator to explore the application of new tools and methodologies, and capture expert knowledge to develop the Navy Ship Design Process Model. He assisted SEA05D in the development of the Ship Design Process Roadmap and continues to provide support to NSWCCD, SEA05D, and SEA05T in related efforts. [dhelgers@csc.com]

Seth Cooper—Mr. Cooper is the senior naval architect and cost estimator, NAVSEA 05C. He has worked as a ship concept manager, a technology transition program officer, and a ship cost estimator, and is currently in charge of NAVSEA investment in software development. [seth.cooper@navy.mil]

Gilbert Goddin—Mr. Goddin is a systems engineer at Naval Surface Warfare Center, Dahlgren Division (NSWCDD). He earned his BS degree in electrical engineering from Old Dominion University in 1986. Goddin joined NSWCDD in 1990, where over the past 20 years he has performed combat systems engineering and analysis related to numerous initiatives including the Aegis Combat System, Aegis ballistic missile defense, the Area Air Defense Commander support system, the USS George H. W. Bush (CVN 77) and PCU Gerald R. Ford (CVN 78) warfare systems, the DDG 1000 mission system, and product line systems engineering. Goddin is currently the chief engineer of the Warfare Systems Department at NSWCDD. [gilbert.goddin@navy.mil]

Gene Allen—Mr. Allen is a senior engineer with NSWCCD, Code 22. His career has focused on using computers to improve engineering. He uses collaboration as a tool to bring together needed resources for technology development and commercialization as described in “Collaborative R&D: Manufacturing’s New Tool,” published by Wiley. Allen’s systems engineering expertise is from his experience as a Navy nuclear trained officer and his Nuclear Engineering degree from MIT. He has served as defense procurement/economic development advisor to Senator Byrd, and retired as a commander in the Navy Reserve after working on the staff of the Chief of Naval Operations for 15 years and spending five years on active duty on USS Arkansas (CGN-41) from pre-commissioning through shock test and completing first deployment. Allen worked at MSC Software as director, business development, federal group, and as director, collaborative development, from 1993 to 2008, where he established himself as a leading champion for simulation as a means to improve the ability to use computers as tools to improve engineering. [gene.allen@navy.mil]

Daniel Billingsley—Mr. Billingsley is the senior partner of Grey Ghost LLC, an Annapolis, MD, firm that provides confidential analysis and assessment of information systems for the marine industry. Billingsley formed Grey Ghost in April 2007 following 38 years of government service. After graduation in 1969 with a BS in engineering science from Louisiana State University, most of Billingsley’s early career was in ship structural design and engineering at Puget Sound Naval Shipyard, the Naval Ship Engineering Center, and in structural safety policy development at the Coast Guard Office of Merchant Marine Safety. After joining the Naval Sea Systems Command in 1982, most of his career involved the development, implementation, and application of computer tools for ship design. Billingsley played a key role in initiation of the Navy/Industry Digital Data Exchange Standards Committee in 1986 which led to the current ISO 10303 Industry Standards for the Exchange of Ship Product Model Data (the STEP standards). He served as Head of NAVSEA’s Computer Aided Engineering Division from 1988 to 1997, as CAE program manager from 1999 to 2001, and as the technical warrant holder for product data integration and exchange from 2002 to 2004. His last assignment was as the Navy program manager for the National Shipbuilding Research Program from 2004 to 2007. He transitioned NSRP from an OPNAV-funded program headed for

termination in FY 05 to a PEO- and congressionally funded program with ~ $40 million in federal and industry matching funds in FY 07. While at NAVSEA, Billingsley won the Meritorious Civilian Service Award in 1991 and the Superior Civilian Service Award in 2007. [dwbillingsley@gmail.com]

Sean Gallagher—Mr. Gallagher earned a Bachelor of Engineering in mechanical engineering at the University of Delaware, an MS in mechanical engineering at the University of Wisconsin–Madison, and an MS in systems engineering from Pennsylvania State University. He has worked as a mechanical engineer at the Naval Surface Warfare Center–Carderock Division (NSWCCD) since 2004 and is currently a member of the Advanced Machinery Systems Integration Division in Philadelphia, PA. He is also co-author of four patents as a result of his work for Carderock's Innovation Center team investigating the sea-based transfer of personnel and cargo.

Abstract

With support from the Office of Naval Research and the Office of the Secretary of Defense High Performance Computing Program, the Naval Sea Systems Command and the Naval Surface Warfare Centers have been collaborating on the development of a Ship Design Process Reference Model (SDPRM). Through a series of workshops and separate meetings, expert knowledge on the design process has been captured using new process modeling tools. The practice and discipline of process modeling has provided immediate benefits and promises longer range benefits in process planning, software assessment, process improvement, and training. Better understanding and management of the design process will enable more cost effective design.

Introduction

Robust design of ships and ship systems has become increasingly difficult in recent history in part because the Navy has transferred a substantial portion of its in-house ship design capability to private industry. This is problematic for design because it reduces our own technical competency as well as creates the need to coordinate design efforts across multiple contractors and potentially dozens of subcontractors. Efficient flow of information is one of the keys to a quality design process that creates a high-quality product; this becomes more difficult as the number of the stakeholders increases and the nature of their objectives diversify. Additional difficulty in ship system acquisition is brought upon by the increasing complexity of the systems themselves, which then has tremendous impact on the design and integration requirements. These include, but are not limited to hull, mechanical, electrical, and mission systems. Therefore, when problems arise, not only is there an increase in the number of systems affected, but the magnitude of the impact also increases. While the ship design considerations are becoming increasingly complex and interconnected, there remains a need to inform decision-makers of all of the options. A design process model can help to achieve these goals by allowing tradeoffs to be made between design cost, design schedule, and design quality while a program is being planned, executed, and tracked.

Past efforts to document the U.S. Navy ship design process have not produced a persistent, easily used model, have not kept pace with the changing nature of the acquisition process, and have not reflected the interaction of the many participating organizations involved in surface combatant design. An understanding of the baseline ship design process is needed in order to be able to improve the process and identify where software tool development would be most beneficial. The Office of Naval Research and NAVSEA sponsored a series of Ship Design Workshops, which have provided a forum for the Navy ship design community to review the state of practice and emerging technologies impacting the field. The expertise of the individuals from the Navy, industry, and academia attending the workshops represented a valuable resource of design expertise and knowledge of the design process.

The workshops included breakout sessions by ship design discipline, including hull, survivability, machinery, and others. The coordinators of these breakout sessions had captured from the design experts much of the data needed to model the overall process. Each breakout session allowed experts to reach a consensus on the activities that comprised particular processes and the characteristics of those activities. Typically, data on inputs, outputs, activity duration, learning curve, required resources, and descriptions of the processes were captured. When all of the activities are connected together, the entire complex ship design process emerges.

The PLEXUS® software used by the process modeling team has proven to be effective and easy to use. The team evaluated a number of software tools that supported process modeling. A homegrown database effort was initiated to capture and manage design process data. Exploring the use of PLEXUS, it was determined that the basic objectives could be met with commercial off-the-shelf (COTS) software, and subsequent modeling was performed using this tool. Other software, such as ADEPT® and LATTIX®, were investigated and found to have merit. PLEXUS offered the ability to capture process data in a database, display it in elegant flow chart formats that are navigable using simple user interaction, produce design structure matrix displays that compactly show the dependencies between activities, produce Gantt charts for the process and show critical paths, export data to other applications such as Microsoft Project® or Primavera®, and perform process simulations that can investigate risk, cost, and schedule trade-offs. Prior efforts to capture design expertise and knowledge did not produce persistent products. Reports may have included charts or text describing the process, but these were not easily updated and, as a result, not kept current with the changing organization and requirements. Typically, these reports were known only to those that created them. An important philosophy regarding the team’s selection of process modeling tools is that the organization should not be dependent on a specific tool but should use tools that can transfer data to other tools when the alternatives offer better capability. This philosophy is analogous to a ship design product model. Process data is gathered in a well-defined, sharable format, and we view that data in multiple ways. Every view of the process information, whether in Gantt chart, DSM, “boxes and arrows,” or other format is based on the same core data. Plexus couples a database with a dynamic user interface to provide an agile and powerful process modeling tool.

In addition to being able to capture and represent the process, the software and the model have the additional advantage of being able to simulate the process and, through simulation, optimize the process. The complexity of the process means that there are many possible iterative loops. Anyone familiar with warship design knows that designs can be tweaked and iterated forever, but in reality we have to make some compromises. There may be some iterations that we do fewer times, or some we don’t do at all, settling for historical data and rules of thumb. Even given a well-defined process and flow of information, there is a nearly infinite number of possible paths one could take to reach a completed design, and each path can be represented by a unique Gantt chart. The Gantt charts show each task as it is performed in time and if it is performed a second or third time during an iteration. Some tasks, when performed a second time to refine that area of the design, show a real benefit, by improving the quality of the design, and others just add time and cost to the process. But there is no way of identifying these processes without defining the whole process and looking at all of the alternatives. We do this through simulation.

A design process is simulated as a series of discreet events. There is some variability in the length or cost of each event and some learning that happens as certain events are repeated, so each simulation can be run several times to take into account the randomness. Once the final event is completed, the simulated schedule time and cost for that path through the design process is determined. The schedule time and cost for each variation of doing the design process can be compared, but there is one more important factor that we need to analyze in order to compare properly: that is design "quality," or its inverse, "risk." This is done by tracking a metric for quality as we move through the process. The quality is always less than perfect but is improved based on doing more iterations through the individual activities. The details of this method are a subject for another paper, but the important point here is that there is an infinite number of paths we can take to complete a ship design, each represented by a unique Gantt chart, and we can simulate each and grade them in terms of cost, schedule, and quality.

If two paths through the design process are compared and found to have the same length of schedule and the same cost but one has a better quality, then the one with the better quality is clearly better. One design is said to "dominate" the other. Any design that is dominated by another is clearly not an optimal path. If a path is superior to all other paths in any one of the three categories—cost, schedule or quality—then that path is said to be "non-dominated," or "Pareto optimal." When many simulations are completed, we are left with several "non-dominated" paths. This set of paths now represents an optimized trade-space for trading off cost, schedule, and risk. It is then up to other external concerns such as budget, politics, and urgency to determine the proper path forward, but this can be done with the knowledge of, for instance, how much risk you are taking on in order to shorten your schedule and save costs.

Each surface ship class in the United States Navy has a set of defined mission requirements and capabilities that it must perform, both as a single entity and as a member of a battle force. Similarly, each ship class has a projected operating environment within which it is expected to carry out its missions. The total ship represents a formidable warfighting asset with a specific set of capabilities to navigate, maneuver, communicate, project power, and provide defense of key, high value assets both at sea and ashore. The required operational capabilities for Navy ships are executed by the ship itself as well as by the warfighting systems that are resident aboard the ship. The collection of these warfighting systems is referred to as the mission system. The ship and mission system designers must design and integrate systems to satisfy these complex and demanding operational needs. The ship design process should specify the necessary engineering activities and interdependencies between engineering disciplines and engineering organizations to design, build, and deliver quality, useable products for the warfighter.

Although the ship and the mission system must come together into a single total ship design that can execute mission requirements, two distinct and separate design areas emerge during the acquisition phase. One area is the design of the hull, mechanical, and electrical (HM&E) aspects of the ship, which is referred to as ship design integration. The other area is the design and integration of the mission system. Ship design integration focuses on areas such as hull systems, propulsion/power/machinery, stability, hydrodynamics, human systems, and survivability. The mission system design area focuses on the design and integration of systems to enable the ship to counter emerging threats in its intended operating environment.

The ship design integration and mission system design areas come together at the points where mission system is to be installed on a given ship. The placement of systems aboard ship has implications for ship design integration. Depending on the nature of mission system upgrades required to counter evolving threats, mission system changes could be software focused, hardware focused, or both. The extent of the hardware changes and the required placement aboard ship will determine the severity of impacts on the ship design integration process. These ship impacts can be as minimal as new cable runs between existing equipment suites, or as severe as the installation of a new topside element that will have major ship structural and stability impacts, such as the installation of a new high power, high capability sensor system high in the deckhouse. Other potential impacts include changes to ship space arrangements, which could require changes to power and cooling locations to accommodate new equipment. In either case, the ship design integration community needs to understand the physical details of the mission system equipment suite as well as the locations for placement of specific pieces of equipment, and this information is required as soon as possible during their concept design phase. However, in most cases the mission system information required by the ship design integration community is not available when needed. Further, from a mission system perspective, knowledge and insights into information needs by the ship design integration community is not generally well understood. Similarly, from a ship design integration perspective, the type of mission system design information at various stages of design maturity is not widely known. Figure 1 illustrates the alignment of the ship design integration and mission systems acquisition processes.

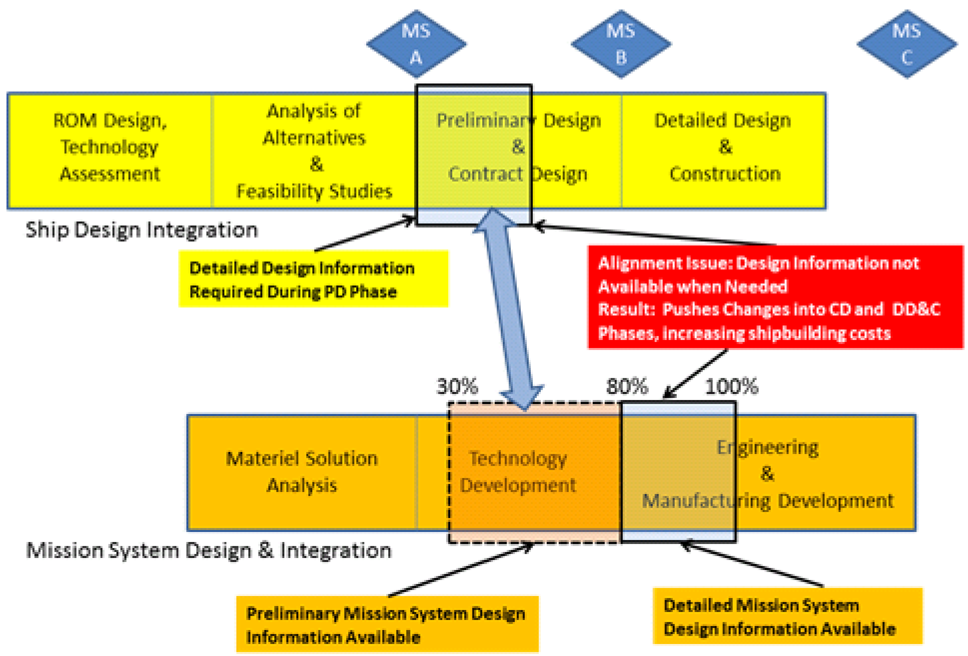

Figure 1. Alignment of Ship Design Integration and Mission Systems Acquisition Processes

The acquisition approaches for the ship and the mission system do not enable mission system details to be available when required by the ship design integration community. These two design areas have different timelines, different products, and different lexicons. In order to overcome this, information is passed between the two design communities at critical decision points, usually after key design decisions have been made. However, as stated previously, the reason for the information need by one community or the realistic expectation of what is available from the other is not well understood across community boundaries. For this to be more effective, regular and detailed interactions should be held between the mission system and ship design integration communities at key process points. A general understanding by each community of the other's design processes would help facilitate these communications. Members of the mission system design community have teamed with the ship design process modeling team to define the mission system design process. This work to define the ship design integration and mission system design processes in a single process modeling tool, including the required interactions between the two design areas at key process points, should help alleviate many of the design inconsistencies that have been an issue in the past.

The review of the mission systems portion of the SDPRM by representatives from the combat systems community at the 5th Ship Design Workshop revealed the major disconnects between ship design and combat systems communities. The mission systems portion of the model had been drafted by naval architects. While it represented what they thought was needed in mission systems, it did not reflect how the combat systems community designs weapons systems. Senior representatives from the combat systems community used the Plexus model to describe their own process through a series of meetings at NSWC Dahlgren and two Combat Systems Design Workshops. It became evident that similar efforts at SPAWAR, NAVAIR, and other organizations would have similar benefit.

Capturing design processes concisely improves communications across the various disciplines needed to design a Navy surface combatant. A well-defined process tells us what information needs to be transferred to whom, when, and why. The integrated process model reduces the risk of talking past each other when we believe we are communicating and the risk of not providing necessary information at the appropriate time.

The use of computer software that helps define, visualize, and optimize the design process offers multiple advantages to the ship design community. The combined efforts of experts from the ship design community, the technical leadership from the Naval Sea Systems Command and its Warfare Centers, the Office of the Secretary of Defense High Performance Computing Program, and the Office of Naval Research have demonstrated the promise of commercial software and the discipline associated with process modeling through a series of workshops and practical applications. The community is now transitioning this practice to ongoing acquisition programs to confirm and explore the value of new process modeling methods by using them to plan design activities.

The SDPRM provides five key benefits to the design community, as listed in Table 1. During the transition of the research effort to current acquisition programs, the emphasis is on project planning. In addition to these foundational benefits of the process model, the team that developed the model sees several organizational benefits in its application.

Table 1. SDPRM Benefits

1. **Staff & Design Tool Capability Analysis—**The original motivation for documenting the process was evaluating new software design tools and resource allocations to determine which offer the greatest return on investment.
2. **Process Improvement—**Evaluating changes in the order of work and the nature of the activities within the design process at various stages determines what benefits might be achieved.
3. **Project Planning—**The fundamental use of a ship design process model is planning specific ship designs and documenting the dependencies between activities so that commitments and expectations among the design team can be understood up front and effectively managed.
4. **Enable Design Execution—**Through documentation of expert knowledge and identification of precursor requirements, deliverables, required resources, applicable references, and other aspects of design effort, the model enables the community to execute the process.
5. **Training—**Finally, by documenting the process, a training resource is created. Young or newly assigned engineers can be shown how the process works and their role in the process. A better educated team member can be expected to be more effective.

An analysis of NAVSEA/PEO Macro Cash Flows revealed that expenditures for ship acquisition and support are comprised of the following:

- 48% for materials—purchased equipment and components plus all other non-labor costs;
- 19% for touch labor—work physically associated with construction and service life support (e.g., fitting, welding, assembling, testing); and
- 33% for knowledge work—analysis, decision making, and problem solving associated with development, construction, and service life support (e.g., engineering, planning, program management).

Cuts in labor cost can provide savings without reducing the capability of the delivered product. Existing processes are undocumented, vary by program, and are frequently based on constraints imposed by last-generation media (e.g., paper). A great deal of labor is spent locating, retrieving, verifying, and transforming information, and on data-checking that would be unnecessary with contemporary design tools. Reducing labor costs can be achieved through improved processes and better tools. Improved processes are difficult to conceive and implement without first acquiring a baseline understanding of existing processes. The Navy Ship Design Process Workshop series has pioneered an effective and agile methodology of mapping activities and information flow.

The Ship-to-Shore Connector (SSC) demonstrated the value of thoroughly planning the design effort before beginning. As we continue to work in an austere budget environment, it is essential that we achieve efficiency wherever possible so that scarce resources are focused on delivering value to the Fleet. Before designing a ship, we need to design the process for how we will design the ship.

Looking back over the previous two years of workshops and other efforts to create and explore how to use the SDPRM, we see immediate, mid-term, and longer-range benefits. These are summarized in Table 2. The community has achieved immediate benefit from the very process of discussing the ship design process. During facilitated sessions with experts who had not documented the processes they follow, the outcome of describing their process was rewarding. In some cases, such as machinery arrangements, the result of facilitating a process model description produced an immediately useful description of how machinery arrangements are prepared and updated as the design evolves. In other cases, segments of the community already had text documents describing their processes, but the new tools permitted powerful visualization of those processes. Particularly rewarding were discussions about the interaction between the hull, mechanical, and electrical engineering (HM&E) effort and the combat systems engineers had to be incorporated. The dialog that occurred over the course of a year included two workshops dedicated to combat systems processes and integration of those processes with HM&E processes. Combining the models forced the community to overcome communication gaps and align separate processes. Participants gained insight from seeing the design process from the perspective of other participants with different contexts. The HM&E community was used to thinking of Milestone B as a very significant end point in the design development, while the combat systems processes continued longer and incorporated more rapid cycles of change. Definitions of even basic terms such as *architecture* conveyed different meanings between communities. An immediate benefit was gained from discussions about the process, definitions of terms, and discussions about dependencies between communities.

Table 2. SDPRM Benefits

Timeframe	Benefit	Discussion
Immediate	Documentation of expert knowledge Creation of process diagrams Improved understanding	Expert knowledge was captured in written and database formats to create a persistent description that could be referenced and used by many.
Mid-term	Expert knowledge documented in the SDPRM enables planning of new design efforts, including: - DDG51 Flight III - LSDX - LHA 8 - R&D and S&T projects supporting designs	The SDPRM lists activities organized within commonly used groupings of activities. While every design may not use every activity in the SDPRM and, in some cases, additional activities are required for unique systems or integrated requirements, the generic model is a good reminder of activities that are generally required. Using the SDPRM speeds up the initial planning process.
Long-range	Common repository of reference process models for many types of ships; configuration controlled data provides consistent information on the required activities. Experts familiar with the data and tools are available to consult with Ship Design Managers when required.	A Center of Excellence for SDPRM enables efficient capture of process information using consistent terminology. Persistent data enables re-use of information with less subjective interpretation of how past programs were managed. The SDPRM becomes a digital "Red Book."

As a mid-term benefit, the current model will offer benefits to DDG 51 Flight III, LSDX, and LHA 8 programs as a result of their exploratory application of the model. The generic ship design process model is anticipated to provide participating programs with benefits that offset the required investment in time. There is also interest in applying the process modeling approach to benefit technology development initiatives. Figure 2 shows a potential application of the reference process model to the planning and management of an acquisition program.

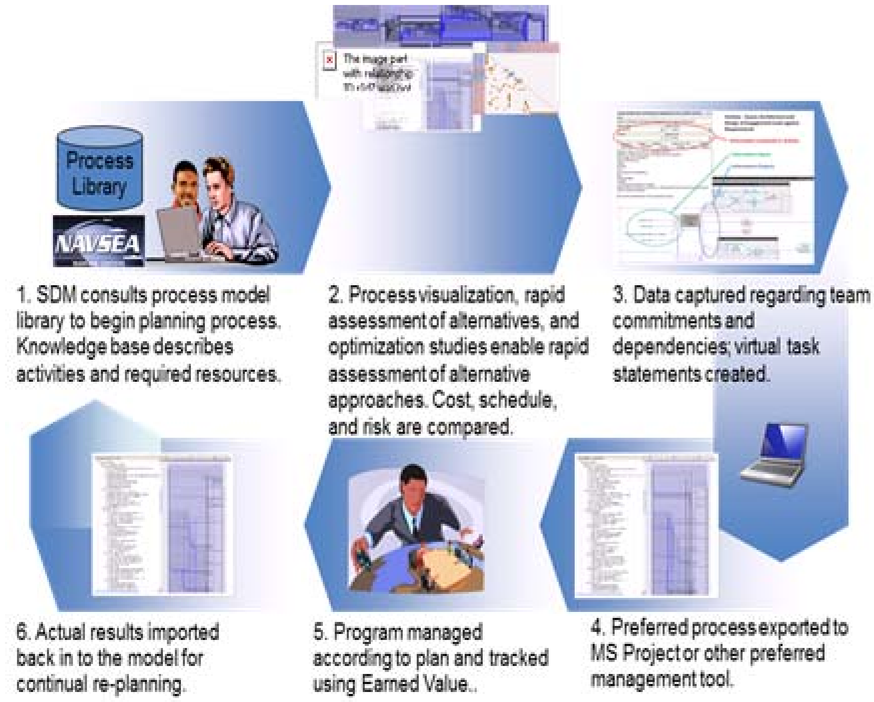

Figure 2. Using the SDPRM in Project Planning and Execution

Future benefits will result from an integrated effort to manage process model data and promote the use of the process model. After obtaining feedback from programs that experiment with the process model, improvements will be made. Feedback regarding actual processes will be gathered and a library of reference models created. NSWCCD will serve as caretaker of the process model data and will implement a configuration management system that will ensure that the data is persistent, available, and useful. The use of the process model information captured using the PLEXUS software should not be mandatory. The team fully expects that the benefits of using a process modeling approach, the general ease of using COTS process modeling software, and the availability of the reference model data, will make using these resources sufficiently attractive that ship design managers will insist on serious process modeling prior to beginning a design.

Acknowledgements

It is important to recognize and thank Ms. Kelly Cooper of the Office of Naval Research for her insightful support of process modeling initiatives. The investment in research has demonstrated the value of both tools and the discipline of process modeling.

Additional Tables: Software Evaluations

The following tables capture key points regarding some of the process modeling tools explored as a result of the workshop efforts.

Table 3. Modeling Tools Explored: ADePT

Modeling Tools Explored: ADePT	
Name:	ADePT design builder
Vendor:	AML Technologies
Cost:	Approx $9K for 36 months
NMCI:	TBD
DADMS:	TBD
URL: http://www.adeptmanagement.com/amltechnologies/tools.html	
Contact Info:	enquiries@amltechnologies.com AML Technologies 3207 Grey Hawk Court Suite 170 Carlsbad, CA 92010 phone: +1.760.727.5829 fax:
ADePT Design Builder is the product of Adept Management Ltd, a management consulting company for the AEC (civil architecture, engineering, and construction) industry. The features of the tool are particularly suited to project management. ADePT was developed in response to demand by customers for a tool to support internal application of their proprietary management technique. It provides a unified tool for project planning, quick identification of deliverable status, and the compound impact of delinquent deliverables. It seems especially powerful for dynamic re-planning in the face of disruption, delay, and late-changing requirements. ADePT is interfaced with PrimaVera, the AEC industry favorite program management tool. An interface to MS Project Manager was in development in 2009.	

Table 4. Modeling Tools Explored: LATTIX©

Modeling Tools Explored: LATTIX©

Name:	LATTIX LDM
Vendor:	LATTIX, Inc.
Cost:	Low cost
NMCI:	TBD
DADMS:	TBD
URL:	http://www.lattix.com
Contact Info:	Frank Waldman Lattix, Inc. 352 Park St, Suite 203W North Reading, MA 01864 phone: +1.978.664.5050 fax: +1.888.662.4497

LATTIX supports design structure matrix analyses. The main focus of LATTIX is the optimization of software using DSM concepts. The software can be used for a variety of DSM and multi-domain applications. It is inexpensive, well supported, suited for a common PC environment, and requires no special hardware or operating system. Output is in classic DSM format and the program interfaces with other data formats and programs with ease. LATTIX does not produce "boxes and arrows" views of processes. It is intended to explore dependencies between objects and has a comprehensive suite of algorithms for ordering sets of data. This software is inexpensive and powerful. It is recommended, but is not sufficient for the purpose of building a process model database.

Table 5. Modeling Tools Explored: PLEXUS

Modeling Tools Explored: PLEXUS	
Name:	PLEXUS
Vendor:	PLEXUS Planning, Ltd.
Cost:	Approx $30K for 12 months
NMCI:	TBD
DADMS:	Approved
URL:	http://www.plexusplanning.com
Contact Info:	Ian Poccachard, Managing Director Plexus Planning University Gte East, Park Row, Clifton, Bristol, BS1 5UB UK phone: +44(0)845.643.9640 fax: +44(0)845.643.9641
Plexus is a database-centric software for documenting and studying processes. Plexus uses a database to capture and manage process information, displaying the information in flow diagrams, design structure matrices, or Gantt Charts. An optimizer permits simulations to be run which permit risk-cost-time tradeoffs and allow alternate processes to be explored. Plexus can import from and export to other software.	

Table 6. Modeling Tools Explored: LOOMEO

Modeling Tools Explored: LOOMEO	
Name:	LOOMEO
Vendor:	TESEON
Cost:	Approx $5K for 12 months
NMCI:	TBD
DADMS:	Approved
URL:	http://teseon.com/en/loomeo-en
Contact Info:	info@teseon.com TESEON GmbH Parkring 4 85748 Garching bei München phone: +49(0)89/307.48.15-0 fax: +49(0)89/307.48.15-29
Loomeo is suitable for a holistic understanding of a system by enabling general exploration of a system, the components that comprise that system, and the relations between them. It is the product of Teseon, a startup company incubated by Technische Universitat Munchen (TUM) and primarily composed of researchers working in support of BMW, Audi, and Boeing. It has a fairly convenient user interface, allows dynamic reconfiguration of DSM/DMM matrices, and allows dynamic development and reconfiguration of force-directed diagrams and supports integration of a multiple-domain matrix. It appears to facilitate visibility, insight and understanding of both complex products and complex processes.	

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