NPS-AM-11-C8P18R02-064

EXCERPT FROM THE PROCEEDINGS

OF THE

EIGHTH ANNUAL ACQUISITION RESEARCH SYMPOSIUM THURSDAY SESSIONS VOLUME II

A Better Basis for Ship Acquisition Decisions

Dan Billingsley, Grey Ghost LLC/Siemens

Published: 30 April 2011

Prepared for the Naval Postgraduate School, Monterey, California 93943

The research presented at the symposium was supported by the Acquisition Chair of the Graduate School of Business & Public Policy at the Naval Postgraduate School.

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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
555 Dyer Road, Room 332
Monterey, CA 93943-5103
Tel: (831) 656-2092
Fax: (831) 656-2253
E-mail: jbgreene@nps.edu

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Preface & Acknowledgements

During his internship with the Graduate School of Business & Public Policy in June 2010, U.S. Air Force Academy Cadet Chase Lane surveyed the activities of the Naval Postgraduate School's Acquisition Research Program in its first seven years. The sheer volume of research products—almost 600 published papers (e.g., technical reports, journal articles, theses)—indicates the extent to which the depth and breadth of acquisition research has increased during these years. Over 300 authors contributed to these works, which means that the pool of those who have had significant intellectual engagement with acquisition issues has increased substantially. The broad range of research topics includes acquisition reform, defense industry, fielding, contracting, interoperability, organizational behavior, risk management, cost estimating, and many others. Approaches range from conceptual and exploratory studies to develop propositions about various aspects of acquisition, to applied and statistical analyses to test specific hypotheses. Methodologies include case studies, modeling, surveys, and experiments. On the whole, such findings make us both grateful for the ARP's progress to date, and hopeful that this progress in research will lead to substantive improvements in the DoD's acquisition outcomes.

As pragmatists, we of course recognize that such change can only occur to the extent that the potential knowledge wrapped up in these products is put to use and tested to determine its value. We take seriously the pernicious effects of the so-called "theory–practice" gap, which would separate the acquisition scholar from the acquisition practitioner, and relegate the scholar's work to mere academic "shelfware." Some design features of our program that we believe help avoid these effects include the following: connecting researchers with practitioners on specific projects; requiring researchers to brief sponsors on project findings as a condition of funding award; "pushing" potentially high-impact research reports (e.g., via overnight shipping) to selected practitioners and policy-makers; and most notably, sponsoring this symposium, which we craft intentionally as an opportunity for fruitful, lasting connections between scholars and practitioners.

A former Defense Acquisition Executive, responding to a comment that academic research was not generally useful in acquisition practice, opined, "That's not their [the academics'] problem—it's ours [the practitioners']. They can only perform research; it's up to us to use it." While we certainly agree with this sentiment, we also recognize that any research, however theoretical, must point to some termination in action; academics have a responsibility to make their work intelligible to practitioners. Thus we continue to seek projects that both comport with solid standards of scholarship, and address relevant acquisition issues. These years of experience have shown us the difficulty in attempting to balance these two objectives, but we are convinced that the attempt is absolutely essential if any real improvement is to be realized.

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

- Office of the Under Secretary of Defense (Acquisition, Technology & Logistics)
- Program Executive Officer SHIPS
- Commander, Naval Sea Systems Command
- Army Contracting Command, U.S. Army Materiel Command
- Program Manager, Airborne, Maritime and Fixed Station Joint Tactical Radio System

- Program Executive Officer Integrated Warfare Systems
- Office of the Assistant Secretary of the Air Force (Acquisition)
- Office of the Assistant Secretary of the Army (Acquisition, Logistics, & Technology)
- Deputy Assistant Secretary of the Navy (Acquisition & Logistics Management)
- Director, Strategic Systems Programs Office
- Deputy Director, Acquisition Career Management, US Army
- Defense Business Systems Acquisition Executive, Business Transformation Agency
- Office of Procurement and Assistance Management Headquarters, Department of Energy

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 18 – Advances in Acquisition Cost Analysis and Estimation

Thursday, May 12, 2011	
11:15 a.m. – 12:45 p.m.	**Chair: Dr. Daniel Nussbaum,** NPS, former Director, Naval Center for Cost Analysis ***Costing Complex Products, Operations, and Support*** Michael Pryce, Manchester Business School ***A Better Basis for Ship Acquisition Decisions*** Dan Billingsley, Grey Ghost LLC/Siemens ***Back to the Future: The Department of Defense Looks Back at the Should Cost Review to Save Buying Power in the Future*** Martin Sherman, DAU

Dr. Daniel Nussbaum—Professor, Operations Research, NPS. Dr. Nussbaum's expertise is in cost/benefit analyses, life cycle cost estimating and modeling, budget preparation and justification, performance measurement and earned value management (EVM), activity based costing (ABC) and Total Cost of Ownership (TCO) analyses. From December 1999 through June 2004 he was a Principal with Booz Allen Hamilton, providing estimating and analysis services to senior levels of the U.S. federal government. He has been the chief advisor to the Secretary of Navy on all aspects of cost estimating and analysis throughout the Navy, and has held other management and analysis positions with the U.S. Army and Navy, in this country and in Europe. In a prior life, he was a tenured university faculty member.

Dr. Nussbaum has a BA in Mathematics and Economics from Columbia University and a PhD in Mathematics from Michigan State University. He has held postdoctoral positions in Econometrics and Operations Research and in National Security Studies at Washington State University and Harvard University. He is active in professional societies, currently serving as the Past President of the Society of Cost Estimating and Analysis. He has previously been the VP of the Washington chapter of INFORMS, and he has served on the Board of the Military Operations Research Society. He publishes and speaks regularly before professional audiences.

A Better Basis for Ship Acquisition Decisions[1]

Dan Billingsley—Senior Partner, Grey Ghost LLC. Grey Ghost is an Annapolis, MD, firm that provides confidential analysis and assessment of information systems for the marine industry. Mr. 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 Mr. 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. Mr. 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 2005, to a PEO- and Congressionally funded program with ~$40 million in Federal and industry matching funds in FY 2007. While at NAVSEA, Mr. Billingsley won the Meritorious Civilian Service Award in 1991 and the Superior Civilian Service Award in 2007. [dwbillingsley@gmail.com]

Abstract

Naval ship acquisition is widely thought to be too expensive, too long, too uncertain, and too risky.

Throughout the ship development process, decision makers at all levels are afflicted by unreliable estimates and projections of *cost, performance, schedule, and risk* of competing alternatives. In this context, "decision makers" includes senior Navy leadership, program officers, and ship design managers, all of whom make decisions affecting the eventual product.

How can estimates and projections of *cost, performance, schedule, and risk* be improved? To some extent, decision making in the face of uncertainty is an inescapable part of the development of naval warships due to their unrivaled complexity. This is especially true in the early stages of ship development. However, analysis indicates that the quality of *cost, performance, schedule, and risk* estimates could be substantially improved by actions addressing the root causes of poor estimates.

This paper examines four root causes of poor *cost, performance, schedule, and risk* estimates and projections in the context of ship information development and flow. Eight solution vectors are identified that can provide higher quality estimates and projections earlier in the design process, reducing the uncertainties faced by decision makers, saving expensive engineering labor, and increasing assurance that the delivered ship will satisfy requirements. The relationship of particular solution vectors to the particular root causes is provided in tabular and discussion form.

[1] Originally published as Billingsley (2010). Reprinted with permission.

Ship Acquisition Woes

Naval ship acquisition is widely thought to be too expensive, too long, too uncertain, and too risky. In the eyes of Congress,[2] "Our ships are simply too expensive"; and "I believe the Navy needs to look very hard at their requirements process to determine if marginal extra capability is worth significant construction or integration costs." In the eyes of the Navy,[3]

> Inarguably the underlying challenge—indeed, the pressing requirement—before us today in shipbuilding is affordability.
>
> The fact is that ship costs are rising faster than our topline….To this list I need also add performance, for on even our most mature programs, we have experienced cost growth as a result of performance shortfalls and quality escapes.
>
> The reality is that there is no single fix to turn around this trend, but rather a large number of initiatives, practices, and standards that we need to attack across the board….
>
> We need to ensure that our requirements are balanced by our resources....The key here is to inform the process with realistic cost estimates and realistic risk assessments at the front end. This drives the difficult decisions early, where there are true choices, and true opportunities….
>
> To meet these objectives, we must be smart buyers. The acquisition workforce has been downsized over the past decade and a half to the extent that our professional corps has been stretched too thin and we have outsourced too much of our core competencies. Accordingly, we must rebuild our Navy acquisition workforce.

In the eyes of the Defense Department,[4]

- "Many weapons systems are over-budget, late, and don't meet performance goals" (e.g., GAO-06-391[March 2006]).
- "Lengthy and rigid acquisition process degrades ability to address rapidly changing irregular, catastrophic and disruptive threats."
- "Many of these problems can be traced to an ineffective design process."
- "Our present design tools are inadequate to produce an integrated design with few flaws."

Cost overruns and schedule slips would perhaps be more tolerable if the results were unquestionably world class. Instead, recent years have seen the emergence of

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[2] The Honorable Gene Taylor (D-MS), Chairman of the Subcommittee on Seapower and Expeditionary Forces of the House Armed Services Committee on Shipbuilding Effectiveness, in his opening statement for hearings on July 30, 2009.

[3] The Honorable Sean J. Stackley, Assistant Secretary of the Navy (Research, Development and Acquisition), and Vice Admiral Kevin M. McCoy, Commander, Naval Sea Systems Command, in prepared testimony for the Subcommittee on Seapower and Expeditionary Forces of the House Armed Services Committee on Shipbuilding Effectiveness on July 30, 2009.

[4] Mr. Al Shaffer, Principal Deputy, Defense Research and Engineering, at the 2009 High Performance Computing (HPC) Modernization Program Users Group Conference, June 17, 2009.

unbalanced ship designs, designs so optimized for a particular characteristic (e.g., stealth or high speed) that their general suitability has been questioned.

Clearly, ship acquisition is not working out as planned. To face the challenges of the coming decades, we need an acquisition process that is swifter, more efficient, and more credible.

The Culprit—Poor Decision Support Information

No doubt if past decision makers[5] had understood how things would work out (the *cost, performance, schedule, and risk* implications of their decisions), they would have chosen alternate courses of action. In fact, decision makers must currently rely on poor quality *cost, performance, schedule, and risk* estimates, especially in the very early stages of ship acquisition—when the opportunity to excel and the opportunity to err are greatest.

To some extent, decision making in the face of uncertainty is an inescapable part of the development of naval warships due to their unrivaled complexity. This is especially true in the early stages of ship development. However, it is clear that decision makers are operating with far more uncertainty than necessary, due to being served by inexperienced ship design organizations, frequently staffed by inexperienced ship design engineers. In turn, these organizations and engineers must frequently rely on missing or inaccurate analysis tools and must apply these tools with missing or late analysis inputs.

Root Cause #1—Inexperienced Ship Design Organizations

Successive generations of Navy leaders have underestimated the difficulty of naval warship development. They begin with the notion that management and analysis techniques that have worked well for simpler products will suffice for a task with the complexity, scale, and scope of a naval ship acquisition. As they learn otherwise, their tenure in office comes to an end, and the cycle is repeated.

The challenges of warship development have humbled otherwise highly competent organizations and corporations. To fully appreciate the difficulties they face, it is necessary to understand certain aspects of naval warship design development. This process is in many ways different from the acquisition and/or development of other DoD military items. Key differences are as follows:

- Product Complexity—The typical ship is comprised of hundreds of times as many parts (and more kinds of parts) as the typical aircraft, thousands of times as many parts as the typical power plant, and ten thousands of times as many parts as the typical vehicle. Indeed, our more complex ships fly aircraft off the roof, have vehicles running around inside, and have a couple of power plants in the basement—all incorporated in a floating city capable of moving at high speeds around the oceans of the world.
- Process Complexity—As illustrated in Figure 1, the process of ship development is likewise complex, particularly for naval warships. It involves thousands of individuals in hundreds of corporations, and governmental and regulatory bodies operating throughout the world. Each ship is in some ways unique. A ship may have a conception-to-retirement lifespan of 50 years,

[5] In this paper, "decision maker" is intended to refer to decision makers at all levels, including senior Navy leaders, Program Managers, and Ship Design Managers.

involving both those not-yet-born when it was launched, and those who will retire before it retires. Certainly today's ship will outlive several generations of information technology applied to its development, construction, and service life support.

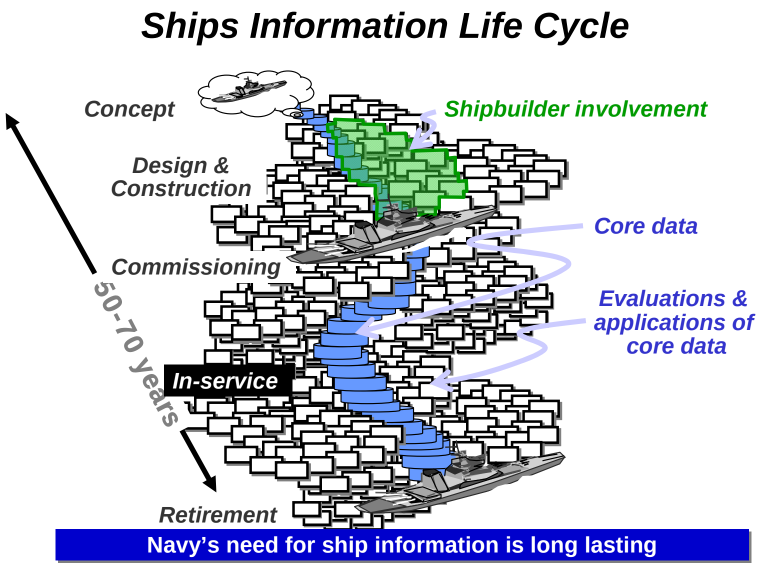

Figure 1. A Long Process With Many Participants

- System of Systems—As illustrated by Figure 2, the fluid-supported, self-contained, self-propelled, multi-mission, and self-sustained nature of ships necessitates tradeoffs between competing requirements. The optimal total ship design will be comprised of many sub-optimized elements. Conversely, a collection of optimized elements will not work as a total ship. Solution of these conflicts is an intrinsically iterative process.

Figure 2. Warship Designers Must Trade-off Conflicting Requirement for Scarce Resources

- Slow Development of Definition—As illustrated in Figure 3, physical detail emerges as the design matures, typically over the course of several years.

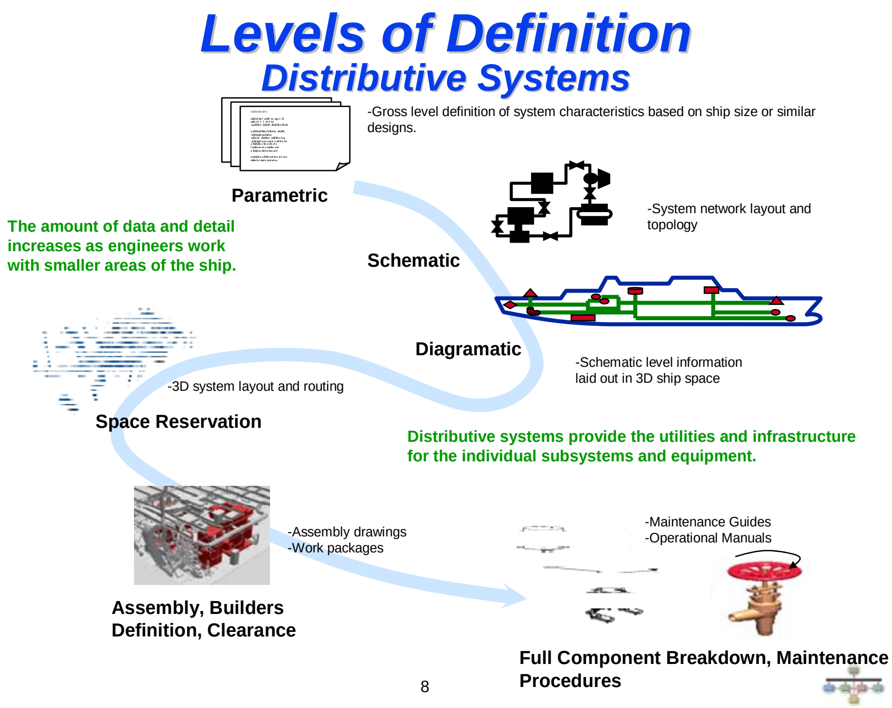

Figure 3. Physical Detail Emerges as the Design Matures

Early Stage Focus—The essence of early stage design is the ability to correctly predict the cost and behavior of the millions of parts that will comprise the completed ship—and to do so years before most of those parts have been identified. Critical decisions must frequently be made based on inadequate information. The emphasis is on total ship behavior, swift iteration through multiple options, lightweight definition with accurate allowance for "known unknowns," and identification and reduction of total ship system risks.

Later Stage Focus—The essence of later stage design is to prepare instructions for the manufacture and assembly of the ship. The emphasis is on local fit, assurance of system function, avoidance of configuration changes with widespread impact, and detailed manufacturing definition—detailing or accounting for every part. We have discovered that individual or organizational skill in the later stage domain does not engender skill in the early stage domain and vice versa.

A mature, experienced design organization must have in place the organizational structures, procedures, and margin policies to deal effectively with the multiple creative tensions and uncertainties within early stage design. Prior to the 1990s, early stage design was the domain of NAVSEA and predecessor organizations. By accomplishing several designs per year and with an institutional culture of continuous process improvement, NAVSEA successfully completed development of designs for virtually all of today's U.S. Naval force.

It is ironic that an organization which understands and embraces so completely the need to approach the chaos of war with sound experience, training, organization, and doctrine takes such a casual, ad-hoc approach to the chaos of naval ship acquisition. Since the advent of Acquisition Reform in the early 1990s, every new ship design effort has been undertaken by a design team formed specifically for that effort. It is no wonder that results have been less than satisfactory. Nor should we expect better results by repeating this approach.

Root Cause #2—Inexperienced Ship Design Engineers

It takes about five years of experience with the unique characteristics of the marine environment and the challenges of ship operations, before the typical engineer has acquired the experience necessary to effectively support ship design. Consider, for example, an experienced structural engineer new to ship design. He discovers that the basic structural element, the stiffened plate panel, is unlike anything found in civil structures. Rather than a fixed foundation to which loads can be reconciled, he finds a distributed foundation which is *in motion* (somewhat analogous to a continuous earthquake). He also discovers that, despite decades of research, real-world loads are somewhat indeterminate and that a certain amount of buckling/panting is permissible to achieve structural weight targets.

In recent years, engineers charged with developing key elements of front-line warships are all too often "rookies," in terms of early stage ship design experience. And hard-learned lessons are not systematically captured in a form that new ship designers can use.

Ad-hoc, single-project design organizations are not incentivized to attract, and certainly not to retain, engineers with the requisite experience. In coming decades, this situation will be worsened by the severe shortage of science, technical, engineering, and math (STEM) workers forecast for the U.S.

It is encouraging to see a number of initiatives aimed at filling the pipeline of STEM workers available for naval ship design, including the following:

> The Science, Mathematics And Research for Transformation (SMART) Scholarship for Service Program established by the DoD to support undergraduate and graduate students pursuing degrees in STEM disciplines. The program aims to increase the number of civilian scientists and engineers working at DoD laboratories. Recipients receive a cash award, full tuition, and related educational expenses, health insurance, summer internships, and post-graduation career opportunities.
>
> The ONR Naval Research Enterprise Intern Program (NREIP) provides an opportunity for students to participate in research at a Navy lab during the summer. Recipients receive a stipend for a 10-week summer internship.
>
> The ONR National Naval Responsibility for Naval Engineering (NNRNE) Program has initiatives aimed at students from middle school to graduate school. One of those initiatives, in partnership with NAVSEA and NSWC, is the Center for Innovation in Ship Design (CISD) at Carderock (Naval Surface Warfare Center, n.d.). CISD conducts both summer projects with NREIP interns, and longer term (3–6 months) projects in collaboration with government, academia, and industry.
>
> Through NSRP, NAVSEA sponsored the Shipbuilding Engineering Education Consortium (SEEC) working group (comprised of representatives from government, academia, and industry) in 2009 to develop an overarching strategy for educating engineers across the spectrum needed by NAVSEA and the shipyards. NAVSEA issued a solicitation based on the recommendations of the group and is now evaluating proposals.

NAVSEA's Naval Acquisition Intern Program is hiring engineers and other professionals and providing a rotational training to equip them for careers in NAVSEA.

The collective success of these programs is increasing the pool of talent from which experienced ship designers can be developed.

Root Cause #3—Missing or Inaccurate Analysis Software

Software used by ship design engineers are of two primary types:

- definition software (e.g., Computer Aided Design, CAD) to reflect and communicate the developing design, and
- analysis software (e.g., spreadsheets, Computer Aided Engineering [CAE], Modeling and Simulation [M&S]) to estimate the characteristics and predict the performance of the developing design.

Shortcomings in this latter category of software account for many of the uncertainties of *cost, performance, schedule, and risk* with which decision makers must contend.

The complexity of ships demands a wide variety of analysis tools and, for many design disciplines, different tools at different stages to be compatible with definition information available at that stage. Surveys have shown that availability and quality varies widely across disciplines from "very good" to "non-existent." Overall, the availability and quality of analysis software has eroded with the passage of time. There has been inadequate investment to keep pace with changes in computer technology, weapon systems technology, and ship technology (materials, hull configurations, power density, etc.).

Analysis software is, of course, one of many estimation or evaluation methodologies that can be brought to bear on an engineering problem. Methods are as follows (in rough order of accuracy):

- Engineering judgment,
- Hand calculations,
- Class rules,
- Spreadsheets,
- Adapted commercial off-the-shelf (COTS) CAE software,
- Special purpose COTS CAE software,
- Custom CAE software,
- Modeling and simulation,
- Model testing, and
- Full scale trials.

Currently, tool investment shortfalls are causing increasing reliance on engineering judgment at a time when an increasing number of engineers who have that judgment are retiring from the ship acquisition workforce.

Sources of Ship Design Software

The preferred source for analysis tools is COTS. Where ship design needs are similar to general design needs (e.g., pipe flow analysis, electric load analysis, structural response), COTS provides economical, well supported, and generally well-verified analysis software. Unfortunately, only 25%–30% of ship design software needs can be satisfied by COTS. The rest is so ship-specific that there is an inadequate market to attract COTS providers, and/or it is too military-specific for an open-market solution.

Non-COTS sources of analysis software include ONR-sponsored research software, ship acquisition program office sponsored software, and the CREATE Program (Post et al., 2008, p. 12090).

ONR has been a substantial provider of software for ship design. ONR-sponsored software is frequently a by-product of research in disciplines of interest to ONR programs. These may or may not align with ship design needs. The user interface of research software is typically barely adequate for the needs of research scientists and can be incomprehensible to a ship design engineer. Additionally, much of the software developed under ONR grants ends up not belonging to the Navy. Lastly, research software rarely has the validation or assured range of applicability one would desire for acquisition design.

Ship acquisition program offices have been substantial sponsors of software for ship design. Focus is usually on technical problems unique to the specific acquisition program. Timing is frequently an issue. By the time an acquisition program is established and funded, and the software need is identified, there is frequently inadequate time remaining for software development to take place.

The CREATE program was established in 2008 to leverage and apply the availability of high-performance computing to defense needs. CREATE is making substantial investments in scalable design and analysis software for ship hydrodynamics, shock, and rapid design. The ship design community looks forward to the availability of CREATE-developed software in the years to come.

The naval ship engineering community was an early adopter of computer technology to assist with the problems of ship design. Much of the software used to support ship design decisions today originated at NAVSEA in the 1970s, 1980s, and early 1990s. Throughout this period NAVSEA maintained an office or program focused on design process improvement including the following:

- Computer Aided Ship Design and Construction (CASDAC) Program,
- Computer Supported Design Program,
- Computer Aided Engineering Division,
- Ship Design, Acquisition and Construction (DAC) Process Improvement Program, and
- Computer Aided Engineering Program.

These programs provided system architecture, definition software, and software interfaces to permit available software to function as an integrated design system. Additionally, these programs provided “infill” funding for critical software (e.g., weight engineering) that did not have the glamour or program-specific focus to attract sponsorship from the sources mentioned above. Since the demise of the CAE program in 2000, there has been virtually no source of architectural leadership or integration and infill funding for early stage design computer software.

Design Software Plans and Surveys

NAVSEA periodically developed a blueprint or roadmap to provide a comprehensive vision of ship design and integration software status, needs, and future direction, including the following:

- **Simulation Based Design for Ships Master Plan** (NAVSEA, 1995) characterized the investment needed to realize the potential of newly available design technologies as $80 million over the FYDP and proposed a cost-sharing arrangement among NAVSEA, ONR, and OPNAV.

- **Certification Scorecard—An Investment In Seapower** (NAVSEA, 2000) laid out a system of metrics for the quality of ship certification software and updated the development cost projections from the SBD plan to include support cost.
- **Engineering Tools Survey** (2004; NAVEA, 2005) used a system of metrics to roll up a numerical summary estimate of the readiness of NAVSEA engineering software. An excerpt is provided in Figure 4. Resources limited this survey to approximately half the design disciplines of interest.

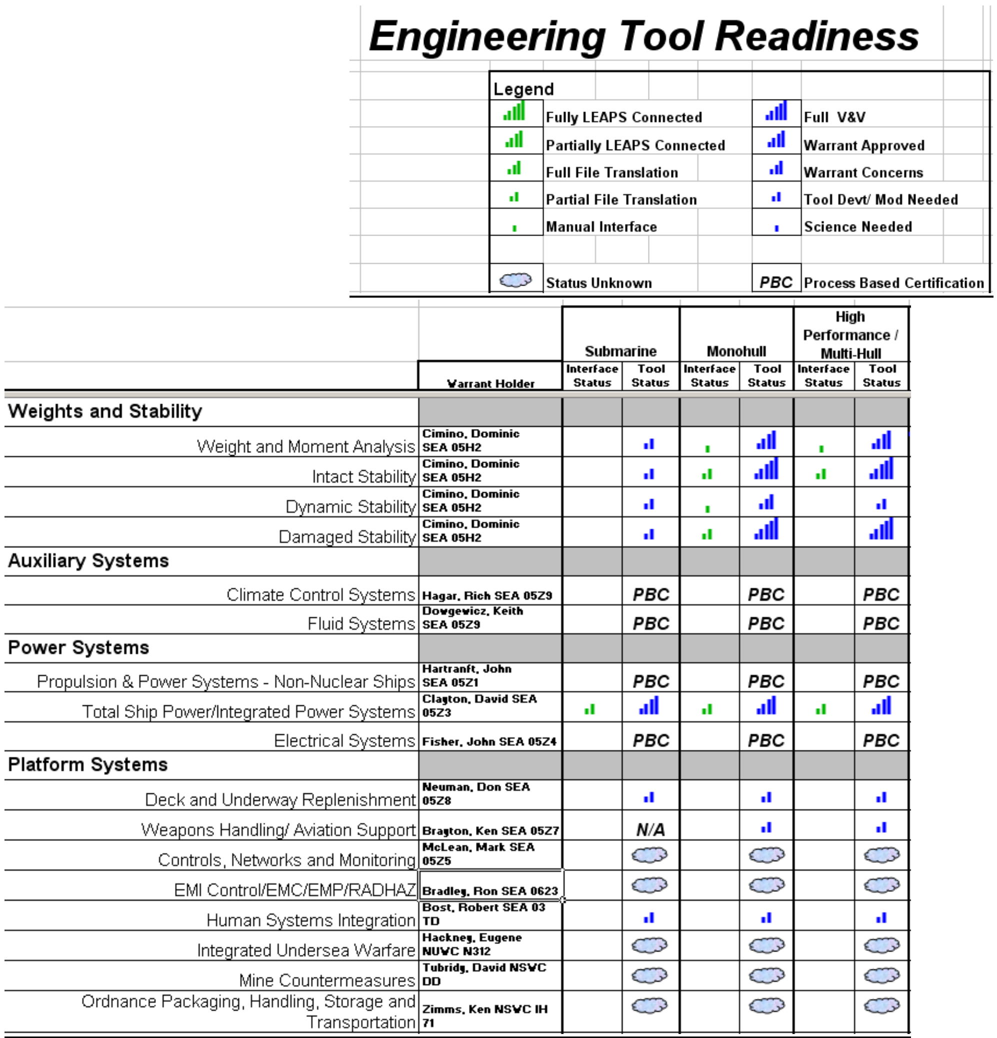

Figure 4. Excerpt From Phase I Engineering Tool Survey Final Report

- **Naval Ship Engineering Process Issues and Opportunities** (2006; NAVSEA, 2008) is an exposition of the cost and benefits associated with coordinated investment in each of four broad areas, as follows:
    - o Product Data Interoperability,
    - o Concept and Feasibility Design Tools,
    - o TWH Tools for Certification of Design, and
    - o Design Community Tools Coordination.

- **Design Tools Roadmap** (in progress) employs more intensive interviews of technical warrant holders and development of a design process model to pinpoint the most cost-effective areas for investment. Progress has been fitful due to funding limitations.

Investments in the 1990s and Early 2000s

During the late 1990s and early 2000s, program offices made independent investments in program-specific and shipyard-specific Integrated Product Data Environments (IPDEs; also known as IDEs and other names). Primary focus was on CAD systems for manufacturing definition, coupled with Product Data Management (PDM) systems for configuration management. The net result is a number of partially complete, detail design, and construction-oriented systems that are not interoperable with each other.

The NAVSEA engineering community was able to afford very little for early stage software development and support during this period and was unable to afford the effort involved to maintain a comprehensive picture of the status of its engineering tools. However, the efforts listed above sustained a collective awareness adequate to discern particularly glaring needs. 60–70% of ship design analysis areas have one or more of the following problems:

Evaluation software is of poor quality:

- poor algorithms inadequately represent underlying physical phenomena,
- misleading user interface,
- poor verification and/or validation, and
- application outside valid range.

Evaluation software is unavailable:

- new warfighting threats and/or technologies have emerged,
- fundamental understanding of the physical phenomena involved is inadequate,
- unconventional materials (e.g., composites) have been introduced, and
- unconventional configurations (e.g., multi-hulls, unprecedented electric power densities).

These shortcomings have been addressed in the past as problems for the ship design community, which they are. Of more national importance, however, is that these poor quality and/or missing software are the source of cost, performance, schedule, and risk estimates relied upon by decision makers when making expensive and far-reaching decisions. Good software is cheap, compared to the cost of compensating for failed systems in service.

Root Cause #4—Missing or Late Analysis Inputs

Even if quality analysis software is available, it does little good if timely and accurate input is not available. For example, the most commonly used software to evaluate ship vulnerability to weapons impact requires the following:

- Adequate definition of ship structure (thickness of plating and stiffener size and spacing for bulkheads, decks, and shell) to model blast penetration, and
- Adequate definition of component placement and distributive system routing (diagrammatic level of definition) to model system failures resulting from blast penetration.

At present, lack of adequate definition and inefficient data transfer into vulnerability analysis tools delay the availability of vulnerability estimates well beyond the point where they could most effectively influence design development. There are similar examples in other disciplines suggesting the need for the following:

- More rapid development of candidate definition information,
- More rapid transfer of definition information to analysis programs,[6] and
- Surrogate definition from previous design efforts similar enough to the intended definition to support at least a rough estimate.

The problem of data availability can be especially challenging when analysis is required to respond to an emergency involving a ship in service.

The NAVSEA engineering community is developing Leading Edge Architecture for Prototyping Systems (LEAPS) as a design product model to address this problem. LEAPS provides unique capabilities not available commercially. Some tools are tightly coupled to LEAPS. Others use LEAPS data via translators. LEAPS serves as somewhat of a Rosetta Stone, capable of accepting configuration/definition information from a variety of sources, such as commercial CAD systems, and transforming them into inputs for analysis programs. LEAPS also provides a seamless mechanism for sharing analytical results between different disciplines. Additionally, LEAPS maintains a trace between definition source information and analysis results based on it—a “pedigree” of analysis results.

LEAPS has yet to be implemented as the core data exchange mechanism for an ongoing design project. This is partially due to system maturity, partially due to less-than-comprehensive coverage of all disciplines, but mostly due to the lack of a NAVSEA-led design effort in recent years.

The CREATE Program is sponsoring further development of LEAPS as part of its Rapid Design Integration/Ships Project aimed at streamlining the Concept Design phase.

Solution Vectors

Clearly, inexperienced ship design organizations, inexperienced ship design engineers, missing or inaccurate analysis software, and missing or late analysis input are introducing substantial uncertainty about the *cost, performance, schedule, and risk* of acquisition alternatives. These root causes are contributing to poor decisions, leading to cost overruns, schedule slips, performance shortfalls, and inadequate and untimely response to emerging threats and requirements. Following are eight solution vectors that will tackle the root causes discussed. Figure 5 depicts the relationship of these solution vectors to the root causes, that is, which root causes will be mitigated by which solution vectors.

[6] The data transfer mechanism most frequently cited in recent surveys is “look and enter”—the designer looks at hard copy products of previous design efforts and keys input data for the next analysis.

	Solution Vectors	Root Cause #1 – *Inexperienced Ship Design Organizations*	Root Cause #2 – *Inexperienced Ship Design Engineers*	Root Cause #3 – *Missing or Inaccurate Analysis Software*	Root Cause #4 – *Missing or Late Analysis Input*
A	National Design Organization	O	O	O	O
B	Development of Design Engineers		O		
C	Mature Interim Design Products	O	O		O
D	Standard Components / Product Standards	O	O		O
E	Design Exercises	O	O		
F	Design Software Demand Signal			O	O
G	Integration and In-fill Software		O	O	O
H	Expedite Data Transfer	O			O

Figure 5. Relationship of Solution Vectors to Root Causes

Solution Vector A—Build and Sustain a National Design Organization (NDO)

The country needs a national organization that is experienced, practiced, and prepared in the organizational art of naval ship design—one able to provide quality *cost, performance, schedule, and risk* estimates for decision makers and one able to provide sound designs swiftly in response to emerging needs.

This organization must be focused on the Navy as its customer and provide an enterprise resource for ship acquisition. Roles of the NDO would include leadership of early stage design, establishment of design and engineering standards, and providing of a focal point for fleet feedback. A robust NDO would naturally pursue the other seven solution vectors identified below. These vectors have value in the absence of an NDO, but there would be significant synergism were they coordinated.

Continuity is the key for an NDO. It must be line funded by a sponsor who is able to annually rise above the program-centric nature of the Navy and the DoD. It must efficiently provide a service needed by all. There is likely to be no increase in net cost compared to the multiple, independent design organizations now being supported by various program offices.

The NDO must be process focused and oriented to continual process improvement. Analysis (NAVSEA, 2008) has revealed that 33% of the combined budget of NAVSEA, PEO Ships, PEO Subs, and PEO Carriers is spent on knowledge work—work intimately related to information development and flow during ships' life cycles. In contrast to extremely sophisticated *product* analysis methodologies applied to the ships themselves, *process* analysis methodologies are rudimentary. Examples abound of duplicate development of information. NAVSEA's Design Tools Roadmap Project (proceeding in fits and starts, due to limited funding) has discovered a number of powerful process analysis tools used in other industries, but virtually unknown within the Navy.

An important product of the NDO would be design process guidelines and documentation. These are important for training staff replacements and as baseline references for continuous process improvement. Currently, little process documentation can be found, and what there is, dates from the 1970s and early 1980s. It can usually only be found in personal collections, rather than in a central repository.

There are various organizational constructs for an NDO.

The top candidate is a government-led organization with support as required from contractors. This option is intrinsically aligned with the Navy's interests and would provide natural channels for fleet feedback. The Navy-wide demand for designs would naturally maintain the experience level of the organization and its staff. This approach would reinstate the successful approach that provided designs for virtually all of today's U.S. Naval force.

A second candidate is an independent Federally Funded Research and Development Center (FFRDC). This organization might enjoy more freedom of action than a government activity and would be buffered somewhat from acquisition politics. Conversely, communication with Navy leadership and the fleet could be more constrained and formal.

A third candidate would be a consortium of shipbuilders and the Navy, with similar advantages and disadvantages as an FFRDC. The many near-death experiences of the National Shipbuilding Research Program (NSRP) have illustrated the vulnerability of this construct to uncertain sponsorship. More of the Board of Directors' time and energy would likely be dedicated to efforts to maintain sponsorship than to providing oversight and direction. The consensus nature of this model would likely result in a less tightly-integrated design approach than the previous candidates.

A fourth candidate is separate design organizations for the two corporations (General Dynamics and Northrop Grumman) controlling the nation's largest shipbuilders. This might provide some competition, while at the same time, ensuring some duplication of effort and expense. There would be demand for fewer designs than for a single NDO, resulting in less experienced organizations and staffs. Fleet feedback and commonality of equipments for the future fleet would be harder to achieve. Additionally, the needs of smaller shipbuilders now producing significant numbers of fleet units would not be served. Lastly, early stage design organizations within the shipbuilders would be subject to continual pressure due to being outside the mainstream business of their respective companies.

Absent a decision in favor of an NDO, Option 4 is the most likely outgrowth of the status quo.

Solution Vector B—Development of Design Engineers

Experienced staff is a key component of any solution to ship acquisition woes. Engineering judgment is the ultimate fallback for *cost, performance, schedule, and risk* estimates in the absence of any more sophisticated methods. It is generally acknowledged that an experienced ship designer with poor tools will provide better *cost, performance, schedule, and risk* estimates than a novice ship designer with sophisticated tools.

As noted in the "root problem" discussion, there are several initiatives oriented toward increasing the supply of STEM workers for the Navy and the DoD. It is important that those individuals with particular aptitude and inclination toward early stage ship design have a "landing pad" (e.g., the NDO), lest they be dispersed to other parts of the DoD or industry and be unavailable to the Navy.

Solution Vector C—Mature Interim Design Products

"Mature interim design products" refers to systems and/or subsystems that have been designed to near-production level of definition and evaluated in detail. Because of this refinement, the *cost, performance, schedule, and risk* of incorporating these interim products into a ship design is much more certain than for an ad-hoc system design developed at a lesser level of definition in the course of early stage design.

Interim design products can be developed for a range of requirements, for example, shipboard electric plants for a range of power levels. Development of mature interim design products provides an excellent training opportunity for engineering staff.

This approach was used in the Mid-term Sealift Technology Development Program's Engine Room Arrangement Modeling (ERAM) project to develop, in advance, and in collaboration with shipbuilders, a range of engine room options that were later incorporated in various Sealift designs (Keane, Fireman, & Billingsley, 2005).

An alternate means of acquiring mature interim design products is to extract them from ships in service. This can be difficult, because they may be "hidden" within proprietary CAD models structured for assembly rather than systems review. Data transfer technology has matured to make this type of extraction and data transfer feasible for cooperating engineering organizations. The effort of separating system information and measuring as-built performance provides an excellent training opportunity and provides very high quality *cost, performance, schedule, and risk* estimates for the interim design product.

A library of mature interim design products would enable faster ship design development in the face of emerging threats or requirements. It would allow us to emulate the 21st century auto industry's ability to quickly configure and bring to market, vehicles engineered to suit particular needs, but comprised largely of previously developed and tested components (engines, brakes, seating, navigation, etc.).

This contrasts with ship standardization, which emulates Henry Ford's one-product-fits-all Model T approach.

Solution Vector D—Standard Components and Product Standards

A number of studies and projects[7] over the years have highlighted the benefits of reducing the proliferation of similar parts in the fleet. The most notable benefit is reducing the substantial logistics cost of maintaining inventory for redundant functions. NSRP's Common Parts Catalog has also identified acquisition cost savings by reducing the number of parts used by various shipbuilders in various new designs.

[7] For example, the Affordability Through Commonality Program.

An ancillary benefit of these commonality efforts is the increased certainty about *cost, performance, schedule, and risk* by using familiar parts in new designs. Existing programs along this vector should be supported and consideration given to opportunities for synergy among them.

Solution Vector E—Design Exercises

Periodically, at least annually, a team should be assigned design of a major interim product or an entire ship as an exercise (just as warriors frequently participate in various exercises). These exercises would have three objectives, as follows:

- Training for individual designers and the design organization,
- Experimentation with new design processes such as set-based design and LEAPS-centered design, and
- Putting design products "on-the-shelf," both to reduce uncertainty in *cost, performance, schedule, and risk* estimates for similar projects, and to allow more rapid response to emerging threats.

Similar exercises are being conducted currently by CISD with the main focus being training and introduction to the naval ship design community for students. To achieve the organizational training goals, these design exercises should be conducted by the NDO, if one is established. If not, they could be conducted by CISD as a more intense version of their present practice.

Solution Vector F—Design Software Demand Signal

As discussed in Root Cause #3—Missing or Inaccurate Analysis Software, ship design software comes from a variety of sources, indeed, from wherever it can be obtained. However, these sources are, in general, not well informed about the needs of the ship design community. Annually, the design community should report the status of design tools currently available. The report should be in consistent terms, year to year, and should address accuracy, verification, user confidence, usability, and range of applicability from the perspective of subject-matter experts and technical warrant holders.

This demand signal would serve several functions, as follows:

- An annual checkup using consistent metrics on the health of ship design software. Are we getting better or getting worse?
- Focus leadership attention on areas where tool defects are contributing to uncertainty regarding *cost, performance, schedule, and risk*.
- Provide a guide for potential sponsors of physical research and software development—yielding an additional criterion for project selection.

Experience has shown that it is initially difficult to formulate such a status report. Once the baseline is in place, however, and the structure, terminology, and metrics are established, the annual updates should not be so onerous.

Ideally, the demand signal would be formulated by the NDO. If not, it could be assembled by an independent consultant or other third party.

Solution Vector G—Integration and In-Fill Software

As discussed in Root Cause #3—Missing or Inaccurate Analysis Software, sources such as COTS, ONR, ship acquisition programs, and CREATE provide significant software to the ship design community. However, there is a need for architectural leadership, definition software, and software interfaces to permit the collection of available software to function as an integrated design system. Additionally, there is a need to provide “infill” funding for critical software (e.g., weight engineering) that does not have the glamour or program-specific focus to attract sponsorship from the sources mentioned above.

Based on comprehensive estimates from the 1990s, adjusted for inflation, the annual requirement is for about $25 million to address these needs with a coordinated approach. It is not known how much is currently being spent to address these needs in ad-hoc, program-specific efforts.

Integration of tools directly bears on the issue of streamlining knowledge work—work intimately related to information development and flow during ships’ life cycles. As noted earlier, approximately 33% (perhaps $10 billion) of the combined budget of NAVSEA, PEO Ships, PEO Subs, and PEO Carriers is spent on knowledge work.

Provision of these design tools permits more rapid development of design options, addressing the Root Causes of “Missing or Late Analysis Inputs” and “Missing or Inaccurate Analysis Software,” and providing better *cost, performance, schedule, and risk* estimates for decision makers. Additionally, streamlining design processes, better tools, and better integration reduce the numbers of experienced staff required to complete design development. Lastly, the more rapid feedback provided by efficient design tools will speed the maturation of inexperienced staff.

Pursuing this vector would be an intrinsic activity of an NDO. If an NDO does not exist, then a consortium is the preferred approach (Transportation Research Board, 2002) to fulfilling this need.

Solution Vector H—Expedite Data Transfer

This solution vector has two parts:

- Implement data transfer standards that have been developed for ship definition, and
- Develop data transfer capability for information relating to operating plans, production plans, and support plans.

As discussed previously, ship design engineers have been primarily concerned with definition and analysis, and with systems and software to facilitate these processes. The Navy and the shipbuilding community have developed implementable standards[8] and contract requirements[9] to achieve interoperability of definition data across programs, between organizations, and across time (archiving and retrieval). The shipbuilders believe the implementation of NPDI will lower costs, improve design-build cycle time, and reduce the cost of changes. Navy leadership needs to ensure that NPDI specifications are incorporated into acquisition specifications for all future ships.

However, there are more factors impacting the *cost, performance, schedule, and risk* of a ship than its physical configuration (definition). The way it is operated, the way it is manufactured and assembled, and the way it is supported in service can all affect *cost, performance, schedule, and risk* without a change to the physical product. Figure 6

[8] ISO 10303 Standard for the Exchange of Product Model Data/Shipbuilding Application Protocols.

[9] NSRP/Navy Product Data Initiative (NPDI)—Integrated Product Data Environment (IPDE) Specification, June 30, 2008.

illustrates the categories of knowledge work, information, and software involved in ship development and service life support.

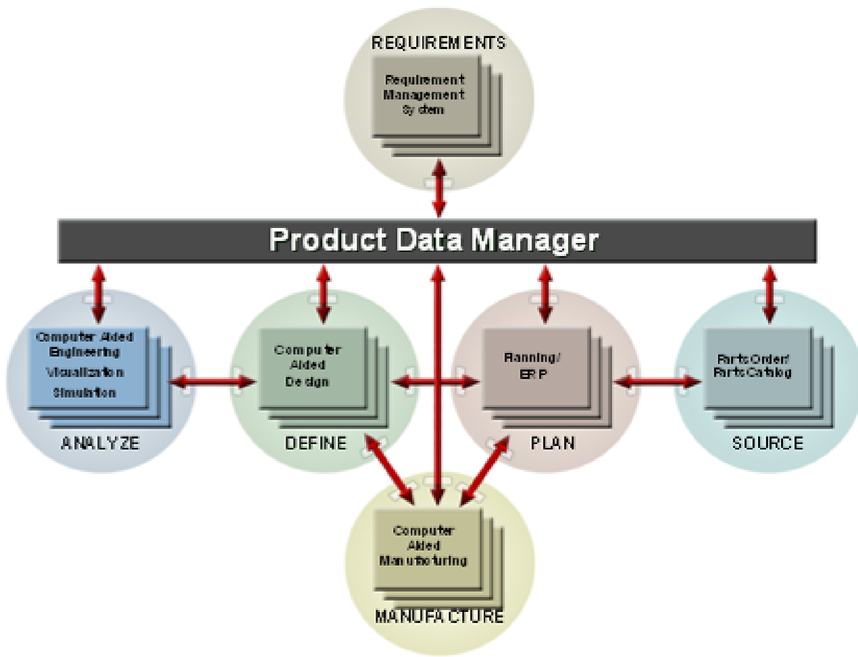

Figure 6. Categories of Knowledge Work, Information and Software for Ship Development, Construction, and Service-Life Support

The Navy and the industry initially focused on the capability to transfer DEFINITION information. Having developed content standards, format standards, acquisition policy, and contract terms, complete success is at hand.

By contrast, information about operational plans, production plans, and support plans are inferred, perhaps inconsistently, when developing *cost, performance, schedule, and risk* estimates. No means of sharing this information in computer-sensible form is available. The Navy and the industry need to focus on developing the capability to transfer PLANNING information with equal facility as DEFINITION information.

Conclusion

Proposals to improve ship design capability, as an end unto itself, have not gained much traction with senior Navy leadership. The issues are complex and improvements can be hard and expensive to obtain. However, if these same proposals are viewed in the context of critical ship acquisition decisions impacting the nation's security and committing billions of dollars, then reducing uncertainty about the *cost, performance, schedule, and risk* of alternatives seems very worthwhile indeed. Quality engineering may be expensive, but mistakes in ship acquisition are horrifically expensive (and may not be recoverable).

References

Billingsley, D. W. (2010). *Engineering a solution to ship acquisition woes.* Paper presented at ASNE Day 2010, Arlington, VA.

Keane, R. G., Fireman, H., Billingsley, D. W. (2005, October). *Leading a sea change in naval ship design: Toward collaborative product development*. Paper presented at SNAME Ship Production Symposium, Houston, TX.

NAVSEA. (1995, March 14). Simulation based design for ships master plan (SEA 03 ltr to OPNAV & CNR).

NAVSEA. (2000, March 3). *Certification scorecard—An investment In seapower.* Draft report.

NAVSEA. (2005, January 24). *Phase I Engineering Tool Survey final report* (Ser 05D/017).

NAVSEA. (2008, October 24). *Naval ship engineering process issues and opportunities* (Ser 05D/521).

Naval Surface Warfare Center. (n.d.). Center for Innovation in Ship Design (CISD). Retrieved from http://www.dt.navy.mil/tot-shi-sys/cen-inn-shi

Post, D. E., et al. (2008). A new DoD initiative: The Computational Research and Engineering Acquisition Tools and Environments (CREATE) program. *Journal of Physics: Conference Series, 125*, 12090.

Transportation Research Board. (2002). *Naval engineering: Alternative approaches for organizing cooperative research* (Special report 266). Washington, DC: National Academies Press.