An Information Technology Blueprint for the Twenty-first Century Amphibious Warship

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The United States Navy's next generation of Amphibious Transport Dock Ships, the USS SAN ANTONIO (LPD 17) Class, will be the most technologically advanced Expeditionary Warfare vessels afloat. Capitalizing on the tenets of Acquisition Reform and utilizing the concepts of Integrated Product and Process Development (IPPD), the LPD 17 Project Team has implemented an Integrated Product Data Environment (IPDE). This IPDE is an information system that enables the LPD 17 team to work more effectively and efficiently by providing a common data structure in a real-time environment. The IPDE provides an architecture that facilitates the integration of a central product model database, including 3D-model geometry; associated support data such as drawings, technical manuals and training materials; and program execution information such as plans, schedules and procedures. This architecture satisfies the data and usage requirements of both the Government and contractor throughout the life cycle of the ship.

The IPPD approach and the related success of IPDE implementation by the LPD 17 team are trends that will continue in future Navy shipbuilding programs. In an era of declining defense budgets and increasing need to replace an aging fleet, innovative advances in ship acquisition, such as those taken by "Team 17," will become the industry norm. The core of each shipbuilding program will be an IPDE, which has as its purpose the support of the ship throughout its life.

INTRODUCTION

In today's information age, timely and accurate data presented in the appropriate format is a necessity. The LPD 17 vision for an Integrated Product Data Environment (IPDE) is one of "cradle-to-grave" service and support. This vision encompasses the full spectrum of acquisition, in-service use, modernization, repair and disposal, with the IPDE being a driver for Total Ownership Cost (TOC) reduction.

The Navy deemed it essential to team with industry leaders, and a great deal of effort was invested to that end. The Avondale Alliance (a team consisting of Avondale Industries Incorporated, General Dynamics/Bath Iron Works, Intergraph Corporation and Raytheon Systems Corporation) won the LPD 17 contract with Avondale as the Full Service Contractor (FSC). The result is the Navy/Alliance Integrated Product and Process Development (IPPD) structure described in this paper. To support IPPD, the Navy envisioned an IPDE that would encompass the Information Technology (IT) requirements for the life cycle of the ship.

The reality of current defense budgets and the competitiveness of the shipbuilding industry necessitate that most ship acquisition programs foster extensive collaboration between several ship design and construction entities. Collaboration on any project with the scope and technical breadth of ship construction requires an enormous amount of information interchange among the involved parties. The IPDE plays a key role in enabling collaboration on ship design and production. Using technology to provide common "look and feel" to all applications through a Web interface and making all data appear on the desktop of the user are essential to reducing training costs, process time, and travel costs. While some collocation is required in such a project, particularly for program management functions, most of the technical work can be done most efficiently online using current technologies. Client/server networks, high-speed Wide Area Networks (WANs) and the extensive use of video teleconferencing enable collaboration at the national level.

In addition, the Navy envisioned that the LPD 17 IPDE would be an enabler of many Department of Defense (DoD) Acquisition Reform initiatives. By utilizing the latest advances in information technology, the IPDE provides the LPD 17 Project Team ("Team 17") with the capability to conduct collaborative and distributed concurrent engineering. Through use of this process, the team perfects the product model development tools while the ship design is in progress and the production process and facilities are being designed. This approach allows the process to evolve while the ship design is being perfected.

IPDE facilitates another essential tenet of Acquisition Reform – the concept of Integrated Product and Process Development (IPPD). It allows use of basic IT applications, such as e-mail and desktop office software, sophisticated engineering and design tools, and modeling and simulation, and provides support to other Simulation Based Acquisition (SBA) concepts.

This paper will look at the genesis of the LPD 17 IPDE, its status and its concepts for both a Shipboard IPDE and a Life Cycle IPDE. It will also demonstrate how the Navy and Industry teamed to produce a technologically advanced Expeditionary Warfare (EXW) vessel design. By leveraging technology, Team 17 has extended integrated ship design to the highest level of performance heretofore seen in naval surface ship construction.

NOMENCLATURE

AIM – Asset Information Manager
AT – Acceptance Testing
Alliance – The Avondale Alliance (AII, GD/BIW, Raytheon and Intergraph Corporations)
ATN – Alliance Test Network
C4I – Command, Control, Communications, Computers and Intelligence
CCB – Configuration Control Board
CPT – Cross Product Team
C/SCS – Cost/Schedule Control System
DFO – Design for Ownership
EBOM – Engineering Bill of Material
ERP – Enterprise Resource Planning
EXW – Expeditionary Warfare
FSC – Full Service Contractor
GUI – Graphical User Interface
HLA – High-Level Architecture
IMP – Integrated Management Plan
IPDE – Integrated Product Data Environment
IPPD – Integrated Product and Process Development
ISDP – Integrated Ship Design and Production
IT-21 – Information Technology for the 21st Century
IPT – Integrated Product Team
ISET – Integrated Ship Electronics Team
IV&V – Independent/Integrated Verification and Validation
LCS – Life Cycle Support
LPD – Landing Platform Dock
MBOM – Manufacturing Bill of Material
MIRWS – Master Integrated Resource and Work Schedule
NDE – Naval Data Environment
NSSN – New Attack Submarine
OT – Ownership Team
PDCT – Process Development Core Team
PDM – Product Data Manager
PDR – Preliminary Design Review
PEO – Program Executive Office
PMS 317 – LPD 17 Navy Program Office
PMT – Program Management Team
SBA – Simulation Based Acquisition
SIR – Ship Information Repository
SIT – Systems Integration Team
SWAN – Shipboard Wide Area Network
TIG – Technical Integration Group
TIM – Technical Interchange Meeting
TOC – Total Ownership Cost
TSET – Total Ship Engineering Team

NAVY/INDUSTRY VISION FOR LPD 17

With the advent of Acquisition Reform and the need for receiving the best value in any acquisition program, the Navy has developed the concept of the Full Service Contractor (FSC). This new concept was based on an acquisition strategy that had a single team responsible for the design, construction and key life-cycle support functions for the entire ship class throughout its operational lifetime. The expected outcome was reduced ownership costs. The main elements of the Navy's acquisition strategy were established early by the Navy Program Office (PMS 317).

These included:

- The Full Service Contractor (FSC) concept
  FSC involvement in the Life Cycle Support (LCS) of the LPD 17 Class
- On-site collocation of the Program Office (PMS 317) team at the contractor's facility
- The IPPD concept and the IPDE

This new approach in ship acquisition required an infrastructure of new processes and tools with an unprecedented level of information accessibility. To implement this vision, a new environment was needed to take full advantage of emergent commercial computer technologies. Planners recognized that this environment required a greater degree of integration than had ever been achieved in naval shipbuilding and had to allow a widely distributed user community access to dynamically changing data. The concept of an IPDE was created to fill this need. The IPDE was established in order to satisfy the data requirements of both the Government and the FSC over the life cycle of the ship. [1]

The two primary reasons the Government called for an IPDE in their Request for Proposal (RFP) were to reduce the costs of developing, delivering and maintaining information and to increase its accuracy and availability to the end users.

Total Ownership Cost (TOC) reductions are generated by using complete electronic development of data, reuse of electronic data throughout the life cycle, and the maintenance of the central data repository throughout the life cycle of the class. Accuracy and availability of the information is improved by giving online data access to all members of the Navy/Industry team and by using a single location for current ship configuration data (develop once, use many times). The IPDE is defined as follows:

IPDE is the information system capability that implements, through phases, the integration of a central product model database, associated data products such as drawings, technical manuals, GFI, training materials and program execution information such as plans, schedules and procedures in order to satisfy the data requirements of both Government and contractor. The IPDE features the capability to concurrently develop, capture and reuse data in electronic form in a fashion that leads to data integrity, efficiency and configuration control throughout the life cycle of the ship. [2]

LPD 17 APPROACH TO ACHIEVING THE IPDE VISION

The Alliance, in proposing a solution that matched this vision, took the concepts of IPPD and IPDE and developed a new approach to design, process and infrastructure. This approach followed the Government's intent as described in the ensuing vision statement:

It is the intent of the LPD 17 Program that data and data products will be developed, maintained and utilized throughout the program life cycle in digital form. The goal of this program is to capture data in digital format at the point of creation and to organize, integrate, maintain and make available to all program participants information in digital form for life cycle reuse. [3]

A key part of this approach was the product data model for the digital program data. The three-tiered concept displayed in Figure 1 was adopted as the overall product data model. Level I data is the 3D Product Model that contains all of the three dimensional drawings and integration of the data elements and their attributes. These attributes include part, sub-system and system definitions; design data; physical information; engineering data; process information; and logistics support information. Level II data supports data products derived from Level I data. These include test procedures, vendor drawings, technical manuals, simulations, procurement specifications, etc. Level III is the integration of process data that includes the Integrated Management Plan (IMP), the Master Integrated Resource and Work Schedule (MIRWS), IPPD team processes and metrics and any associated updates. The concept and data structure described above constituted the nucleus of the IPDE and also provided a framework for its development.

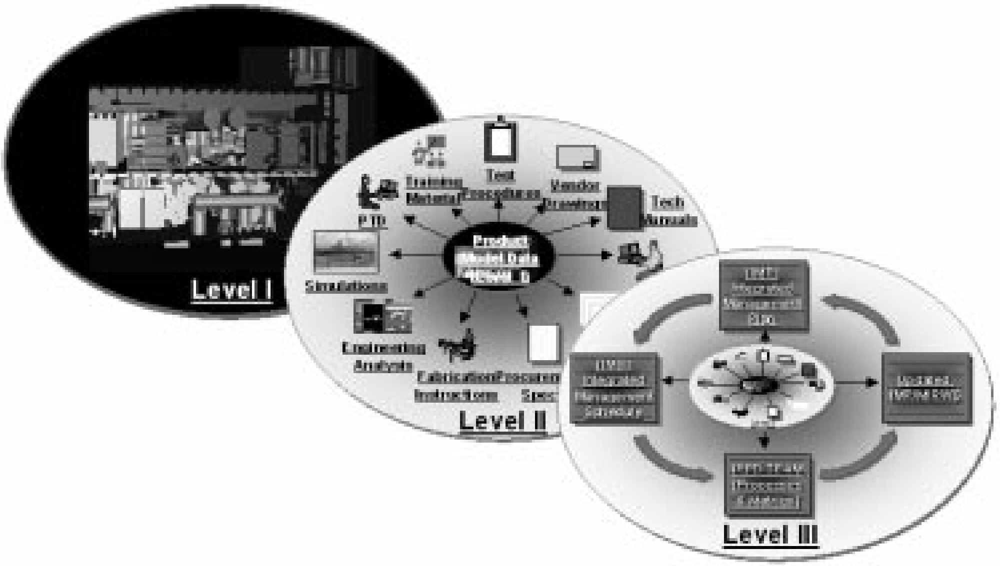

Figure 1
IPDE – Three-Tiered Architecture

SELECTION OF TECHNOLOGY PARTNER

During the formation of the Avondale Alliance, the ship construction partners of AII and BIW wanted to add a strategic partner who could provide not only hardware and software but also provide a full range of IT integration capabilities. Intergraph Corporation was selected in early 1996 based primarily on their extensive experience in the Navy CAD-2 contract, which offered the same range of services that the Alliance required.

Part of the LPD Program doctrine is the ability to provide timely technology refreshment for IPDE. The addition of Intergraph to the team has helped fulfill this need. The second critical component of the IPDE that Intergraph provides is close integration of the CAD geometry tool, Integrated Ship Design and Production (ISDP), and the enterprisewide data management toolkit, Asset Information Manager (AIM). Intergraph also developed a shipbuilding-specific COTS tool called the Ship Information Repository (SIR) that integrates ISDP with AIM. SIR provides the mechanism for posting geometry and attribute information from ISDP to the AIM product structure for functionally significant items. Once this product structure is established, the ownership and manufacturing teams can then add post-design information, such as maintenance parts lists, mean time between failure information and other life-cycle data, to the product model. This information will subsequently be used to account for and store TOC tradeoffs, life-cycle support information, and manufacturing-specific information.

IPPD TEAM STRUCTURE

One of the fundamental components of the LPD 17 Program is the use of Integrated Product Teams (IPTs) in an Integrated Product and Process Development (IPPD) environment. A dynamic and cost-effective approach to the concept of teaming, IPPD is unique in team make-up and scope. Each team is composed of individuals empowered to conduct day-to-day business in their specific disciplines. Multiple disciplines are represented on each team, giving the team a broad cross section of expertise and product ownership. Each team's scope of effort is focused on a particular product related to the design, construction and life-cycle maintenance of the ship.

The definition of the Integrated Process and Product Development states the following:

"IPPD is a management approach that integrates all activities from product concept through production field support using a multifunctional team to simultaneously optimize the product and its manufacturing support processes to meet cost and performance objectives. [4]

IPPD is a process that spans the entire project and life cycle of the ship. The daily activities of the program are executed upon the foundation of IPPD. A crucial step in the successful implementation of IPPD is the total commitment of the top executives from each of the Alliance members. During the proposal phase, the LPD team conducted several workshops that focused on how IPPD was to be implemented. The workshops, which were supported by senior management, proved very beneficial in emphasizing the positive differences between the traditional ship acquisition project management approach and the IPPD approach. In December 1995, Al Bossier Jr., CEO, Avondale Industries Inc., commented, "I am convinced that we must begin the implementation of this process at Avondale to ensure our future success." [5] This directive from the top down was instrumental in driving past the initial roadblocks to a successful implementation of the IPPD process within the Alliance.

The organization formed to implement the team-based IPPD process for LPD 17 had several management layers. At the top layer of the team structure, the Navy's Program Executive Officer (PEO) and the Alliance CEOs formed the Alliance Executive Board. This team is responsible for broad program oversight and execution. They meet on a regular basis to review contract progress, cost performance, and schedule achievement and to discuss critical programmatic issues.

Figure 2
TEAM 17 - Cross Product and Integrated Product Team Relationship

The next layer under the Alliance Executive Board is the Program Management Team or PMT. The PMT is responsible for setting policy and guidance in the program and for conducting working-level management of all program activities. The PMT is composed of program managers from each of the Alliance partners and the Navy, plus team leaders from each of the Cross Product Teams (CPTs). The PMT meets several times a week to conduct the business of the program. At the third layer are six CPTs who report to the PMT for matters involving cost, schedule or performance. Each of the CPTs represents a distinct discipline in the ship design and construction or life-cycle support process that is responsible for delivering a product to an internal or external customer.

Figure 2 is a graphic representation of the CPTs and the Integrated Product Teams (IPTs). The specific orientation and placement of the teams on the chart represents part of their functionality in the overall LPD 17 Program. IPDE provides the enabling environment in which the CPTs and IPTs conduct their business. IPDE provides the necessary electronic data infrastructure to execute this challenging state-of-the-art approach to concurrent design, construction and life-cycle support. This is also the reason that a circle, encompassing the total organization of the LPD 17 Program, is used to represent IPDE. In that context, the IPTs also represent specific, more detailed product development and production areas. Table 1 provides further amplification of the CPTs, their subordinate IPTs and general areas of responsibility.

Subordinate IPTs may further subdivide their product development tasks to lower-level IPTs, focus groups or other working team structures that best accomplish the task. The hierarchical system of teams provides the foundation on which the IPPD process builds.

In a traditional ship acquisition process, the program office is located at the Naval Sea Systems Command (NAVSEA) Headquarters in Washington, D.C. The local Supervisor of Shipbuilding (SUPSHIP) provides on-site Government representatives who are located on or near the shipbuilder's facility. The shipbuilder typically forms a core project management team to run the program, and various functional disciplines supporting the core team are scattered around the shipyard in various office buildings and shops. This structure requires many visits between sites and increases the time needed to pass data back and forth for approval at each step in the design and construction process.

Cross Product Team	Integrated Product Team	General Responsibilities
Ownership CPT	Ownership IPDE Sub-Team	IPDE development of the Ownership IPT
	Total Ownership Cost Reduction Team	TOC reduction across the program
	Configuration Management Team	Configuration Management of program data
	Technical Manual Focus Group	Implementation of technical manual requirements
IPDE CPT	System Integration Team	IPDE system integration and IPDE project management
	Technical Integration Group	Technical integration and IPDE system development
	Software Development Team	Software development in accordance with user requirements
	Web Development Team	Developing and implementing applications on the Web
	Configuration Management Team	Manage software and hardware configuration across the Alliance
	Shipboard IPDE Team	Responsible for development and implementation of the shipboard IPDE
	Training Team	Develop and conduct training for the Alliance
	Modeling and Simulation Team	Develop and implement modeling and simulation systems across the Alliance
Total Ship Engineering Team (TSET)	Machinery IPT	Responsible for the design of the LPD machinery systems
	Hull IPT	Responsible for the design of the LPD structure and hull
	Mission IPT	Responsible for the design of the LPD mission systems
	Distributive Systems IPT	Responsible for the design of the LPD distributive systems
	Accommodations IPT	Responsible for the design of the LPD accommodations and supporting systems
	Topside IPT	Responsible for the design of the LPD topside systems
	Integrated Ship's Electronics Team	Responsible for the design and integration of the LPD electronics systems
Combined Test Team	Design Integration Team	Responsible for design integration testing
	Shipboard Test Team	Responsible for shipboard testing
	Factory Test Team	Responsible for factory testing
Cost Estimating Team	No sub-teams	Responsible for cost estimate development
Program Management Team	No sub-teams	Responsible for LPD program management functions

Table 1

IPT and CPT Relationships

The LPD 17 program and IPPD brought a new paradigm to the management of shipbuilding programs. A critical element of the IPPD concept is collocation, with the majority of the team members at one site. Not only are representatives of all the disciplines at one site, but they work from the same building, many on the same floor. The Navy customer (from the Alliance perspective) is collocated with and integrated into the CPTs and IPTs. Alliance Team Leaders sit next to their Navy counterparts. The bulk of the Navy program management team was moved from Washington, D.C., to the Alliance site at Avondale in New Orleans. Certain functions, however, remain at NAVSEA Headquarters in Washington, D.C., in order to keep headquarters and Pentagon sponsors informed. The collocation of Navy program management staff with their Alliance counterparts has greatly streamlined communications and reduced the time needed to conduct problem resolution. The resolution, once reached, is then "owned" by both the contractor and the Navy, thus reducing communication and approval times. Conversations that were traditionally conducted by telephone are now held face-to-face. Meetings that once required lengthy periods of travel are now completed in a matter of hours with far better results and issue follow-up. Perhaps one of the greatest advantages of the collocation of Navy and Alliance personnel is the unplanned, yet highly productive, "passageway meetings" that occur throughout the project office on a regular basis. These frequent, short business meetings, often prompted by just seeing someone, solve many problems while they are still small and manageable.

In order to maximize the benefits of this collaborative environment, participation from other remote locations is often necessary. This invariably requires spanning great distances. Communications technology was employed, in addition to collocating personnel, in order to reduce cost. In this context, the IPDE facilitated a collaborative environment for design while the program's WAN facilitated video teleconferencing, e-mail, scheduling and calendar event notification at the desktop. The LPD 17 Program's WAN is depicted in Figure 3.

The entire decision-making process has been streamlined by the IPPD approach. Because the teams are multidisciplinary in their representation, they bring a much wider consideration of views associated with an issue to the decision-making process. Many teams are managed by requiring team members to reach a consensus on all decisions. This approach

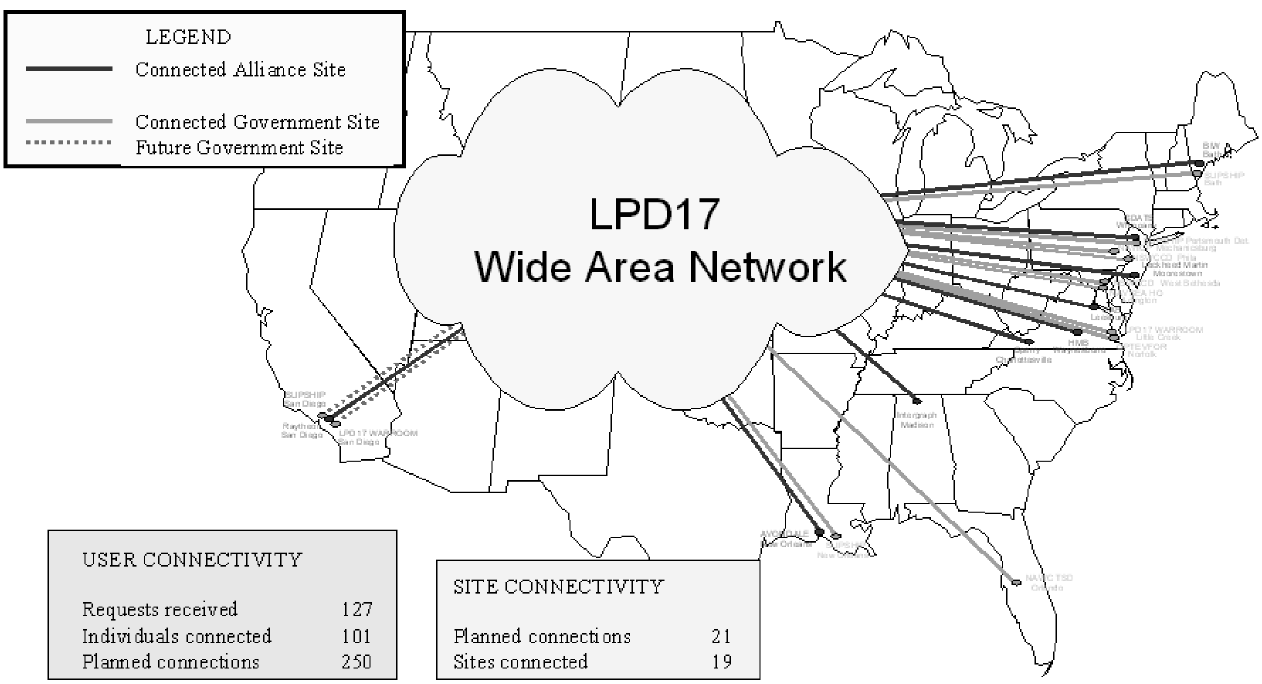

Figure 3
LPD 17 Wide Area Network (WAN) Connectivity

brings new perspective and consideration to issues that decision-making in a traditional setting often bypasses. The larger number of contributing viewpoints results in better decisions and subsequent cost savings. Especially critical in the decision-making process is the "voice of the customer." Through on-site design and construction IPTs, the Navy has immediate input on design decisions and can strongly influence the ship's ultimate configuration. This collaborative decision-making should prevent costly changes from occurring late in the design process or during actual construction.

IPDE STRUCTURE

IPDE Product Model Architecture

The approach used to define the IPDE architecture reduces infrastructure development costs by using Commercial Off-The-Shelf (COTS) hardware and software. Data necessary to manage the program, to design the ship and to support it over the life cycle will be available in a physically distributed but logically centralized location. For the LPD 17 Program, the Alliance selected Intergraph's Integrated Ship Design Program (ISDP) as the CAD tool and Intergraph Asset Information Manager/Ship Information Repository (AIM/SIR) as the Product Data Manager (PDM) system. These software applications are being integrated with additional software created or purchased by the Alliance as well as with legacy software previously in existence at the shipyards and system integrators.

AIM/SIR is an object-oriented PDM system that will be used to manage the product structure and all functionally significant components in the LPD design. The part that AIM/SIR plays in the IPDE architecture is depicted in Figure 4. This is a significant departure from the conventional PDM systems, which manage data at the CAD file level and cannot normally manage components. Another function of the AIM/SIR PDM system is to make the information on these components and any other data attached to the product structure available to all program participants by use of a Web browser. This enables better and more informed management of ship design and construction objects and documents, as well as logistics data used by the Navy and the FSC.

Parts data is captured and managed in an Oracle-based system written by the Alliance for this purpose. Production data is managed both in AIM/SIR and ISDP and implemented through integration with legacy systems at each construction yard (Avondale and BIW).

The Engineering Bill of Material (EBOM) and the Manufacturing Bill of Material (MBOM) are managed in an Oracle database attached to the CAD tool but integrated with the PDM system and interfaced with

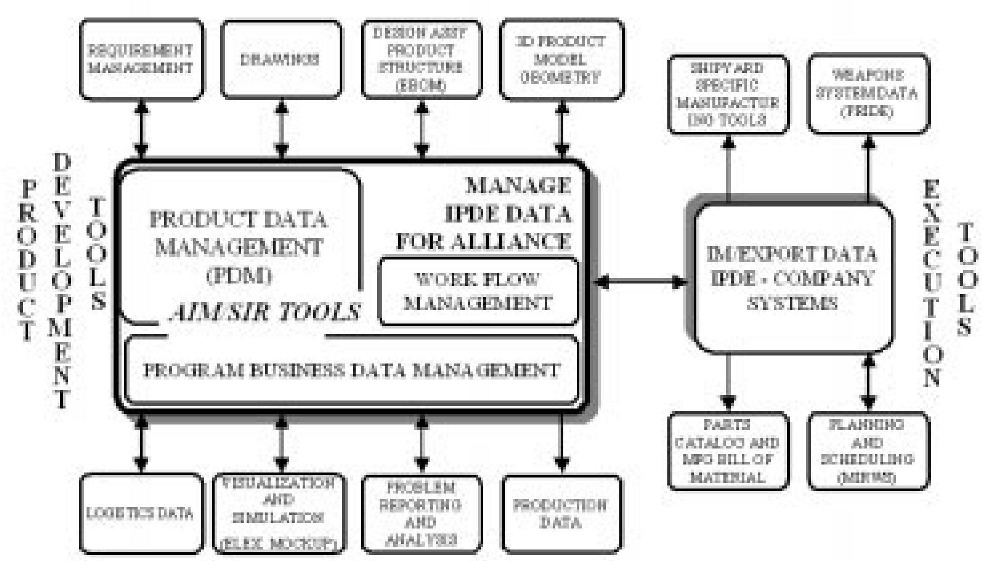

Figure 4
IPDE Functional Architecture

the shipyard legacy systems. Oracle was chosen since it is the underlying database for ISDP and is therefore easily linked to the 3D product model. Additional software is used to perform specific functions such as engineering analysis, pipe bend details, ventilation details, steel lofting and cutting, and ILS deliverables and analysis. These software applications all interface with the LPD 17 product model database and produce their products based on configuration-managed and -approved data.

The LPD 17 IPDE is based on a client/server architecture using the Microsoft Windows NT and UNIX operating systems, which take advantage of emerging COTS technology and provide a cost-effective solution that can be easily upgraded over time. This approach also maximizes the scalability of the enterprise, allowing growth and shrinkage, as the program's needs dictate.

The major elements of the LPD 17 Product Model database are:

(1) 3D Product Model Geometry
(2) Design Assembly Product Structure data Engineering Bill of Material (EBOM)
(3) Parts Catalog
(4) Manufacturing and Construction Assembly Bill of Material (product structure data called MBOM)
(5) Logistics support data
(6) Visualization and simulation data
(7) MIRWS schedule and performance data
(8) Production data (pipe details, vent details, steel and sheet metal lofting, etc.)
(9) Drawings (system diagrams, arrangements and construction drawings)
(10) Electronic mockup

These elements are included in an overall architecture that was designed by the Alliance for the LPD 17 Program. This architecture provides for capture, configuration management and accessibility by program participants over the LPD WAN as depicted previously in Figure 3.

Part of the problem in implementing an IPDE for shipbuilding is the breadth and scale of the data required. Shipbuilding is unique in the amount of data required to fully capture, disclose and manage a design, construction and life-cycle support project. The major elements listed above amount to millions of objects requiring hundreds of gigabytes of data storage accessed by large numbers of people spanning both distance and time. Another part of the problem is that few vendors of COTS software can provide customization for an entire shipbuilding suite of applications. It then falls to a shipbuilder to select COTS applications and, with the help of vendors and shipbuilders experienced in integrated systems, to develop the architecture and then drive its implementation.

To support the development of IPDE, the LPD 17 Alliance established a Systems Integration Team (SIT), a Process Development Core Team (PDCT) and a Training Team. The SIT, whose purpose is to oversee the integration of systems development, together with another team of technical experts – the Technical Integration Group (TIG) – established a requirements definition and development process for the systems to be built. The PDCT took on the very important function of developing and documenting the new processes necessary for collaborative design in an IPDE environment. The training team took the system development documentation and the process information and developed curricula necessary for training more than 1,000 personnel in the process and in the use of the new tools. These three teams have worked closely together and established pilot projects to test tools and processes before full production. They are leading the development and implementation of a world class IPDE that will help satisfy the Navy's vision for total ownership cost reduction.

PRODUCTION INTEGRATION

Avondale and Bath Iron Works each have their own internal production systems, production control systems, shop floor control systems, inventory and parts management systems, as well as internal cost tracking and management systems. In order for these shipyards to use the IPDE, an integration task involving each of the production systems in each shipyard is necessary. The products and outputs of the IPDE have to be designed to furnish data in a form that each shipyard can use. Thus, the SIT and PDCT decisions are made collaboratively with an eye toward making the integration task as easy as possible.

There is a formal release process with the products of the design process captured and made available to the production planning teams of each of the shipyards in the object-oriented AIM/SIR database. This information is being developed and formatted by the ship designers to adhere as closely as possible to the format desired by the production planners. Once approved for issue, the data will be transferred to the design team information vault – analogous to an electronic filing cabinet – within AIM/SIR for capture and redistribution into production vaults. Production planning will assemble the data into work packages that correspond to the shops and production processes used to build the ship. This is a significantly different approach to data management than currently used within the shipyards.

Previously, drawings were the issued product from which information was manually extracted and reformatted to meet shop production processes. Considerable opportunity for error existed in the numerous transfers of data from one source to another. Quality checks and subsequent rework were a normal part of business in this system. By applying the concept of "entered once, used many times," the information is placed in AIM/SIR by the ship designers, electronically transferred to a point of use in the production department and ultimately transformed into the ship itself. Costs are reduced by eliminating data transfer, quality checks for data transcription errors and problems of having multiple data sources for the same or similar data.

In addition, each of the Alliance shipyards has invested in production automation for steel cutting, pipe bending and sheet metal cutting. These automated production systems rely on geometric data to create the parts from sheets of metal and blank pipes lengths. The 3D-product model offers a unique opportunity to extract directly the necessary work authorization paper as well as the geometry necessary to feed automated systems. The Alliance is taking maximum possible advantage of the opportunity to exploit the product model in the construction and manufacturing process. "Digits to Steel" is becoming a reality for the Alliance.

PRODUCTION

The Alliance is taking advantage of the electronic product model database in the preparation of work paper as well as the interface to automated systems such as lofting, pipe bending and sheet metal cutting. A production vault is being prepared in the AIM/SIR PDM tool, which will allow the configuration managed release of design objects (data) to production with the necessary product structure and the required 2D geometry for work paper. Production planning will be able to access the product structure in the production vault as well as the released objects (documents, drawings, material lists, etc.) to produce electronic work authorizations, which are tied to the MIRWS schedule and released to the trades to construct the ship.

An interface has been created between the Intergraph 3D model and the Avondale SPADES lofting system. This interface was made to be as generic as possible to allow connection ultimately to the BIW Lofting system. The interface transfers geometric shapes and material information to the lofting system, which is then used to nest many geometric shapes for cutting on one sheet of metal to minimize waste and scrap. In order to test the production process as well as the tools, a pilot project was performed on an inner-bottom unit, which exercised the process from 3D modeling through actual cutting of steel in production. The "Digits to Steel" pilot, as chronicled in the next section of this paper, enabled the Alliance to test the capabilities of the tool as well as the very important process of managing and transferring the electronic data from engineering to production.

The Alliance is also preparing an interface to an application that will produce all of the pipe detail drawings (spool pieces) in a batch process using the geometric and product model data in the design database. Both Avondale and BIW will use this to produce the piping needed for the ships to be built at each shipyard. The drawings will serve as the work objects and the ISDP geometry will be used to generate the instructions to run the pipe benders. For sheet metal cutting in support of Heating, Ventilation and Air Conditioning (HVAC), geometry from ISDP will be used to create detail drawings. These will be posted as objects to the AIM/SIR production vaults to be used to create work authorization instructions in the manufacturing process. The geometric shapes will be transferred to the sheet metal cutting program. Avondale and BIW both use the same programs for this activity. The nesting of the shapes and the generation of the cutting path are handled inside the sheet metal program.

It is expected that these steps in automation and the use of the 3D product model will enable a much more efficient manufacturing process while taking advantage of the product model data that was produced in the design process.

UNIT 2311 PILOT

Prior to scheduled production start, the Alliance commenced a pilot program to build a hull unit of LPD 17 (Unit 2311). The purpose of this evolution was to test the "Digits to Steel" interfaces and prove the IPDE concept as reality. This major milestone validates the use of the IPDE to shorten design time and improve design accuracy. A photograph of Unit 2311 production is provided as Figure 5.

Figure 5
"Digits to Steel"

The ISDP suite is used in conjunction with Avondale's SPADES steel production system to help minimize fabrication and schedule risks. During this process, the 3D structural models were authenticated, reviewed and checked for interference using ISDP and the Deneb 3D-visualization tool. Intergraph's Design Review tool simulates the manufacturing process and allows the designer to take a virtual walkthrough of the 3D model. The ability to detect and correct any errors before construction begins will result in lower construction costs and shortened construction schedules.

"This is an important achievement for the program," said Avondale's David L. Bergeron, Vice President of Operations, Planning and Scheduling. "We are exploring new waters with the computerized design of LPD 17. Each time a product or new process is validated, we push the envelope for future Navy shipbuilding and acquisition programs that will continue to be driven by Total Ownership Cost Reductions." [6]

REDUCING TOTAL OWNERSHIP COSTS

Concurrent engineering is the primary source of cost reduction during the design phase. It is impossible to achieve these savings without the utilization of the IPPD team structure under the umbrella of IPDE. Together, these provide the necessary ingredients to achieve cost savings. The ability to determine the cost of ownership is referred to as Total Ownership Cost (TOC) and has the following definition:

Total Ownership Cost includes all costs associated with the research, development, procurement, operation, logistical support and disposal of an individual weapon system including the total supporting infrastructure that plans, manages and executes that weapon system program over its full life and the cost of requirements for common support items and systems that are incurred because of introduction of that weapon system but excludes indirect "non-linked" Navy infrastructure costs that are not affected by individual weapon system's development, introduction, deployment or operations. [7]

Concurrent engineering practices and the use of a state-of-the-market IPDE is an enabler of IPPD, which in turn provides for a TOC-conscious environment. The goal of TOC reduction occurs in every phase of the program, including detail design, systems integration, construction, testing, logistics and life-cycle support. Reliability, maintainability and supportability design criteria and characteristics are considered early in detail design and focus on significant TOC reductions while achieving new standards of ship readiness. [8]

The LPD 17 Class is being designed with four fundamental principles. It will be:

- Warfare Capable
- Mission Flexible
- Technically Adaptable
- Affordably Supportable

The lack of configuration control and configuration management is currently the top readiness problem in the Fleet. The LPD 17 configuration management strategy is the data-centric approach of the IPDE and its use for information management. The purpose of this approach is to prevent the segregation of information from the database and the geometric relationships conveyed by the associated drawings. Information will be stored one time in one place and interpreted in any number of contexts. This approach means that a user can extract a drawing from a database at any time with confidence that if any changes occurred in the design, the drawing reflects such changes without the effort of researching what has changed. The key point to the data-centric approach is the higher level of reusability of information. In a data-centric approach, the basic information about the objects and components within a project can be reused in another application of this information in other locations throughout the ship. Using the data-centric approach to configuration management will reduce process time and significantly increase the accuracy of the data to support the systems or equipment, thus eliminating costly errors in procuring logistic support. [9]

CURRENT STATUS OF DEVELOPMENT

The IPDE provides the umbrella of automated functionality necessary for the cross-disciplined teams of the IPPD to function at their maximum efficiency in the application of concurrent engineering. Traditional shipbuilding practices are frequently characterized by data generated and stored numerous times in numerous places to facilitate use by nonintegrated, disparate tools. This approach requires a data synchronization and validation process to be applied before the data can be reused in the design, construction or support of the ship. If there is a mismatch in the data, further effort must be expended to determine the correct data source. Databases must be compared and synchronized in order to generate the appropriate products. Configuration control of the data becomes a maze of extensive processes and procedures, and personnel charged with keeping the data in order are often called upon to perform heroic actions. The IPDE prevents these wasteful validation activities by making data from a valid source available to multiple users across a widely dispersed geographic set of program participants.

Furthermore, IPDE is not dependent on a specific vendor or tool. It is an information system composed of many software and hardware applications that are flexible enough to support the technology upgrades anticipated in the future. This technology-friendly approach will contribute to the reduction of the total ownership cost by allowing the information system to respond to cost saving advances and upgrades.

Cultural Changes

One of the most significant aspects of the implementation of IPPD and IPDE has been the cultural change thrust upon the entire Alliance. Each of the Alliance partners has established methods of operation unique to their products, processes and locations. In many cases, it has been necessary to put aside those distinctions and either create new processes and business approaches or accommodate a partner's best practice. As one might expect, this accommodation does not come without some resistance and struggle. Compounding the challenge has been the concurrent implementation of the IPDE hardware, software and network systems. A high degree of automation has been the norm for BIW and Raytheon Corporation for some time. For Avondale, however, wide-scale automation was a major step forward. The development and implementation of new design tools and associated processes have been difficult, especially when coupled with the implementation of the principles of IPPD and the design of a "first of the class" ship.

At two-plus years into the program, it is gratifying to see the progress made by the Alliance in the development and implementation of the new technology, hardware, software and processes. Over 1,140 workstations have been deployed, and more than 130 software configuration change bulletins have been issued implementing various software packages and upgrades. The WAN and Alliance partner's LANs are in place and functioning as designed. Collaboration with remote sites on design and program issues is a daily occurrence utilizing VTCs, e-mail and collaborative presentations.

The 1,140 workstations and 57 servers use the latest available (at time of purchase) Intel processors and are typically configured in one of two ways. Designers and 3D modelers use workstations with 256 MB of RAM, 10 GB drives, and dual-boot operating systems (Solaris x86 version of UNIX and Windows NT). General users accessing the IPDE utilize workstations with 128 MB of RAM and 10 GB drives running on Windows NT.

Organization Changes

Upon award of the LPD 17 contract, the IPDE IPT was established to implement the new data environment. The initial charter for the IPT was to create a world-class IPDE that would support the design and construction of the LPD 17 Class ships. The scope of effort under this team touched on all aspects of the IPDE development, from software and hardware to network system implementation. The team had full representation from each Alliance member and included several senior managers.

Shortly after the contract was awarded, the IPDE IPT joined all the other IPTs for an intensive six-week period of team building and organizational alignment. During this period, the IPDE IPT generated the task statements and vision of how the initial phases of the

IPDE would be brought into existence. It was anticipated that the IPDE IPT would be the focus of all the efforts and, in fact, would accomplish much of the necessary hands-on work needed to bring the environment into existence.

The first – and initially the largest – task was to provide hardware and network services to all of the LPD 17 Program participants. This entailed purchasing workstations, routing network connections and setting up the hardware after it was received and assigned. This task was accomplished by a group of technicians and system administrators who reported to the senior managers on the IPDE IPT. Concurrent with the infrastructure setup was the task of establishing the IPDE system data architecture. Although the ISDP and AIM products were COTS, both required customization to precisely meet the requirements of the new users. The integration of the multiple systems that were part of the total IPDE was key to the data architecture. This integration also became key to the future organizational make-up of the IPDE. This organizational structure and approach to system development was in place until October 1997. At that time, it was determined that the scope of the effort went far beyond the capability of a single team to adequately manage and control. A strategic planning session was held in October 1997, and a new, multiple-team structure was implemented.

This team structure is represented in Figure 6. It was nicknamed the "Basket Weave" for obvious reasons. The "Basket Weave" is characterized by a group of horizontal, cross-product teams that are responsible for disciplines that crossed the broad spectrum of functionally specific teams. These are the areas of System Engineering, Training, Operations, Infrastructure, Configuration, Change & Data Management, Integration & Testing and System Implementation. Interwoven between these cross-discipline teams is a set of "vertical teams." These teams represent specific, well-defined areas of functionality. The vertical teams are responsible for the identification of functional concept of operations, requirement identification, test plan development and functionality implementation. Spanning all teams is the Systems Integration Team (SIT). The SIT is responsible for integration of all other teams and for providing the necessary project management to keep such a large-scale development effort on track. The IPDE IPT provided oversight, guidance and strategic vision to all of the teams, and maintained an interface with the program level CPTs.

This team structure proved to be more successful in implementing and executing the software development activities. The major focus of the teams' efforts centered on the identification and documentation of

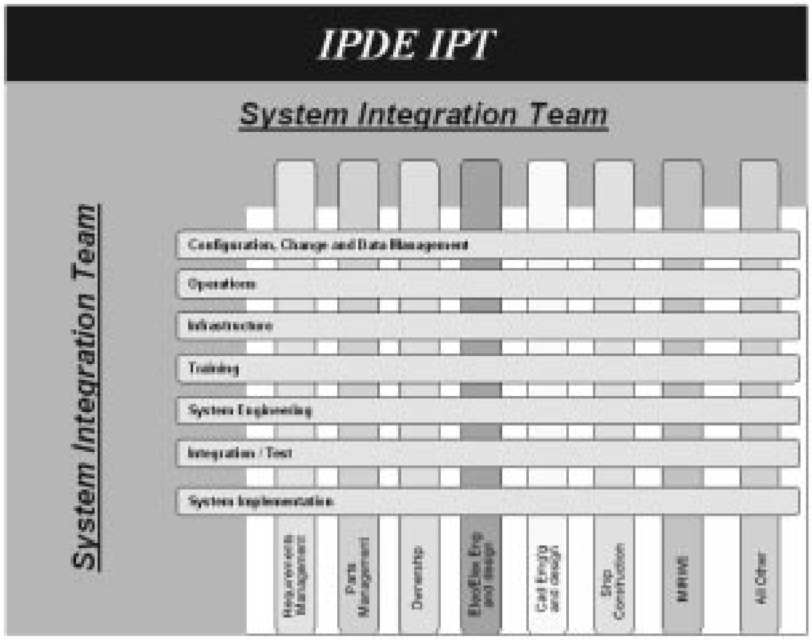

Figure 6
"Basket Weave" Team Structure

the functional requirements for the software development areas. Teaching shipbuilders how to write adequate software requirements was not a trivial task. The SIT strived to establish an appropriate and implementable scope of functionality that fit within the schedule constraints imposed by design activity and contract requirements. Several high-level integration efforts were attempted but did not result in a tightly knit set of requirements and software capabilities. In spite of these trials, the horizontal and vertical team structure provided an adequate framework to execute several software rollouts.

Although successful in the implementation of new software functionality, the "Basket Weave" organization was insufficient for conducting large-scale integration across the full spectrum of capabilities that are needed to design and build a new ship. Another strategic planning session was held in November 1998 to re-assess the organizational structure of the IPDE group. It was acknowledged that the vertical teams had performed the tasks necessary to generate functional requirements, but bringing all the input together and creating a cohesive and implementable software bundle was very difficult. Team member feedback also indicated that there needed to be a more efficient manner in which to accomplish integration. The solution to the challenge was to create the Technical Integration Group (TIG). The TIG is responsible for the technical integration of the diverse functionality of the IPDE. In response to team leaders and team member feedback from the first major product model rollout, the SIT also took the opportunity to restructure the remaining IPDE teams into a more efficient organization.

Figure 7 graphically displays the current team structure. The SIT is still responsible for the overall execution of the IPDE implementation but is now assisted by the TIG in the integration of the IPDE functionality. Vertical teams from the "Basket Weave" organization were retained to provide specific areas of focus such as Ship Construction, Ownership and Engineering. These teams provided the necessary user input for requirement development, and later in the process provided resources for testing the software products. A new team was created to handle the configuration management of the software and hardware systems. Other teams were created to increase focus on the development of Web technology, Shipboard IPDE, training and IPDE system operations and infrastructure management. An additional team was created and located at Intergraph to handle the software development effort resulting from the requirements developed by the users. This organizational structure has proven very capable in handling the project management, development and implementation tasks of the IPDE.

SOFTWARE DEVELOPMENT APPROACH

In instances where COTS products were insufficient to meet program needs, software modification

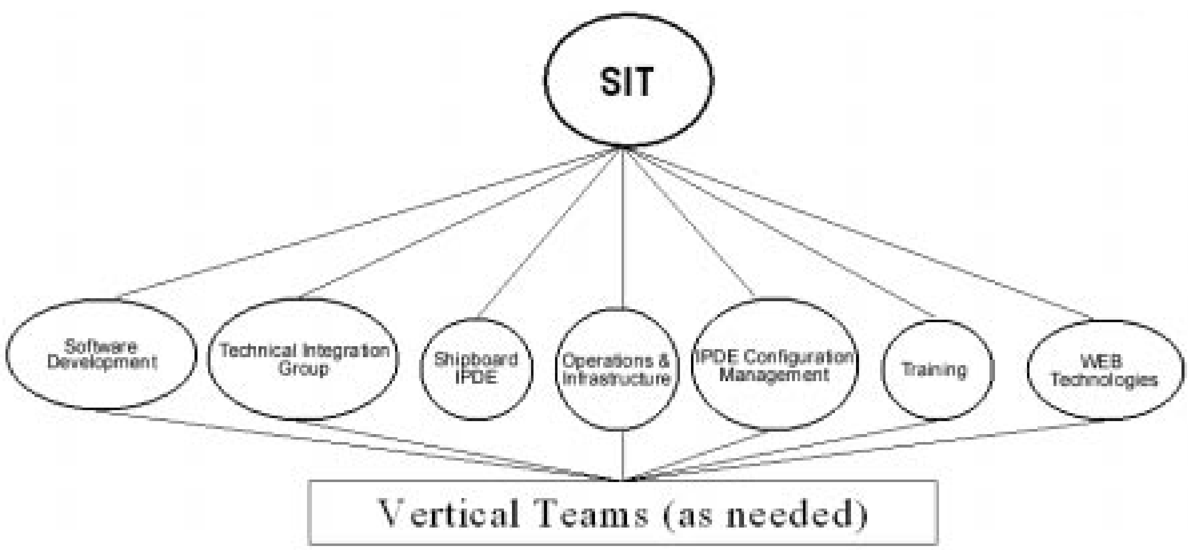

Figure 7
Current IPDE Team Structure

and customization were required. The software development approach employed by the Alliance for each development cycle consists of four distinct phases:

- Requirements Identification and Definition
- Design and Coding
- Testing
- Production Implementation

These phases are graphically represented in Figure 8, the "Waterfall Chart."

A good requirement can be handed to a software developer who is able to understand with complete confidence that the written document accurately expresses the needs and expected functionality of the new software. With clear unambiguous requirements, software development can proceed, and the users can be assured that the product they requested will indeed be what is developed.

Customized development of the baseline COTS products based on user requirements proceeds in a phased, structured approach. Using the customer-provided requirements, system analysts work with development personnel to refine the requirements into a preliminary system design document.

Once the document is complete, system analysts and developers conduct a detailed software Preliminary Design Review (PDR) with the System Integration IPT. When the document is approved by the System Integration IPT, detailed design proceeds. The detailed design includes sufficient "top-down" information for coding to proceed and provides supporting information back to the test team for their preparation of test documents.

In the traditional software development cycle, there are four testing phases. The first phase is the testing of the software at the code level. The purpose of code testing is to determine if the design and development of a specific section of code functions properly. The next phase is unit testing. The software is combined with other similar software modules and tested to ensure compatibility between modules. If the modules interact as expected, the level of integration is increased and the software is tested in a hardware and software environment that exactly replicates the production environment for which the new functionality is designed. This phase of testing is called Independent/Integrated Verification and Validation (IV&V) testing. IV&V testing is conducted by independent testers under strictly controlled conditions.

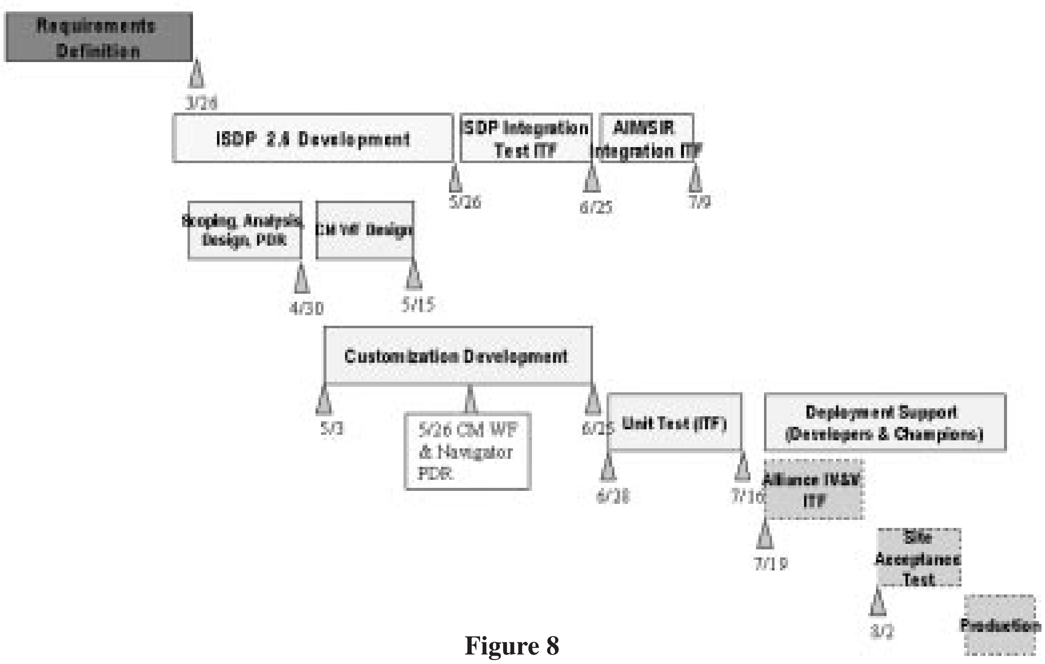

Figure 8
Software Development "Waterfall Chart"

This document accounts for each requirement in the design of the architecture and the specific implementation of the software code, Graphical User Interface (GUI), and inputs and outputs of the system.

Once a satisfactory level of success has been demonstrated in the IV&V environment, the software is moved to the production site. There testing is conducted in a second environment on the actual hardware and workstations that will be used to create production products. This testing is called Acceptance Testing and is accomplished by the actual software users with support from the System Analysts and development personnel as necessary.

Upon successful completion of Acceptance Testing (AT), user training and process implementation, a formal Alliance Configuration Control Board (CCB) reviews the completion of the exit criteria used to determine production readiness and recommends implementation of the software into the production environment for daily use. The CCB also dictates that all Alliance sites load the same software on their Alliance-approved hardware configuration within a few weeks.

IMPLEMENTATION OF A WEB-BASED INTERFACE TO THE IPDE

In one specific example of custom development, the Alliance has a requirement to provide IPDE access to hundreds of Alliance and Navy personnel who have a "need to know." Often this access may be for only a brief time and occur no more than once or twice a year. Therefore, the Alliance needed an easy and intuitive interface. The development and deployment of LPD Navigator fulfills this requirement. LPD Navigator provides a Netscape Navigator Web-based interface to IPDE. It controls access through both application and AIM user and group authentication. The LPD Navigator interface can be used to search and view attributes of objects and files attached to these same objects. Files can be independently checked and marked up using the AIM/Redline application. AIM manages and registers each layer within the AIM database management application. The addition of LPD Navigator has greatly simplified the training process and has enabled numerous casual users to have productive access to the necessary data to perform their jobs.

SHIPBOARD IPDE APPROACH

A logical extension of the IPDE supporting the design, construction and life-cycle management of LPD 17 data is the application of a subset of the IPDE aboard each ship of the LPD 17 Class. The vision for this application is broad and extensive in its approach to the implementation of new technology, the integration of critical Navy data systems and its potential for saving labor and money. The Alliance has developed a Concept of Operations that details a baseline system reflecting current system capabilities and a long-term vision for a sophisticated, highly capable system. This system capitalizes on the latest Web and Internet technologies and leverages other Navy and industry initiatives.

The function of the Shipboard IPDE is to enable the crew to gain access to any appropriate data that may be contained in the IPDE. The Shipboard IPDE is considered to be a subset of the overall IPDE since certain data, such as production specifications, is not normally required for crew use. As with all naval electronic systems, the Shipboard IPDE will be both Y2K and IT-21 compliant. Y2K is well documented and, at this point, requires little amplification. IT-21 stands for Information Technology for the Twenty-first Century. It represents the DoD vision for a common, integrated Command, Control, Communications, Computers and Intelligence (C4I) infrastructure. This includes both tactical and nontactical systems (as is the case with Shipboard IPDE). Other DoD initiatives include the Defense Infrastructure Initiative and Common Operating Environment (DII/COE) and the Joint Vision for 2010 (JV2010). Both of these programs set goals, guidelines and architectural requirements to ensure interoperability and commonality over a common information back plane.

The objective of the Shipboard IPDE is to provide a tool that allows rapid access to centrally managed ship product configuration and associated data. Specific objectives of implementing the Shipboard IPDE are to:

- Provide a single source for ship configuration data and some set of ship support data
- Logically distribute information to the user when and where it is needed
- Improve business processes and administrative operations
- Represent data <u>once</u> in a central repository
- Control and manage that data at a single source
- Improve the ship-to-shore interface for configuration data
- Ease the availability and use of the ship and class information
- Capture feedback for update of the configuration data
- Provide a management tool for executing the life-cycle management functions
- Integrate other information from various sources

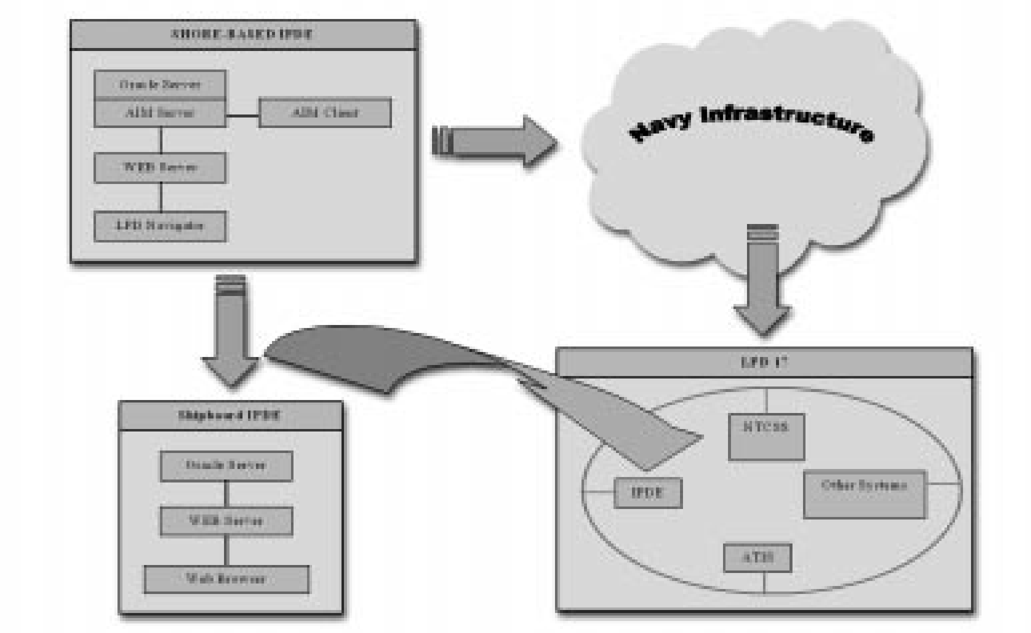

Figure 9
Shipboard IPDE Baseline

Shipboard IPDE data is hosted on its own server and is distributed through the Shipboard Wide Area Network (SWAN) to shipboard operators, crew and maintainers when and where it is needed. The baseline Shipboard IPDE is a nontactical, unclassified, read-only and non-mission-critical system. This baseline is depicted in Figure 9. It has the capability to improve onboard processes while providing easy-to-use interfaces to both the shipboard and land-based information infrastructures. It is the common source for ship configuration and other support data and contains update and feedback mechanisms that serve to interface with (instead of duplicating) existing systems. The Shipboard IPDE product data is a subset of the shore-based IPDE.

While Figure 9 represents the relationship of the baseline Shipboard IPDE, there has been much discussion on the envisioned future system concept. Taking inputs from two separate Design for Ownership (DFO) workshops with the Fleet, this future concept could integrate the nontactical IT systems on board ship. Such an effort will require teaming across traditional systems' command boundaries, which has been initiated by "Team 17." The vision of the future Shipboard IPDE is applicable for other classes of ships, and will hopefully set a precedent for increased integration of all nontactical shipboard IT systems.

LIFE CYCLE SUPPORT IPDE VISION

Another aspect of the IPDE includes the concept of a Life Cycle Support (LCS) IPDE. The LCS IPDE is envisioned to be the tool set used by operators, maintainers, logisticians, and infrastructure support personnel. The LCS IPDE will be that portion of the IPDE that supports future maintenance, upgrades and configuration management of the ship class. The life-cycle IPDE should be able to communicate with existing and future Navy maintenance information systems and maintenance organizations. Of particular note is a current NAVSEA (SEA 04M) initiative, which is the consolidation of all maintenance functions under a single COTS-based management information system (MIS). Such a system would be used at all levels of the maintenance infrastructure and obviously affect any solution to the LCS IPDE. The life-cycle support aspects of the LPD 17 Program are still under study and are being coordinated with the Life Cycle Support Integrated Product Team (LCS IPT).

As previously mentioned, one initiative under review at NAVSEA is the concept of a single maintenance MIS, also known as Enterprise Resource Planning (ERP). This ERP system will replace the legacy programs in use at intermediate and depot level maintenance facilities. NAVSEA expects to contract for a COTS ERP solution by the end of Fiscal Year 1999. A parallel initiative, known as the Naval Data Environment (NDE), is being championed by CINCLANTFLT. This initiative involves the integration of six legacy maintenance systems and is also an enabler to implementation of an ERP. These initiatives, coupled with additional improvements to the shipboard maintenance architecture, will allow a more seamless approach to maintenance processes. It is logical to conclude that the life-cycle IPDE will be linked with any fleet-wide maintenance MIS (NDE and/or ERP). Such a progression of the life-cycle IPDE would be beneficial to the entire fleet and have additional significant TOC ramifications.

THE FUTURE OF IPDE

The LPD 17 IPDE has pushed the use of information technology in a naval shipbuilding program to the furthest point heretofore achieved in an acquisition program. Future technology will allow other Navy ship acquisition programs, such as DD 21 and CVNX, to push the IPDE envelope even further. Continued success by the LPD 17 Program will shift the paradigm for these future naval shipbuilding programs and allow for immediate process improvement within these programs.

The cultural changes fostered by IPPD and IPDE have also changed the paradigm. To help facilitate this awareness, "Team 17" has leveraged experienced personnel and lessons learned from the NSSN, DDG-51 and other programs. The personnel with this experience have provided invaluable contributions in the areas of process development, requirements definition and total system architecture. A series of Technical Interchange Meetings (TIM) between the Navy's new acquisition program offices has also begun. Specific topics discussed at these meetings include modeling and simulation, testing and programmatic lessons learned. Highlights from these meetings will be shared with Navy and Industry partners.

It is clear that as the proliferation of information technology continues, vastly improved systems will be developed. The integration of this technology in a system-of-systems environment will have far-reaching implications on future ship design, construction, maintenance, repair and disposal. In the future, it is hoped that LPD 17 will be looked upon as the "cutting edge" program of its day, and that using IPDE as an enabler provided significant TOC reductions and opened new doors for future generations of naval construction programs.

ENDNOTES/REFERENCES:

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[8] Ibid.
[9] Ibid.