Re-Use of Ship Product Model Data for Life-Cycle Support:

Final Report

November 18, 2006

Prepared by:

Tom Rando - Electric Boat Corporation
Ted Briggs – Intergraph Corporation

(Developed under NSRP ASE Panel Project 2005-384)

Executive Summary

With the advent of full service contracts by the Navy, shipyards have become responsible for the life cycle support of ships, including maintenance and logistics data over the life of the ship. Hence, it will become increasingly important for shipyards to efficiently integrate acquisition data with lifecycle support products. In particular, the use of an Integrated Data Environment (IDE), mandated for all ACAT1 acquisition programs, serves to collect and configure design, engineering and production information during acquisition. This information is also required to develop the logistics data for the ship, including technical publications, as well as support life cycle support systems. The shipyard's cost and performance of these new Navy contracts will depend on the efficient incorporation of this engineering and design information.

The Navy and the aerospace domains are moving toward the adoption of a new the life cycle support standard for technical publication: the International Specification for Technical Publications utilizing a common source database (a.k.a. S1000D). This standard applies to both land and sea specific applications, as well as defense and commercial uses. The purpose of the specification was to address the dramatically rising costs of managing life cycle support information. The specification adopts ISO, CALS, and W3C standards. In fact, it uses STEP AP239, Product Life Cycle Support (PLCS) as one of its normative standards

The Integrated Shipbuilding Environment (ISE) project has published a technical architecture, including XML-based information models, for the sharing of product model data to exchange design, engineering, and production data. The direct use of such data in the population of technical publications could result in significant savings.

This paper discusses the requirements and use cases necessary to define the architecture and process to populate portions of the 'common source database' for ship life cycle support using product model data in ISE format. Specifically it addresses the issues involved in generating PLCS technical data directly from ISE product model data and populating a database in accordance with the S1000D standard. Both the S1000D standard for interactive technical documentation and AP239, lifecycle support data, will be analyzed based on the ISE technical architecture. The integration of the document-centric S1000D standard with the data-centric AP239 and ISE standards is discussed.

NOMENCLATURE

ACAT1	Acquisition Category One
AP	Application Protocol.
API	Application Programming Interface.
CAD	Computer-Aided Design.
CALS	Continuous Acquisition and Life-Cycle Support
CES	Complete Equipment Schedules
DEX	Data Exchange Set
DoD	Department of Defense
DoN	Department of Navy
DTD	Document Type Definition
ECM	Enterprise Content Management
ETM	Electronic Technical Manual
GUI	Graphical User Interface
HTML	Hypertext Mark-up Language.
IDE	Integrated Data Environment
IPC	Illustrated Parts Catalogue
IPDE	Integrated Product Development Environment
IETM	Electronic Technical interactive Manual
ILS	Integrated Logistics Support
ISE	Integrated Shipbuilding Environment (Projects under NSRP ASE Program)
ISEC	Integrated Shipbuilding Environment Consortium
ISEA	In-Service Engineering Agent

ISO	International Organization for Standardization
IT	Information Technology
MRC	Maintenance Repair Card
NSRP	National Shipbuilding Research Program
OEM	Original Equipment Manufacturer
OSS	Operational Sequencing System
PARM	Participating Manager
PDM	Product Data Management
PLCS	Product Life Cycle Support
PMS	Planned Maintenance System
S1000D	International Standard for Technical Publications
SGML	Standard Generalized Mark-up Language
STEP	Standard for the Exchange of Product Model Data (ISO 10303). Defines a neutral file format for product model data and 3D graphics.
W3C	World Wide Web Consortium
XML	Extensible Mark-up Language
XSL	Extensible Stylesheet Language.

INTRODUCTION

With the advent of full service contracts by the Navy, shipyards have become responsible for the life cycle support of ships, including maintenance and logistics data over the life of the ship. Hence, it will become increasingly important for shipyards to efficiently integrate acquisition product model data with lifecycle support product model data. In particular, the use of an Integrated Data Environment (IDE), mandated for all ACAT1 acquisition programs, serves to collect and configure design, engineering and production information. This information is also required to develop the logistics data for the ship. After ship delivery, the acquisition data is required to initialize life cycle support systems for the ship. Technical publications, required to operate and maintain the ship, also require similar ship product model information. Hence, the shipyard's cost and performance of these new Navy contracts will depend on the efficient transfer and incorporation of ship product model data.

However, three different, but interrelated, product model standards have emerged for acquisition, logistics, life cycle support, and technical publications. The Integrated Shipbuilding Environment (ISE), under program sponsorship of the NSRP ASE Program, has developed and published standards-based information architecture. The ISE information models for the exchange of acquisition data have been published utilizing W3C and STEP (ISO 10303) standards. The Integrated Shipbuilding Environment Consortium (ISEC) includes the major US shipyards and a number of information technology companies. AP239, Product Life Cycle Support (PLCS), is a STEP standard for logistics data and life cycle support. The project was sponsored by leading international organizations and Government departments, including a number of aerospace companies. US shipyard participation was limited to attendance of ISO team meetings. The Navy and the aerospace domains are moving toward the adoption of a new the life cycle support standard for technical publication: the *International Specification for Technical Publications utilizing a common source database* (a.k.a. S1000D). This standard applies to both land and sea specific applications, as well as defense and commercial uses. The purpose of the specification was to address the dramatically rising costs of managing life cycle support information. The specification adopts ISO, CALS, and W3C standards, including STEP AP239 as one of its normative standards.

The re-use of ship product model data over the life cycle of the ship will require the ability to exchange product model data across these standards as illustrated below in Figure 1. Automation of such product model transfers could result in significant savings. Potential benefits include:

- Reduced cost, faster development of logistics, technical publications, and life cycle support products

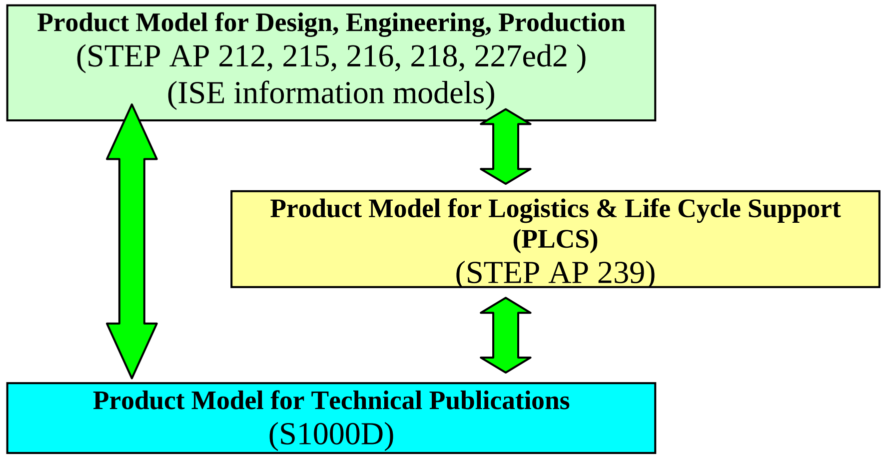


Figure 1: Notional re-use of Ship Product Model Data

- Increased accuracy, reduction of human data entry errors
- Correct and accurate technical data utilizing correct revision and change information
- Reduced rework due to accurate technical data

The potential benefits for authoring technical publications are particularly noteworthy. Today, the extraction of data from drawings is primarily a manual process, involving days of effort. In addition to the extraction time, any changes or updates require additional investigation time – possibly up to a week. This data is typically used for input to downstream systems, which also require updates – this can be weeks of effort. Technical Manuals and Training Guides are also developed from this basic data as well as utilizing additional drawing information for parts lists, maintenance, and disassembly; all of which require significantly more effort.

This work was proposed and funded as a one year NSRP Systems Technology Panel project, awarded early this year. The objective of the project is to define the architecture and process to populate portions of the 'common source database' for ship life cycle support using product model data in ISE format. Specifically, the project was intended to addresses the issues involved in generating PLCS technical data directly from ISE product model data and populating a database in accordance with the S1000D standard. This requires further analysis, based on the ISE technical architecture, of the S1000D standard for interactive technical documentation and AP239, lifecycle support data.

The paper first provides an overview of the ISE information architecture, PLCS information model, and the S1000D standard. The requirements to integrate and interoperate the ISE information models, PLCS model, and S1000D model are then discussed. The requirements include a discussion of the authoring/update process and life cycle support processes, each with separate use cases.

Finally, in addition to using these emerging standards to integrate more closely with shipyard's product model, it has been clear that there is a need for such a standards-based approach in the next generation on-board non-tactical information systems. Today's on-board non-tactical information systems are deployed on a variety of hardware and infrastructure platforms spanning several computing generations. The deployment of applications for on-board use is hindered by this disparity of computing environments. A new generation of onboard information systems is being contemplated. Without a well-engineered coordination of the PLCS, S1000D and ISE standards, this new generation of systems will repeat the incompatibility issues of the past. This paper concludes with recommendations for such a coordination among the emerging information standards.

ISE OVERVIEW

In 1999, the National Shipbuilding Research Program (NSRP), in conjunction with industry participation, funded the Integrated Shipbuilding Environment Consortium (ISEC) to address the problem of lack of information interoperability for the product model data associated with ship design, engineering, and construction. The ISE projects have developed an architecture and a tool set based on the integration of the STEP standards (ISO10303) and eXtensible Markup Language (XML).

The information interoperability problem has arisen primarily due to the proliferation of digital applications. Software applications from one vendor do not necessarily interoperate with other applications from the same or different vendors. This makes integration of systems difficult and expensive - within a department, shop, yard, or ship program. Further, the replacement cost of software must now include interoperability and integration costs – changing software applications is difficult and expensive.

Information interoperability has become a critical problem due to the US shipbuilding industry's migration to a digital product model. In the 1980's and 1990's, the US Navy and its shipbuilders began the migration from a design process that captured ship design information on 2D drawings to a process in which ship design information is formulated electronically (with geometry represented in 3D) and captured as a digital product model. The family of systems required to create and maintain a digital product model has come to be known as the Integrated Data Environment (IDE) or the Integrated Product Development Environment (IPDE).

Each major US Navy shipbuilding program in recent years has built its own IPDE from scratch or by modifying pre-existing components. Collaboration team members typically deploy a lesser, satellite instance of the lead yard's IPDE or rig up connectivity to the primary IPDE. As a consequence, the team member is compelled to support and maintain one or more ancillary IPDE environments. The landscape is illustrated in Figure 2.

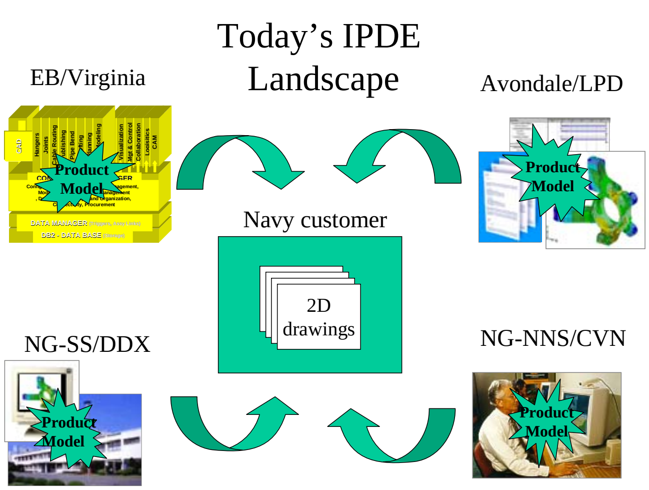


Figure 2: Today's IPDE Landscape

Each major program boasts a different IPDE implementation. The most widely publicized difference is the selected CAD platform, but, in fact, the more crucial difference is in the surrounding shipyard IT systems, the application systems, the data management systems and the plexus of integration threads that hold the system together. At the core of each IPDE is the digital product model which is authored, managed, used internally for analysis and manufacturing, and ultimately transformed into the design deliverable. However, the digital product models are different for each program. One reason for the discrepancy is that the constituent elements of the product model deliverable have not been unambiguously specified at a fundamental level. This deficiency impedes the prospects for collaboration of product data as well as for the collaboration of IPDE system components (i.e. plug and play).

There are a number of process-related and technological prerequisites to the next generation IPDE capability. The ISE project has focused on one of those prerequisites: information interoperability. Information interoperability is the sharing of information across system, application and organization boundaries. Information interoperability is a key enabler of next-generation IPDE; it is a necessary but not a sufficient condition of its production deployment. Surprisingly, the primary focus of information interoperability is not on data exchange for collaboration. The vast majority of the information exchanges take place (thousands of times a day) among the application systems within a single IPDE.

The ISE architecture and prototypes have defined how to create the formal documentation of the requirements for digital product model deliverable. The goal of this activity is to specify the digital product model for shipbuilding, to a level of detail and aligned with current Web capabilities, that enables the production-worthy sharing of the product model between and within various IPDE deployments. This is illustrated in Figure 3.

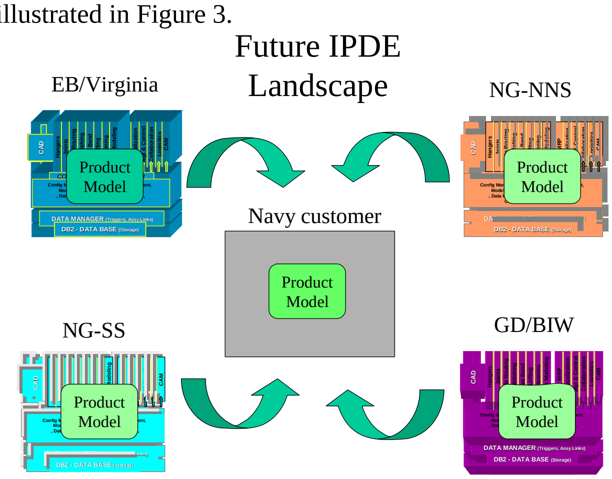


Figure 3: Future IPDE Landscape

The shipbuilding problem universe is broad, but it is comprised of a finite number of well-understood application domains. The information interoperability lifecycle is virtually the same for each application domain.

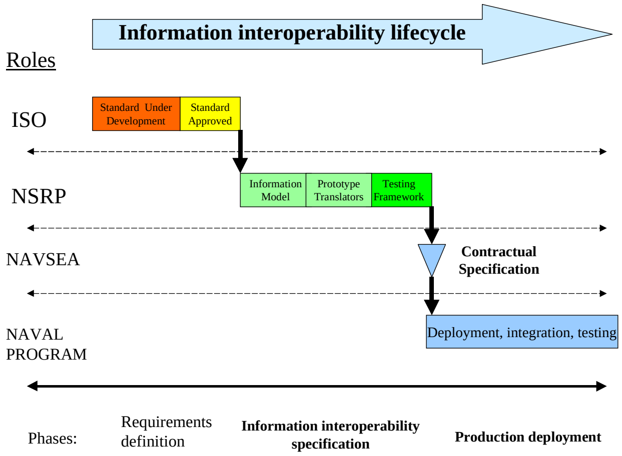


Figure 4: Information Interoperability Life Cycle

Figure 4 depicts the stages and responsibilities of the information interoperability life cycle. The first role belongs to the international standards organizations (such as ISO and, at a more technological level, the World Wide Web Consortium -- W3C). Work to define the digital ship product model has been underway since the 1980's and is now substantially complete. This work consists of the definition of the universe of information elements needed to represent a ship across the stages of the product development life cycle.

The second role is the purview of the ISE project; it entails the production level refinement of the standards-based information requirements into a form suitable to provide information interoperability. The ISE project has developed a very detailed technical approach. It is important to understand that broad directives to use STEP, XML or any IT standard, while well-intentioned, are NOT SUFFICIENT to provide information interoperability.

A detailed description of the ISE process is available on the ISE website [7] and in references [1-4]. The following summarizes the technical approach. The international standards published by ISO/STEP initiate the move toward implementation level consensus, but they are not sufficient; the ISE process elaborates the STEP standards, making them suitable for production use by simplifying, bounding and testing the standard. The process steps (illustrated in green in Figure 4) have been proven, prototyped and demonstrated by the ISE project in selected application domains.

1. ***Information model.*** This step consists of the definition of a use case specific information model, that is, an unambiguous delineation of the information elements needed for each significant ship design/build/support usage scenario. Please note an important technical detail - the information must employ end-user friendly information elements, not impenetrable STEP-specific jargon. The bulk of the effort at this stage consists of simplifying and scoping the information requirements. This entails correcting deficiencies and eliminating ambiguities that still exist in the broad standards. Once the content is resolved, a consensus must be developed on format issues for various representations. As one example, DoN and industry are moving toward standard name spaces that can be utilized by XML implementations to facilitate data interoperability.

2. ***Development of prototype translators.*** This pertains to CAD as well as other applications. The primary purpose for developing prototype translators is the need to ensure completeness of each interaction in a way that cannot be ensured by a mere paper review. This stage generally results in the realization of some commercially available translators but does not guarantee a production capability or deployment.

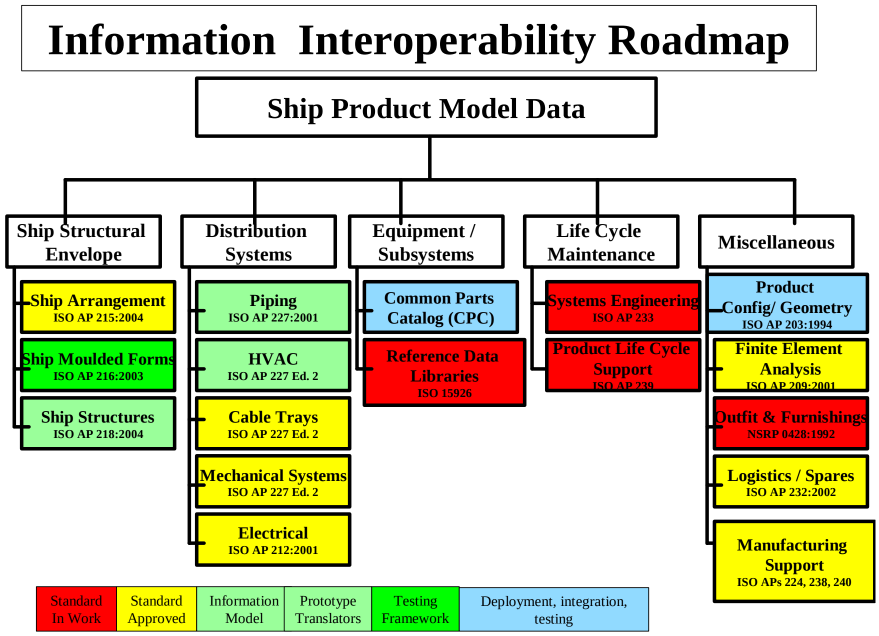


Figure 5: Information interoperability Roadmap

3. ***Test framework.*** The ISE work has revealed that two stages of testing are needed. The first stage consists of automated testing using ISE tools; the second consists of end-user testing with actual data files.

Figure 5 is the Information Interoperability Roadmap; it shows the current status, what's done and what's left:

PLCS OVERVIEW

AP239, Product Life Cycle Support (PLCS), known officially as ISO10303-239 [6], is an international standard for the definition and exchange of product data needed for the long-term support of very complex products, such ships. The development of this standard was led by a joint industry and government initiative dedicated to the goal of accelerating new standards for product support information. Work on the standard commenced in November 1999 and as of this date is in the final stage of adoption as an international standard.

Although the name of AP239 is Product Life Cycle Support, the standard is focused on a particular category of product and support scenarios. Specifically, AP239 is intended for use with complex, high value products, with numerous unique parts and product configurations and a long service life and demanding in-service support requirements. Not surprisingly, for such products and support scenarios, in-service costs comprise a significant proportion of the total cost of ownership. Clearly, the scenario applies to ships, and even more emphatically to US Navy warships.

The PLCS initiative has identified the following business drivers that will be satisfied or supported by an international standard for product life cycle support information:

- ***Reduced cost of ownership***. The end-users of products, for example, the US. Navy, are looking to reduce the total cost of ownership by improving the reliability and maintainability of ships. Reductions in the time needed to undertake essential maintenance and ship upgrade operations also result in increased availability of the war ship.

- ***Exploit prior investment in product data.*** The life cycle support community relies heavily on the product data developed during the design and manufacture phases of ship construction. Today the delivery of this product data to the life cycle systems is expensive, time-consuming and entails a good deal of manual intervention.

- ***New business opportunities.*** Shipbuilders are looking downstream (so to speak) to generate additional revenue from providing life cycle services. The ability to synthesize design product data with life cycle support data greatly streamlines the role of full service provider. AP239 will also provide a formal specification for shipbuilders that want to bid such work.

- ***Product lifecycle management.*** There has been increased emphasis on the managing of product information throughout the ship life cycle—from concept to decommissioning. This leads to a more pressing need for exacting product and support information throughout the product life cycle and even across the supply chain. As a consequence, there is a need to reduce the cost of acquiring, maintaining and delivering product support information.

- ***Extended enterprise/ Navy's One Shipyard Vision.*** With the increasing complexity of systems and collaborations, there is an increased need for knowledge workers to share information across organizational and system boundaries. WWW technology has made new strides possible.

- ***Product configuration management.*** Because of the complexity, longevity, and strict reporting requirements of the ship life cycle support scenario, product configuration management is, perhaps, the major challenge. Keeping the information to operate and maintain the ship aligned to an accurate product configuration representation throughout its life is exceedingly difficult. In addition, there is a need to align support information with product information, looking back, and with technical documentation, looking forward. There is a serious need for improved configuration management and provision of feedback on as-maintained configuration, usage, properties, operating state and behavior.

The scope of the information domain for PLCS is quite broad encompassing static characteristics, such as states of the environment, of people, of the product, as well as dynamic characteristics, such as activities performed by the product (operational behavior, diagnostic data) and activities performed by people (e.g., test, repair, move).

For better comprehension the information scope of AP239 has been categorized as follows:

- ***Product Description***. The ability to define product requirements and product configuration, including a variety of product views and product structures.

- ***Work Management.*** The ability to request, formulate, approve, plan and capture feedback on work activities.

- ***Property, state, behavior***. The ability to describe, capture and share feedback on product properties, operating states, and usage. This includes activity history as well as product history.

- ***Support engineering***. The ability to define the necessary support for a particular set of products on the ship and to plan the support opportunity, facilities, and resources.

AP239 has been developed in a modular fashion, adopting an approach that should interoperate nicely with the ISE information architecture. The single integrated information model that is AP239 has been assembled from a number of modules. A Data Exchange Set (DEX) is a subset of the overall AP239 schema. Each DEX, like an ISE context schema, supports a specific business process or purpose (information use case). The PLCS information models have been developed using both EXPRESS and XML technologies.

Finally, AP239 introduces the concept of reference data, which is described as standardized, computer-interpretable data that can be used to extend or tailor an information model: specializations that can be applied for a particular industry or usage scenario. Reference data is used within AP239 primarily to define classifications of items, such as classes of documents, tasks, or for enumerated code lists, such as fault codes. Reference data is intended to allow adoption of the standard within a specific domain and will likely be used to create the ISE ship life cycle support information model and context schemas. The use of this kind tailoring leads to the need for registering such information and will likely entail cooperation with the DoN XML repository.

S1000 OVERVIEW

The S1000D specification is an international standard that was developed to establish standards for authored content used in creating documentation for vehicles or equipment of any type. It offers benefits to both consumers and producers of such content. For producers, these benefits include greater data re-use stemming from its modular nature, the better streamlining of publishing since material is authored in one format and then published in multiple ways, and the cost benefits associated with following a common standard that will ideally provide better low-cost off-the-shelf tools for authoring, managing and processing of such data. With regards to consumers, the benefits stem mainly from having an international standard embraced by its suppliers, resulting in such data becoming more interoperable with improvements in data communications and data mining. In addition, the cost benefits associated with using standardized software such as off-the-shelf viewers and the improved quality and maintenance of documentation is also envisioned.

Background

S1000D originated in Europe in the 1980s. U.S. interest has increased in recent years as the specification evolved to include requirements addressing military needs. U.S. military projects, such as the Air Force's Global Hawk and F117A programs have elected to utilize the specification. Various Navy programs, such as the CVN21, are also expecting to make use of S1000D for its reactor plant documentation. The S1000D specification today is managed by a consortium consisting of representatives from government and industries from the United States and eight European countries.

Why the progression to S1000D?

- S1000D is wining converts. Previous attempts to establish a standard have failed, resulting in a hodge-podge of information models for documentation. Some military standards, such as 87269, have been developed, but have been customized for specific projects or interpreted differently – compromising their effectiveness as standards. S1000D on the other hand is now becoming a true standard amongst document producers with wide interest in the U.S. and Europe.
- The growing need for a single unifying information model for the document development process to allow content producers to benefit from commonality amongst the document producing communities is apparent. Currently most document producing organizations use a homegrown approach to creating documents. This approach typically consists of some customized information model(s) and collection of custom tools for authoring and producing documents that is highly proprietary. As one would expect this homegrown approach results in the dependency on costly and perhaps cumbersome tools which are developed in-house or customized extensively. Such tools are typically inflexible, unlikely to be interoperable, and costly to maintain and replace. The producer's document development processing environment (content authoring, content management through delivery) often stagnates, making adaptation for new work or tools difficult.
- The perceived benefits from content re-use that can be achieved with S1000D warrant consideration of the standard for many documentation producers. S1000D by design allows content authors to construct reusable chunks of content. The granularity of the chunks is flexible and in the hands of the author and their organization. This flexibility allows documents to be constructed and managed as virtual documents, where modules of the document are linked together to produce the final document. The modules can be used and re-used in numerous documents simply through the module linking mechanisms built into S1000D itself. This allows document producers a better way to create and manage specific documents constructed from shared content. The modules themselves can also be configuration managed in a more straightforward manner as independent entities. S1000D also allows for the insertion of applicability information associated within module itself, so that the module can identify the products with which it is associated. For instance, an authored module can include information about what version of equipment it is specifically for. Modules can also be re-used by other document producers as well. For instance, a part's supplier module can be re-used within the documentation of the part's buyer documentation, greatly simplifying the construction of documents using content from different organizations.

Data Modules

The S1000D is organized around the concept of Data Modules. Each data module type has its own DTD (Document Type Definition) to describe how content in the module is structured. The modules available are the following:

- ***Descriptive Data Module*** **–** This module is used to contain the descriptive text (e.g. introductory material, purpose, planning, …) found in the front section of most technical publications. In addition to traditional document content (i.e. paragraphs of text, titles, tables, etc.), this module can also capture applicability information associated with the module.

- ***Procedural Data Module*** – This module is used to contain the content associated with the steps of maintenance or operations procedure, content areas include preliminary requirements, maintenance function and close-up procedures. The preliminary requirements sections is used to capture any conditions and resource requirements that must be in place before the procedure can be executed. The maintenance section is to be used to contain the actual procedure's steps that user must follow to complete the activity.
- ***Illustrated Parts Data Module*** **–** This module is used to contain information that may have previously been contained within an Illustrated Parts Catalogue (IPC) or a Complete Equipment Schedules (CES) document. Table and graphic information can be attached as well.
- ***Fault Isolation and Reporting Data Module*** – This module is used to contain Fault Diagnostic information. The Isolation section describes the known faults and the associated isolation procedures. Fault localization is handled through a series of questions. Graphics can be attached to aid in the fault location process.
- ***Maintenance Planning Data Module*** **–** This module is used to contain planning information. This information consists of timeline data, data associated with task to be performed for maintenance, data about routines checks (scheduled checks, unscheduled checks, etc).
- ***Aircrew Operator Data Module*** **–** This module is specific for use for flight information data.

Storage model

Today's businesses increasingly compete on their ability to collectively create, process, share and distribute content. Most businesses that generate documents must rely on an integrated Enterprise Content Management (ECM) system to manage their documents and their associated content. Enterprise Content Management (ECM) can be described as the category of software that helps an organization manage all of its unstructured information - or content- in its enterprise. This information exists in many digital forms: text documents, engineering drawings, XML, still images, audio and video files, and many other file types and formats. ECM helps organizations create content with common desktop applications that are seamlessly integrated with the ECM. ECMs can also aid in capturing and incorporating existing content from a variety of sources.

ECMs that are particular effective for S1000D based documents provide operator aids specifically for the management of S1000D modules and the construction of S1000D-based document deliverables. These deliverables can be paper documents, standalone electronic documents (i.e. PDF files), or content delivered by electronic presentation systems (e.g. web servers, database driven IETMs, etc.). Seamless integration of the ECM with desktop authoring tools such as XML editors that understand S1000D content, are also integral to efficient authoring of content and creation of S1000D-based documents.

S1000D specific processing aids that may be provided by the ECM include:

- The tracking of references to other modules by a module
- The validation of module references, assuring that the modules referenced exist and are contained within the ECM
- Searching and locating modules based on metadata or on module identifiers allowing for re-use of module content by the author
- The automated extraction of module information as modules are added to the ECM
- The identification of dependencies of a module on other modules to facilitate change management

Authoring documents under S1000D using an ECM and a desktop XML editor mainly consists of authoring individual S1000D modules and then using S1000D's module referencing to essentially stitch together the authored content into a single document. Under this model, the lowest level of reusable content is the module. Modules are authored and validated as individual chunks of content and may be re-used repeatedly in one document or in many documents. An ECM can be used to manage modules as individual objects with information with regards to versioning and access control of the objects maintained by the ECM. ECMs may also be use in conjunction with a workflow engine to route the authored content and associated documents for approvals. Finally the ECM is often used to perform the necessary extractions of modules, the bringing together the set of modules needed to create a particular document, which is then used to produce the deliverable document.

Presentation model

S1000D can also be viewed as presentation content standard, not just as a standard for content authoring. The international recognition of S1000D will allow a new market for vendors in the IETM presentation market. Previously tools developed for presentation of content had to be extensively customized to handle in-house information models, and were limited by the degree of customization often needed and the lack of integration. Now with the use of S1000D modules these vendors can instead develop tools that focus on being interoperable at the module level, and work with little customization for the customer. The document development community can now capitalize on the commonality of S1000D to save these customization costs, improve content sharing and re-use, and reduce time for document presentation development through better and more integrated tools. Different presentation engines, for instance to handle different presentation formats, can now readily be applied to S1000D standard captured content without the need for customization of content.

REQUIREMENTS

This section outlines the requirements for data exchange and interoperability between the three product model standards.

Author/Update Product Model Data for Ship life Cycle

The entire range of product model data for design, engineering, production, logistics, life cycle support, and technical publications is developed in a similar fashion during both ship acquisition and ship operation & maintenance. Table 1 below lists the agencies in both the shipyard and Navy that are responsible for authoring and updating this product model data.

	Shipbuilder	Navy
Acquisition	Construction Yard	PARM
Operation	Planning Yard	ISEA

Table 1: Author/update agencies

The two ship processes that require authoring/updating product model data are:

- ***Acquisition.*** The ship is under construction. The Construction Yard (and associated ILS department) develops product model data for the ship and systems under contract. The Navy PARM develops product model data for government furnished systems.
- ***Ship Alteration (Modernization).*** Plans are developed to modernize a portion of the ship. The Planning Yard (and associated ILS department) develops product model data for the ship and systems under contract. The Navy ISEA develops product model data for government furnished systems.

The product model data, in both processes, is authored and developed as illustrated in Figure 6 below. The design, engineering, and production data must first be defined before logistics and support data can be developed. Traditionally, design and engineering data is defined to the level of form, fit, and function. Logistics and support data incrementally extends his information, based upon the selection of a particular OEM part. Technical publications incorporate both types of data.

The two data exchange/update use cases of interest are:

- ***Updating Logistics and Support Data.*** Design, engineering, or production data is changed or updated, necessitating a change or update to logistics and support data.

  Examples include:

  New equipment is added, requiring a logistics and supportability analysis.

  Equipment is modified, resulting in new logistics and support requirements.

  Equipment is deleted, removing logistics and support requirements.

- ***Updating Technical Publications.*** Design, engineering, production, logistics, or support data is changed or updated, necessitating a change or update to the Technical Publication.

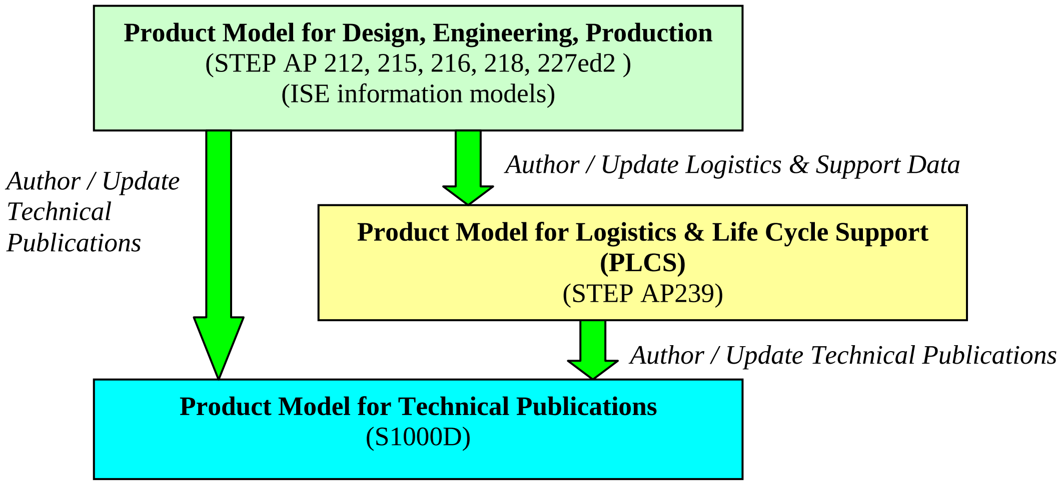
  Examples include:

  Equipment is added/modified/deleted, requiring changes to functional description, parts lists, illustrations, repair procedures, troubleshooting procedures, warnings, and drawings.

  Logistics data is changed, requiring changes to parts lists, illustrations, repair procedures, troubleshooting procedures, warnings, and drawings.

Support data is changes, requiring changes to the repair and troubleshooting procedures.

Both the ISE and PLCS product model standards contain configuration management information. The update problem is often further complicated when the shipbuilder is trying to maintain information for a class of ships or an ISEA maintains data for multiple versions/configurations of the same system.



. Figure 6: Author/update product model data

Use of Product Model Data in Ship Life Cycle

The entire range of product model data for design, engineering, production, logistics, life cycle support, and technical publications is used during the following ship processes:

- ***Ship Operation***. The startup and shutdown of every major piece of equipment and combat system is specified by a government–furnished OSS. Training requires understanding of the associated Technical Publications.
- ***Damage Control.*** Diagrams are provided for all spaces showing every major piece of equipment and damage control information.
- ***Maintenance.*** Maintenance is performed shipboard or at a depot. The procedure is defined by a Maintenance Repair Card (MRC) and may require the associated Technical Publication. Preventative maintenance is scheduled based on Planned Maintenance System (PMS) data distributed to all ships. Work candidates with an associated list are parts are created for each maintenance action. Several applications have also been developed to perform continuous condition assessment on key equipment.
- ***Repair.*** Repair is performed shipboard or at a depot, based upon the associated Technical Publication. Work candidates with an associated list are parts are created for each repair action.

The ship processes listed above are facilitated if product model data from several domains may be accessed. This is illustrated in Figure 7 below.

The three data use cases of interest are:

- ***Reference Design, Engineering, or Production Data.*** User is viewing a Technical Publication and needs to reference product model data.

  Examples include:

  Detailed part information

  Detailed engineering information

  Specific drawings or visualizations

- ***Reference Logistics or Support Data.*** User is viewing a Technical Publication and needs to reference product model data.

  Examples include:

  Availability of parts

  Specific drawings or visualizations

  Repair history

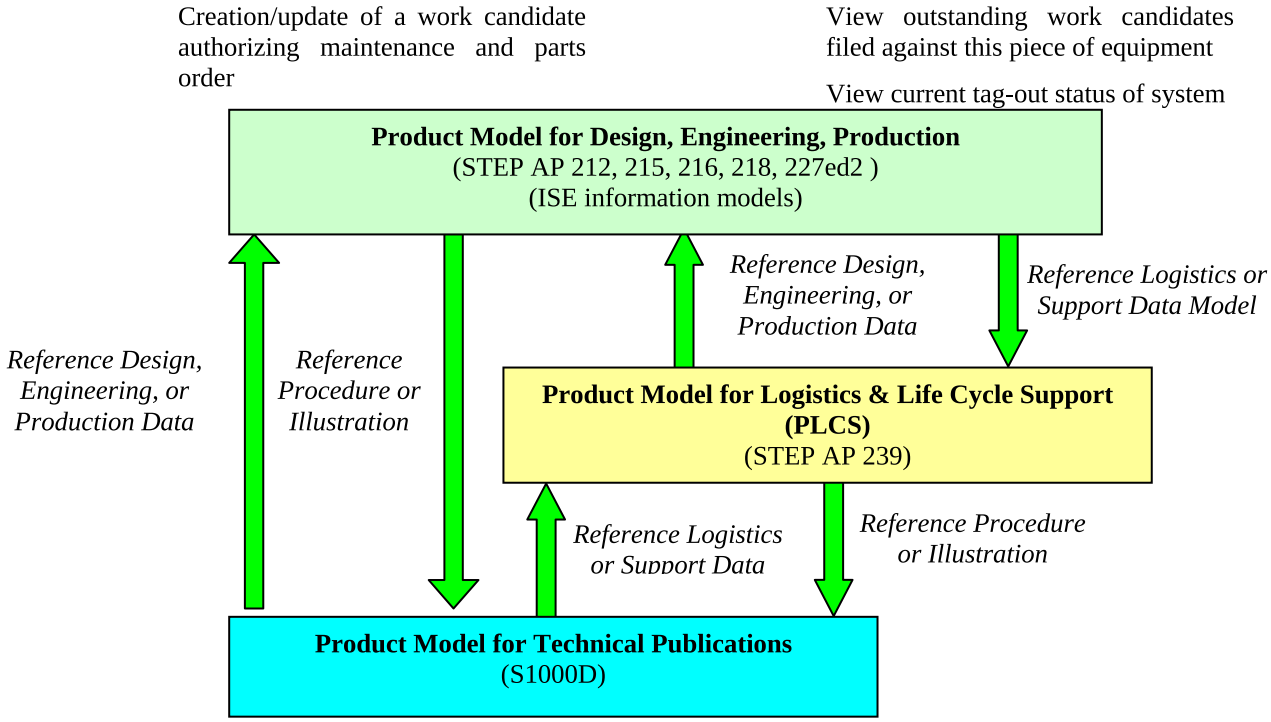


Figure 7: Interoperability Model

- ***Reference Technical Publication Information.*** User is in an application which manages product model data and needs to reference Technical Publication information.

  Examples include:

  Illustrated Parts Breakdown

  Repair procedure

  Troubleshooting procedures

  Illustration

COMPARTMENTS AND ZONES

The preceding use cases illustrate the degree to which the information in three standards are inter-related and in need of coordination. One telling example is the treatment of compartments and zones. Each standard has its own approach. The approaches are not necessarily incompatible but without explicit planning they could lead to duplication or, in the worst case, incompatibility.

Compartmentation and zoning are but two aspects of the broader process of product structuring. For a complex structure such as a ship, the location and breakdown of its constituents parts can occurs in various ways (physical, functional, damage control) and different breakdowns are important to different users at different stages of the ship life cycle. This kind of product structuring does not add new items to the ship per se, but it does provide a ready means to locate or categorize items.

In ISO10303-215 (AP215) compartments are defined broadly as volumes "suitable for the stowage of cargo, operation of machinery, and occupancy by crew and passengers." AP215 further defines zones as volumes "for the purpose of controlling access, designating design authority, or applying specific design requirements." Properties and functions may be assigned to each compartment or zone. AP215 supports a variety of kinds of zones including fire zones, design zones, subdivisions (survivability zones), subsafe zones. A zone is "an abstract boundary identifying a region of a ship with unique requirements or characteristics which must be specially treated in the design or manufacturing process." To a certain degree the designation of the kinds of zones to use is left to the user community.

S1000D, in chapter 3.4, treats zoning and access. S1000D describes separate zoning strategies for surface ships and submarines. The purpose of this zoning is "to help in locating the [ship's] equipments, assemblies, access doors and panels, ports, etc. within the data modules and identifying locations for maintenance planning. It recommends that this breakdown by used during the ship design process.

A zone is identified by a standard, 'intelligent' number. The first digit signifies the major structural area of ship, the second the side of the ship, and the last signifies the sub-zone. These identifiers are not destined only for the information systems but will appear as markers within the ship. For surface ships zones are defined to provide self-contained survival zones in the event of nuclear, biological or chemical damage. Each zone is designed to for self-contained operation for a period of up to 12 hours and is normally provided with electrical power, firefighting equipment, smoke containment, internal communications, etc. For submarines the goal is to divide the submarine into a number of zones with smoke-tight boundaries between them.

PLCS has, perhaps, the broadest approach to compartments and zones. It invokes the concept of a breakdown, a hierarchical organization of the elements of the ship according to various product structures. Breakdowns are organized around different criteria. A functional breakdown organizes its elements according to the function they provide. A physical breakdown corresponds to a traditional part-of product structure. A system breakdown organizes elements into ships' systems. A catch-all hybrid breakdown is used for non-specific partitionings. Finally a zone breakdown establishes the zones within the ship.

Clearly the suggestion in S1000D that consistent zone and compartment definitions should originate with the design and carry through to support is well merited. The potential to achieve interoperability among these standards exists. The effort simply needs to be made to consummate it.

RECOMMENDATIONS

Background

U.S. Naval ships are complex artifacts that demand a high level of availability in the face of perpetual and uncertain change. More and more the management of that change is accomplished on board Navy ships by means of non-tactical information systems. In fact, the typical non-tactical information system on board a Navy ship is, in many respects, a microcosm, an isolated replica, of the enterprise information systems that were used to design and build the ship. Unfortunately, these systems suffer from the same obstacles that have beset the larger enterprise systems: a significant number of software applications are needed to support the mission, and these applications tend to be independently developed with widely various context dependencies. The network infrastructures required to support such disparate applications inevitably become specialized to the point at which each class of ship, often even ships within a class, host different infrastructures. In such an environment it is difficult or impossible to attain a high degree of interoperability; worse, applications developed for one platform are typically not portable to other platforms.

There are further parallels between the shipboard information systems and the shipbuilders' enterprise information systems of a decade ago. At that time the migration from manually generated drawings to computer-based 3D design data had just begun. This migration was not a simple technology upgrade; rather it ushered in a generation of tumultuous culture change. The same scenario is unfolding today as a result of changes in the shipboard information systems. Paper based systems are being replaced with computer-aided systems and databases; users are adapting to new processes and procedures as a result. The authoring of technical documentation is also undergoing a similar upheaval as the impetus for improvement gradually forces content authors to learn the new systems based on XML technology. This has been a painful change because content authors are writers first and foremost, not technologists; and the move to XML-based authoring and content management systems is well outside their comfort zone. Finally, recent deployments of on-board systems are moving toward a Web-based architecture, alienating many of the original developers who were accustomed to stand-alone applications and databases.

In May 2005 the DoD issued the Global Shipbuilding Industrial Base Benchmarking Study (GSIBBS). The GSIBBS made recommendations for improving the efficiency of the design and construction of Navy ships. Because shipboard information systems are accompanied by many of the same growing pains as the shipbuilding information systems, some of these recommendations are pertinent to on-board systems as well. The GSIBBS found the most substantial opportunities in the realms of ship design and design for product. The report cited a root cause: "International shipyards have a standard approach to ship design with well-defined stages and clearly specified outputs for each stage." (p. 37) What is most significant about this finding is that, though the authors are not computer technologists, they keenly identified the root cause behind much of the turmoil we have seen in the deployment of information systems -- not just for ship design but for on-board support systems as well. An unquestionable deficiency in today's on-board support systems is that there is no documented consensus, across ship classes, regarding the "specified outputs for each stage" of the life-cycle support processes. There are understandable reasons for this deficiency. In the past, with paper based systems the output of each process stage, a drawing or technical manual, was passable so long as it could be read and understood by a person. That standard is no longer viable. With today's systems the output of a process stage is clearly specified only when it is in a form that can be interpreted by another computer application. The documentation of the output of each and every process stage is a daunting task, made more difficult by lack of a multitude of interested user communities and limitations of information technologies.

The Navy has already begun the process of upgrading its on-board non-tactical data processing systems. That upgrade is just taking its first steps. The following recommendations should be considered in the plans for this upgrade.

Recommendation #1:

A single vision or set of guiding principles is needed in order to ensure that the newly developed non-tactical information systems are interoperable and portable across the various ship platforms.

The non-tactical on-board support information system encompasses a distressing array of inter-related functions: including logistics support (spare and replacement part); technical documentation (procedures, wiring data, exploded and illustrated parts lists); parts catalog, maintenance, repair and overhaul (MRO) functions (such as task planning, resource allocation, work paper); valve and plant management; plant status; maintenance history; product model data; various breakdowns or product structure of every aspect of the ship. In addition to a well-engineered description of the functional requirements and use cases pertinent to ship's force operation, there is a need for a single vision of the technical and information architecture needed to support this multifarious and secluded enterprise.

Recommendation #2:

The deployment of the non-tactical on-board information systems should be based on Web services. Even after a network infrastructure or middleware interface has been established, there still remain a number of options for application to application communication. It may be tempting to hard code specific Java interfaces in an attempt to confect a single integrated application; however, this approach is too restrictive and not well-engineered for the current requirements. Applications in this realm will continue to be independently-developed, niche applications. There will not be a single ERP-scale solution to this problem. Moreover, interactions between applications are data-centric not method-centric. The system should be view as a shared information space foremost, rather than as a large integrated application. (More specific recommendations relating to Web services are listed below.)

There is one cautionary note regarding the Semantic Web. The Eurostep organization has been working with PLCS for the UK MoD. They also endorse the use of Web services as the system architecture that best suits PLCS deployment. However, they go on to endorse the use of Semantic Web technologies. A careful reading of their recommendations reveals that the functionality that they are most interested in obtaining from the Semantic Web is the ability to access remote entity instances by means of a persistent identifier anywhere on the Web. This is an indispensable capability, and we discuss our recommendation below. The Eurostep recommendation, nevertheless, leaves the impression the information modeling and inferencing capabilities promised by Semantic Web adepts are also suitable to the deployment of a PLCS-based support system. We disagree with this assessment. On the one hand, Semantic Web implementations are still in their infancy. Moreover, the core technical approach of the Semantic Web is not consistent with the needs of on-board support systems. The Semantic Web, whose information models are called 'ontologies', attempts to support the circumstance in which multiple, possibly incomplete, and autonomous ontologies need to be reconciled after the fact by means of inferences about their metadata. The deployment of on-board support systems is not subject to such technical difficulties; there is no reason that its information model cannot be fully specified and documented. In fact, that is one of our key recommendations. The Semantic Web supports a more difficult use case and brings (somewhat untested) technologies to bear to provide that support.

The Web infrastructure for the on-board support system should support the following capabilities:

1) ability to locate an instance from any datastore by means of its persistent identifier: In its simplest form this requirement corresponds to the ability to access each addressable resource or instance in the system by means of a hyperlink. (Some of the requisite link connections are enumerated below.)
2) ability to locate instances by means of queries: It should be possible to formulate

these queries with respect to the consensus information model. Participating applications may use alternate representations for their data. There must be a means to execute the consensus model query within each participating application or datastore.

3) ability to execute a Google search on the entire datastore: The search should not be limited to pages in a common repository or manual but should encompass data that is held in the system's databases, both common and application-specific. In order to provide this capability, all information in the system must be accessible as a Web document that can be crawled (and indexed) by the search engine.

Recommendation #3:

There should be a commitment to the establishment of a well-documented information model that is crafted to capture "clearly specified outputs for each stage" of the support process. There must be a commitment to the adherence to this information model for all shared information. The information model should be consistent with open, international standards. To that end the adoption of the PLCS standard (ISO10303-239) and the S1000D standard for technical documentation are needed first steps. However, the lessons learned from the ISE project demonstrate that in themselves they are not sufficient to attain the desired interoperability. A plan for the adoption of these as well as the other ISE standards (Product Data Interoperability, 3./14/2005) has been presented to the ECB and to Adm Sullivan. (Specific recommendations related to ISE technical approach are stated below.)

Recommendation #4:

Both PLCS and S1000D are ambitious and far-reaching standards. Naturally they overlap in a variety of functional realms. These overlaps need to be reconciled; in some areas one standard is stronger than the other. The following is a partial list of information realms that need to be reconciled:

a) The notion of persistent identifiers is crucial in both standards. Not surprisingly, each standard has a slightly different take on the makeup of its persistent identifiers. In the STEP world the notion of a persistent identifier was a late-comer. Many schemas, and in fact the information modeling approach, had been developed to support data that used only local identifiers. S1000D, on account of its document heritage, boasts persistent identifiers that are perhaps overloaded with document metadata. Nevertheless, despite the handicaps they inherited, both standards recognize the vital importance of persistent identifiers at the instance level. Both standards have moved beyond the dated approach of applying persistent identifier only at the gross level of drawing or model or document. In order to support the fully interoperable and portable repertory of applications that makes up the on-board support system, there needs to a clear definition of the minimal set of data components that comprise a persistent identifier – irrespective of which standard defines the data element.
b) It is hard to imagine an enterprise information system that does not use documents. Documents are modeled in both PLCS and S1000D. The document model in PLCS is rudimentary, coming from a data-centric world in which documents are viewed as undisciplined but unavoidable adjuncts to the more important product data. Even worse PLCS builds on document model that predates the WWW and its approach to documents via URL. S1000D possesses a rich and up-to-date document model. It views documents as collections of addressable content rather than as a black box. It makes extensive use of URI and Web links as document part identifiers and links.
c) Both standards support the concepts of zones, compartments and other breakdowns. Both the life cycle support data and documentation need to manage a variety of product structure views of the ship. These views can be organized by function, by location, by zone, etc. The ability to define such product structures or breakdowns is provided in both standards; and, indeed, in the end, the breakdowns for the data and document need to be fully aligned. Each standard has its own style for defining these product structures. The two approaches are not necessarily incompatible, but they are different nonetheless and need to be harmonized.
d) Finally, there are innumerable horizontal entities that show up in most enterprise information models. These include such widely re-used entities as person, date, time,

approval, and geometry. Such entities appear in both PLCS and S1000D.

Recommendation #5:

As described above, the implementation of hyperlinks between PLCS data and S1000D content is a key aspect in the interoperability of the two standards. The two standards should be analyzed closely in the light of the relevant use cases in order to flush out the useful links. It is important to note that the interconnections between these two standards flow in both directions. For example a repair or maintenance procedure defined in S1000 will refer to product items (end items, sub-assemblies, parts, tools, and/or spare parts) that are managed as PLCS data; while a planned task within a work order (PLCS) will refer to procedures captured in S1000.

Recommendation #6:

At some point a concrete implementation decision will need to be made. There will be applications that are PLCS-based and applications that are S1000D-based. One issue that always plagues systems such at the on-board support system is configuration management. Further investigation is needed to develop a strategy for the implementation of configuration management (CM). To some degree configuration management of the on-board system is simpler than the configuration management of ship design. Information is confined to a single hull so the on-board PLCS data would not be concerned with hull effectivity. However, document content may still be versioned with respect to hull. It may be advisable to use the CM capabilities of the PLCS system to manage the effectivity of documents as well as of PLCS data.

Recommendation #7:

The following are recommendations that are specific for adherence to an ISE interoperability approach and should be followed to maximize interoperability between on-board support systems and shore-based design, build and overhaul systems.

a) PLCS uses the concept the Data Exchange Set (DEX). A DEX is a subset of the overall PLCS information model that is tailored to service a particular use case. This concept is directly analogous to the ISE concept of context schema. The PLCS Sponsors are publishing their DEX's in OASIS format. Our recommendation is to harmonize and adopt, as appropriate, the DEX's already developed and to complete the definition of needed use cases and context schemas. However, the resulting work should be published in ISE format, using the DoNXML repository if appropriate.
b) S1000D provides a detailed format for the representation of wiring data. Currently, the ISE team is developing context schemas for wiring data based on AP212. These two standards need to be harmonized. Our recommendation is to produce ISE context schema and mediators that unite the wiring information models from AP212 and S1000D.
c) S1000D provides a detailed format for the representation of compartments and zones. PLCS provides a detailed format for the representation of product breakdowns, which encompass compartments and zones as well as functional breakdowns such as system. Currently, the ISE team is developing context schemas for compartments and zones based on AP215. These two standards need to be harmonized. Our recommendation is to produce ISE context schema and mediators that unite the breakdown information models from AP215, AP239 and S1000D.
d) The PLCS information model is highly modularized and extensible, relying in great measure on reference data libraries (RDL). The idea is that PLCS data needs to interoperate with a number of outside data stores, whose scope is a specialization or extension to the PLCS information model. In short PLCS expects some degree of industry specific configuration. This approach is well-aligned with the ISE information architecture, which seeks to integrate various, disparate information models. For example, one of the reference libraries envisioned by PLCS is a parts catalog.

NSRP has already developed a common parts catalog and its information model. We recommend that PLCS be configured to utilize the CPC schema for its parts data. Finally, PLCS envisions that various metadata will be made available to the PLCS system through RDLs. The ISE metadata repository should be used as the primary metadata RDL in the on-board support system.

REFERENCES

1. R. Wood, T. Rando, B Gischner, J. Mays, and T. Briggs, *Improving Interoperability through use of ISO 10303,* Proceedings of 12th International Conference on Computer Applications in Shipbuilding, Busan Korea, August 2005.

2. R. Wood, T. Rando and K. Bates, *Product Data Sharing in the Integrated Shipbuilding Environment,* Proceedings of 11th International Conference on Computer Applications in Shipbuilding, Malmo Sweden, September 2002.

3. T. Briggs and T. Rando, *XML Schemas for Shipbuilding*, Proceedings of 11th International Conference on Computer Applications in Shipbuilding, Malmo Sweden, September 2002.

4. L. Benthall, T. Briggs, B. Downie, B. Gischner, B. Kassel and R. Wood, “STEP for Shipbuilding: A Solution for Product Model Data Exchange”, Journal of Ship Production, February 2003.

5. The Department of the Navy, *The Department of the Navy Vision for the Extensible Markup Language: Using Enabling Technology To Achieve Information Management/Information Technology Goals In Support of Maritime Superiority*, February 2002.

6. ISO 10303-239:2004 - “Application Protocol - Product Life Cycle Support”.

7. ISE website, *www.isetools.org*.

8. Letter to RADM Sullivan, re Product Data Interoperability, from NSRP Executive Control Board, dated March 14, 2005.

9. Re-Use of Ship Product Model Data for Life-Cycle Support, by Ted L. Briggs1 and Thomas C. Rando 2 and Thomas A. Daggett2 presented at the 2005 Ship Production Symposium in Houston