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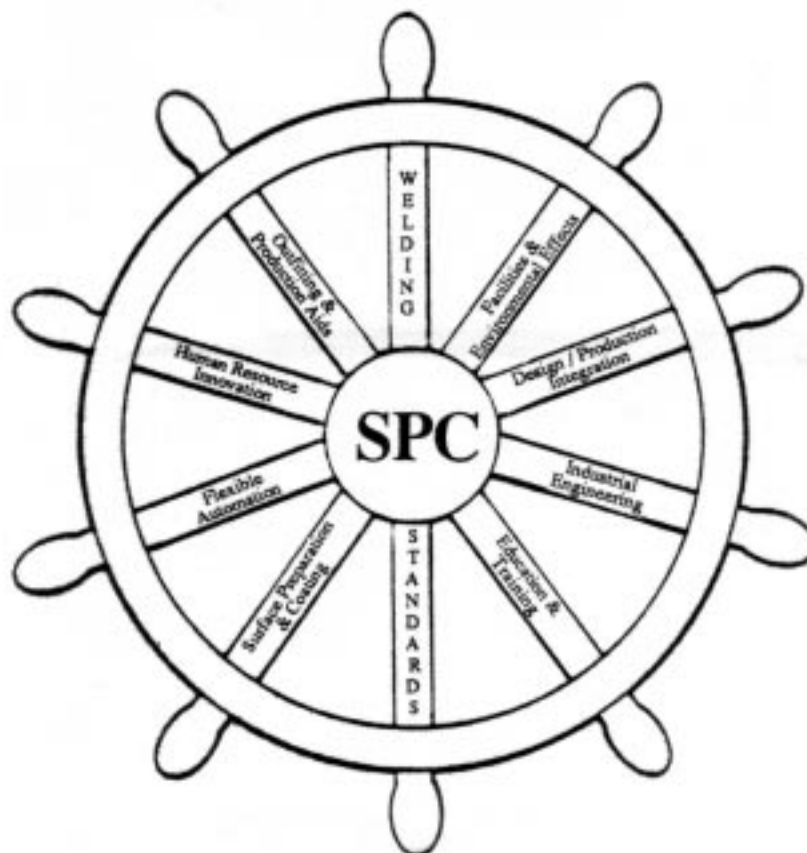
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SEAWOLF Producibility II: Transition From Design to Production

7A-2

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ABSTRACT

SEAWOLF Producibility initiatives have been presented to past Ship Production Symposiums. The technical content of these papers was based on work accomplished during the SEAWOLF Detail Design effort and articulated the point of view that the SEAWOLF Producibility Program was an important step in advanced ship production. The lead ship of the SEAWOLF Class started construction in late 1989. The opportunity now exists to validate a number of the elements of the design for production. Electric Boat Division, as Lead Shipbuilder, has the opportunity to review a number of the specific initiatives, such as Digital Data Transfer, Sectional Construction Drawings, Planning and Sequence Documents, Computer Integration of information processing and the combination of SEAWOLF products that support improved work control. The method of approach is to describe the SEAWOLF producibility element developed during detail design and then assess the benefit to the shipbuilding process.

INTRODUCTION

The SEAWOLF Program has reached a pivotal point in its history. During the last 10 months, the Detail Design and Lead Ship Construction have become coincident, as Detail Design continues and lead ship construction gets underway. The Program has entered perhaps its most active phase, and in essence, the software products of the design effort are being converted into hardware at the Electric Boat Shipyard in Groton, Connecticut.

The design products now being utilized in Groton are different than for previous submarine designs. The difference is due to advanced technology being infused into the submarine design and construction effort, and developed into design deliverables through what has become

known as the SFAWOLF Producibility program. Although the final quantitative results of the Producibility effort are still to be determined, several of the features have developed to the point where their benefit can be evaluated.

The products of two broad efforts, the Digital Data Transfer Program and the SEAWOLF Advanced Planning Program, have been extensively utilized during the pre-construction and early construction phases of the lead ship contract. The design deliverables from these two programs that are provided to the Shipyard are based on procedures and agreements that are embedded in the SEAWOLF Ship Specification and Detail Design contracts. The impact of these deliverables on the construction activity can now be evaluated with an environment in which ships are being built using conventional design products.

SEAWOLF PRODUCIBILITY

The SEAWOLF Producibility program originated from the goal of greater affordability in ship construction. Shipyard modernization programs at Newport News Shipbuilding and Electric Boat Division provided the opportunity to change the philosophy and products of submarine design. The Producibility Program was initiated with construction as the primary focus; however, it has become increasingly apparent the post delivery phase of the ship's life cycle will realize significant benefit. In fact, the logistics community has already begun the effort to utilize the digital information available from the design to initialize the logistics data base.

The SEAWOLF Producibility effort was inaugurated primarily because computer technology and zone logic based construction had reached sufficient maturity in the submarine

shipyards to facilitate a change in design philosophy. Although the principle of designing for production was nothing new, the SEAWOLF Program extended the logic beyond previous experience in naval ship production. A number of self evident assumptions underlie the producibility effort. Those particularly important to this paper are:

- Create data once and use it many times;
- Electronically transferred data is superior to paper products:
- Close inter-relation of the design product to the construction plan will yield greater control over both processes; and
- An electronic schedule management tool has the capability to simplify the immensely complex task of building a ship

These assumptions could be supported as intrinsically valid, but could they be developed by the SEAWOLF Program into design products that fully supported construction?

Design

The SEAWOLF ship specification required the design to be computer based, electronically transferrable to the two potential shipbuilders and to utilize a product work breakdown structure that supported submarine zone (modular) construction.

In early 1987, the program moved from a contract design competition between Electric Boat and Newport News into dual design yard responsibility for detail design. Part of the transition process was to create the organizations that would formalize the embodiment of the goals into well defined design products. The goal of transferring digital products from design yard to construction yard was the task of the SEAWOLF Digital Data Transfer Working Groups. The process of structuring the design to support modular construction was assigned to the SEAWOLF Producibility Steering Group.

Transition to Construction

The flow of information from design to construction will be explored by reviewing the effort that created the design product in

question, noting the present design status, if appropriate, and then looking at the state of implementation in the construction process. The producibility process that developed the form of the design deliverables has been previously documented. For clarity, however, portions of those presentations will be re-presented. The information concerning the design status and construction development has been gathered at the Electric Boat facilities in Groton and Quonset Point, Rhode Island from whom the authors determined to be the most knowledgeable management personnel available. The construction managers were asked to compare the SEAWOLF product with the parallel SSN688 or TRIDENT class design deliverable and comment on the change to their particular job.

DIGITAL DATA TRANSFER

The first area of interest is the Digital Data Transfer process. A similar capability had been developed at both design yards to conduct transfers of various types of data to the shipbuilders. For lead ship construction at Electric Boat there are several additional steps in the process for data received from Newport News for lead ship construction, such as processing the data through the IGES Translator. However, in most cases, the origin of the product delivered to the ultimate user in the construction yard is invisible.

DRAWINGS

The ability to exchange drawings among the design and construction yards was an early goal of the program, which received a large share of the attention and developmental resources. The initial assessment was that an electronic exchange of drawings would provide the construction yard, and later the planning yard and maintenance activities, with a complete, controllable and computer usable set of electronic drawings. The thrust was to make the exchange virtually "perfect" with each graphic detail passing through the translation process in the exact form in which it was created in the originating design yard.

Design

The Initial Graphics Exchange Specification (IGES) was chosen for data exchange since it was a universally recognized standard and

avoided the restrictions of a direct translator. However, the IGES standard, while a powerful guideline for which most Computer Aided Design (CAD) vendors have written translators, is primarily focused on graphic details and does not deal in a straight forward process with the sophisticated embedded intelligence capable of being produced by many CAD systems. Therefore, much work had to be done to modify, or "flavor," the translators to allow clean exchange of drawings between Newport News and Electric Boat. Even now, with considerably enriched translators in place, developed in cooperation with the CAD vendors, a few restrictions must be placed on the CAD user. These restrictions reduce, to some extent, the entire range of features available to the designer in order to accommodate drawing transfer. Nevertheless, providing the drawings are constructed in accordance with the SEAWOLF Program developed procedures, it is possible to consistently exchange nearly perfect drawing files between shipyards.

Drawing Exchange

This process has been used to a limited extent during SEAWOLF design and the early phase of construction. Actual exchange is by specific request, with the requestor paying for the preparation, processing and material cost. Therefore, the requestor selects to receive only the drawings for which modifications at the receiving site will be made. It is anticipated that drawings will be electronically exchanged between Design and Construction agents to complete Selected Record Drawings, as-built drawings and other shipbuilder responsible drawings. Although the exchange of drawings between design yard and shipbuilder is presently limited, it is anticipated that a major exchange of electronic drawing data will occur to position the drawings for SEAWOLF life-cycle maintenance.

To verify the SEAWOLF procedure and attempt to extend the drawings transfer to additional CAD systems, a small data transfer effort was undertaken by Electric Boat, Newport News and General Electric (Information Technology Group, Syracuse, New York). A working group was established to IGES transfer drawings utilizing SEAWOLF documentation. The effort lasted about six months and was highly successful in transferring a variety of SEAWOLF drawings.

PROCESSABLE DATA

Processable data is data element based text information that is used in design and construction in a variety of manners and locations. Therefore, it is data which is most valuable in electronic database format, positioned so that it can be accessed, manipulated and used for multiple applications. Since the SEAWOLF is being designed by two design yards, an important goal has been to achieve electronic exchange of this type of data so that the data can be assembled in one location, the construction site, in the most efficient and effective form.

Design

Since the target data in this instance is textual, an early goal of the SEAWOLF data exchange program was to create a data dictionary, defining the content and configuration of each data element which was a potential exchange candidate. The next step was to group data elements such as part number, material type, etc. into logical sets for exchange. These lists, such as part number catalog and the engineering parts list, became the targets for development of exchange procedures. A variety of processable data exchange categories have been developed and are supported by the SEAWOLF Data Element Dictionary. Principal data transfer reports are listed in Figure 1.

Clearly, the most important target for data exchange is material information, represented by the Part Number Catalog

1. ENGINEERING PARTS LIST
2. PART NUMBER CATALOG
3. JOINT/SURFACE INDEX
4. MATERIAL QUALITY ASSURANCE LIST
5. STOWAGE LOCATION LIST
6. SHIP'S DRAWING SCHEDULE
7. HIGH IMPACT SHOCK DATA
8. PROCUREMENT SUMMARY INDEX
9. WEIGHT AND MOMENT DATA
10. RADIOGRAPHIC SHOOTING SKETCH LIST

FIGURE 1. PRINCIPAL DATA TRANSFER REPORTS

(PNC) and the Engineering Parts List (EPL). Early emphasis was placed on this exchange and has resulted in a working system which consistently provides material information from Newport News which is loaded directly into and merged with the Electric Boat data. A similar process is accomplished at Newport News with Electric Boat data.

Other areas of planned data exchange are going into production at this time. The first tapes of non-destructive test data, containing joint indices and material quality assurance lists, for example, will be exchanged shortly. Procurement summary indices, provided by the shipbuilder and containing information on material order by Electric Boat scheduling and status, have been made available electronically to Newport News. Most of the other data relates to logistics and life cycle maintenance and is not immediately required for construction. Plans for these exchanges are being completed and the data will move among the established logistics systems, such as the lead design yard developed SEAWOLF advanced integrated logistics support system (SAILSS).

Processable Data Exchange

The concept of electronic exchange of data, particularly with respect to material data, has been well received by both the design and construction yards. They have established good working relationships, and an excellent approach through the development of a common data dictionary, since it is recognized by all parties that success would be a win-win accomplishment.

According to the shipbuilder, recognizing that the EPL is essentially the complete definition of the ship without the graphics, early identification is important. Electronic exchange provides this insight, particularly if material data captured early in the design process and made available. The ability of the design agent to concentrate on the capture of material description data and early availability of this data, even if preliminary, is an essential feature of a systematic lead ship construction process.

In addition to earlier visibility, the electronic exchange of data has afforded other advantages. It has eliminated tedious manual loading of thousands of lines of information, with the attendant labor

saving and reduction of errors. Also, it maintains the responsibility for accuracy with the data originator, rather than transferring that responsibility to the user upon when manually loaded into his systems. This reduces data verification by the user to an overall system check and allows problem correction at the source, as it should be.

One area that requires additional procedural development in the processable data is the need to relate various types of data (drawing schedule to material to joint list to material qualification, etc.). Presently, separate tapes, each containing one type of information, are exchanged on a regular (monthly) basis. While eventually all the data can be tracked and linked, several exchange cycles may be necessary before all of the data required to support, say, a particular drawing is available. A potential improved system would establish and agree upon a base "root" such as the drawing schedule, and time the release of all related data to the root release.

MODEL DATA

The initial emphasis in the SEAWOLF data exchange program was placed on drawings and processable text. Model exchange (Three Dimensional (3D) CAD representation of geometry) was considered potentially valuable, but the perception was that this exchange would be more technically demanding. The model exchange effort was initiated by evaluating the different design and construction disciplines from the standpoint of utility in the manufacturing process. The decision was made to focus the initial effort on structural and piping models, since considerable numerical control manufacturing capability was resident in both Shipyards. It was believed that success in these two areas would be more advantageous than partial success in all disciplines.

Design

Although much time was spent determining the format, content and procedures for model transfer, the technical issues proved to be less demanding than for the drawing transfer process. This is because the aim of model transfer was to exchange geometry, rather than the subtleties of text and embedded intelligence. Geometry is what IGES was developed to handle, and once agreement was reached on what to exchange, the "how" was

relatively straightforward. This was particularly true for structure, for which it was agreed to exchange wire frame geometry, grouped to define individual piece parts, with only piece identification numbers being overlaid as added intelligence. A 2D representation of a wire frame model is shown in Figure 2. The development of procedures to exchange piping was somewhat more difficult in that both shipyards were using piping design systems developed in-house, and therefore each yard had to develop its own IGES translator. In addition, piping data transfer is more complex due to the need to include complex detail such as fitting valve and joint design data. In fact, this effort has been so successful that the methodology has been drafted into a formal procedure (protocol) and submitted to the committee that oversees improvements to IGES for inclusion in the specification.

The status of the production exchange of model data is that procedures for structure and piping data are complete and tested. Structural data has been flowing through the system since late 1989, and the initial packages of piping data are beginning to appear. The model exchange, by agreement, is done by transferring the appropriate data contained within a structural or piping SCD, essentially in parallel with the issue of the hard copy drawing.

The process in place for transmittal of structural models to the construction agent, and their subsequent uses: For design work being done at Electric Boat, the issue of an SCD triggers an action in the Engineering Data Support group to collect the models from which the SCD was created, activate specially designed software that generates a single model, stores the model in the manufacturing database, and informs Construction Planning of the completed action. For design work being done at Newport News, both the model geometry tapes and hard copy drawings are received by the SEAWOLF Engineering Configuration Management group at Electric Boat. The drawings are processed for distribution, and the model tapes are forwarded to Engineering Data Support. This group processes the model through the IGES translator, stores it in the manufacturing data base and informs construction planning of its availability.

For piping, the process is generally similar, except incoming data from Newport News is translated into input for the Electric Boat piping design/manufacturing system. After being run through this system the output in the form of both graphic detail sheets and NC data is stored in the manufacturing data base from which it is retrieved on schedule demand by the planning group for work package preparation and by manufacturing for numerically controlled pipe detail bending.

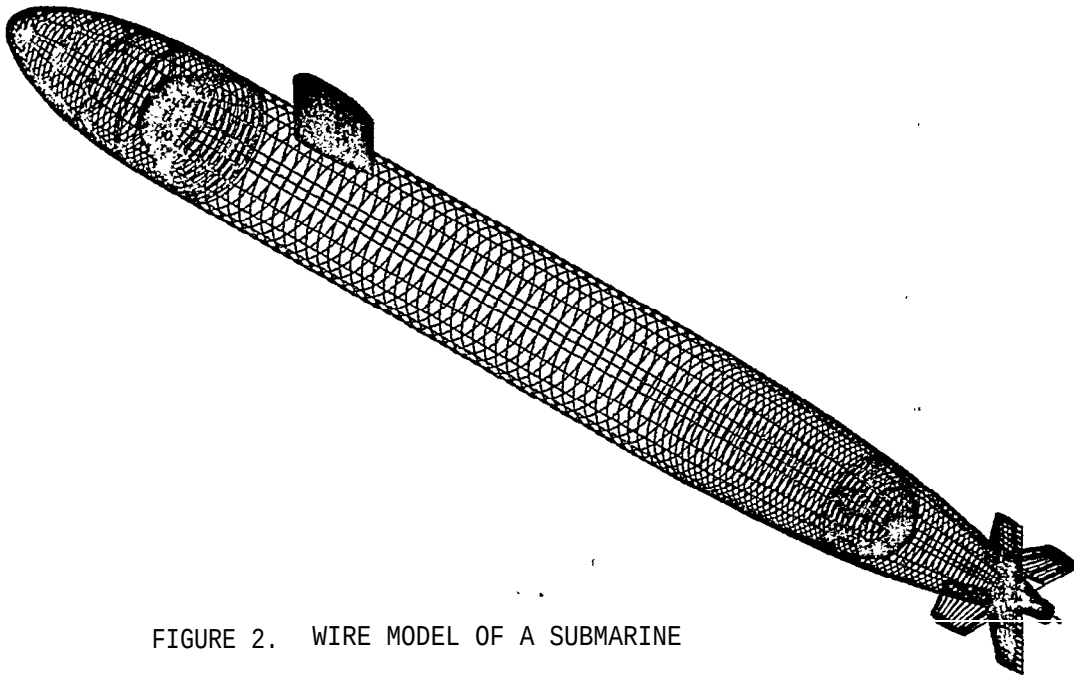


FIGURE 2. WIRE MODEL OF A SUBMARINE

Model Data Exchange

As a result of the data exchange processes developed for SEAWOLF, the methodology for preparing steel parts for cutting, the traditional "lofting" function is changing significantly.

With previous designs the traditional design deliverable was a paper drawing of an assembled structural component, piece-marked and dimensioned to define individual piece parts. The loftsmen deduced the shape of each part from the assembled views shown and the explicit and implicit dimensional data. From other information provided, such as weld requirements, orientation, thickness, and shipyard construction experience and preferences, he determined the additional manufacturing details such as kerf, bevel, expansion and extra stock. When all of this data was accumulated he wrote the "program" which created an electronic description of the geometry and ultimately drove the numerically controlled burning equipment that cut the pieces.

For SEAWOLF construction, the data provided to the construction agent is of two forms: an SCD with a chapter showing and dimensioning the true design shape of each steel piece as well as chapters showing assembled and installed views and dimensions, and a full scale electronic wire model of the structure with each piece identified as a separate 3D entity.

The availability of this data changes the process for part preparation. - Now a part planner/analyst studies the individual part geometry as well as its context in the assembly and installation shown in the various SCD chapters. He then simply annotates the part drawing with the required manufacturing details and passes it to a part programmer. The part programmer, skilled in manipulating geometry on a CAD system, calls up the design geometry of the individual part from the electronic model provided and adds the manufacturing details. At that point, the numerical control programs are automatically generated for eventual incorporation into a plate nest of many parts for cutting. A series of computer graphic plots of this process are shown in Figure 3.

This new process, currently being employed in SEAWOLF construction at Electric Boat, results in several significant improvements over the traditional methods. First, the availability of individual part as well as assembly data in the drawing,

along with the actual electronic model, allows a division of labor in part preparation which was not practical before. The analyst must be an individual with substantial construction and construction planning experience, but he need not be skilled in part programming, since the part geometry is already defined and electronically available. Similarly, the part programmer need not possess the skills of analyst, since he is only required to modify the existing geometry based on the analyst's direction.

The division of skill mix allows more flexibility and ease of staffing. Worker's skills and job assignment are more easily matched and optimized to maximum efficiency. Design geometry need not be recreated, or even checked, since it is provided in the same model form from which the drawing was created. This reduces transcription and interpretation errors.

This last point highlights an even more important difference than part preparation labor saving. With the old method, the loftsmen had to re-create the geometry developed by the designer in order to provide data for part cutting. In essence, this transferred responsibility for geometric accuracy from the designer to the builder. For SEAWOLF, with part geometry being provided electronically by the designer, responsibility for geometry remains with the design agent. This important cultural change must be equally realized by both designer and builder. The designer must be sensitive to producing 100% accurate geometry, not just a picture with reasonable likeness. The builder must resist making geometric changes that could alter the design intent. Instead, he is obligated to feed geometric change data back to the designer for model correction.

At Electric Boat, these processes have been employed since the start of SEAWOLF Construction in October 1989. At the time of this writing only a small percentage of the total steel parts have been processed, many of which are large structural hull pieces. Therefore, definitive process improvement and cost saving parameters cannot yet be quantified. However, certain trends are beginning to emerge.

The Steel Process Group reports that less time is now required to process parts than with traditional methods, although this saving is more evident with complex parts than with

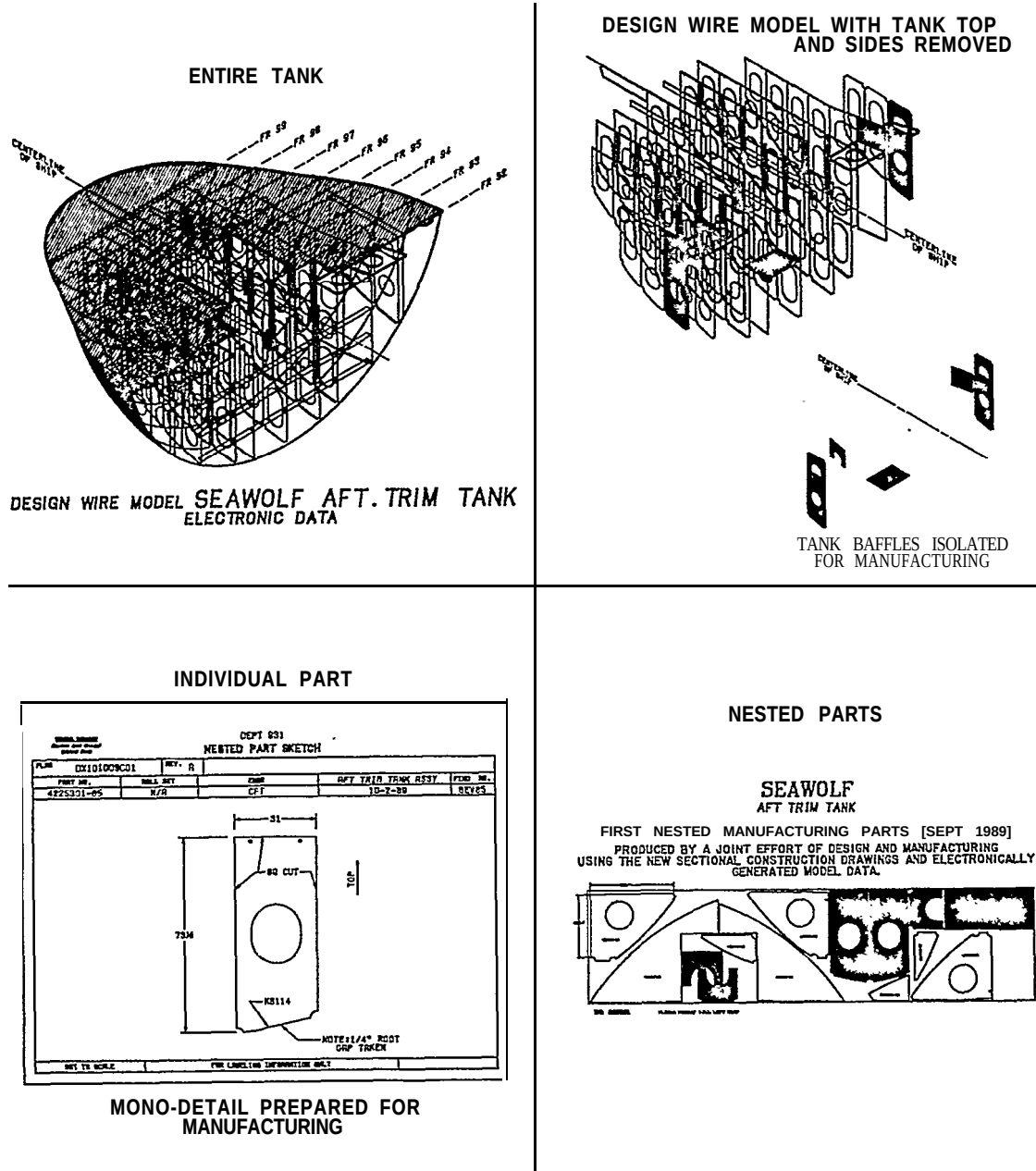


FIGURE 3. GRAPHIC PLOTS OF THE COMPUTER LOFTING AND NESTING

simple shapes. Also, they have been able to staff up more easily due to the skill separation noted above. The group reports that it is not necessary to validate design geometry; and they rely totally on what is provided in the electronic model. Evaluation to date does not indicate any problems in manufacture or assembly due to geometric errors in the models. An additional advantage is the ability to use the model geometry and available CAD software to expand shaped parts to flat cutting patterns without manual lofting, and the ability to create roll templates directly from the

electronic model. Other advantages noted are the ability to easily produce electronically generated sketches of parts annotated with manufacturing data such as bevel and root gap. These are provided to the assembly trades as supplements to the assembly views of the SCD's, promoting better visualization of the fit-up and welding requirements. To quote one steel processing supervisor: "The difference in methodology is like night and day. We still don't know all of the advantages to be realized as a result of the availability of the electronic model".

FUTURE DATA EXCHANGE ACTIVITIES

The initial data exchange activities have matured to success over the last three years. It has become apparent to both Design and Construction management that value could be added to the SEAWOLF Program by expanding data transfer into other disciplines. A study of future data exchange possibilities was conducted. The areas of overall greatest potential were Heating, Ventilation and Air Conditioning (HVAC) Ductwork and Electrical Wireways, due to existing facilities that would immediately benefit from the receipt of digital data. Both of these areas could be approached in a two phase development that permitted early results followed by a more complete and richer procedure.

For HVAC, both shipyards have agreed to use the same procedures to develop most of the ductwork from a series of standard parametric shapes. Using these shapes, software automatically generates the flat patterns for manufacture. Therefore, to achieve immediate aid in manufacturing, the first phase will be to exchange the size parameters of the standard shapes, which can be processed by the manufacturer directly. In the follow-on phase, the approach will be expanded to exchange complete model geometry from which the recipient can extract the parameters as needed for manufacture. This procedure will be particularly useful for any sheet metal structure, especially those composed of non-standard shapes.

For electrical wireways, the primary data requirement is associated with cable routing. That is, the routing of each cable through the individual wireway hangers of the ship. The transfer of the cable routing information, essentially textual data in a tabular format, would be the first phase of effort. The second phase will expand the procedure to include 3D model data of the wireway and associated hangers.

A third new data exchange medium recently began in the area of critical path network scheduling data. Both shipyards and the Navy are using the same network scheduling system. A logical extension of data exchange was to transfer each other's data so that all parties had complete planning networks available in native format to provide the user maximum utility of the software. The primary focus of the procedure development was to coordinate data element similarity and ensure network detailing was

compatible. The completion of this effort has facilitated the future transfer of scheduling data from design yard to shipbuilder, extending the SEAWOLF philosophy of maximizing construction planning in the design phase.

CONSTRUCTION PLANNING

The second producibility initiative explored is that of construction planning. The traditional task of the various planning groups was to assemble design information, primarily drawings, and create the work packages, schedules and other information required by the trades to construct the ship. The tools of the shipyard planner have changed from a number of separate bodies of data that were entirely paper based to computer data bases that have the capability to be interrelated.

The design deliverables to the construction yard are dramatically different than those received from previous submarine efforts. The conventional "class" system based drawing has been replaced by the zone based Sectional Construction Drawing (SCD). In addition, detailed schedules are provided in the form of planning and sequence documents. As related earlier in the digital data transfer section, construction planning has been approached in a similar manner. A description of the design products is re-presented below from previous efforts and the utility of the new product is recounted from discussions with construction management personnel.

SEAWOLF Drawings

A special effort of the SEAWOLF Producibility initiative was the redefinition of the types, formats and levels of detail of SEAWOLF drawings. This redefinition was required to fulfill the goals of improving the utility of construction drawings, supporting zone construction and reflecting the results of the planning effort conducted during detail design. The SEAWOLF ship specification defines three types of construction drawings to be created during the design process:

1. Configuration:
2. Sectional Construction; and
3. Ship Support.

Configuration drawings are system oriented drawings that are required to create the design data base. Most configuration drawings require approval from government agencies such as NAVSEA or the cognizant Supervisor of Shipbuilding. The format of the configuration drawings has changed little from the "class" drawings that are common to previous ship designs. The level of detail is reduced in some drawings, since any detail not required for approval, but was previously added only for construction, does not appear on the configuration drawing. SCD's are a translation of the same data base used to develop the configuration drawings, reconfigured to support zone oriented construction. The intent of the SCD is to provide the shipbuilder with all the information needed to construct the ship in the most useful format possible. A detailed review of the SCD and its role in SEAWOLF construction is provided later. Ship support drawings will be used in the life cycle support of the SEAWOLF and are composed of configuration and SCD's; and an additional group of drawings created for life cycle support such as docking drawings, equipment removal flow path drawings and Selected Record Drawings.

Sectional Construction Drawings

The SEAWOLF ship specification defined the purpose of an SCD, but it was left to the Producibility Steering Group to structure this new type of drawing. The goals in creating the SCD were:

1. Support zone oriented construction;
2. Create logical work packages;
3. Insure the drawing could stand alone in the work place; and
4. Reduce additional planning by the shipbuilder.

Supporting the construction scheme through the SCD's was accomplished by equating each drawing to an interim product, whether that product is a small item or a large module. The SCD starts with the definition of the interim product and then works through the material and processes that create that product. In the case of an item level product, such as a foundation or a package of pipe, the SCD starts with a raw material parts list, consumes the material in manufacturing processes,

prepares the item for joining with other products and may install the item on the next higher level if appropriate. A module SCD would start with previously assembled interim products, such as items, and sub-modules, and then work through the required sequence to assemble the module. An illustration of the work breakdown structure and interim products is shown in Figure 4.

In order to identify the interim products and provide an easy to use linkage for the SCD work elements, a system to "intelligently" number the SCD's was created. Since constructing an interim product is in most instances a multi-step endeavor, the creation of an interim product can be divided into steps that logically define the process. Figure 5 shows the chapter expansion of an SCD that fabricates and assembles a package of pipe. The numbering of the chapters is uniform: for example chapter 04 always assembles structural piece parts and chapter 34 always assembles piping piece parts.

The SCD Chapter is structured so that it can stand alone as a work package with minimal additional documentation. If any design reference provides information actually required for manufacture, then the information from that reference is included in the SCD. The chapter can also stand alone from the overall drawing, in that it can be detached from the SCD and sent to the work center that requires the information.

The complexity of nuclear submarines has increased dramatically over the years and SEAWOLF will continue that trend. The SCD provides the shipbuilder a tool to handle the complexity by presenting detailed yet simplified views of what is to be built, without extraneous information. The SCD presents the construction planner with the logical work packages that reduce the need for detailed advanced planning. The work breakdown or "granularity" of the work units has been refined to the point that resource accountability can become a reality. The completion by a shop of a drawing chapter indicates that a product has been built, or a specific value added, such as sandblast and paint of a unit. The shortened work timeframe and improvement in the ability to equate work package scope to physical progress brings a better tool to the construction process. The SCD achieves the goals that are detailed in the ship specification and is a measurable achievement in advanced ship production.

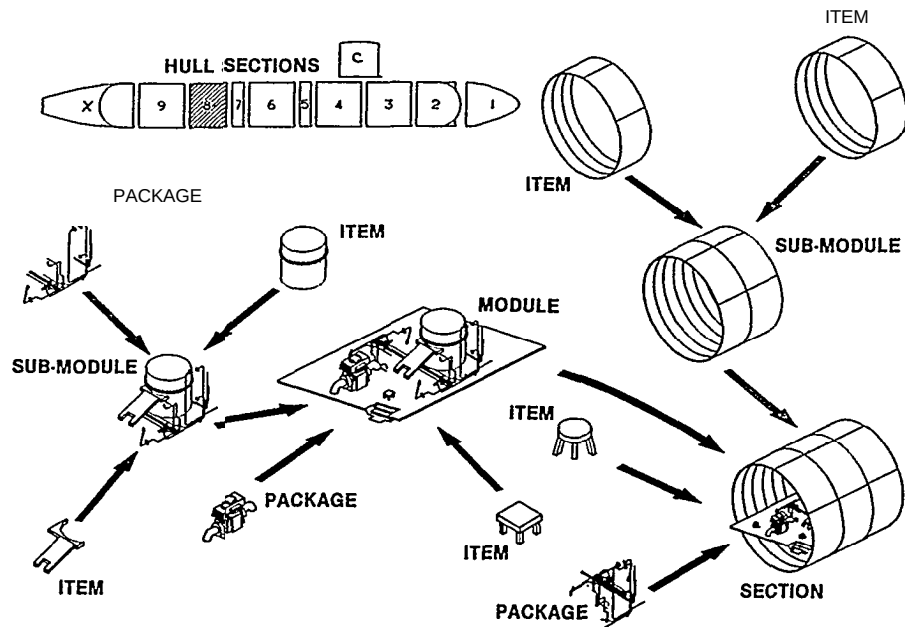


FIGURE 4. SEAWOLF PRODUCT STRUCTURE

Planning and Sequence Documents

The process of creating interim products from the item level up to the section level evolves a logical sequence of assembly above the SCD Level. As the design is iterated and the design spiral tightens, the assembly sequence becomes a parameter affecting design decisions. To assist designers in understanding the construction process, knowledgeable construction planners have been brought into the SEAWOLF detail design effort. One of their tasks is to

arrange the fabrication and assembly of interim products into a scheme that fits into the facilities and practice of submarine shipbuilders. The planning group utilizes a computer based critical path software to lay out the logic of SEAWOLF assembly. All the SCD's necessary to produce an interim product at the module or section level are networked together to permit review and analysis of the proposed construction sequence. These networks are titled "sequence" documents and are the foundation for creating additional schedule related

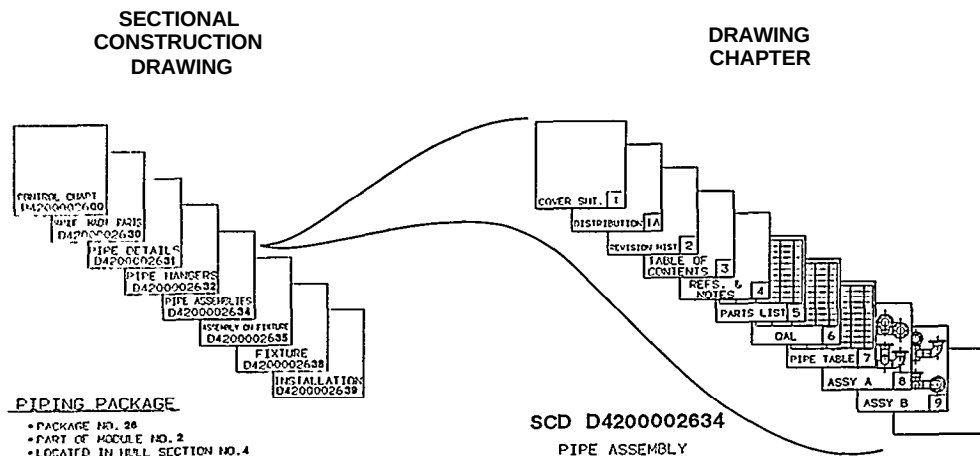


FIGURE 5. SECTIONAL CONSTRUCTION DRAWING CHAPTERS

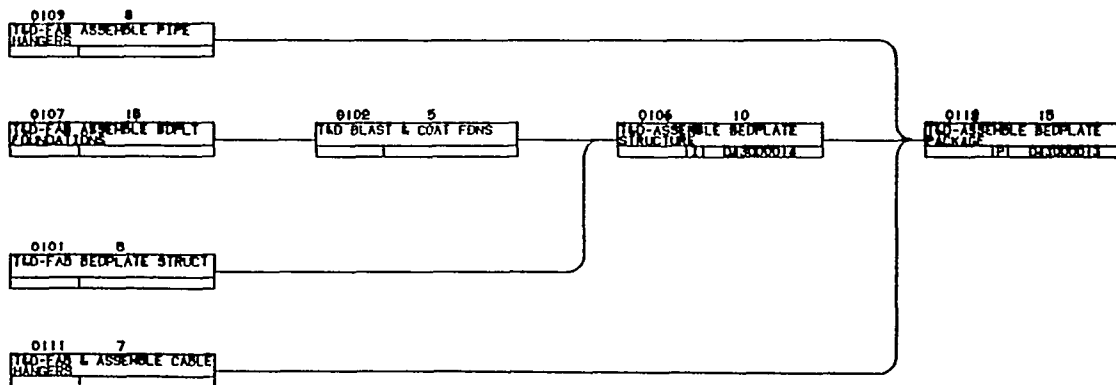


FIGURE 6. SEAWOLF SEQUENCE DOCUMENT

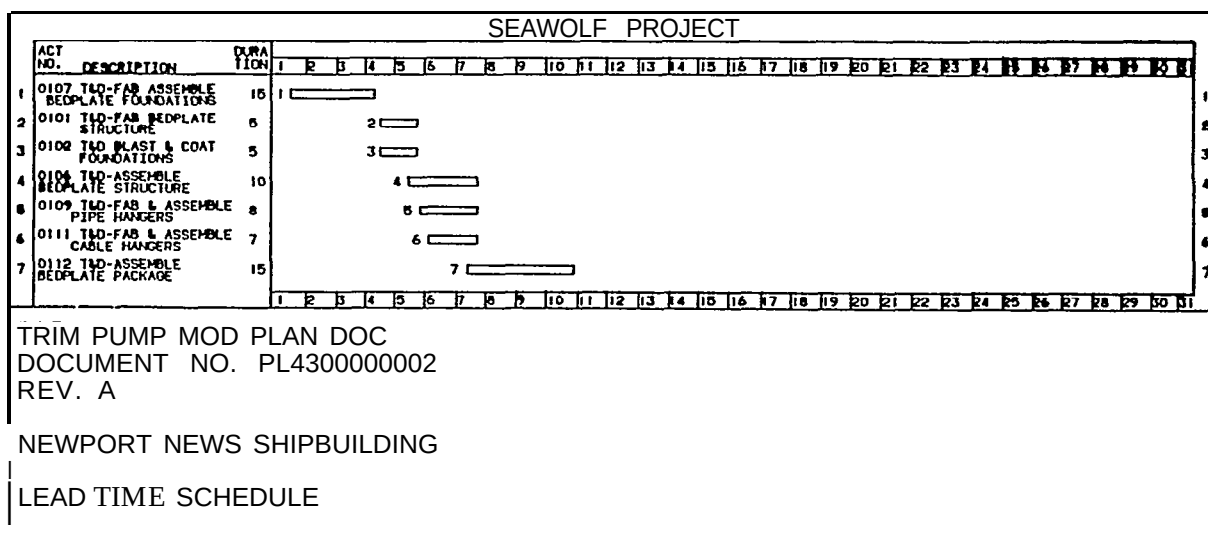


FIGURE 7. SEAWOLF PLANNING DOCUMENT

products. An example of a small portion of a sequence document is illustrated in Figure 6. The first derivative product is created by the addition of an estimated time frame to each event of the sequence network, yielding the "planning" document. The utility of the planning document is the ability to capture information necessary to work out a finite construction period and allow critical path analysis of the nominal construction plan. The companion planning document to the sequence document in Figure 6 is depicted in Figure 7. Condensation of each planning/sequence network into a single event becomes the basis of the Master Construction Schedule (MCS).

Figure 8 illustrates the evolution of an MCS activity from the planning and sequence documents. Since the MCS is produced from a "bottom-up" approach, based on a product by product evaluation, it is a valid scheduling tool that is available at the outset of construction. From the MCS, other data bases, such as the drawing issue and material ordering schedules, are linked in order to achieve an integrated construction plan. The products needed by the shipbuilder, in accordance with the Master Construction Schedule become the driving force in meeting design issue schedules that support lead ship construction.

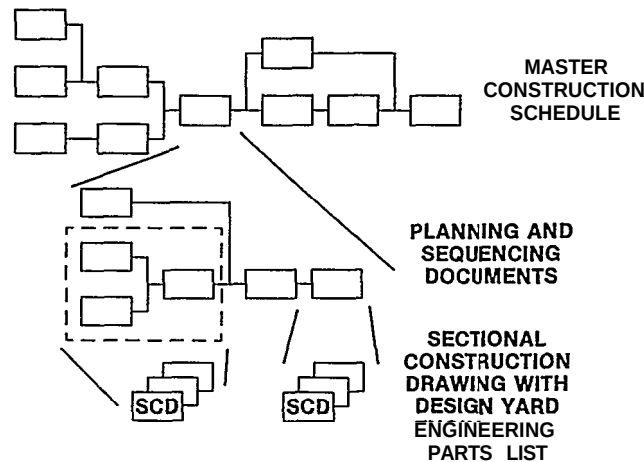


FIGURE 8. RELATIONSHIP OF SECTIONAL CONSTRUCTION DRAWING TO PLANNING AND SEQUENCE DOCUMENTS TO MASTER CONSTRUCTION SCHEDULE

SHIPBUILDER PLANNING

The inclusion of product structure planning in the SEAWOLF design contracts, the availability of the SCD's and the use of computerized network planning tools are generating significant impact in the preparations for construction, according to Electric Boat planners.

The SEAWOLF design contract requires that planning for construction be integral with detail design and that the SCD's be configured to follow the construction sequence. Electric Boat planners say that this results in the evaluation of the construction sequence "two or three times" before final preparation of the deliverable drawings and sequence documents. This, in turn, provides a running start in the planning of shipyard specific work packages, providing more insight, at an earlier point in time, into the total ship construction requirements. Furthermore, the finer detail in the product structure provided by the design agents allows more accurate, detailed and timely forecasting than has ever been possible before.

This comprehensive and detailed pre-planning paves the way for development of shipyard work packages and schedules with far shorter work scope time spans and more specific requirements than was possible with conventionally prepared design documentation. This in turn is leading to better, earlier visibility of material and manpower requirements, more precise tracking of progress, and better problem feedback, with more rapidly applied corrective action. The Electric Boat planners are convinced that there will be no more

"three year, 43000 hour work authorizations" for which we are expected to track progress, monitor cost, and react to problems and changes. With a two-week work scope, you can monitor and identify potential problems and react before they can blow up."

While it is acknowledged that not all operations may require SCD's (such as for valves, liners, standard and small parts, etc.), they are valued as the primary "building blocks" for development of construction work packages. In particular, the construction planners stress the expected value of higher level SCD's which define assembly and installation requirements for large modules. They see these as providing invaluable information and graphic aids to the assembly trades. So valuable are the SCD's perceived to be, that the construction planners have said they would "go crazy" if forced to revert to conventional drawings.

Product structuring and the of computerized networking tools have made the construction planner's job easier. Furthermore, they facilitate more precise and timely status reporting to management. The real world of shipbuilding will undoubtedly cause the planning group to accommodate a variety of problem scenarios. The planners will develop deviations and work arounds to the optimum class product structuring and construction sequence to maintain the ship construction schedule. Keeping track of the lead ship networks, while still maintaining and relating to the class baseline will prove to be a challenging task. Also, as more and more detail is added to the networks, there is concern that a point may be

reached beyond which they are unmanageable. Only experience will provide solutions to these problems.

Other advantages which have been realized or anticipated as a result of this new dimension in construction planning include long range manpower forecasting, more precise and complete impact analysis of future changes, and better cost return data for future construction proposals. However, in the words of the Manager of Advanced Planning, "We've only started, we have yet to determine all of the benefits of these new systems."

CONCLUSION

The SEAWOLF program has introduced significant changes in methodology and deliverables into the design process. The benefits of these changes are now being realized in construction of the lead ship. The early returns indicate a large measure of success in application to construction. Digital data exchange is providing more accurate information, in many cases at an earlier time. Also, less effort is required to prepare it for direct use in construction. The SCD's and Planning and Sequence Documents provide the Shipbuilder with product-structured and planned information which simplify his task of construction planning. Tangible and positive evidence of these improvements can be seen at Electric Boat as the pace of SEAWOLF construction accelerates.

These positive results were not achieved easily, however. They have required substantial cultural change in the design force; reorganization and process change and the absorption of increased work load and responsibility for the Design Yards. These challenges are being met and the payoff is being realized.

FUTURE AREAS OF REVIEW

The changes implemented in the SEAWOLF program have not only generated successes, they have also shown potential avenues for additional improvements to the design and construction process. For example, the success of data exchange indicates the need to expand its horizon in future programs. Extension of the exchange to encompass all graphic data, and the closer linking of graphic and business data through efforts such as PDES, Navy Industry Digital Data Exchange Steering Committee (NIDDESC), IGES, and CALS, should be actively pursued.

The SEAWOLF experience shows that it need not be an "all or nothing" solution. That is, data exchange can be implemented incrementally and selectively, in manageable groupings, and still achieve large measures of improvement.

Likewise, we must continue to seek ways to improve the methodology for providing design disclosure to the Shipbuilder. The SCD is a major step in providing the information in a form convenient to the builder rather than to the designer. But it need not stop there. With the ever increasing level of computerized design and data management capability, it may be possible to deliver the data required by the shipbuilder totally in electronic form and eliminate the paper drawing as we know it. This would provide the ultimate flexibility for preparation of shipyard work packages by allowing the construction planner to select the relevant data and graphic views exactly suited to his construction methodology from the design data bases.

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