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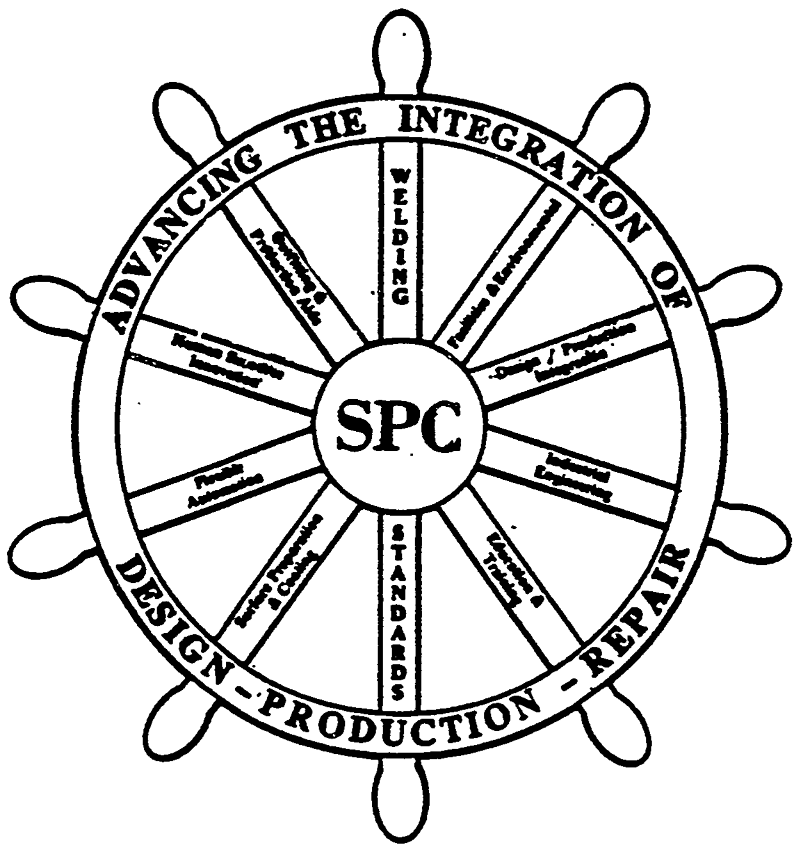

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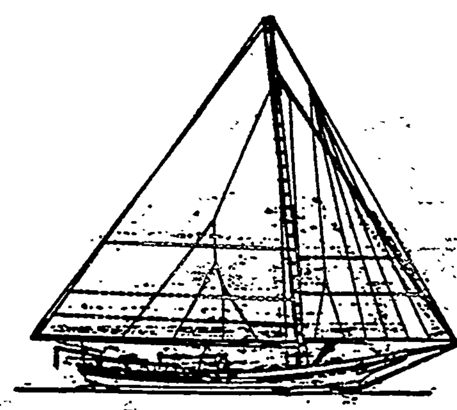

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No. 13

NIDDESC: Meeting the Data Exchange Challenge Through a Cooperative Effort

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[The opinions expressed herein are those of the authors and not necessarily those of the Department of Defense, the Department of the Navy, the National Shipbuilding Research Program, or member organizations.]

ABSTRACT

The application of Computer Aided Design (CAD) and Manufacturing (CAM) techniques in the marine industry has increased significantly in recent years, With more individual designers and ship yards using CAD within their organizations, the pressure to transfer CAD data between organizations has also increased. The Navy/Industry Digital Data Exchange Standards Committee (NIDDESC) prow-ales a mechanism for public and private organizations to cooperate in the development of digital data transfer techniques.

Organizationally NIDDESC is a cost-sharing venture, between private firms and government organizations. This effort arose from the Naval Sea Systems Command (NAVSEA) in cooperation with the National Shipbuilding Research Program. The members include leading professionals in the marine industry from several major design firms, private ship yards, naval ship yards, and government laboratories. All members are directly involved in CAD/CAM in their organizsations and together represent a broad spectrum of experience and perspectives.

NIDDESC has many sub-committees devoted to specific areas of digital data transfer. The basic objective is to develop an industry-wide consensus on product data models for ship structure and distribution systems. Efforts include contributions to the Initial Graphics Exchange Standard, the Product Data Exchange Standard, preparation of a Recommended Practices Manual and the analysis of ship production data flows. NIDDESC has made contributions to the development of CALS standards including MIL-STD-1840, DOD-IGES, SGML, and MIL-D-28000.

INTRODUCTION

Nature of The Ship Design Process

The information exchange problem of the Navy and the marine industry *is one* of the most challenging faced by any group of organizations in the world. This is due to:

* The complexity of the product,
* The life span of the product, and
* The number of participants in the design, construction and service life support process.

Naval ships are among the most complex devices known to man. Their design and construction requires from 7 to 12 years. They roam the oceans for 30 years following their construction. They accomplish complex missions in hostile environments while providing hotel accommodations for their operators. Only a few of each type are built, with each hull differing to some extent from her sisters. By the standards of most industries, these collections of 8,000,000 or so parts are all engineering prototypes.

Unlike aircraft and most mechanical products, ships are not designed, built, operated, maintained, and modernized by vertically integrated corporate giants. Rather these functions are accomplished by a series of government activities and private companies. Competitive pressures make it impossible to know in advance who the participants in the process will be. Further, the process itself tends to vary somewhat from ship to ship.

All of the activities and companies involved have improved this process by utilizing computer tools. For example, many major builders have found Computer Aided Design (CAD) applications a cost-effective means of avoiding costly interferences during construction.

The automation efforts within each activity or company have required subatantial investments in hardware and software (both custom and commercial), in training, orientation, and adaptation of work processes to capitalize on computer capabilities. The range and extent of investment is even more impressive considering the general decline and low profitability of the marine industry. There can be no denying that the marine industry is serious about CAD!

Investment choices made by different activities and companies have quite naturally led to the selection of different systems. Even companies with identical systems have developed different application techniques. Together with the variations in the process noted above, the Navy and the marine Industry are squarely faced with a requirement to be able to transfer product information between and among all activities and companies. This transfer must take place at all stages of the product life cycle including design, construction, and service life support.

Purpose of NIDDESC

One primary effort by the Navy and the marine industry to address this requirement is the Navy/Industry Digital Data Exchange Standards Committee (NIDDESC).

NIDDESC is a cost sharing, cooperative effort involving Navy & Industry technical experts in CAD applications.

NIDDESC seeks to avoid costs associated with regeneration of data bases by enabling the exchange of digital data between successive agents during the ship life cycle.

Cost Sharing Cooperative Effort. The NIDDESC effort is being executed through a National Shipbuilding Research Program (NSRP) style cooperative agreement between the Maritime Administration and Newport News Shipbuilding. Newport News has executed purchase orders with each of the commercial participants. Under the terms of the cooperative agreement, each commercial participant has waived profit and all but direct labor fringe overhead. Thus, the companies involved are absorbing one-third to one-half of the labor costs.

Technical Experts. The Working Group is comprised of the CAD Manager or a principal deputy from each of the companies and activities. Each member typically has 5-15 years experience developing and introducing CAD to complex ship design, construction, and support activities. As a result NIDDESC is a standard-setting activity working at the leading edge of CAD application technology.

Avoid Cost. The costs associated with the regeneration of ship technical data by successive agents during the ship life cycle are substantial. These costs are usually budgeted as expected costs of doing business using traditional techniques. A few examples hint at the cost avoidance potential:

* Bath Iron Works was able to avoid 96% of the labor (approximately a manyear) usually associated with production lines fairing on the DDG51 by capitalizing on digital hull form information made available by NAVSEA. This was possible as a result of a technology transfer developed under the Research and Engineering for Automation and Producibility of Ships (REAPS) Project in the 1970's.

* PDS 350 and PMS 400 have spent several million dollars each on digital data exchange programs for the SEAWOLF and DDG51 classes respectively. In each case, they were able to justify the costs of the digital data exchange program based on an expected reduction in the rate of follow builder claims for geometric discrepancies.

Enable the Exchange of Digital Data. This is the ultimate challenge. Following a history of NIDDESC and identification of the participants, is a description of how NIDDESC has broken this problem into manageable pieces and is developmg solutions for the critical ones.

History of the Program

NAVSEA has responsibility for the design, acquisition, and service life support of Naval ships. During the course of the ship life cycle, NAVSEA contracts with numerous design agents, shipbuilders, equipment vendors, and logistics agents to fulfill this responsibility. These organizations have individually developed or acquired various computer systems to support their efforts. The result of their individual selections and the highly competitive nature of the Naval ship design, construction, and service life support process present a generic need on the part of the Navy and the marine industry, to transfer digital data among different computer systems.

This need was foreseen by many Navy and industry leaders, and was formally articulated in Toward More Productive Naval Shipbuilding, a National Academy of Sciences/National Research Council report sponsored by NSRP and issued in December 1984. As a result of several meetings following the issue of this report, NIDDESC was formed in June 1986 as a joint project of NAVSEA and NSRP. The Honorable Everett Pyatt, Assistant *Secretary* of the Navy for Shipbuilding and Logistics was instrumental in the formation of NIDDESC. His office, together with various ship acquisition projects and the Computer Aided Acquisition and Logistics Support (CALS) program, has provided most of the financial support. The participants in NIDDESC are shown in Table I.

Table I. NIDDESC Participants

Navy	Industry
CHENG-L	Bath Iron Works
CEL-PA	Designers & Planners
DTRC	Electric Boat
PDS 350	Gibbs & Cox
Puget Sound NSY	Ingalls Shipbuilding
NAVSEA 05	JJH
NAVSEA 06	NASSCO
NAVSEA 93	Newport News Shipbuilding
SEACOSD	The Jonathan Corporation
SupShip-Bath	The Baham Corporation

The NIDDESC working group executed a Plan of Action and Milestones (POA&M) approved by the NIDDESC steering group in August 1986 and updated in September 1987. By May 1989, the working group had substantially completed this POA&M at approximately 65% of the projected cost. While there were literally hundreds of interim products, the salient accomplishments under this POA&M were:

* Establishing an approach to the transfer of the ship definition data,
* Establishing marine-industry-wide agreement on the structural and piping information to be transferred, and

* Influencing national and international standards development efforts to support marine industry needs.

In May, 1989, the steering group approved a second POA&M to guide the next phase of NIDDESC efforts. The working group efforts continue under this POA&M.

OVERVIEW OF NIDDESC APPROACH

In breaking down the digital date transfer problem into achievable pieces, NIDDESC has been guided by a few fundamental principles concerning digital data transfer. The first principle is that all digital data tranafer projects require the completion of four steps before an assured data transfer capability exists. The second principle is that all transferred ship information falls into four categories.

Development of an Assured Data Transfer Process Capability

The development of an assured data transfer capability involving any type of information, exchange technique, or media can be divided into four steps. Specifically, they are:

Step 1. Identify Data for Transfer. NIDDESC is applying information modeling technology to obtain explicit agreement on the information to be transferred. Information modeling allows a precise statement of complex entities and relationships between data types with minimal ambiguity. The resulting model is in a form understandable by computer specialists, engineers, and managers. This model is the basis for the data transfer process. This step is not expensive, but takes time.

Step 2. Define Data Format. Once the subject data is determined, a data transfer format can then be defined. The DoD CALS initiative has emphasized the development of computer-based design, construction, and maintenance processes through national standards and DoD applications of these standards. NIDDESC is committed to this approach. A data transfer capability built on these standards can achieve significant economies baaed on commercially developed and supported software. Like step 1, this step is not expensive, but also takes time. NIDDESC has a number of tasks, described later, aimed at assuring that national and DoD standards support the marine industry.

Step 3. Develop or Acquire Translators. This step requires a substantial investment of resources and time. It is principally a software development effort that can only be undertaken when the requirements (i.e. data to be transferred) and the design (i.e. format of transfer) are completed. NIDDESC is not involved in the development or acquisition of digital data translators. In this area, NIDDESC is looking to the development of commercial translators based on CALS standards. This approach has been confirmed with the development of the Initial Graphics Exchange Standard (IGES). With each successive release of IGES, commercial products have become available implementing portions of the new standard. where specific ship projects have economically pressing needs for data exchange capabilities which are beyond the scope of commercial products, NIDDESC can facilitate the development of specific software by having completed steps 1 and 2.

Step 4. Test and Validate Transfer Techniques. Testing and validation brings the data transfer capability to a production status. This step may require substantial *resources* and time. Extensive testing and validation is required prior *to* contractual data transfers. Due to resource constraints and the project-specific nature of test and validations efforts, NIDDESC is minimally involved in this area.

Ship Product Model Information Categories

Ship technical information falls into four broad categories as illustrated in Figure 1. These categories have different characteristics and uses.

The first category is *Requirements* information. The ship is designed, acquired, and maintained to fulfill some set of *functional and mission requirements* These guide the initial ship *Definition* which is analyzed for its ability to fulfill these requirements. During the design stages, the ship *Definition* becomes more explicit and *procedural specifications* are developed to guide further design efforts. Ship requirements data must be accessible not only in design and construction stages, but also in service life stage to determine suitability of alternate components or configurations during maintenance and modernization efforts.

The process of developing the *Associated Technical Products* may highlight areas where the ship *Definition* needs modification. Alternately *Requirements* frequently change during the 7 to 15 year duration of the design and construction stages. All of the *Associated Technical Products* have the characteristic that a change in ship *Definition* invalidates them *to* some extent and requires them to be updated or regenerated.

During the design stages many *analysis models* and *analysis results* are created based on the developing ship *Definition. Analysis results* are evaluated against *functional and mission requirements* and provide the basis for ship *Definition* changes and *Requirements* for successive stages.

As the production planning and fabrication stages begin, *fabrication and assembly instructions are* developed and *purchase orders* are generated. *Test plans and instructions are* developed to verify that *Requirements* have been satisfied. *Operating, maintenance and training plans* and *support requirements* generally are developed by the shipbuilder as part of an integrated logistics support package.

Configuration Accounting information is needed to support various configuration management and change control processes applied to the ship *Definition,* the *Associated Technical Products,* and to the *Requirements.* This information is comprised of *approval* status: hull *applicability* and *product structure* information. This latter is most

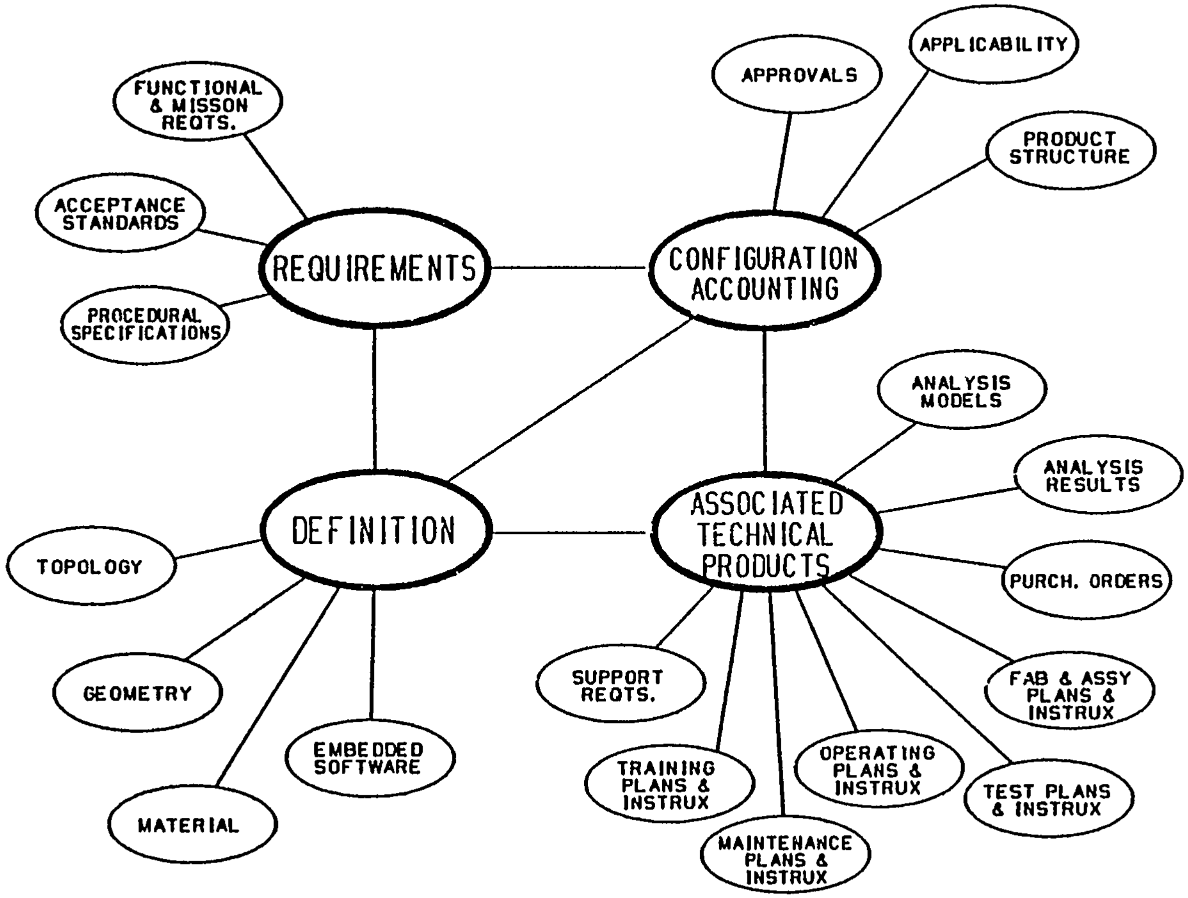

Figure 1 – Information Model Categories

frequently system-oriented ESWBS numbers, but at various stages can be compartment-oriented and/or assembly-oriented numbering systems.

Definition information is the representation of the ship that we want to design, build, operate, or maintain. *Definition* includes geometry (shape), *topology (what* pieces are connected to what), and *material (what* it's made of) data. Because combatant ships these days resemble floating computers which behave differently with different programming, *embedded software* is included.

All these categories of information are of prime importance to complete *one* task or another. Analysis reveals, however, that almost every task requires *Definition* information. This lead NIDDESC to focus on *Definition* data as the key element. The additional realization that the ship is constantly changing has also forced NIDDESC to include a minimal amount of *Configuration Accounting* information in their initial scope.

All of these categories of information are developed and many are communicated today via traditional media including drawings and documents. It is clear that the marine industry is in the process of a media-shift from paper-based to computer-based procedures. What is not so clear is that there are many degrees of computerization.

The simplest degree of computerization is "Image Capture." At this level the computer can display a video image of the paper product which can be reproduced or replaced relatively conveniently. Otherwise it has few advantages and some disadvantages compared to traditional media.

The next degree of *computerization is* the "2-D CAD Drawing." In addition to the advantages of "Image Capture" this degree allows ad hoc changes of scale and content and portrayal of alternate configurations. A trained user is still required *to* understand the 3-D product being displayed, and *even* trained viewers frequently develop different mental images based on the same set of drawings.

The next degree of computerization is the "3-D CAD Model." In addition to the advantages of the "2-D CAD Drawing" this degree allows ad hoc changes of the viewpoint and assures that all views represent the same 3-D product. This makes it easier for any *user* to form a correct mental image of the product and makes interference detection possible.

The next degree of computerization is the "Builder's Definition." In addition to the advantages of the "3-D CAD Model" this degree allows computer checking of comp onent compatibility (no flanged joints to threaded connectors) and association of CAD models to material control systems, weight control systems, etc.

NIDDESC has chosen to operate at the builder's definition degree of computerization. This is the degree that leading builders are utilizing in their detail design and construction systems and which is of the most potential economic benefit for lead-builder follow-builder data transfers. Additionally this is the degree of computerization which the Navy will be able to capture as the basis for service life support and modernization design. Finally, this degree of computerization can be decomposed to a lower degree easily, whereas the opposite movement is difficult if not impossible.

Implementation of NIDDESC Objectives

NIDDKSC's basic objective is to develop an industry-wide agreement regarding the data to be transferred. Once the data set for transfer has been defined, it is possible to define the format for transfer, develop the transfer software and test the results in a manufacturing environment. The progressive nature of Digital Data Transfer (DDT) implementation can be depicted in three intervals of time:

1. Near-Term Implementation (1 Year),
2. Mid-Range Implementation (2-5 Years), and
3. Long-Range Implementation (5+ Years).

NIDDESC is persuing data format definition tasks designed to bring results in each time frame. In this way the NIDDESC program can support current ship design efforts and lay the groundwork for future procurements. Each of these time frames requires a unique approach as the CAD systems, data transfer standards and ship construction projects change. An overview of the NIDDESC approach is shown in Table II.

Table II. Overview of NIDDESC Approach

I. Basic Objective - Identify Data for Transfer
  A. Analyze Data Flows
  B. Electrical Systems Data Model
  C. Catalogs for Distribution Systems
  D. Combat Systems
  E. Outfitting & Furnishings

II. Near-Term (1 Year) Implementation
  A. Recommended Practices Manual
  B. MIL-D-28000 Application Protocol for 3-D Pipe

III. Mid-Range (2-5 Year) Implementation
  A. IGES Implementation Baaed on HVAC Model
  B. IGES Implementation Based on Structural Model

IV. Long-Range (5+ Year) Implementation
  A. PDES Inputs for Structure
  B. PDES Inputs for Distribution Systems
  C. PDES Logistics Models/Information

The Development of Basic Agreement Tasks will identify the data for transfer. These include the analysis of data flows, ship product models and catalogs for these models.

The Near-Term Implementation Tasks are designed to give nearly immediate enhancements in the ability to transfer CAD data. These tasks make use of current CAD platforms and IGES Application Protocols. Also included is the development of a Recommended Practices Manual.

The Mid-Range Implementation time frame of 2 to 5 years dictates enhancements to present platforms and CAD software. These tasks focus on incremental enhancements to IGES.

The Long-Range Implementation Tasks are designed to take advantage of the next generation of CAD systems. These CAD systems will utilize The Product Definition Exchange Standard (PDES). PDES will include the definition of data at the engineering object level.

BASIC OBJECTIVE - IDENTIFY DATA FOR TRANSFER

The basic objective of the NIDDESC project is the development of an industry-wide agreement regarding the information to be transferred. information modeling techniques are used by software developers to define data and a framework for understanding that data.

Information Modeling Techniques

At this point, a few words on information modeling techniques will help to provide a context for the discussion that follows. An information model is simply a blueprint for understanding information. It provides a means for unambiguous communication between individuals. An information model defines a common context for the interpretation of information. The modeling process is independent of computer technology.

NIDDESC has developed information models of ship systems using the Nijssen Information Analysis Method (NIAM), (1). A NIAM diagram defines entities and their relationships. Entities can be objects or concepts. They are represented by circles. The second major element in NIAM diagrams are roles. Roles define the relationships between entities. They are represented by boxes that contain verb phrases. In NIAM diagrams the relationships between entities can be read as simple English sentences. This provides another means of representing the model which can be used for verification.

There are several types of constraints in NIAM diagrams that apply to entities and the roles between them. Constraints are the rules of behavior invoked when entering of retrieving data. They guarantee the consistency of the information. Constraints, in combination with entities and roles, provide a complete definition of the database. This definition allows individuals to communicate via the database. It can be used within one computer or as the basis of transferring information between different computers.

A complete information model includes diagrams, English statements derived from the diagrams and a dictionary definition for every entity.

NEAR-TERM (1 YEAR) IMPLEMENTATION

One thrust of the NIDDESC implementation effort is the development of digital data transfer standards for CAD systems equipped with IGES translators. These systems provide real and immediate capabilities within present limitations. *In* addition, the development of these near-term implementations provides test cases for emerging national standards.

Recommended Practices Manual

This document presents recommended practices' for digital data transfer among various government agencies, ship yards and design agents. Included in the scope is transfer between NAVSEA headquarters, Lead Builder, Follow Builders and Planning Yards. The entire ship life cycle is covered in this analysis; including design, construction, maintenance and overnaul of Navy ships. The manual is based on experience gained from current ship acquisition projects Including DDG51 and SEAWOLF.

The manual is divided into two parts. The first part includes a general Introduction of the management of digital design information throughout the ship life cycle. The second part provides specific solutions on the types of data and the transfer mechanisms to be employed. Alternative solutions are provided that are time dependent based on anticipated Improvements in hardware and software capabilities and the implementation of national and international standards. The manual is coordinated with current published or developing standards such as MIL-D-28000. The manual also includes draft ship specifications, Contract Data Requirements List, and contractual inputs for inclusion in future contracts.

IGES Application Protocols

The IGES standard (2) was developed to provide the means of transferring graphic data from one CAD system to another using a universal data file format. The IGES standard is comprised of entities that represent elements commonly found in CAD systems. To date, none of the major CAD systems vendors have provided a full implementation of the IGES standard. However, each has implemented a portion of the standard using the entities that most closely represent the capabilities of their respective systems.

In order to use these IGIS translators successfully, it is necessary to limit the product modeling to the subset of entities available on the target CAD systems. Once this subset is defined, it is necessary to prescribe a relationship between the CAD system entities and the product elements that they define. Finally, a test program is necessary wherein the elements of the CAD model are carefully tested with data that is representative of the design data. It is only after this process is complete that the successful transfer of CAD data with IGES entities can be achieved.

The procedure described is often known as an IGES Application Protocol (AP). The development of AP's can require significant resources. If organizations were to develop these procedures independently, there would be a major duplication of effort. In addition, the resulting AP's would be unique. The goal of universal data transfer offered by the IGES standard would be lost. The National Institute of Standards and Technology (NIST) has recognized the need for standard AP's and has developed a guide for their development (3). NIST is working with members of the IGES Organization to develop AP's. As they are developed, AP's will be submitted for inclusion in MIL-D-28000. AP's identify the information requirements of a particular engineering discipline (such as 3-Dimensional Piping) using the terminology and practices particular to the discipline. AP's include the following elements.

1. Information Models. The first step in the development of an AP is the definition of the data comprising the product model. This model is independent of any CAD system implementation and can be validated by an expert from the application area. Once the model is defined the IGES entities are selected.

2. Format Specification. Along with the information models, it is necessary to develop a usage guide for the selected IGES entities that defines restrictions on the global and parameter data sections of the IGES rile.

3. Test Cases. The final portion of the AP includes the protocol test cases. The test cases include test data and a test methodology including procedures and criteria for evaluating the test results.

The NIDDESC project is contributing to the development of Application Protocols in three technical areas, including:

* 3-Dimensional Piping Model,
* HVAC Model, and
* Ship Structural Model.

3-Dimensional Piping Model

The 3-Dimensional Piping IGES Application Protocol (4) being developed by NIDDESC is based on the model developed under the SEAWOLF Digital Data Transfer Program. The SEAWOLF model has been has been generalized and expanded for this effort. This AP is geared to using IGES constructs and entities to pass enough information to capture the design and permit the fabrication of a piping system. No attempt has been made to pass either preliminary design concepts or life cycle and logistical information. The AP makes use of IGES Version 4.0 with the addition of version 5.0 attribute data. The AP enables the exchange of the following piping entities:

* Pipes
* Stave Damping Assemblies
* Joints
* Hangers
* Catalog Parts
* Components
* Attachments
* Product Structures
* Piping Attributes

Figure 2 presents the NIAM diagram showing the piping parts relationships. The Piping Part entity *is* represented as a solid circle in the center of the diagram. Solid circles are used to define real world objects. In this case, Pipe, Piping Part, Geometry, etc. are all components of ship piping systems. These components are related in two major ways. The first type of relationship is the subtype relationship. This is shown by a line pointing from the subtype to the supertype such as the relationship between Pipe and Piping Part. All instances of subtype are automatically instances of the supertype and all properties of the supertype are inherited by the subtype. As entity relationships can be read in both directions, the relationship between Piping Part and Pipe can be read as follows:

A Pipe is a kind of Piping Part.
A Piping Part may be a Pipe.

The second type of relationship between entities is the role relationship. This can be illustrated by the Product Structure and Piping Part relationship. A Product Structure is an aggregation of parts for a specific purpose or function. A product structure may be a System, Assembly, Drawing or Pipe Run. In NIAM diagrams, the role relationship is depicted by a rectangular box divided in half. This box contains verb phrases that describe the binary role relationships. In this case the roles can be described as follows:

A Product Structure may associate any number of Piping *Parts.*
A Piping Part may be associated by any number of Product Structures.

The role relationship is subject to various constraints that serve to further define the relationship. One such role restraint is simple uniqueness. This means that the role is unique. This constraint is shown by a double arrow by the role. Uniqueness is paraphrased "only one." A second constraint is simple totality. This means that the relationship between the object and the role must always occur. This constraint is shown by a "V" drawn on the line connecting the role and object. Totality is paraphrased "every." The relationship between Piping Part and Pipe Port demonstrates both the uniqueness and totality constraints. In one direction, no constraints apply:

A *Piping Part has any number of Pipe Ports.*

However, the converse relationship contains both uniqueness and totality constraints as follows:

Every Pipe Port is of only one Piping Part.

With the rules described above, the relationships of Piping part to the other entities of can be read as follows:

A *Pipe* is *a kind of Piping Part.*
A Component is a *kind of Piping Part.*
A Piping Part may have any number of Pipe Ports.
Every Pipe port is of only one Piping Part.
Every Piping Part has only one Attribute Set.
Every Attribute Set is *of only one Piping Part.*
Every Piping Part has only one Geometry.
E-very Geometry is of only one Piping Part.
A Piping Part may be attached by any number of Attachments.
Every Attachment attaches only one Piping Part.
A Piping Part may be associated by any number of Product Structures.
A Product Structure may associate any number of Piping Parts

A NIAM diagram showing Pipe and IGES Relationships is given in Figure 3. Please note this figure was developed to define the Pipe/IGES relationships. Other relationships have not been included for the purpose of clarity.

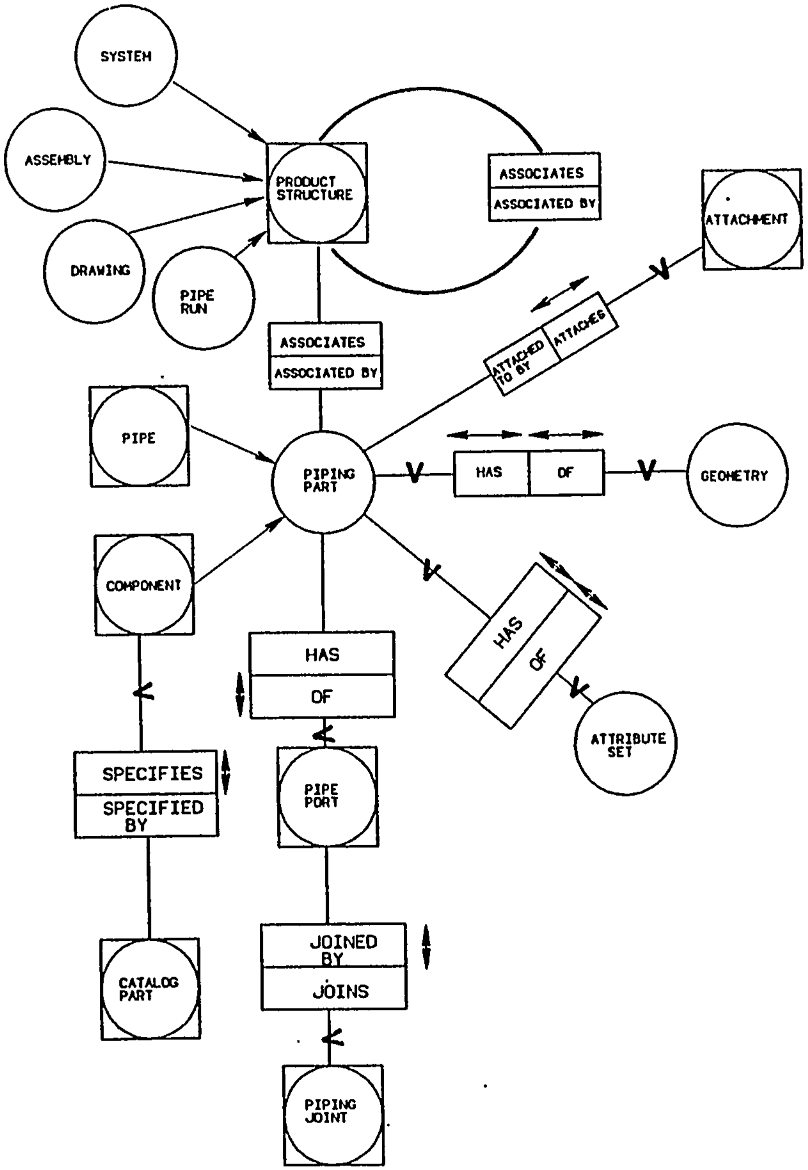

Figure 2 – NIAM Diagram of Piping Part Relationships
(From NIDDESC IGES Pipe Application Protocol)

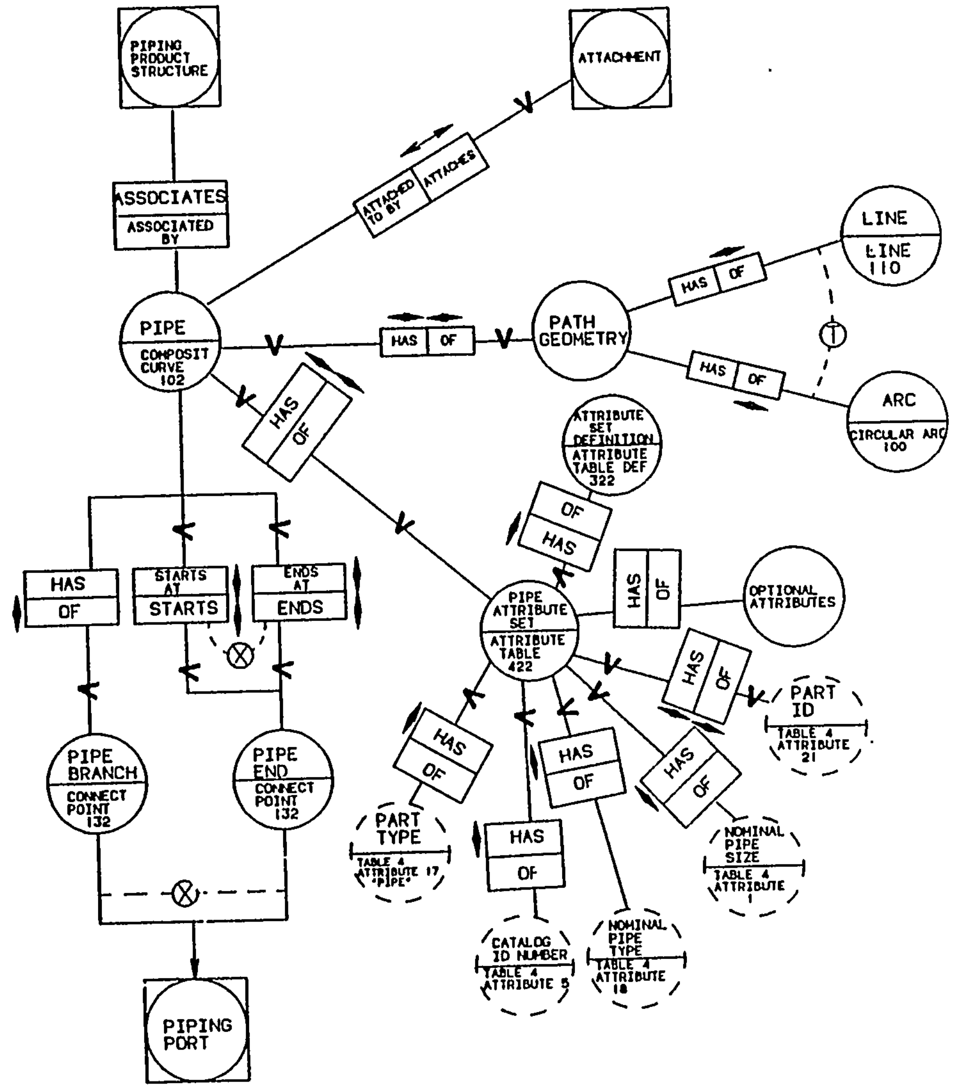

Figure 3 – NIAM Diagram of IGES Implementation For Pipe
(From NIDDESC IGES Pipe Application Protocol)

In Figure 3, the top half of the circle symbol defines the piping elements, the lower half of the symbol defines the IGES entity used to represent the piping element. IGES has no specific entity for pipe, therefore it is necessary to select from the available entities one which will represent pipe. In this case the Composite Curve (Entity 102) was chosen. The use of the Composite Curve Entity is not unique, it is also used to represent piping joints (such as tees and elbows) and pipe stave damping. As the Composite Curve is used to represent several piping elements, it is necessary to differentiate between the applications. This is done through the use of the Attribute Set as follows:

Every *Pipe has only one Pipe Attribute Set.*
Every Pipe Attribute Set has only one Part Type, only one Catalog *ID Number, only one Nominal Pipe Type, only one Nominal Pipe Size, only one Part ID, and only one Attribute Set Definition.*
A Pipe Attribute Set may have any number of Optional Attributes.

The Pipe Attribute Set is represented by the IGES Attribute Table (Entity 422, Form 0). The Attribute Set Definition is represented by Table 4 of the IGES Attribute Table Definition (Entity 322, Form 0). In IGES version 4.0, this list contains only 17 attributes. This AP makes use of attributes 18 through 27 which have been approved by the IGES committee and will be included *in* IGES version 5.0.

The Pipe geometric definitions, also shown in Figure 3, can be described as follows:

Every pipe has only one Path Geometry.
A Path Geometry has only Lines and/or Arcs.

Note the "T" between the Line and Arc objects. This is a subtype total constraint which connects all valid subtypes. From the above discussion, the centerline of a pipe is totally defined by any number of lines (IGES Entity 110) and/or circular arcs (IGES Entity 100).

Note the "X" between the near roles for the Pipe End. This is a role exclusion constraint which indicates that the roles are mutually exclusive. The treatment of pipe ends can be read as follows:

A *Pipe may have one or* more *Pipe Branches.*
Every Pipe starts at only one Pipe End.
Every Pipe ends at only one Pipe End.
Every Pipe End either starts a Pipe or ends a Pipe.

The complete AP (4) contains similar diagrams for Component Occurrence, Pipe Hanger, Stave Assembly, Joint, Attachment, Product Structure, Catalog Part, Catalog Part Geometry and External Reference.

HID-RANGE (2-5 YEAR) IMPLEMENTATION

The mid-range implementation time frame of 2 to 5 years dictates enhancements to presently available platforms and CAD software. During this time frame the majority of CAD system users will upgrade, but not completely replace, their present investment. This time frame allows for revisions of the IGCS standard. In order to take full advantage of IGES standard development, NIDDESC has sent representatives to the quarterly IGES meetings. The goal of this activity is the development of extensions to IGES that will facilitate the transfer of ship product data. This effort has taken direct advantage of the SEAWOLF DDT program for ship 3-Dimensional pipe and the data transfer specification developed for the DDG51 DDT project. The results of this effort will be available for mid-range ship acquisition programs, CALS and other Navy CAD data transfer requirements.

NIDDESC plans to continue these mid-range implementation activities with the following efforts:

* Participation in the IGES Organization,
* IGES Changes for HVAC, and
* IGES Changes for Ship Structure.

LONG-RANGE (5+ YEARS) IMPLEMENTATION

IGES is the data transfer standard presently in use in the CAD industry. It was developed to transfer graphical data entities between different CAD systems. In practice, designers employ these CAD entities to represent physical entities. The relationship between CAD entity and the physical entity is often inferred and does not reside within the computer database. Future CAD systems are being designed to resolve this problem. These CAD systems will possess databases that allow the definition of physical entities. For instance, Figure 3 shows the relationship between piping elements and the IGES entities that represent these elements. In future CAD systems this relationship will be an integral part of the system, transparent to the designer.

The Product Definition Exchange Standard (PDES) is being developed to take advantage of the ability *of* future CAD systems to define product models. PDES will provide for the transfer of this product data without loss of information or the introduction of ambiguities. To achieve this goal, PDES development requires a three layer architecture including applications layer, logical layer and physical layer. Information models required to communicate between these layers are being developed by experts in several engineering disciplines.

PDES version 1.0 (5) was published in the fall of 1988. It included mechanical piece parts, mechanical assemblies, electrical printed wiring board products, AEC models (including the ship structural model), FEM models and drafting applications. NIDDESC contributed the AEC ship structural model and has since begun the development of a distribution systems model. NIDDESC plans to continue the PDES development effort with the following tasks:

* Participation in PDES Organization,
* Reference Model for Ship Structural Systems,
* Reference Model for Distribution Systems, and
* Reference Model for Ship Logistics Data.

PDES Ship Structural Model

The NIDDESC Reference Model for Ship Structural Systems (6), was endorsed by the PDES Architecture, Engineering and Construction Committee in October 1988. The goal of this document was the developmentof a ship structure information model that allows the transfer of the majority of the ship structure without manual Intervention or interpretation of the results. This model has been incorporated into the first draft of the PDES standard. and as such is being reviewed and revised by the members of the PDES Organization. The Ship Structural Systems model defines the ship structural product at the completion of detailed design and lofting. Nesting data has heen excluded as it is typically unique to individual ship yards. The ship product model includes the following geometric, topological and property information:

* Molded Hull Lines;
* Stiffened Surfaces (shell, bulkheads, decks, etc):
* Cutouts, Lightening Holes and Penetrations;
* Weld Data and Bevels:
* Stiffener Data;
* Material Definition (thickness, type, material);
* Brackets, Collar Plates;
* Stanchions;
* Units/Assemblies;
* Foundations; and
* Rudder.

Definitions. The definition of the ship structural product model is contained in a series of NIAM diagrams showing the relationships between ship structural elements. The relationship between hull, assembly and subassembly is represented in the NIAM diagram shown in Figure 4. The elements shown have the following definitions:

* Hull: Collection of Systems which comprise a ship.
* System: Functionally related group of elements.
* Structural System: Collection of structural parts used to divide and support other Systems.
* Unit Assembly: Collection of parts and/or Sub-Assemblies in a logical or physical grouping.
* Sub Assembly: Collection of parts and/or other Sub-Assemblies in a logical or physical grouping.
* Part: Unique structural element or component consumed during the production process.
* Material: Substance making up a part including description of material and properties.
* Path Segment: Bounded portion of a molded curve beginning and ending at nodes.

Relationships. These elements have the following principal relationships as shown in the figure:

Every hull is made up of one or more Systems.
A Structural System is a kind of System.
Every Structural System is made up of one or more Unit Assemblies.
A Sub-Assembly is a kind of Unit Assembly.
A Sub-Assembly may be made up of Sub-Assemblies and/or Parts.
Every Part must be of exactly one *Sub-Assembly.*
Every Part must be either a Plate Part, Shape Part or Library Part.
Every Part *must be Identified* by *only one Part ID, creased at only one Date/Time and made of only one Material.*
A Material may be used for any number of Parts.

In this network, it can be seen that the structure of the ship hull is comprised of plate, shape and library parts. The model defines the relationships of each of these parts. For the purpose of brevity, the following discussion will be limited to shape parts. The complete model defines relationships of plate and library parts to a similar level of detail.

Figure 5 presents a NIAM diagram showing structural shape relationships. Structural shapes attach to a surface or plate along a straight or curved line. They have standard or non-standard cross sections. They may be twisted. They are intercostal or continuous. They are bounded by surfaces, plates or other shapes. Shapes have end cuts which can take on a wide variety of configurations. The following relationships can be seen from the figure:

Every Shape Part must start with only one End Cut.
Every Shape Part must end with only one End cut.
A Shape Part is defined by any number of Path Segments.
A Shape Part has any number of Shape part Edges.
Every Shape part is oriented by one or more Shape Orientations.
Every Shape Part is Iota ted by only one Shape Reference Point.
Every Shape part starts with only one Shape Clearance *and ends with only one Shape Clearance.*
Every Shape Part is offset by only one Shape Surface Offset.
Every Shape Part is identified with only one Cross Section.
A Shape Part is marked by any *number of N/C Marks.*
A Shape Part is joined by any number of Nodal Joints.
Every Shape Part is identified with only one Shape Part Type.

The complete model (6) contains descriptions of ship geometry and topology, parts (including plate, shape and library), joints and openings.

PDES Distribution Systems Model

In addition to the Ship Structural Model, NIDDESC is developing a Distribution Systems Model for the PDES standard. Like the Ship Structural Model, this is being developed *in* conjunction with the PDES AEC Committee. The Distribution Systems Model defines engineering systems whose function is to distribute fluids or energy including, 3-dimensional piping, electrical and HVAC systems. The developers of the model have a primary orientation to shipboard systems, however, the content and structure of the information defining these products are transferable across industries. In this way the marine community, through NIDDESC, is making a contribution toward the general goal of CAD integration through the development of international standards. The model is focused on the definition of elements which

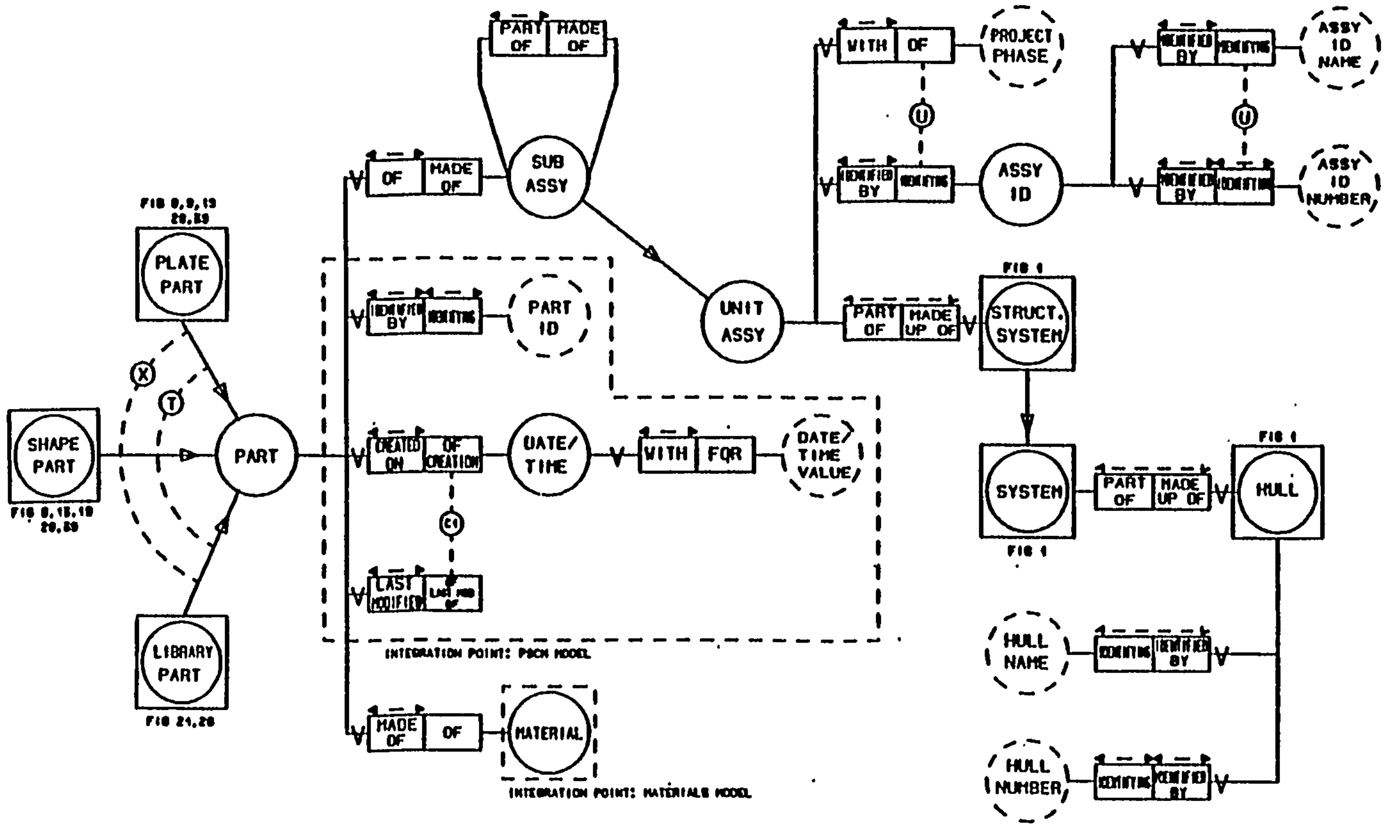

Figure 4 – NIAM Diagram of Hull/Assembly/Part Relationships
(From NIDDESC Ship Structural Model)

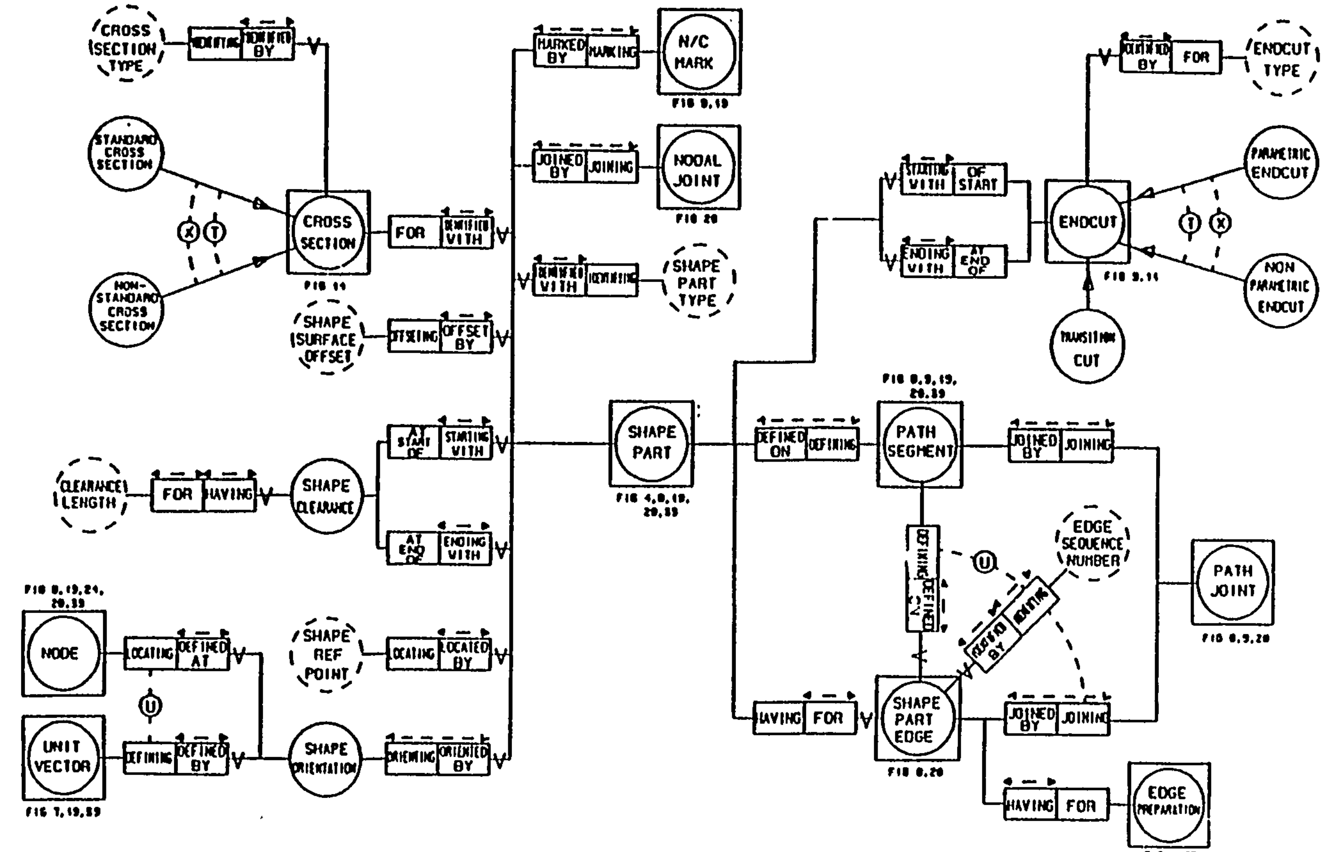

Figure 5 – NIAM Diagram of Structural Shape Relationships
(From NIDDESC Ship Structural Model)

comprise the distribution system including shape, topology and geometry. The life cycle focus is on the detailed design phase and the development of production data.

Many organizations are contributing to this effort by reviewing and commenting on the contents of this model. As a result it is being continually revised. The figures that follow represent the state of the model as it was developed in April 1989. This model is scheduled to be submitted to the PDES organization in October 1989. in the following discussion a general overview of the model will be presented. The complete model, in its latest form, can be found in Reference (7].

Definitions. Figure 6 shows the hierarchy of systems and parts in the Distribution System Model. In this diagram all part classes are subtypes of the System Part. *The* concept of inheritance is used so that attributes and other detailed information are conveyed to subtypes from the parent supertype. For *instance,* the Piping System Part must have one or more interface ports because it is a subtype of the Distribution System Part. The following definitions apply:

* Distribution System Parts: Parts of an engineering system that distributes fluids or energy within the ship.
* Devices: A part of several systems that needs not have interface ports. Devices tend to be more complex than Distribution System Parts. Devices may occur in more than one system.
* Instrument A Device used for monitoring and/or control within the system.
* Equipment A complex Device that, can belong to more than one system (e.g. pump, compressor or heat exchanger).

Relationships. The principal relationships shown in the figure can be stated as follows:

An Engineering System Part is a kind of System Part,

Every Engineering System Part must be either a *Mechanical System Part, a Distribution System* Part, *or a Device.*

Every Distribution System Part connects at one or more Interface Ports.

Every Distribution System Part must be either a Piping System Part, an HVAC System Part or an Electrical System Part.

Every Device must be either an Instrument or Equipment.

A Device may connect at any *number of Interface Ports.*

In the complete model, Piping, HVAC and Electrical Parts are further broken down into their respective part types. Figure 7 shows the Part/Catalog Relationships. Catalogs of parts are used extensively in describing ship systems. This figure is a generalization of the concepts which will be applied to all specific parts. Important concepts here are the relationships between Catalog Reference Part and Specific Part and the different Attribute Sets.

In short, a Part can be explicitly defined or referenced from a catalog of standard parts. If a Part is explicitly defined, then it has an Explicit Part Attribute Set which contains, among other things, explicit part geometry. If a part is referenced from a standard parts catalog, then it is described by a Catalog Reference Part Attribute Set.

CONCLUSION

NIDDESC is an unqualified success. Three years ago the Navy and the marine industry were non-players in the digital data exchange standards world and their needs were being ignored. For example, draft versions of PDES at that time did not support the concept of a volume bounded by surfaces such as a ship compartment. Today, through NIDDESC, the Navy and the marine industry is an acknowledged leader in digital data exchange.

* The NIDDESC Structural Model is part of the PDES First Working Draft and Its international equivalent ISO/STEP.
* The NIDDESC Distribution Systems model is well on the way to incorporation in PDES.
* The NIDDESC 3-D Piping Application Protocol has been found to support the needs of the process plant industry as well as the marine industry. It will be incorporated in MIL-D-28000 during 1989.
* Many change requests originated by NIDDESC participants have been incorporated in IGES Version 4.0 or are being incorporated in IGES Version 5.0.
* NIDDESC has established a track record of producing top-quality products on the schedules promised.

There are many reasons for this transformation:

* The technical qualifications and can-do attitude of the participants.
* The teamwork displayed by NIDDESC members from different companies and government activities while working toward common goals. Their cooperation has been in the finest traditions of NSRP and REAPS cooperative efforts.
* The establishment of formal POA&Ms to structure and focus NIDDESC activities.
* Corporate willingness to absorb part of the cost of NIDDESC operation and corporate tolerance for what was frequently an uncertain funding situation.
* Navy sponsors' willingness to support a project aimed at a general benefit.
* The utilization of information modeling to obtain explicit and lasting agreement on the information to be transferred.

The authors are pleased and gratified to be associated with NIDDESC. We have the feeling that at the end of our careers, we will look back and say, "NIDDESC was an effort that really made a difference."

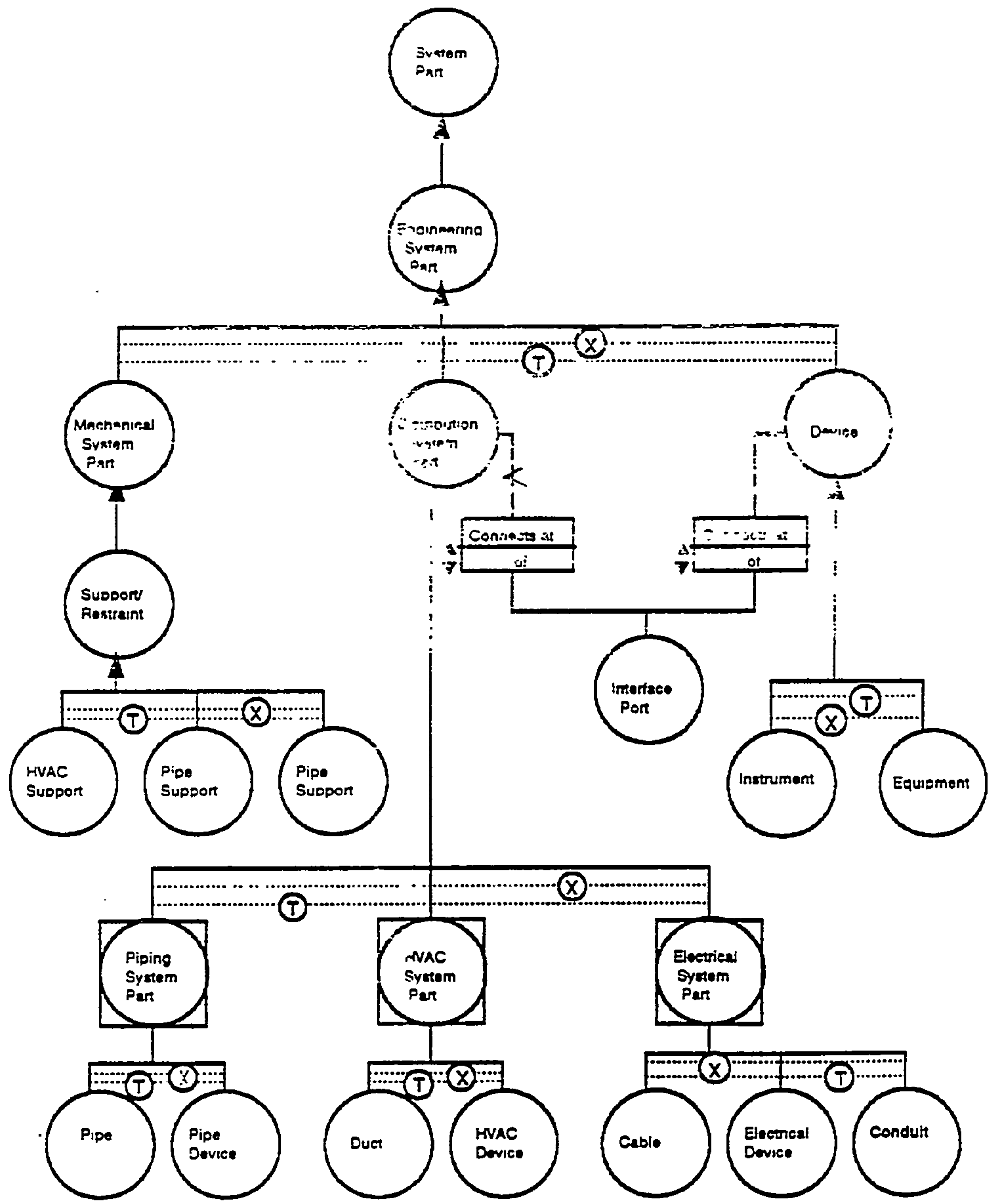

Figure 6 – NIAM Diagram of Part Hierarchy *(From NIDDESC PDES Distribution Systems Model)*

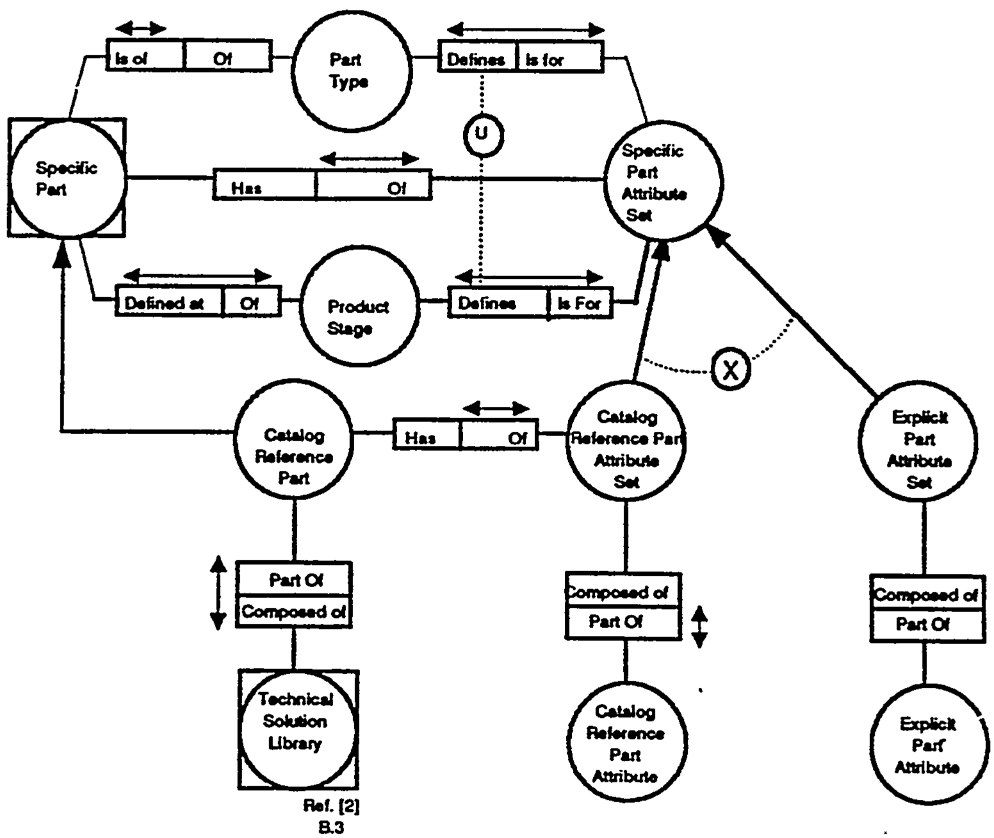

Figure 7 – NIAM Diagram of Part/Catalog Relationship
(From NIDDESC PDES Distribution Systems Model)

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