01/27/2003

Integrated Steel Processing Environment (ISPE)

Shipyard Requirements Final Report

SCOPE

This document presents the results of the ISPE project for Phase 0. Included are:

- A Common Process Model based on consolidated requirements from each participating shipyard (NGSS-Ingalls, NGSS-Avondale, NG-Newport News, and General Dynamics-Electric Boat)
- A Common Data Model designed to meet the steel processing data requirements of each participating shipyard
- A Concept of Operations that prescribes the proposed functionality and operational rationale for the ISPE
- A proposed ISPE Pilot development strategy

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ACRONYMS

AP: Application Protocol
API: Application Programming Interface
BOM: Bill of Materials
CAD: Computer Aided Design
CAM: Computer Aided Manufacturing
ConOps: Concept of Operations
COTS: Contractor Of-The-Shelf Software
DES: Defense Enterprise Solutions
EAI: A Numerical Control data Format
ER Diagram: Entity Relationship Diagram
ESSI: A Numerical Control data Format
HTML: Hypertext Markup Language
ISE: Integrated Shipbuilding Environment

ACRONYMS (continued)

ISPE:	Integrated Steel Processing Environment
MRP:	Material Resource Planning
NC:	Numerical Control
NG:	Northrop Grumman
NGNN:	Norhtrop Grumman - Newport News
NGSS:	Northrop Grumman Ship Systems
NSRP:	National Shipbuilding Research Program
Plib:	Parts Library
RD&M:	Requirements Development and Management
SIP:	Strategic Investment Plan
STEP:	Standard for the Exchange of Product Model Data
TWR:	Torpedo Weapons Retrieval
UoF:	Unit of Functionality

1. Introduction

1.1 Scope

This document serves as the Final Report for the Integrated Steel Processing Environment (ISPE) Phase 0 Requirements Analysis project. It contains a review of the Phase 0 goals, a description of the common ISPE data and process requirements, an explanation of the ISPE Concept of Operations, and a proposed ISPE Pilot development strategy. Additional information about the ISPE project is contained in the following documents:

- ISPE Technical Proposal
- ISPE Phase 0 Program Management Plan
- ISPE Requirements Development and Management (RD&M) Reference Manual.

1.2 ISPE Goals

The ISPE project was chartered and sponsored by Northrop Grumman Ship Systems and the NSRP to:

- Follow the guidance of the NSRP Strategic Investment Plan and develop an industry-wide technology that uncouples Computer Aided Manufacturing (CAM) from Computer Aided Design (CAD) platforms while maintaining interoperability
- Build on the research and standards development investments already made by the NSRP
- Stabilize the critical interface between the CAD systems and the shipyard manufacturing environment
- Provide a cost and resource-saving technology for the shipbuilding industry that enables work-sharing among US shipyards

Figure 1 illustrates the initial ISPE concept for using STEP-based data exchange to initialize a CAM system that is customized to perform yard-specific production engineering functions. This relates to the goal of decoupling CAD from CAM. Sections 2 through 4 further describe the ISPE system requirements.

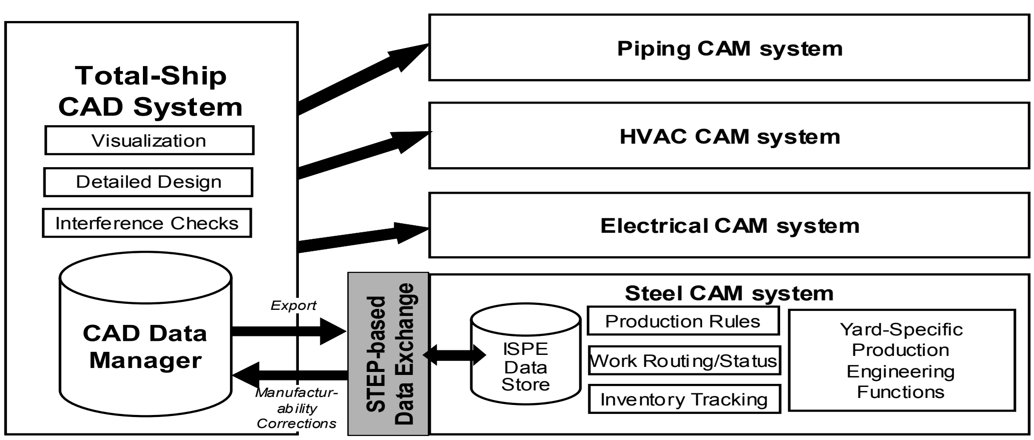


Figure 1 ISPE decouples CAD from CAM

The following sections describe how the ISPE project has met these goals and how the development of the ISPE pilot will demonstrate the technical feasibility of its initial vision.

1.2.1 ISPE Responds to the NSRP Strategic Investment plan

The NSRP Strategic Investment Plan identified a set of goals as a specific part of the overall investment plan and described the following industry-wide needs:

Develop data exchange for CAM

"Development of the Integrated Shipbuilding Environment has attacked the problem of exchanging design-centric information among various CAD systems. However, another important aspect of shipyard integration (which has been largely ignored) involves the problem of exchanging a designed ship between different computer-aided manufacturing (CAM) systems." [NSRP SIP, page 47]

"The emphasis on cross-shipyard teaming has shown that there are significant challenges not only in migrating design information from one shipyard's CAD system into another's manufacturing stream, or within the same shipyard, but also from new 3D CAD systems into legacy manufacturing systems." [NSRP SIP, page 47]

Decouple CAM interfaces from personalities, customer varieties, and evolution of CAD

"The CAM Interfaces sub-initiative under Systems Technologies will enable CAD information to be efficiently transferred to various CAM systems to support the initiatives in Shipyard Production Processes." [NSRP SIP, page 48]

"CAM Interfaces should focus on developing an environment where the evolution of CAD systems is decoupled from the CAM systems, enabling yards to add new CAD SYSTEMS TECHNOLOGIES systems by adding only one pathway to a neutral format CAM database." [NSRP SIP, page 47]

Evolve and leverage the STEP standard in Ship Production

"To date, STEP has not been widely deployed in production-worthy systems in the shipbuilding industry… Due to this limited deployment, STEP has had little real impact on the industry." [NSRP SIP, page 49]

"The highest priority of the Systems Technologies initiative must be to provide an implementation method, based on currently available Internet and object technology, for the STEP shipbuilding product models." [NSRP SIP, page 49]

The ISPE requirements collection has clearly underscored the need described in the SIP and the ISPE ConOps proposes a technical solution that supports the SIP goals. The development of the ISPE pilot will provide a design and a demonstration of the proposed solution.

1.2.2 ISPE utilizes ISE technology and STEP data exchange

Figure 2 illustrates how ISPE builds on the technology and products created by the ISE (Integrated Shipbuilding Environment) project. ISE efforts to develop and certify the emerging shipbuilding application protocols, AP 216 (Molded Forms), and AP 218 (Ship Structural Design), provided a solid foundation for standards-based data modeling and exchange for ISPE.

Phase 0 of ISPE applied these new protocols to representative shipbuilding CAM data requirements, validating their capabilities and identifying needed refinements. In addition, ISPE phase 0 prototyped a component STEP concept to enhance scalability and change management, and evaluated development needs for AP 238 as a means of conveying real-time enterprise data to the shop floor.

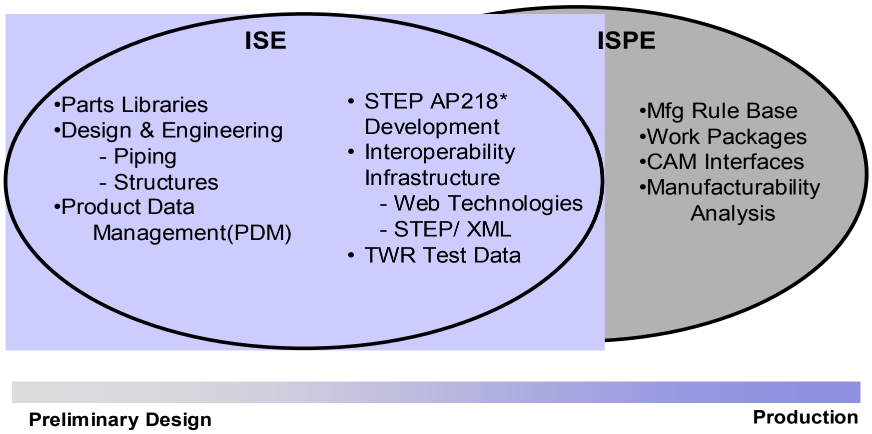


Figure 2 ISPE builds on the ISE

During the development of the ISPE pilot, the ISE-developed STEP exports from a variety of CAD vendors will be incorporated as the input to the ISPE Data Store. The ISE STEP/XML transport, web technologies, and the parts libraries will be used to seed the design of the ISPE pilot.

1.2.3 ISPE will provide the tools to smoothly interface CAD to CAM production systems

The ISPE requirements collection provided a great deal of insight into the methods and practices each yard uses to move through the ship design and engineering steps until each part is defined and all the manufacturing information required to fabricate the part is collected into one place. It brought all the current CAD/CAM system interface problems to the forefront and enabled the ISPE team to define a set of architecture recommendations based on the following principles:

Utilize a STEP-based CAD/CAM data exchange

As described in Section 3.4 the STEP APs map fairly closely to the consolidated ISPE data requirements. This mapping provides ISPE with an internationally recognized standard for organizing and transporting both the design model and the manufacturing model. Without the STEP APs, the goal of the vendor independence and the true separation of the CAD and CAM functions would not be possible in the near term.

ISPE plans to develop a method to validate the STEP 218 files that are exported from the CAD systems and to be able to overcome any performance problems encountered in the use of such a complex data structure. Just as the ISE project worked through the issues of capturing the design model in AP218, ISPE will work through the issues of capturing the manufacturing model in AP218 and AP238. ISPE is also interested in providing the shipyards a method for archiving the design and manufacturing information for a ship in the STEP format. This would allow different CAD or CAM systems to import archived models, without having to translate them from the original vendor product.

Maintain separate, but synchronized design and manufacturing models

Many of the current CAD vendors are working to extend their products into the CAM arena. While that may seem to provide a smooth integration from the design process into the manufacturing process, it creates other unanticipated problems. The requirements of the CAM systems are very different from the capabilities of the CAD systems. The actual need for complex graphical representations on the CAM side is minimal, while the need for manufacturing rules and modeling of the shipyard processes is a strong requirement.
Based on the ISPE requirements, it makes much mores sense to use the strength of the CAD systems to represent the integrated design of the ship and use a different system to model the shipyard processes, manage the CAM interfaces, and generate the manufacturing model. While the synchronization of the two models is a

critical requirement, it is not a technically complex task. Based on the ISPE CAD CAM requirements, the ISPE pilot needs to

- Provide tools that can analyze the design for produce-ability and manufacturing problems
- Track the state of the design as it goes to manufacturing (i.e. answer: how did this part come to being?)
- Maintain all configuration details connecting the two models
- Handle multiple hulls from the same basic design.

Expose all manufacturing requirements and rules

Generally, parts evolve from the "neat" version in the design model to the raw part needed for fabrication in the manufacturing model. This evolution essentially takes the final product and backs it through the fabrication steps to the raw part. Each of the transformations from final part to raw part is based the type of material and the fabrication processes needed to create the finished part. While this knowledge base of transformations is large, it is not unknown. In most shipyards, it has not been systematically documented and captured in an information system.

It is clear that a major value of ISPE is to provide a method to capture that information and allow it to be maintained as the yard's processes change. This information would provide the basis for an automated lofting capability. Potentially, such a system could accomplish a large percentage of the lofting functions that are currently being done by hand. At the least, it could support the lofting function by identifying the changes needed to specific parts and the reasons for those changes.

Ultimately, this function would have to handle the definition of end cuts and edge preparations, the creation of manufacturing aids, setup of all the marking lines, accommodating for weld shrinkage, and a wide variety of other fabrication aids. However, all these functions are well understood and relatively common across shipyards.

Use ISPE as the CAM "front-end"

The requirements clearly demonstrate a need for the shipyards to have a well defined and flexible data source to drive the yard's CAM systems. Once the manufacturing model is developed, it is natural to drive the NC machinery from that model. In fact the construction of the "Fab" package that goes to the yard to guide the routing and fabrication of each piece is the eventual goal of this function. The ISPE research demonstrated the ability to drive a state of the art nesting product using the STEP 238 AP. During Phase 1 and 2, ISPE will implement several CAM requirements, including:

- Interface to Nesting and Robotic Welding applications
- Ad hoc reporting and drawing generation
- Status tracking for individual parts and assemblies
- Interface with planning and other enterprise information systems.

1.2.4 ISPE will enable cost-effective work sharing

Finally, if the ISPE is developed to provide the above described requirements, then the sharing of work among shipyards is cost-effective. The ISPE provides the means to overcome expensive transformations as the fabrication requirements move from one yard to another. Inter-yard work would be facilitated by:

- Published interface standards for exchanging data between yards
- A consistent approach to implementing manufacturing requirements and yard-specific manufacturing rules
- Use of lower-cost tools to share manufacturing data
- Automated application of yard/shop specific manufacturing process once the manufacturing yard has been identified.

The ISPE pilot will be able to demonstrate the effectiveness of the proposed solutions.

2. ISPE Common Process Requirements

2.1 Purpose

The purpose of creating a common process model that spans the needs of the participating teammate shipyards was twofold: it provided an understanding of the domain in which the ISPE will serve and helped define a context for building the ISPE requirements.

For the ISPE to be successful, it must meet the needs of all the participants and provide flexibility to bridge functional gaps wherever they exist. Collecting detailed information of all the yards' processes proved crucial to understanding the inner workings of each yard, highlighted some of the strengths and weaknesses of the yard's processes, and helped frame the approach of the ISPE by leveraging proven solutions.

Although the gathered functional/process definitions from each shipyard resemble each other at a high level, there exist differences in nomenclature and in lower level procedures due, in part, to heritage or resource capabilities/limitations. Because of these differences, it became necessary to define a common context to provide a framework for future ISPE requirements that each yard can relate to its specific requirements.

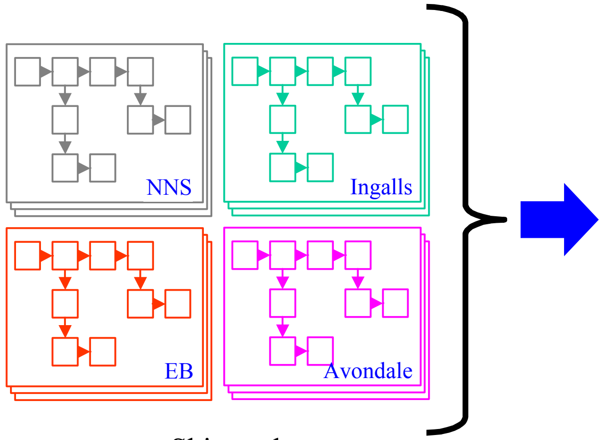
2.2 Methods

The common process model was derived primarily from information gathered during the requirements collection effort early in Phase 0. This data included descriptions of existing processes and procedures, input and output of each process, and any standards or specifications that influence each process. Also, information was collected about the organization within the yard. A format for collecting this data was provided in the RD&M document produced and disseminated by Northrop Grumman Information Technology (IT) Defense Enterprise Solutions (DES) at the beginning of Phase 0. Interviews with domain experts provided further insight and understanding of the processes within each yard, as well as shipbuilding and steel manufacturing in general.

Once all of this information was collected, it was organized into separate spreadsheets to enable sorting and categorization. Using our understanding of the processes and the information mentioned above, data from each yard was compared with the draft common process. Commonalities among the yards helped frame the first version of a common model. Further analysis revealed other similarities that were not immediately obvious. After several cycles of reviewing the data, a complete mapping was generated and a common model was established.

Once the common process model functions and related data were defined, a comparison was made to STEP Application Protocols (APs): 216 (Ship Molded Forms) and 218 (Ship Structures). These APs were chosen since they were designed to model the shipbuilding data structures and lifecycle. The STEP entities, which make up each AP, are grouped into units of functionality. Each unit of functionality defines a set of similar data structures. Mapping STEP units of functionality to ISPE common functions led to the data needs for each process function.

2.3 Cross-yard comparisons



ISPE/Shipyard Function Mapping				
ISPE Function	Avondale Function	EB Function	Ingalls Function	NNS Function
Function 1	Function A	Function F	Function L	
Function 2			Function M	Function W
Function 3	Function C	Function G		Function X
Function 4	Function D	Function H	Function N	Function Y
	Function E		Function O	Function Z
…	…	…	…	…

Shipyard Functions/Processes

Consolidated ISPE Functions/Processes

Figure 3 Comparing yard processes

Once the data related to current processes in use was collected from each yard, it was organized into a yard-specific separate spreadsheet (see Figure 3). Process diagrams were created for each yard to create an overview of the data. Since all of the gathered information was based on a common template (as specified by the RD&M document), comparing the data was straightforward. Functions were compared on their description, the type of information that was required to perform the function, the output of each function, and the group responsible for its execution. The resulting spreadsheet[1] mapped each yard's processes to each of the other yard's processes and to the derived common process. Some of the derived common functions mapped to more than one yard function and vice versa. Not all yard functions mapped to each common function but a common function mapped to at least one function for a yard.

Similarities exist in the overall processes used at each of the four yards. All yards have some process for capturing the design model and transforming it into a manufacturing model. All yards have some form of a loft function and a means of producing work packages that are sent to the production floor. Each yard has a method of managing material as it is procured, released to the yards for fabrication, and a process for tracking unused remnants. All yards maintain a Bill of Materials for commodity and fabricated parts. Finally, all yards have a scheduling system and processes for coordinating the flow of work from engineering to manufacturing.

The differences among yard processes relate to the means in which all of this is accomplished: the systems used and related policies and procedures. Each yard varies with respect to their resource capabilities (e.g., crane lifting capacities, maximum panel and unit sizes, skilled labor size and expertise, etc.). Some yards employ specialized production lines with automated stiffener placement and welding capabilities. Variations also exist in the way that structural plating and profile stock is bent and/or formed. There are also discrepancies in the design and engineering systems in use. There are several different CAD systems in use, all of which have various degrees of customization. Indeed, each yard uses customized systems that were developed in-house. There are different nesting packages, product data management systems, and methods of managing resources and maintaining schedules.

The fact that differences exist was expected – it is the impetus for the ISPE system. It is here that the challenge for the ISPE exists – *to bridge the gap between these disparate systems and resource capabilities*. The ISPE needs to maintain a neutral data model that can be made functional at each yard. With the information gained

[1] A link to this spreadsheet is located in the appendix.

through the requirements gathering effort, we now know more about these differences, enabling us to design and implement the ISPE to support them. Comparing the functional and data requirements at each yard was a good first step at defining the ultimate requirements for the ISPE.

2.4 Common Process Model diagram

2.4.1 Purpose

The common process model diagram (Figure 4) was created to show the interrelationships among the derived common functions including their arrangements into higher-level groupings, major data routes between functions, and relationships to the organizations that perform them. Each common function is further broken down into a description of the function and any inputs and outputs that are used and created. All of this information is contained within a series of linked HTML pages that are organized around the common process model diagram.

2.4.2 Areas applicable to ISPE

Each functional area within the common process model diagram is shaded to reflect the level of support/applicability of the ISPE. Areas with no shading are not applicable to the ISPE. However, it is possible that the ISPE will have functionality that could be used within these phases. *Preliminary Design* is the only area with no direct applicability to the ISPE.

Areas that have lighter shading have an indirect association with the ISPE. Here, ISPE functionality may be used to query data within the ISPE repository, or ISPE functions may be used to supplement some of the activities. These function areas include: *Detailed Design, Material Management, Planning,* and *Manufacturing/Production Control.*

Darker shading refers to those areas that are directly supported by the ISPE. The ISPE will provide functionality that applies to the functions within these areas. These functional areas include *Manufacturing Product Model Definition* and *Lofting*.

2.4.3 Major information routes

The bold lines that connect various functional areas show major data flow between organizational and functional boundaries. The information routes in the diagram broadly define information that is processed within a common yard; more detailed information exists for each route (left-click the line in the diagram). Viewing the detailed data related to each common function provides even more information. Each bold line is labeled appropriately. Clicking the line within the diagram will show a description of the data, referred to by the line, in the lower right frame of the web pages.

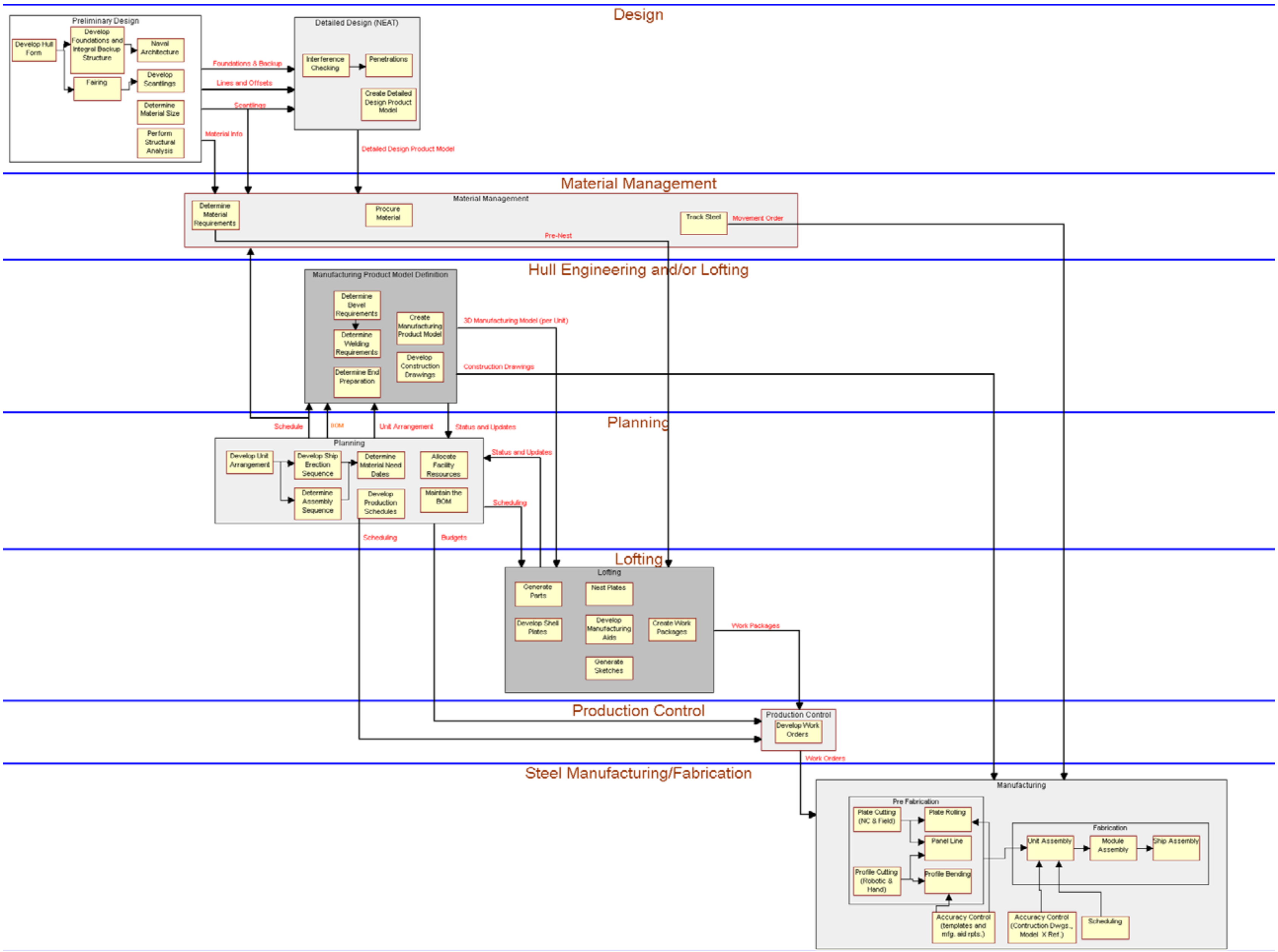


Figure 4 Common Process Model Diagram

2.4.4 Web pages

All data regarding the derived common functions, including the common process model diagram, has been organized within a series of linked HTML pages.[2] To access the main page, double click on the `default.htm` page within the `common html` directory to launch the system's default browser. The web page displayed in the browser will contain three frames: a title/navigation frame at the top and two lower frames with a link to the common process diagram page displayed below (Figure 5).

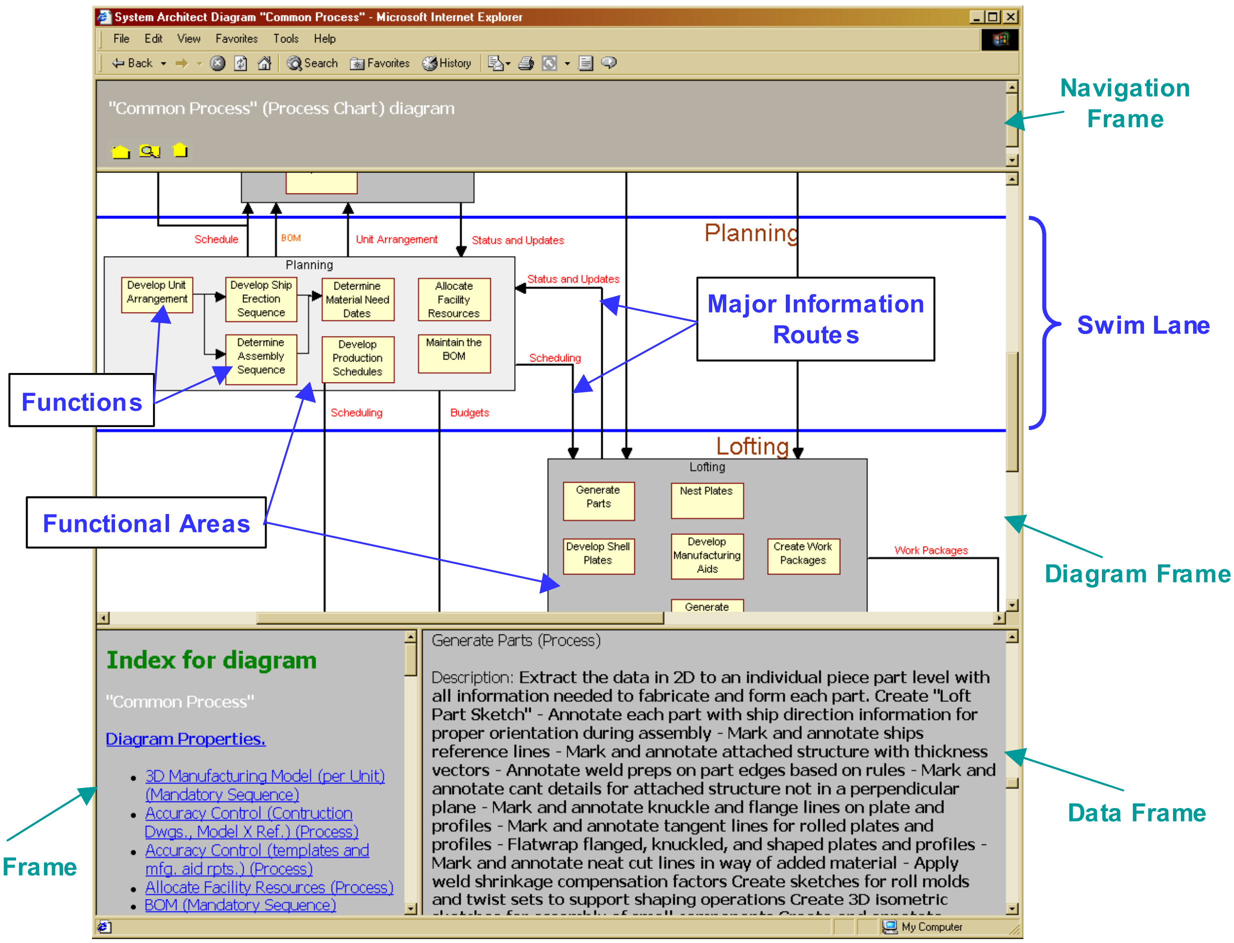


Figure 5 Common Process Model Web Pages

The navigation frame contains navigation icons to return to the main page, access a complete list of all items within the pages, a help page[3], and a method of returning to the previous page. The middle frame contains the common process diagram. Given the size of the diagram, the scroll bars need to be used to view other parts of the image. Each yellow-colored box depicts a common *function*. They are contained within a larger box to depict a *functional area*. The various lines connecting the functions and functional areas represent *major information routes*. Use the mouse to select a common function, functional area, or information route in the diagram - doing so will display additional information in the lower right *data frame* on the page. The areas of interest in the data frame are the *Description*, *Inputs* and *Outputs*, and the various links with the *Definitions Used* section. The additional data associated with each function is contained in a separate spreadsheet, a link to

[2] The HTML pages were created using *System Architect* – Enterprise Modeling Tool – v8.8.13, by Popkin Software and Systems Inc. All HTML and related web files are contained in a separate directory – `common html` – and delivered with this document as part of the final deliverables for phase 0.

[3] The help page is not implemented

which is located in the appendix of this document. Major information routes, swim lanes, and functional areas are further described in the following text.

2.4.5 Time on horizontal axis

The functions within the diagram show the entire lifecycle from design to fabrication and assembly. Each function is placed within the lifecycle based on when that function begins; time progresses from left to right. There was no attempt to show the length of time that each function takes to completion. Functions arranged over one another start, more or less, at the same time.

Function placement was based on the data received from the requirements collection effort. The range of procedures and activities in use at each yard made it difficult or impossible to generate a view that accurately portrayed the detailed processes for each yard. The resultant diagram portrays the major processes and functional processing flow for each yard at a level that simplifies comprehending the shipbuilding process as a whole.

2.4.6 Swim lanes

There are seven swim lanes shown in the diagram. A swim lane is a horizontal row into which one or more functional areas exist. Swim lanes depict the primary part of the organization that is responsible for the associated functions. Again, each yard has unique processes that may or may not exactly match the common process model.

Design represents the part of the yard or contracting organization responsible for the final design of the ship. This includes naval architects, structural engineers, and CAD operators and other engineering personnel. *Material Management* refers to the members of the organization who are responsible for determining or assisting in the process of ascertaining the material needs for the ship, procuring the material, and tracking the material as it's issued to the production floor. *Hull Engineering* helps detail the structural design to meet the ship's structural specifications. The *Lofting* group generates the manufacturing product model and all additional information necessary to cut, fabricate, and assemble the steel parts. *Planning* coordinates the assembly of the ship, the schedules, and the Bill of Materials. *Production Control* manages the daily operation within the yard, including resolving issues between the Loft and *Production*.

2.4.7 Functional Areas

The following section describes the functional areas that were created from the ISPE common process model. Each functional area contains one or more related functions to define a broad level of abstraction of the entire lifecycle. A brief description of each functional area is provided along with the relevance to the ISPE project.

2.4.7.1 Preliminary Design

The Preliminary Design phase produces the initial design of the ship along with necessary calculations to validate the hull and its capacities. Preliminary design functions may or may not be performed by the lead yard, although they are typically completed by another organization. Since the ISPE focuses on the manufacturing portion of the ship lifecycle, relatively little effort was spent on researching this area.

Main functions

- Hull form development
- Naval Architecture
- Scantling creation

Major products produced

- Scantlings
- Structural analysis

Relevance to the ISPE

Functions within Preliminary Design are outside the scope of the ISPE

2.4.7.2 Detailed Design

Within the Detailed Design phase the 'neat' representation of the ship design is completed, albeit void of manufacturing specifications. All piece parts (stiffeners, hull/deck/bulkhead plating, etc.) have been identified and sized with approved penetrations, and the relationships among parts have been established. All of this becomes part of the Detailed Design Product Model.

Main functions

- Interference Checking (with steel and distributive systems)
- Penetrations
- Detailed design model creation

Major products produced

- Detailed design product model

Relevance to the ISPE

The detailed design data serves as a basis from which yard-specific manufacturing rules will be applied by the ISPE to generate a manufacturing product model suitable for the main or target yard.

2.4.7.3 Material Management

Material Management covers all aspects of material requirements, procurement, and tracking. Determining the material requirements is done in conjunction with the Design group. Here, each part is pre-nested to determine the material ordering requirements. Once production commences, material movement orders are generated as steel is moved from the inventory to the shop for cutting and fabrication.

Main functions

- Procurement
- Steel inventory management

Major products produced

- Pre-Nesting to support steel orders
- Procurement
- Material tracking during production

Relevance to the ISPE

The ISPE will provide an interface to the yard specific material management functions and data. Otherwise, material management functions are beyond the scope of the ISPE.

2.4.7.4 Manufacturing Product Model Definition

Generating the manufacturing product model applies directly to the functionality of the ISPE. In this phase, the manufacturing product model is created from the detailed design product model. Also, all data necessary to manufacture steel parts and assemblies, including the definition of all welds, edge preparations, marking lines and labels, etc., is defined.

Main functions

- Determine bevel/welding requirements
- Develop construction drawings
- Create the manufacturing product model

Major products produced

- Manufacturing Product Model

Relevance to the ISPE

The ISPE will define a structure for explicitly representing manufacturing rules and provide facilities to automate the creation of the manufacturing product model, tailored to a target yard's capabilities, using the detailed design model in combination with these rules.

2.4.7.5 Lofting

Lofting entails generating all of the information necessary to direct/instruct Production on how to construct the ship. The Loft creates the data necessary to cut, fabricate, and assemble steel parts/units for production. Also, manufacturing aids (including molds for forming and validating steel plates, pin jig configurations for holding assemblies with curved hull sections, devices to ensure quality after fabrication, etc.) are designed with appropriate documentation. Lofting also directly applies to the ISPE.

Main functions include

- Shell plate development
- Part generation
- Nesting
- Manufacturing aids and jig configuration information
- Fabrication package creation

Major Products Produced

- Work packages, which include instructions, associated drawings, and machine data used by the shops

Relevance to the ISPE

ISPE will provide functions to support shell plate development, nesting, and NC data.

2.4.7.6 Planning

Planning generates and maintains the ship production schedules, budgets, bill of materials, and defines the assembly sequence and resource allocations for unit construction.

Main functions include

- Develop unit arrangement and assembly sequence
- Develop and maintain the ship production schedules
- Maintain the bill of materials (BOM)

Major Products Produced

- BOM
- Ship production schedules
- Build plan

Relevance to the ISPE

The manufacturing rules, made explicit by the development of the ISPE, will be based on the capabilities of a yard or shop within a yard, which will aid in the coordination of production work. Parts, defined within the ISPE repository, will be linked to external MRP systems.

2.4.7.7 Manufacturing/Production Control

Manufacturing and Production Control functions include cutting and shaping steel plates and profiles, unit and module assembly , management and oversight, and the resolution of conflicts between engineering and production

Main functions include

- Work order development
- Production management
- All yard operations

Major Products Produced

- Completed steel construction

Relevance to the ISPE

The ISPE will provide the data necessary to run the NC manufacturing equipment along with reporting functionality.

3. ISPE Common Data Requirements

3.1 Purpose

Developing and implementing a standards-based CAM data representation for steel processing are among the ISPE goals. As a precursor to these goals, steel processing data models were developed for each ISPE yard during Phase 0. Information regarding data lifecycle and data sharing practices was also captured.

The Phase 0 data architecture scope was limited to: capturing most of the entity and attribute business definitions required for steel processing, capturing the general data flow, and resolving steel processing data nomenclature between yards. Detailed physical data models will be developed later in conjunction with the ISPE detailed design.

The common data model is intended to serve more than ISPE specific applications; in fact, it has already been used to make recommendations for advancement of STEP standards with respect to CAM. A standards-based implementation of the ISPE common data model is also intended to help make yard CAM systems interoperable with each other, and help CAM systems interoperate with CAD systems.

3.2 Methods

Steel processing CAM data requirements were gathered from each shipyard by reviewing steel processing documents, interviewing data consumers from each steel processing discipline, and providing candidate data entities, attributes, and entity relationships to each yard for review.

The following information sets were developed for the ISPE Phase 0 Data Architecture. These information sets are consistent with those introduced in the Requirements Development and Management Reference Manual that was provided to each ISPE team member at the beginning of Phase 0.

- Yard Specific Data Architecture Products
  - Steel Processing entity names and business descriptions
  - Steel Processing attribute names and business descriptions
  - Entity relationship descriptions
  - Application of data
    - Data lifecycle information
    - Data sharing practice description
    - Manufacturing rule dependent data (characteristics depend upon lofting rules)
- Common Data Architecture Products
  - Common entity names and business descriptions
  - Common attribute names and business descriptions
  - A common entity relationship diagram
  - Cross yard nomenclature and data requirements comparison
  - AP 218 applicability evaluation

The common data architecture elements are addressed in the remainder of this Section. Although details of the "yard-specific data architecture products" are not discussed, they provided the foundation for the ISPE "common" data architecture, and they are reflected in the ISPE Concept of Operations.

3.3 Description of the ISPE Common Data Architecture

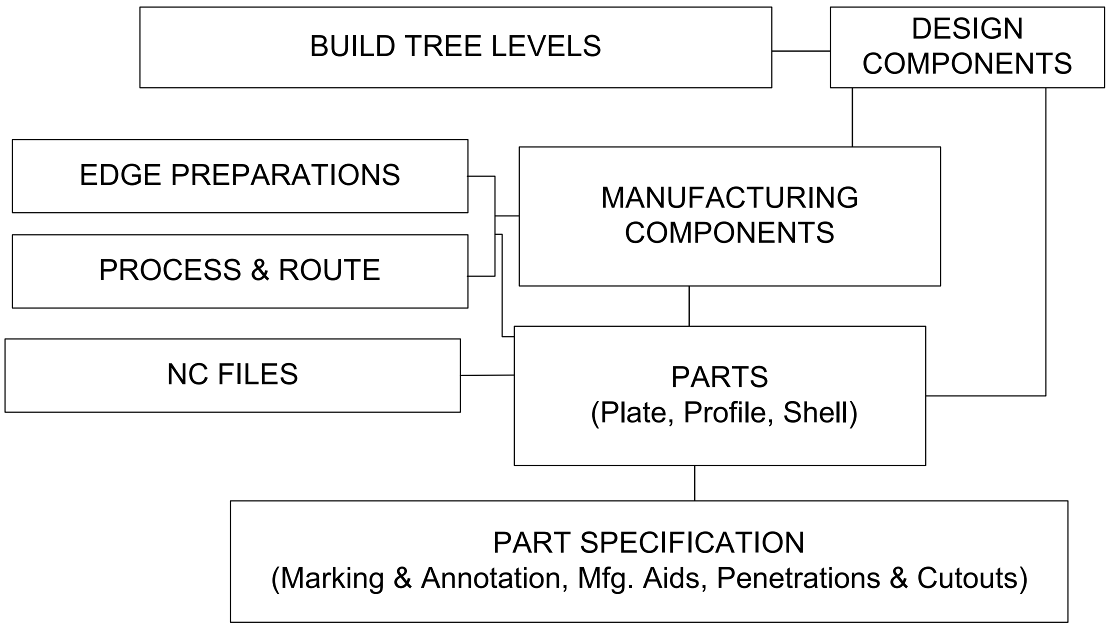


Figure 6 Common Data Architecture Categories

The ISPE common entities and attributes were organized into the Categories shown in Figure 6. These Categories are common among all the ISPE member shipyards, and provide suitable containers for all the steel processing entities.

Figure 6 also shows simplified relationships among the entity categories. The lines connecting the entity categories imply a "have" relationship. For example:

- Build Tree Levels have Design Components which have Manufacturing Components and Parts.
- Manufacturing Components and Parts have Edge Preparations and Process/Route data.
- Parts also have NC Files and a Part Specification which includes Marking and Annotation, Manufacturing Aids, Penetrations, and Cutouts.

Each of the entity categories from Figure 6 is described in the following subsection.

3.3.1 ISPE Data Model - Build Tree Levels

Table 1 is a list of Build Tree entities with Business Descriptions. Build Tree entities define manufacturing assembly stages. Each assembly stage, called a Build Tree Level by ISPE, includes varying levels of sub assemblies. Build Tree entities are important because the majority of steel Planning, Scheduling, and Construction drawing activities center around them.

Table 1 Build Tree Entities

Name	Business Description
Ship Hull	Molded Lines define the geometry of a hull as a surface without thickness. Typically, the inside surface of flush shell plating is on the molded line, as is the underside of deck plating.
Module	A Module or a Superlift is a section of a ship consisting of several units. Module size is subject to each shipyards capacity and processes. For example, the LHD 5 ship produced at Ingalls consisted of 5 Modules.
Unit	A Unit is the last assembly level before the Module. Units are typically the basis for planning, reporting, and scheduling.
Build Tree Level 1	Build Tree Level 1 is comprised of Build Tree Level 2 plus additional parts
Build Tree Level 2	Build Tree Level 2 is comprised of the next lower Build Tree Level plus additional parts
Build Tree Level X	Build Tree Level X is the lowest level construction assembly

Figure 7 is the Build Tree section of the ISPE Entity Relationship (ER) Diagram. This diagram, and subsequent data model diagrams, include entity names, color-coding, and relationship lines. The color-coding implies the following:

- White indicates that the entity nomenclature and use is reasonably consistent across ISPE yards
- Green indicates that the entity is common to all yards, but there are nomenclature differences. In this case, the name shown in the model diagrams is the ISPE common name chosen
- Blue indicates that the entity is not common for all the yards

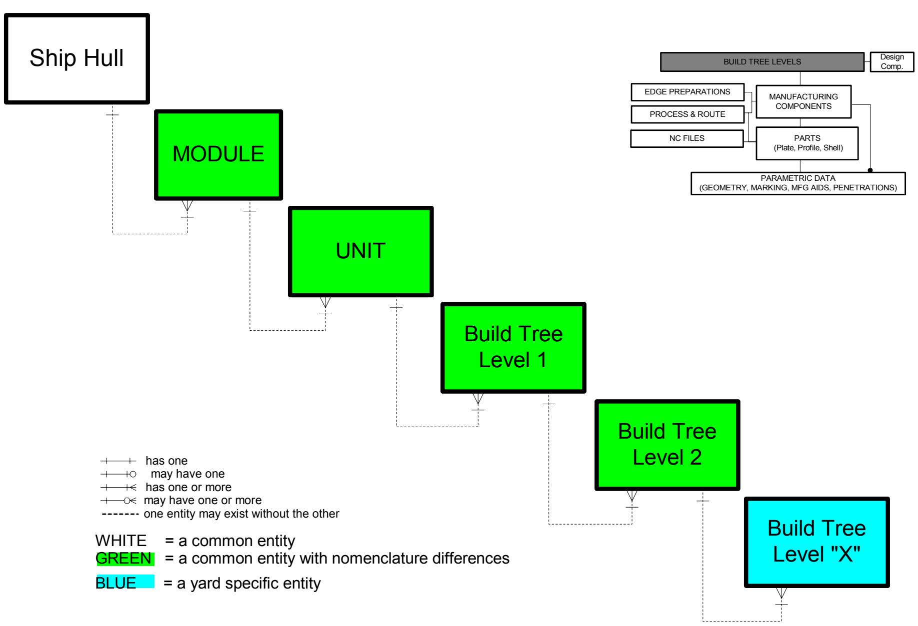


Figure 7 ISPE Data Model – Build Tree Levels

The meaning of the lines connecting the entities (relationship lines), and the nomenclature/commonality color-coding is shown on the lower left hand corner of all the data model diagrams (e.g. Figure 7).

Notwithstanding inter-yard nomenclature differences, all the build tree level entities are common except some yards have more Build Tree Levels than others.

All the Build Tree entities have one-to-many relationships. For example, the Module has one or more Units, and Units have one or more 'Build Tree Level 1' entities.

The common attributes of the Build Tree entities are shown in Table 2. Generally, each build tree entity must have attributes to define its physical description, scheduling, routing, configuration management, hull applicability, and fabrication methods.

Table 2 Build Tree Attributes

Categorization	Common Attribute Name
Physical Description	Footprint
	Mass
	Center of Gravity
	Manufacturing Orientation
Configuration Management	Identifier
	Version
Scheduling	Start Production Date Estimate
	End Production Date Estimate
	Start Production Date Actual
	End Production Date Actual
	Status
Routing	Next Production Stage
	Current Production Stage
General	Hull Applicability
	Fabrication/Manufacturing Methods
	Drawing No

3.3.2 ISPE Data Model – Design and Manufacturable Components

Design Component examples include: Frame, Frame Planes, Decks, Profiles, etc. A list of the ISPE Component Types is shown in Table 4. These components are based upon accepted design nomenclature at each yard, and they are project/hull independent; hence, the definition does not change with yard capabilities or the hull particulars. By contrast, the Build Tree entities are dependent upon the hull particulars and the yard processes. For example, ISPE Units may be defined differently if a larger capacity crane is made available for a project at a production yard; however, the ISPE concept of a Frame or Bulkhead is constant.

Manufacturable Components are design components with yard specific manufacturing information included. Attributes for Design and Manufacturing Components are listed in. The attributes that distinguish Manufacturable Components from Design Components are typically applied based on manufacturing rules, which can vary based on intra-yard and inter-yard processes.

The ISPE Design Component includes data attributes that are used to prime the creation of CAM products such as manufacturing models and part definitions. Because the ISPE will capture these attributes in a standard format that is external to CAD systems, CAM independence from design systems is possible.

Table 3 Design and Manufacturable Component Attributes

Entity	Attribute Categorization	Common Attribute Name
Design Component	Description	Component_Type
		Mass
		Center of Gravity
		Manufacturing Orientation
		Material_Type
		Thickness_Throw
		Geometric_Origin
		Max_Length_neat
		Min_Length_neat
		Load_bearing-strength_requirements
		Material characteristics (type, thickness, grade)
		Attached/adjacent structural entities – Relative thickness – Joining requirements – Relative material types – Structural entity types – Orientation
		Location and orientation within the ship
		Process requirements such as shaping
		Assembly sequence
		Routing (shop assignments)
	Configuration Management	Identifier
		Version
		Hull Applicability
Manufacturable Component	Design Attributes	*All the attributes of a Design Component plus the following
	Yard and Shop Specific Mfg. Attributes	Added_material
		Removed_material
		Chamfers
		Welding_access_and_clearance_features
		Ships_reference_lines_for_erection
		Long_Point_or_Short_Point_geometry
		Beveling
		Surface_Clearance

Figure 8 shows the ISPE Design and Manufacturable Component relationships. Edge Preparation, Welding, Process and Routing, Penetrations, Marking, Labeling, and Design Components are all related to Manufacturable Components. Components also have recursive relationships with themselves because components such as stiffeners may be included in the definition of other components such as decks.

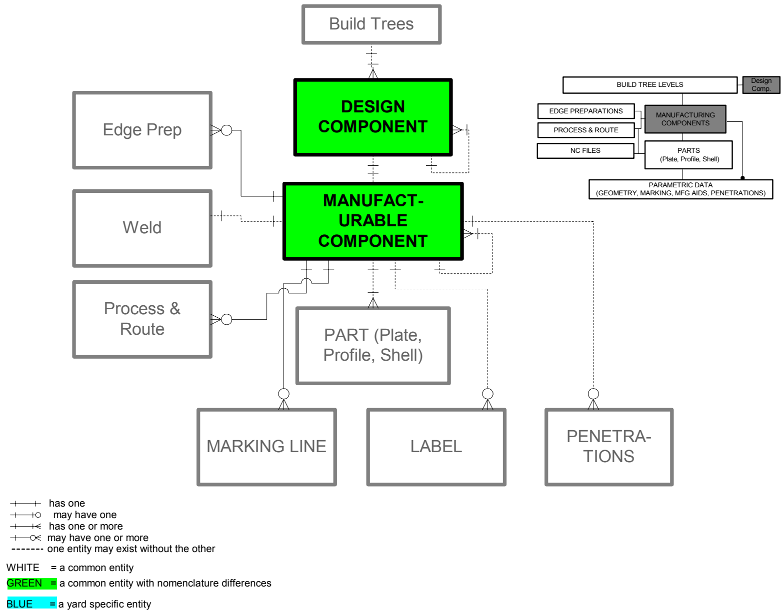


Figure 8 Design and Manufacturable Component Relationships

ISPE "Component Types" with business definitions are listed in Table 4. Most of the Component Types are common among the ISPE shipyards, a common name was chosen where there were nomenclature differences. Component types such as Web Frame, Frame Plane, Platform Flat, Sponson, Transverse Bent, Inner Bottom, Double Bottom, and Bilge were not common across all yards but are included in the ISPE data model for completeness.

Table 4 ISPE Component Types

Name	Business Description
Frame Planes	Frame Planes are a reference lines which can be stiffened with plates or profiles
Deck	A Deck is a continuous horizontal strength member inside of a ships hull that supports equipment and personnel.
Platform/Flat	A platform/flat is a horizontal, non-strength, non-continuous surface inside the ships hull.
Girder	A Girder has the following definitions: 1. A continuous member running fore-and-aft under a deck to support the deck and deck beams. 2. The vertical fore-and-aft plate members on the ship's bottom (shell and tanktop only).
Bulkhead	Bulkhead is a term applied to the vertical partition walls which subdivide the interior of a ship into compartments. Various types of bulkheads (transverse, longitudinal, forepeak, watertight, wire-mesh, pilaster, etc.) are distinguished by their location, use, material type, or fabrication method.
Floor	A Floor is a vertical transverse plate immediately above the bottom shell plating, often located at every frame, extending from bilge to bilge above the shell plating to tank top only.
Sponsons	Extensions of the ship's hull to accommodate the flight deck, weapons system, refueling platforms, etc…
Transverse Bent	Transverse structural arches that support the Flight Deck.
Web Frame	A built up frame to provide extra strength, usually consisting of a web plate which is flanged, or otherwise stiffened, on its edge. Web frames are typically spaced several frames apart, with smaller regular frames in between.
Innerbottom / Double Bottom / Bilge	The area of the ship between the tank top and shell, includes all structural members in between (i.e. floors, longitudinals, etc…)
Stringer Bar	Angle connecting the deck plate to the shell plate
Deck Beam	An athwartship horizontal structural member, usually a rolled shape, supporting a deck or a flat.
Profile	Extruded run of standard structural material used to strengthen or otherwise support plated structures. They are made from stock profile material (T's, angles, bulbs, etc.) and are often described in terms of their Web and Flange components. Profiles are also used in foundations design to support machinery or equipment.
Commodity	Standard components such as bracket and collars

Name	Business Description
Components	
Breast Hook	A Breast Hook is a triangular plate bracket joining port and starboard side stringers at the stem.
Stanchion	A Stanchion is a vertical column supporting decks, flats, girders, etc.
Foundation	A Foundation is a structural support for boilers, engines, gears, machinery, etc.

3.3.3 ISPE Data Model – Parts

ISPE Part types include Plate Parts, Shell Plate Parts, and Profile Parts. Business definitions for each are shown in Table 5. Part definitions are a key contributor to manufacturing artifacts such as reports and NC data.

Table 5 ISPE Parts

Name	Business Description
Plate Part	A Plate Part is the lowest level assembly structural component which has manufacturing data, and can be cut from flat plate. This does not include "hardware" (i.e. washers) or hardware-like accessories.
Shell Plate	Shell Plates form the outer side and bottom skin of the hull
Profile Part	A Profile Part is the lowest level assembly structural component which has manufacturing data, and can be cut from profile stock such as I-beams or flat bar

ISPE Part attributes are summarized in Table 6. The Attribute Categories include: Description, Quantity, Configuration Management, Scheduling, Mfg. and Design Associations, and General.

Table 6 Part Attributes

Attribute Category	Attribute Common Name
Description	Part_Type
	Units
	Material_code
	Plate_thickness
	Min-max_extent
	Area
	Center_Of_Gravity
	Weight
	Length_and_width
	Geometry
Quantity	Required quantity
	Nested quantity
Configuration Management	Identifier
	Version
	Hull Applicability
Scheduling	Estimated Start
	Actual_Start
	Status
Mfg. and Design Associations	Entity References per the relationship diagram
General	Programmer
	Job_number
	Job_name
	Drawing_number
	engineering_remarks

3.3.4 ISPE Data Model – Part Definition

Figure 9 shows the ISPE Part relationships. Parts inherit Edge Preparations, Weld specifications, and Penetrations from their parent Manufacturable Component. Parts also have Nest tape, Process and Route, Manufacturing Aid relationships, Marking, and Labeling information. Each of these related entities will be discussed below, except the Manufacturable Component, which was discussed earlier

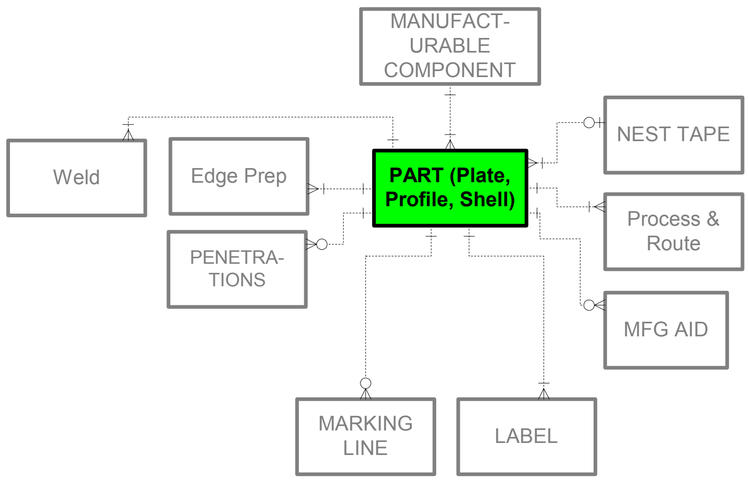


Figure 9 ISPE Part Relationships

Part ***Labels*** and ***Marking Lines*** communicate information to shipyard workers. Part Labels and Marking Lines must enable the manufacturing consumers to identify manufacturing process requirements, routing, and scheduling information that is associated with each Part. Where the Part marking does not communicate this information directly, it must "point to" the proper information using some identifier as a link.

Marking attributes include a type, name, identifier, geometry, and location. Label attributes include a type, name, identifier, location, height, and width. Table 7 shows a list of the ISPE Marking Line and Label types. Generally, each yard has their own unique labels and marking entities. For example, one yard may trace the contour of a knuckle line while another uses an annotated label. Marking and labeling application can also differ depending upon the intra-yard consumer.

The ISPE will ultimately define a logical marking line and label schema that each yard can interpret and apply to parts based on their rules.

Table 7 - Part Marking and Labeling

Entity	Name	Description
Marking Lines	Waterline	Marking Line_Waterline is a line representing the intersection of an imaginary plane at waterline height with the ship's molded forms
	Buttock	Marking Line_Buttock is a line representing the intersection of the molded surface with any vertical longitudinal plane that is not on the centerline. Buttocks are always parallel to centerline
	Frame Line	Marking Line_Frame Line is a line representing a frame PLANE intersection with the surface of ANY structural component.
	Tangent Line	Marking Line_Tangent Line is a reference line that is touching but not intersecting a part or other component.
	Inverse Curve	Marking Line_Inverse Curve is a curve that is occasionally drawn on structural parts that have to be shaped. When the part has been properly shaped, what began as a curve will be a straight line.

Entity	Name	Description
	Other Marking Lines	Shell Landing, Datum Line, Seam, Heating Lines, Thickness Vector, Neat Cut, Post Erection Cut, Drill Hole Center Line, Dimpling Location, Knuckle, Alignment, Attached Structure, Cant Details
Labels	Bevel	The Label_Bevel shows the location and type of Bevels on parts or other structural components. A Bevel is an angle or inclination of surface that meets another at any angle less than 90 degrees.
	Added or Removed Material (stock)	The Label_Stock shows the location and type of stock at Unit breaks. Stock is added material at Unit breaks, the added material helps join the Units. Stock is also added for fabrication purposes.
	Far-Near Side	The Label_Far-Near Side indicates indicate the structural member location relative to the layoff side.
	Frame Line	The Label_Frame Number identifies a frame number on a part or other structural component.
	Material Type	The Label_Material Type identifies the material type and thickness of a part or other structural component.
	Thickness Throw	The Label_ Thickness Throw shows the direction of thickness from a reference edge that meets another surface. NGNN indicates the direction of the material throw by a "hump" in the structural location punch line
	Chamfer	The Label_Chamfer shows the location and type of chamfer on parts or other structural components.
	Knuckle	The Label_Knuckle shows the location and type of a knuckles on parts or other structural components.
	Other Labels	Post Erection Cut, Drill Hole Center Line, Dimpling Location, Reference Line, Ship's Direction, Part/Assembly, Name, Datum Line, Tangent Line, Bending Curve, Roll Line, Alignment Line, Match Marks, Cant Details, Attached Structure, Penetration, End Cut, Routing, Buttock, Waterline, Mold location & instruction

Nest Tape entities, and other NC files, are files that contain numerical control to run automated steel cutting machines. The ISPE data management system will store and distribute Nest Tapes, robotic instructions, and other NC files. Table 8 lists Nest Tape File required attributes. The attribute list was provided by a nesting vendor who is a member of the ISPE team. The Report Data attribute requirements in Table 8 were extracted from a shipyard ISPE team member nesting report.

Table 8 Nest Tape File Attributes

Category	Attribute
Part Geometry Data	Lines Arcs Circles Points Marking Text
Part Engineering Data	Part material grade Material preferential side (tread plate) Part thickness Part grain constraints Part edge constraints (e.g. mill edge/cut edge)
Part Processing Data	Bevel cuts Type of bevel Bevel dimensions Defined on geometric entity level Preferred cutting process Part marking geometry Marking lines, arcs and circles Marking text Punch marked points Surface grinding Cutter path data will be generated by the nesting system. No NC data will be stored in ISPE database.
Part Production Data	Part identification Part number

Category	Attribute
	Drawing number Description Part configuration data Location of geometry data Revision Scheduling data Due date Part quantity Project identifier Work order identifier
Raw Material Data	Interface to yard specific raw material information
Report Data (post NC file processing)	Piece identifier piece mark for each nested part Burning tape no. tape identifier Nest data format (ESSI, EAI, etc.) Remarks Type and location of drawing Material type Center of gravity for each part Length, width, and area for each part Date nested for each part Contract name Label marking options Mode Programmed stops Piercing allowance Post processing options Secondary processes Revision Nest tape status Assumed speed Burning time Center punching time Total processing time Errors and warnings Material requirements Plate utilization Parts nested - Part no. Parts Nested - QTY Piercing time Rapid transverse time - Scrap weight

Manufacturing Aid entities are used to check the accuracy of parts and assemblies, to shape parts, or to support parts during joining processes. ISPE Manufacturing Aid definitions are listed in Table 9. Template, Saddle, Inverse Curve, and Pin Jig nomenclature is common among all the ISPE shipyards. The remaining Manufacturing Aids listed are yard-specific entities.

The ISPE team has collected and analyzed example Manufacturing Aid reports, drawings, and pictures. Evidently, the application of manufacturing aids and the value of manufacturing aid parameters is often yard specific. The ISPE will ultimately define a logical Manufacturing Aid schema that each yard can interpret and apply based on their rules.

Table 9 Manufacturing Aid Types

Type	Description
Template	A Template is a wood or paper full-size pattern, which is placed on materials to indicate the accuracy of curvature and/or twist. It is also used to indicate the size and location of rivet holes, plate edges, etc.
Jig Spawl	A Jig Spawl is a supporting structure for ships modules. It conforms to the shape of the hull at given longitudinal locations.

Saddle	A Saddle is a fixture used to hold a profile in place during welding
Pin Jig	A Pin Jig is a supporting structure used to hold shaped plate parts steady for welding and assembly.
Roll Set	A Roll Set is a composite template set used to check the curvature accuracy of a rolled plate.
Steel Band	Used to check structural members attached to plates after weld shrinkage. Also used to check to make sure one unit will fit to another.
Inverse Curve	Data that allows a curve to be drawn on a straight bar or frame. The bar is then bent until the curved line becomes straight
Box Mold	A Box Mold is a fixture used to form extreme compound shaped parts into the desired shape.
Roll Mold	A Roll Mold is a fixture used to check and form parts that are rolled to angles other than 360, 90, and 180 degrees
Girth Table	Girth Information is used to check the geometric accuracy of shaped parts by comparing the manufactured part to girth length values

In the ISPE data model, ***Penetrations*** are defined as "a cutout to facilitate penetration by an electrical, HVAC, or structural member". Penetrations carry an extra configuration management burden due to the mass change propagation that is caused by distributive system modifications. A single penetration definition is applied many times throughout a ship. For this reason, the ISPE data model will reference reusable penetration objects, apply them, and update the database state accordingly. The ISPE database will also ingest and export explicit STEP definitions of penetration objects when necessary.

Part ***Edge Treatments and Weld*** entities complete the data model discussion. Edge Treatments are bevels, special end-cuts, chamfers, fit-up (removed material), stock (added material for weld shrinkage), and other types of treatments that are applied to part edges. Weld entities are the various weld specifications that are used to join parts.

The STEP AP218 standard has attributes for a comprehensive set of Edge Treatments and Welds. The ISPE database will use these definitions to the extent practical.

Representation and use of Edge Treatments and Welds is yard specific, and shop specific within a yard. During Phase 0, the ISPE team has collected taxonomy and schema information regarding the rule based application of these entities. During ISPE Phases 1 and 2, a Manufacturing Rule Knowledge Base will be developed and used to apply yard specific Edge Treatments and Welds from the standard ISPE definitions.

3.4 Preliminary Mapping of STEP Application Protocols to the ISPE Data Requirements

3.4.1 Background

The STEP application protocols are organized into a series of units of functionality (UoF). Each UoF defines a collection of closely related STEP entities. The subset of UoFs for AP218 that are particularly applicable to the ISPE are listed below:

- Hull Applicability
  Hull Applicability for an item or definition refers to the hull number to which it applies.
- Product Structures
  The Product Structures UoF describes the product structures of a ship from different points of view. Assembly, System, and Part (among others) are all entities contained within this UoF. Each may be associated with a number of other structural items.
- Ship Manufacturing Definitions
  Ship Manufacturing Definitions specify design modifications that are required for manufacturing/assembly purposes. These modifications include the addition of stock to account for weld shrinkage, edge preparations, marking lines, etc.
- Ship Material Properties

The Ship Material Properties UoF describes the materials used for building a ship structure or structural parts.

- Structural Features
  The Structural Features UoF specifies the definition of part features such as cutouts, bevels and chamfers.
- Structural *Parts*
  The Structural Parts UoF specifies abstract specializations of ship parts. Examples of structural parts include profiles and plates. A structural part may be included in different product structures such as assemblies and higher-level units. A framework for defining various interrelationships among separate structural parts is also included.
- Welds
  The Welds UoF contains information weld types and application.

STEP AP218 has a structure for defining design and manufacturing data separately. The design definition hierarchy has constructs for describing the ship structural entities completed as part of Detailed Design; it is the 'neat' representation of the ship. The manufacturing definition has additional features for specifying *Manufacturing Product Model* and *Lofting* information.

3.4.2 Comparison of STEP to ISPE Build Tree Data Requirements

STEP AP218 "Ship" and "Assembly" entities can be used to represent most of the ISPE Build Tree entities (see Figure 7,). The "preconstructed_group", "preconstructed_section", "preconstructed_panels", and "unit_assembly" structures also map to the ISPE Build Tree Data.

Currently, STEP AP 218 can be used to represent some but not all of the ISPE Build Tree attributes (Table 2); a bulleted comparison summary follows.

- STEP "version_ID" and "version_description" can satisfy ISPE Configuration Management
- STEP "assembly_manufacturing_definition" can represent the ISPE physical description data
- STEP "production_date" appears to be the only AP 218 assembly scheduling attribute
- STEP "assembly_stage" appears to be the only AP 218 assembly routing attribute
- STEP "definition" can be used for hull applicability
- "document_reference" can be used for drawing number references

3.4.3 Comparison of STEP AP 218 to ISPE Component Data Requirements

The STEP "structural_part_functional_definition" and "structural_system_functional_definition" can be used to represent many of the ISPE Design and Manufacturable Component types (Decks, Bulkheads, etc.; see Table 4) The AP218 user_defined_function" can be used to fill in the gaps.

The ISPE Component attribute requirements (Table 3) map to STEP AP218 as follows:

- Configuration management requirements for ID, version, and hull applicability can be satisfied by STEP.
- The STEP "co_ordinate_system" structure is adequate to resolve location of ISPE Components within the ship.
- Scheduling and Routing requirements are not covered by STEP AP 218, there is a plan to include this information in future versions of STEP AP 238.
- STEP does not currently have a direct way to represent logical manufacturing data such as material characteristics, strength requirements, and information about adjacent parts. STEP does address most of these attributes at the Part level (discussed later in section 3.4.3.1).
- STEP does not currently have an explicit way to represent manufacturing data such as added material, and edge treatments. STEP does address most of these attributes at the Part level, which is discussed in section 3.4.3.1.

3.4.3.1 Comparison of STEP to ISPE Part Data Requirements

Figure 9 shows the ISPE part relationship requirements. STEP AP 218 can represent all the explicit part relationships except process and routing.

Table 6 shows the ISPE part attribute requirements by Description, Quantity, Configuration Management, Scheduling, General, and Manufacturing Feature categories. STEP AP218 comparisons for these attribute categories follow.

Description:
All the ISPE part attributes under the description heading can be represented by STEP AP 218 except those describing the part min and max extents, area, and center of gravity.

Quantity:
Apparently, STEP AP 218 has no explicit method for representing the required quantity for a part, or the nested quantity of a part. These quantity attributes are included in the ISPE data model for planning, scheduling, and status purposes.

Configuration Management:
STEP AP218 addresses the ISPE requirements for part identification, versioning, and hull applicability.

Scheduling:
AP 218 does not address part scheduling, although there are plans to address scheduling issues in STEP AP 238. Currently the yards do not schedule to the part level; however, the ISPE data model includes scheduling attributes for parts in case a future need arises.

General:
STEP AP 218 has not clearly defined a method to represent part attributes such as programmer, job, sketch number, and engineering remarks.

Manufacturing Features:
STEP AP 218 has a comprehensive structure for defining bevels and welds. All other ISPE manufacturing features (e.g. added material, see Table 6) can be represented except removed material. Functionality for the manufacturing features (e.g. welding access) can be annotated using the AP 218 “functionality” attribute. There is a needed AP218 refinement, from an ISPE requirements perspective, regarding how edge treatments and other manufacturing features are specified. The ISPE requires edge-by-edge specification of edge treatments whereas AP 218 currently specifies edge treatments for an entire part.

The STEP “composite_ feature” can be used for ISPE attributes such as long_point_geometry that mandate both adding material to a design part followed by subsequent beveling to make the part flush with an intersecting surface.

3.4.3.2 Comparison of STEP to ISPE: Marking Line and Label, Nest Tape, Manufacturing Aid, and Penetration Data Requirements

Section 3.3.4 contains ISPE data requirements for part marking lines and labels, nest tapes, manufacturing aids, and penetrations. Comparison of these requirements to STEP follows.

Marking Lines and Labels:
The ISPE marking line and label entities require more context than is currently provide in STEP AP 218. In STEP AP218, marking lines and labels are represented as geometric curves on parts with no description or type.

Nest Tapes:
Although AP218 does not address Nest Tapes, STEP AP238 (which was originally developed for milling) is currently being augmented to provide standard Nest Tape data. The AP238 geometry should be adequate for plate nesting; however, plate specific features, production information, and material data needs to be added.

Manufacturing Aids:
Only the inverse curve manufacturing aid can be represented using STEP AP 218.

Penetrations:
AP 218 has a robust set of parametric attributes that can be used to define penetrations. Currently the STEP AP 218 “interior_cutout_design_definition” appears to meet the ISPE penetration data representation requirements.

4. ISPE Concept of Operations

4.1 Purpose

This section describes the vision of the ISPE and supporting rationale for its main components. Our intent is to highlight the requirements that have been deemed important for an ISPE and to outline a technical approach that we will pursue in follow-on phases. In the first section, we provide a mapping from the derived common process model to the proposed architecture. In the second section, various components of the architecture are described and arranged to show the progression of a sample sub-assembly as manufacturing and lofting processes and data are applied. Finally, several use cases are presented to illustrate how the ISPE will be employed to handle representative, real-world scenarios.

4.2 Methods

The concepts proposed by the team to be incorporated into the ISPE were derived from multiple sources, including domain expertise from each of the project's team members, current design and lofting systems in use, and the functional and data requirements from each of the candidate yards as noted in the previous sections. A parallel effort of evolving the ISPE architecture helped demonstrate how existing software tools can be integrated to support the needs of various lofting and manufacturing requirements. Finally, multiple reviews were held with various experts in the field to help shape and validate the direction of the project and its design.

4.2.1 Mapping to the Common Process Requirements

To provide a context for the ISPE ConOps, three high-level *Common Process Areas* were established and mapped to the derived common process (see Figure 10).

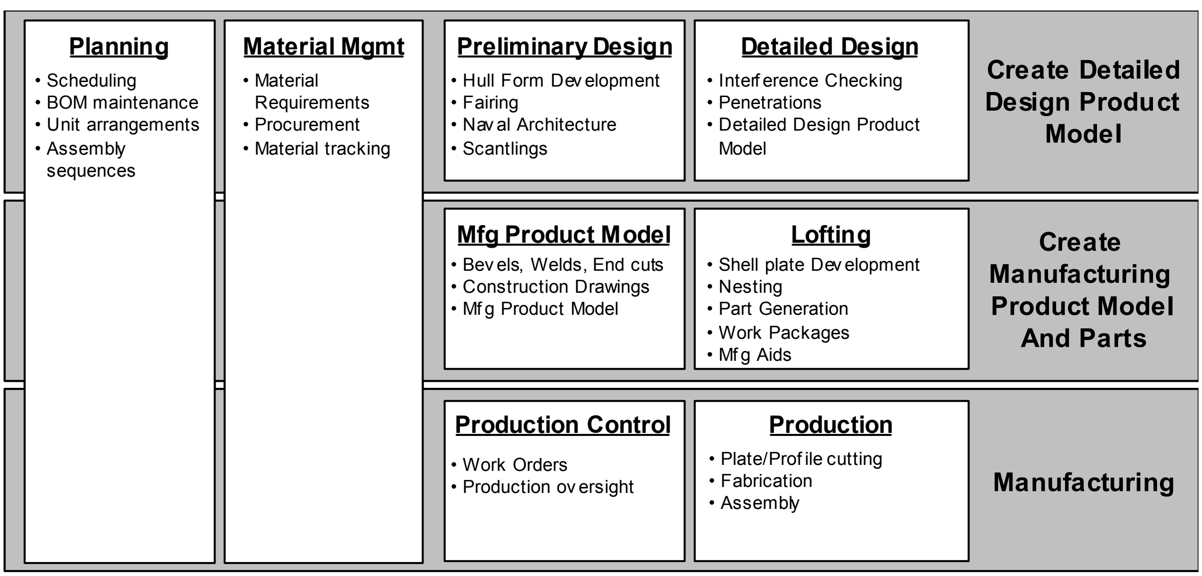


Figure 10 - ISPE Common Process Areas

Create Detailed Design Product Model refers to all of the work within the shipbuilding lifecycle through the generation of the detailed design product model. The detailed design product model, or '*neat*' design model refers to the complete ship design, captured electronically in CAD models, including the definition of all assemblies and units. The steel parts of the hull have been sized and the material specifications have been identified.

Create Manufacturing Product Model and Parts refers to all processing required to produce fabrication packages for manufacturing. This involves modifying the design parts that were defined within *Detailed Design* to account for the needs of manufacturing. This includes:

- Adding material to account for weld shrinkage, forming processes, or unit boundaries
- Defining the flattened boundaries for curved plating
- Defining all edge preparations for plates and profile parts
- Identifying the weld specifications for each welded part boundary
- Generating manufacturing aid drawings and related data
- Generate part definitions with required marking and sketches
- Nesting parts for NC cutting
- Generating macros for robotic machinery
- Generating fabrication packages to be sent to the production floor

Manufacturing refers to the cutting, fabrication, and assembly of steel parts to construct the ship, including management and problem resolution between the shops and engineering. Planning and Material Management are assumed to span all three common process areas.

4.2.2 Mapping to the Common Data Model

An ISPE Common Data Model was created using the steel processing data architecture requirements gathered from each participating yard. This Common Data Model contributed to the information base used for developing the ISPE ConOps. Section 3 is a detailed discussion of the data model. The high level common data categories from Section 3 are re-iterated in Figure 11 below.

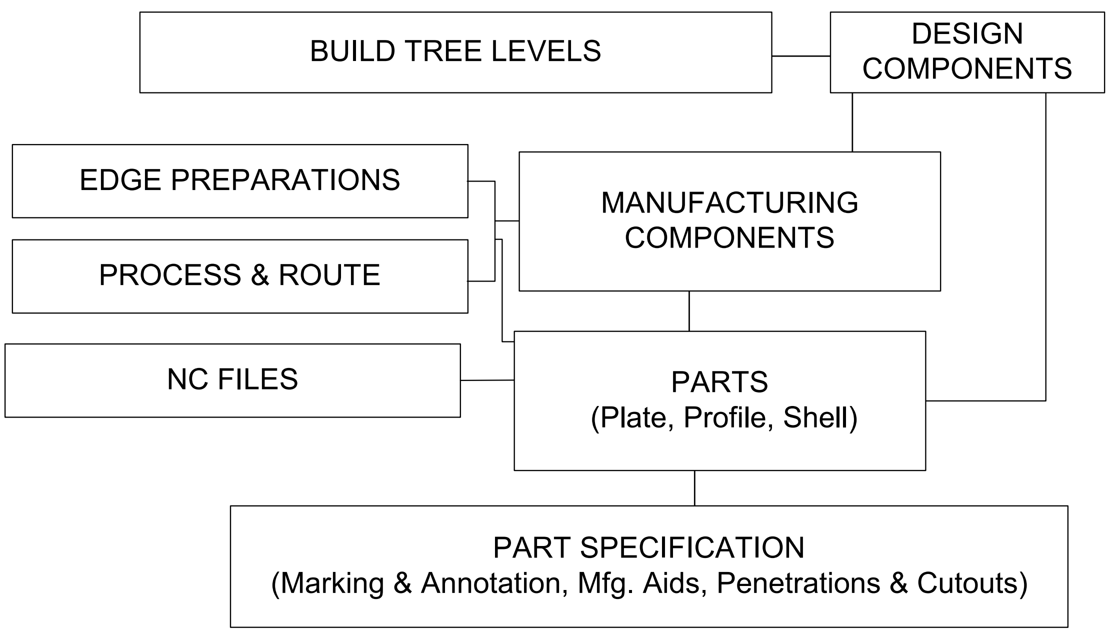


Figure 11 Common Data Architecture Categories

The primary ISPE method for exchanging design and manufacturing design data will be STEP AP218 (Ship Structures). STEP AP218 defines the context, scope, and information requirements for the exchange of ship structural data. The AP218 standard was chosen for its emerging influence in the shipbuilding environment, its suitability as an archival medium, and because it already accommodates many of the ISPE data requirements. Section 3.4 discusses STEP AP 218 with respect to ISPE data requirements.

STEP AP216 and 238 will be incorporated as well to capture basic design definitions and shop-floor data (schedule, routing, tool path) respectively. STEP AP216 provides standard design representations for molded forms such as the hull, bulkheads, decks, longitudinals, transverses, girders, and floors. STEP AP 238 (STEP-NC) extends STEP so that it can be used to define data for numeric control machines. AP 238 was originally developed for milling and is currently being augmented to accommodate information needed for plate nesting and cutting.

Usage Guides for creating valid ISPE STEP AP 218, 216, and 238 files will be developed during Phase 1 and 2 of the ISPE project. Data validation, at the ISPE Interface, will involve programmatic checking and viewing of the data for both content and tolerance. The re-usability provided by the ISPE interface will allow for improvement of the information exchanges over time.

4.3 The ISPE Concept of Operations (ConOps)

The heart of the ISPE will be a set of software components and defined procedures for creating manufacturing product models and lofting artifacts such as 2D part drawings, manufacturing aids, nesting data, and robotic data. A separate knowledge base will contain rules specific to a yard and/or shop. These rules will be used with the design data to generate a manufacturing model that is tailored to the needs/requirements of its intended production area. The rules knowledge base will be maintained separate from the application software to enable scalability and to facilitate modifications.

Using STEP Application Protocols (APs) as a medium for exchanging data provides a layer of abstraction between the CAD design systems and CAM manufacturing systems. It also enables ISPE integration with existing enterprise environments.

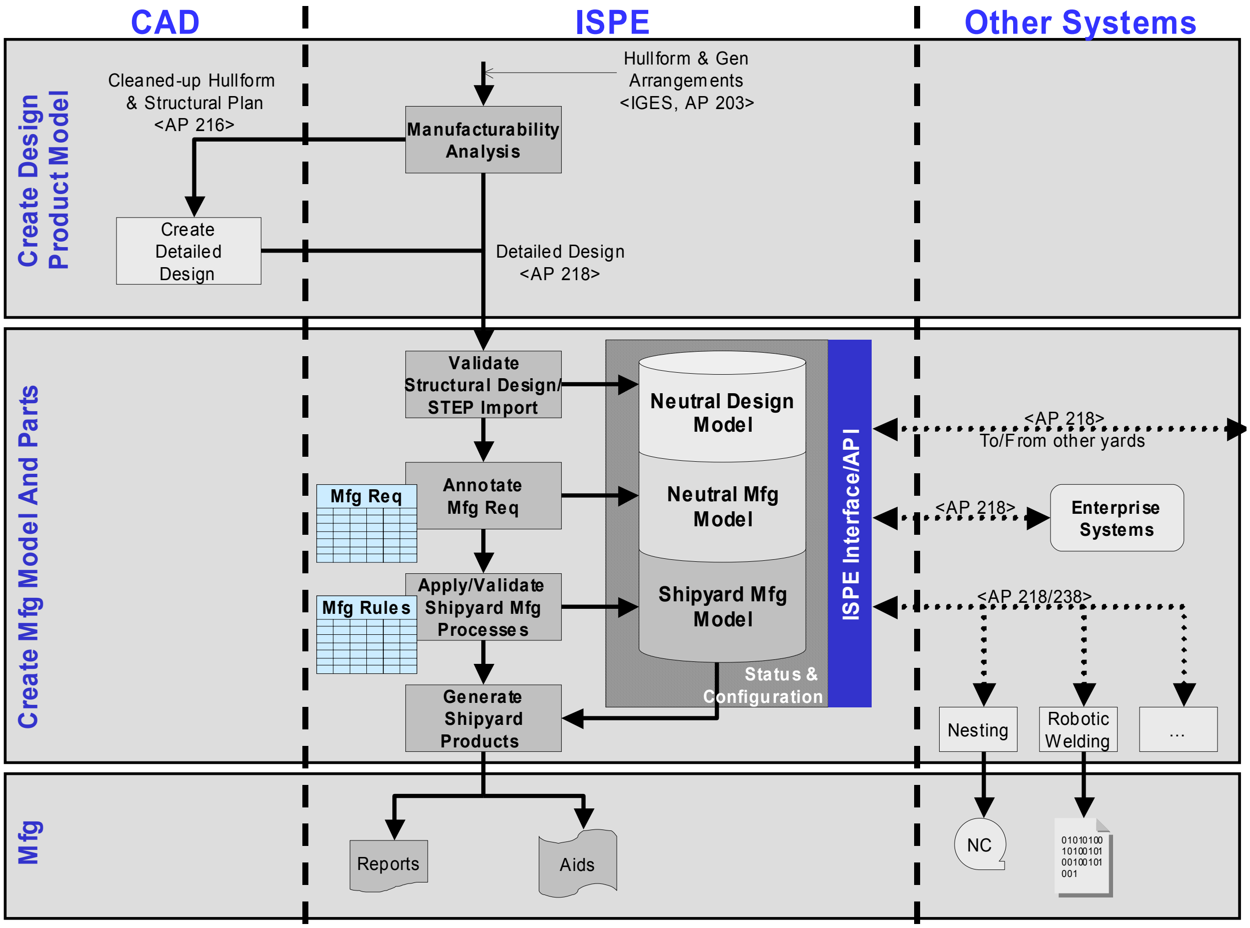


Figure 12 - ISPE Architecture

Figure 12 will be used to describe the components and use of the ISPE architecture. The diagram is a high-level depiction of a shipbuilding lifecycle from design through manufacturing (all dark shaded *functions/boxes* are described later in this section). In Figure 12, *Manufacturability Analysis* is applied prior to generating the Detailed Design. Detailed Design ('neat') data is exported from CAD systems via STEP AP218. The detailed design is validated with respect to content and structure, and is checked against the cleaned-up hullform and structural plan as generated from the *Manufacturability Analysis* process (see 4.3.2 Validate Structural Design/STEP Import) to produce the neutral design model. *Annotating the Manufacturing Requirements* involves the creation of a neutral manufacturing model as a framework for applying manufacturing rules. *Applying Shipyard Manufacturing processes* builds the shipyard-specific manufacturing model through an automated process of applying shipyard-specific manufacturing rules. Various production products including nest tapes, reports, and manufacturing aids are created in *Create Shipyard Products*. The ISPE repository maintains the manufacturing product model, including a means of tracking item version and status. Finally, ISPE contains an interface for extracting and adding data at the user and application level.

The following sections describe the generation of a shipyard-specific manufacturing model along with functionality that uses this data to produce production documents. To demonstrate this process, the lifecycle of a simple, fictitious panel sub-assembly is presented. The sub-assembly progresses from input as design data to the generation of a neutral manufacturing model, lofting functions are used to create a shipyard-specific manufacturing model, and finally, shop drawings and CAM data required for a specific production shop are created.

Throughout this discussion it is important to note that the process of specifying manufacturing information, with the ISPE, is cumulative; manufacturing-related data is added to the design model to provide the additional information required for manufacturing. Thus, the data maintained by the ISPE will grow as the lifecycle progresses, leaving the initial design data and intent unchanged.

4.3.1 Manufacturability Analysis

ISPE will provide manufacturability analysis functionality prior to and in conjunction with the Detailed Structural Design phase of the common process. The purpose of manufacturability analysis is to:

- Perform cleanup and final surface refinements to avoid manufacturing problems downstream
- Evaluate shell plate forming requirements
- Provide a reference to verify the accuracy of the exported detailed design

The design engineer evaluates the faired hullform for manufacturing readiness, including detailed cleanup, surfacing strategy for manufacturability, and preliminary shell plate layout. During this process ISPE provides tools to support offset or surface model entry, surface creation and analysis (e.g., Gaussian curvature), and comparison of alternative surfaces. Curvature analyses are applied to hull plates and verified against the capabilities of a given shop. Strain on compound plates is analyzed to determine the amount of work required to form the plates and assess alternative plate straking approaches. The result is a cleaned-up hullform and structural plan defined using STEP AP216. The hullform and major structural element geometry generated here is later used as a baseline to compare against the exported Detailed Design (refer to 4.3.2 Validate Structural Design/STEP Import).

4.3.2 Validate Structural Design/STEP Import

When exporting STEP from a COTS package, such as a CAD product, there is a need to validate the resulting data. This is based on the following observations:

- STEP Application Protocols often specify a number of Conformance Classes[4]; STEP export capabilities may choose which subset to support
- COTS STEP export capabilities often produce files that do not strictly adhere to the STEP standard
- Export may approximate CAD geometric entities such that tolerances required for ship manufacturing are not achieved.

Therefore, the ISPE architecture includes a two-phase validation of STEP exports before ingesting the exported data into the ISPE database.

The first phase validates that the (potentially) approximated geometric entities contained within the STEP file are accurate within a given tolerance. This validation will be accomplished through an automated comparison of the exported geometry with geometry resulting from the *Manufacturability Analysis* process of the ISPE. While the geometry being validated will likely be a subset of the complete geometry in the exported STEP file, this validation will provide some level of confidence that the exported geometry is sufficiently accurate for manufacturing.

The second phase validates that the exported STEP file conforms to the Conformance Class and determines additional information necessary to create an ISPE neutral manufacturing model. Should the Conformance Class be one that does not provide all of the needed information, the user will be informed and given the option, where reasonable, to provide the additional information needed to create a neutral manufacturing model. This validation phase also ensures that the STEP file adheres to the standard, modifying the file where necessary or notifying the user if noncompliance cannot be repaired automatically.

[4] A Conformance Class categorizes the set of STEP entities that a software package's STEP capability supports. For STEP AP218, there are 15 Conformance Classes, which are grouped by the lifecycle stage of the data (preliminary design, detailed design, manufacturing).

4.3.3 ISPE Repository

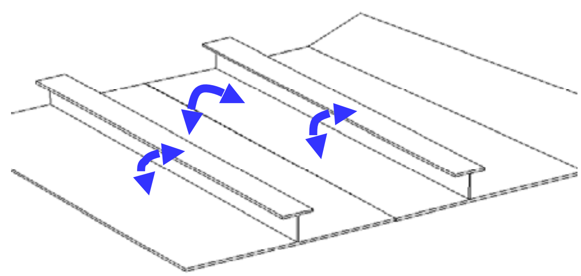
The ISPE repository will house all of the ship's data related to the design and manufacturing product model, including the neutral and yard-specific representations, configuration management and status data, and any data generated throughout the manufacturing engineering and lofting processes. The format of the information will be determined in follow-on phases but will be compatible the shipyard steel processing requirements. User and programmatic interfaces will be provided as part of the ISPE interface (section 4.3.7) to allow for import and export of STEP data to/from external CAD, CAM, and MRP systems.

4.3.4 Annotate Manufacturing Requirements

Identifying the manufacturing requirements ultimately results in the definition of a *neutral manufacturing model*. A neutral manufacturing model will be used together with a yard's/shop's manufacturing rule base to produce a manufacturing model that is tailored to the requirements of a target yard/shop. The format and generic structure of the neutral manufacturing model make it an ideal medium for the exchange of work packages either internal or external to a lead yard. After STEP data is input into the ISPE and validated for conformance, additional steps must be taken in order to 'prime' the design data for the process of automating the creation of manufacturing data. A couple of these steps are identified in the following sub sections.

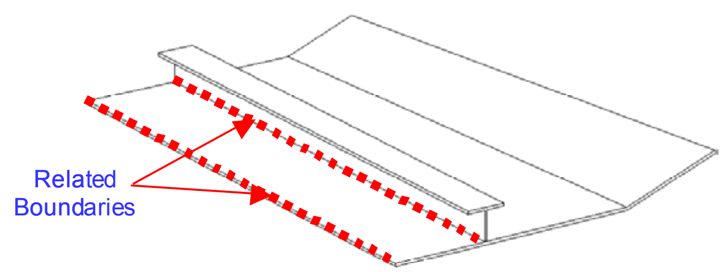
4.3.4.1 Identify/Verify Part Relationships, Material Information

As mentioned previously, associations must be established between parts in order for the ISPE to ascertain the hierarchy and interrelationships among the structural entities. At a minimum, relationships must be created between all parts that are connected. In addition, material information must be identified for all parts. Relationship and material information that exists within the input data can be validated if necessary. Otherwise, the capability to generate new relationships will be provided.



4.3.4.2 Identify/Derive relationship boundaries

Once the relationships between the parts have been established, the shared boundary between each part is determined through automated or semi-automated means. Identifying relationship boundaries will help the process of automating the lofting functions. For example, the shared boundary relationship between a stiffener and a plate can be used to locate a marking line or identify a path for a robotic welder; a shared boundary between two plates can locate an edge for a specific bevel or chamfer, or determine an edge for adding/removing material.



4.3.5 Apply/Validate Shipyard Manufacturing Requirements

The contents of a manufacturing model, for a shipyard, differ from the neutral representation in that the requirements of a specific shop are accounted for. The neutral manufacturing model provides a framework for applying manufacturing data, while the shipyard manufacturing model contains the complete representation of manufacturing data adhering to the requirements specified in the manufacturing rules. The ISPE will define a structure for describing manufacturing rules along with supporting functionality to maintain and use them to produce manufacturing design products.

4.3.5.1 Manufacturing rules

Manufacturing rules are established and maintained by a yard's engineering/lofting group to reflect the needs/capabilities of its production facilities. Specifying a rule set independent of automated lofting software has the following advantages:

- System maintenance and scalability is greatly increased since crucial knowledge of manufacturing processes and decision making is not embedded in the underlying software
- Provides a means of explicitly representing this knowledge, where it traditionally has been confined to the minds of a few domain experts

The ISPE will query the manufacturing rules to determine, for example, the proper bevel to use in joining two plates, the appropriate weld type and symbology, and/or specific manufacturing processes that a target shop requires. The manufacturing rules can also be used to suggest or specify process-related information for fabrication packages.

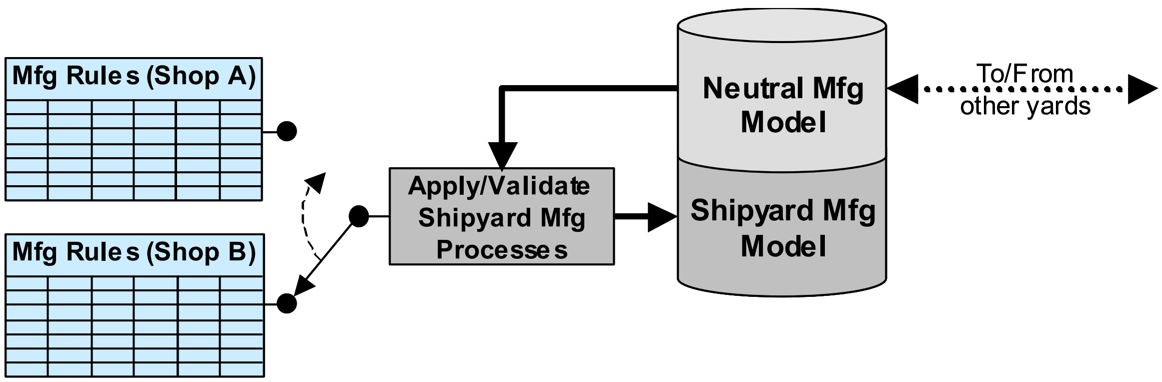
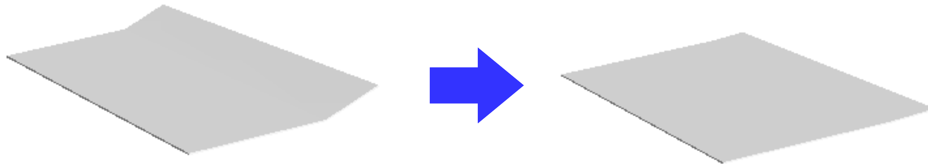


Figure 13 – Applying Manufacturing Rules

Using the neutral manufacturing model as a framework, the ISPE will allow separate manufacturing rule sets to be easily applied (see Figure 13). Lofting functions within the ISPE will base the creation of the shipyard products on the selected rule base. Target yards, in a work-sharing exchange scenario, can apply their own manufacturing rules based on their lofting and production requirements to the given manufacturing model to reduce, or eliminate, the need to retrofit the shared data.

4.3.5.2 Plate Development

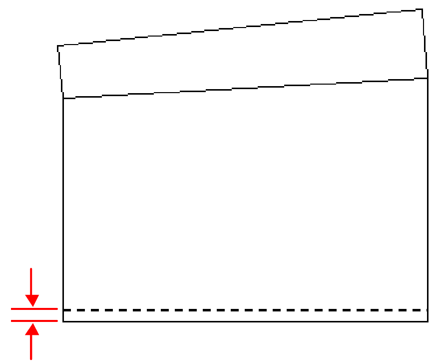
Plate development is the process of flattening the 3-dimensional model of formed steel plating to produce a 2-dimensional representation. Flattened, or unwrapped, plates require additional information to inform the production shop as to the means of forming the plate into its intended shape along with associated markings and annotations to guide the process. Also, separate manufacturing aids may need to be established in order to validate the finished shape.



The ISPE will integrate existing functionality to perform the unwrapping function and base the associated data and resulting processes on the selected manufacturing rule base. The result will be the generation of the 'flattened' geometry together with the specification of the processes required to form the plate. Included will be the appropriate annotations and markings to be applied to the plate to inform the production shop as to the means to fabricate the plate into its intended form.

4.3.5.3 Identify/Verify weld shrinkage allowance

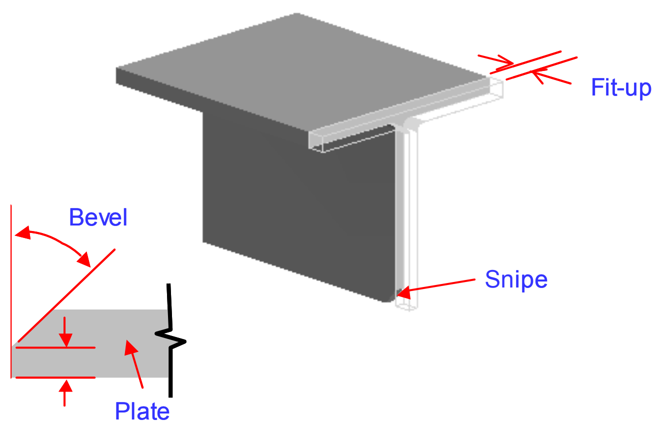
The ISPE will provide functionality for identifying the portions of part entities that need to be increased in size to account for shrinkage due to a specified weld. For example, plate parts normally account for weld shrinkage by extending the plate's design boundary area on one of more of its edges. Since the ISPE data regarding plate parts includes knowledge of the plate's boundary, it will be able to intelligently represent areas required for additional material. This process will be additive in nature so the original design geometry is left unchanged.



The ISPE will allow the integration of future functionality to integrate components that compute the required weld shrinkage allowances. The openness of the ISPE architecture will provide access to the information required to drive these functions and supply the data back into the data repository.

4.3.5.4 Identify/Verify edge preparations/end cuts

Edge preparations and end cut details for plate and profile parts are determined based on material type and size, strength requirements, and the relationship among adjoining parts. The ISPE will provide functionality for applying data within the manufacturing model (material information, part relationships, boundary definitions, etc.) to aid the process of specifying and capturing edge preparation and end cut details. Generated data can then be recalled for part generation to be included in 2-dimensional part sketches and other various working drawings.



4.3.6 Generate Shipyard products

The ISPE will include various utility functions to aid in the generation of fabrication packages for a target shop. These functions will either be integrated with existing products or built as part of ISPE development. In addition to planning-related data, fabrication packages may include nest tapes for NC cutting of plate parts, part sketches with detailed fabrication information for each part, assembly drawings, macros for robotic machinery, and data for jigs and molds to be used as manufacturing aids. This section describes these functions and how ISPE intends to provide this functionality to the user.

- **Part Generation**
  Part generation is the process of extracting individual piece part elements from the manufacturing product model to create 2-dimensional sketches with associated markings and annotations for use by the production floor. The part sketch includes (among others):
  - Ship's reference lines
  - Dimensions
  - Sketches to support additional operations
  - Reference lines for attached structure
  - Neat cut lines

- Weld shrinkage compensation factors
- Weld and edge preparations
- Tangent lines for rolled plates and profiles

Most of the information to be added to the sketch can be derived directly from the manufacturing model. Because of this, the ISPE will apply knowledge related to the manufacturing model to help streamline the task of producing part sketches by intelligently adding this information to generated 2-dimensional views of parts. For example, the location of stiffener marking lines can be derived based on the associated stiffeners. Also, the manufacturing rule base can be queried to determine the selection and placement of appropriate symbology and annotations for edge treatments and welds. The result will be a consistent representation of piece part data and application of shipyard fabrication processes. Viewing and modifications of the model will be accomplished using ISPE 2D and 3D geometry viewers.

- **Nesting/NC Programming**
  Nesting is the process of laying flat plate boundaries, including interior cutouts, onto stock material as a precursor to generating a nest tape file for an NC cutting machine. ISPE will integrate with existing COTS nesting products using STEP AP238 as an exchange format[5]. This integration will provide the capability to extract plate part boundaries from the data repository, nest them on raw stock material (either new or remnant plates), provide a means for manual modification of the nest, include any annotations/markings specified during part generation, and generate the appropriate NC data for the target machine. In addition, the capabilities of the target NC machine will be able to be specified to tailor the NC programming. Finally, the ability to create customized report will be incorporated as well.

- **Robotic Welding**
  Automating the creation of robotic welding control programs will increase the efficiency of robotic systems and greatly reduce the amount of manual intervention for macro generation. ISPE will employ existing research in the area of robotic welding to produce macros for offline programming using data related to part geometry, relationship and juxtaposition of connected parts, and material data maintained within the ISPE repository[6].

- **Manufacturing Aids**
  Manufacturing Aids are created to validate a formed part and assist the production worker in the process of steel fabrication. Examples of manufacturing aids include custom templates for checking the accuracy of shaped parts, built-up structure for temporarily supporting assemblies (e.g. pin jigs and roll molds). Custom molds require detailed design documents and associated instructions to inform the mold fabricator on the manufacturing process. Pin jig data consists of a table of individual heights at which to set a grid of individual steel support 'pins'. The data contained within the ISPE repository can be queried and used to automate the generation of various manufacturing aid products. For example, given the intended position that an assembly it to be placed during manufacture and a grid spacing, ISPE's knowledge of the underlying geometry can be used to generate the table of offset heights at which to set the pins for a pin jig.

4.3.7 ISPE Interface

The ISPE will provide a number of user and software interfaces to input design and manufacturing data, create manufacturing products, and export data to external systems and/or yards. The primary interface for exchanging data will be STEP shipbuilding application protocols (AP216/218/238). ISPE will provide the ability to view

[5] The intended Nesting product to be integrated is SigmaNEST, by SigmaTEK corporation – www.sigmaNEST.com
[6] Refer to NSRP ASE project - AUTOGEN

and modify 2/3-dimensional geometry and enter and edit data within the data repository. Additionally, an Applications Programmers Interface (API) will allow developers to extend ISPE functionality or provide a more seamless link between COTS systems.

4.3.7.1 API

Integrating external COTS and custom applications will be accomplished using exported STEP geometry and/or the ISPE API. Initially, ISPE will integrate with an external COTS Nesting application to satisfy the requirement for the nesting and NC programming functions, plate development functionality, and selected MRP systems. An API provides an interface for software developers to add custom functionality or to integrate existing systems. The ISPE project will provide sufficient API documentation and usage guides for describing and extending the delivered ISPE functionality. Such an interface can be used in future development to integrate with current or planned systems, to interoperate with ISPE algorithms, or to obtain access to the ISPE data repository. Since the software referenced by the API will be part of the delivered system, quality assurance and control procedures will have been completed as part of the system's development. The specifics of the interface will be determined in follow-on phases.

4.3.7.2 Extending Current COTS Systems

The ISPE project will explore the process of extending a selected set of COTS products, through use of vendor-supplied APIs, to provide a more efficient means of connecting with the ISPE. Vendors typically provide a method of customizing and extending their product with software interfaces that allow software developers the ability to interoperate with a system's kernel and enable access to the underlying data structures. Such an interface is useful when customization and/or additional functionality is required. The level that a system can be extended, however, depends on the 'openness' of the supported API. Since the ISPE will interoperate with a variety of existing CAD tools, each with differing levels of support for shipbuilding, an integrated set of ISPE functionality applied during the design phases, for example, would benefit the manufacturing product model definition. Also, having access to the internal structure of existing CAD systems may help in exchanging product information to and from the ISPE. The extent of this integration will be determined in follow-on phases.

4.4 Alternative Usage Scenarios

The following scenarios illustrate alternative ISPE applications to the operations concept described in section 4.3. The ISPE benefits described in Section 1.2, e.g. interoperability and automated lofting, are highlighted in the Scenario themes. Any steel processing CAD or CAM applications, from any yard or contractor, that can produce data in accordance with ISPE Usage Guides can be "plugged-in" to these ISPE scenarios.

4.4.1 Scenario: Subcontractor Builds Units or an Entire Hull to a Lead Yard's Specifications

In this scenario, work share is enabled by using the ISPE standards-based representation for data exchange. Low cost ISPE applications are used for viewing the exchanged data, adding lofting information, and generating manufacturing artifacts.

The scenario begins when a lead yard provides an ISPE compliant neutral design and manufacturing model to a follower yard or subcontractor. The information exchange is sufficient to enable the recipient yard to begin creating a manufacturing model without re-entering the lead yard's design information. Information is versioned by the ISPE interface; hence, incremental data exchanges are possible.

The receiving yard uses ISPE applications to view, configuration manage, and validate the content and structure of the information received. Then an ISPE application is used to add yard specific manufacturing model features and generate manufacturable parts. The ISPE neutral manufacturing model includes logical information to assist with lofting. This information includes:

- Material characteristics (type, thickness, grade)
- Attached/adjacent structural entities
- Relative thickness
  - Joining requirements
  - Relative material types
- Structural entity types
- Orientation
- Location and orientation within the ship
- Process requirements such as shaping
- Recommended assembly sequence

As the shipyard manufacturing model is completed, operators from the follower yard use appropriate ISPE applications to generate manufacturing artifacts such as nest tapes, NC files, and reports. The ISPE neutral manufacturing model is utilized for quality control of the as built unit or vessel.

The scenario ends when the shipyard artifacts are routed to production.

4.4.2 Scenario: A Lead Yard Out-Sources Lofting Functions

This scenario addresses a possible lofting workshare arrangement. For example, Ingalls currently performs lofting functions for Avondale on the LPD-17 project. ISPE will mitigate CAD/CAM cross-training requirements for such workshare by providing a single, CAD-neutral lofting environment.

The scenario begins when the lead yard provides a Neutral Design Product Model in ISPE STEP AP 218 format to a subcontractor who will perform lofting functions for the lead yard. The neutral design model includes logical information that makes the ISPE representation “manufacturing aware”. The ISPE interface checks, validates, and versions the [KR1]information.

The lofting subcontractor then uses ISPE to implement the *lead yard’s* processes and manufacturing rules during lofting operations. The ISPE lofting applications are used to create parts, annotate manufacturing requirements, and generate shipyard artifacts, i.e.:

- Manufacturable Components (e.g., plate parts for decks and frames), including:
  - Edge treatments
  - Weld shrinkage
  - Reference lines
  - Added and Removed material
- Shell Plate Development
- Other Plate Parts
- Manufacturing Aids
- Part Nests on Plates
- Post-processing
  - Nest tapes
  - Robot programs
  - Reports
  - Unit Development Manuals

The subcontractor extracts the developed Shipyard Specific Manufacturing Model from the ISPE repository in STEP AP 218 format. Post-processing artifacts are optional, and are provided in AP 238 (Nest Tapes and Robot Programs) and .rtf formats (Reports and Unit Development Manuals).

The use case ends when the subcontractor provides the Shipyard Manufacturing Model and post-processing artifacts to the Lead yard.

4.4.3 Scenario: Legacy Design is Ingested into ISPE

In this scenario, the objective is to transition existing design and manufacturing information into the ISPE system to enable active use and management of the information. The motivation for moving to IPSE is enable use of modern, supported 3-D modeling tools and the ISPE manufacturing data environment. Information may include: preliminary design data for the ship, i.e.: a faired hullform and other weather surfaces, general arrangements, and example mid-ship structural sections. For some legacy designs, a complete structural design may exist in paper, 2-D digital drawing form, or other non-standard electronic format.

The use case begins with the lead yard or its design agent reconstructing the detailed structural design of the ship from the available information. As described in the following paragraphs, the ISPE system provides a variety of support functionality to facilitate creation and evolution of the manufacturing model.

A designated Design Engineering Team member enters the faired hullform model into the ISPE *manufacturability analysis/structural planning* application. The Design Team member then evaluates the faired hullform for manufacturing readiness, including detailed cleanup, surfacing strategy for manufacturability, and preliminary shell plate layout. During this process ISPE provides tools to support offset or surface model entry, surface creation and analysis (e.g., Gaussian curvature), and comparison of alternative surfaces. The result of this process is surface models of the faired hullform and weather surfaces that have been evaluated and adjusted to ensure manufacturability.

A designated Design Engineering Team member reconstitutes the *structural plan* by entering the fundamental structural layout of the ship using the contract CAD system and the available general arrangements drawings. To facilitate reconstitution of the structural plan, ISPE will provide (via applicable STEP APs) a library of reusable structural components (e.g., transverse and longitudinal bulkheads, frames, decks, and doorways) and commodity parts (e.g., collar plates, brackets, gussets, and stiffeners). The Design Engineer can apply a component or part by accessing the components/commodity parts library and entering a few essential supports or parameters. As the structural plan is composed in the CAD system, ISPE creates the basis of the corresponding CAD-neutral manufacturing model using STEP AP 216, component-STEP, implicit modeling, and Plib techniques. The completed structural plan includes definition of unit/module and compartment boundaries, and surface models of major plate structural components, including: definition of seams and butts on the hullform shell, weather surfaces, and interior plate components.

In addition to defining the desired “as built” dimensions of the plate and profile parts, ISPE embeds knowledge of edge and end conditions of defined parts to support later process application (e.g., edge treatments). The completed structural plan is put under configuration management under the authority of the Model Discipline Manager.

A *preliminary interference check* and penetrations audit is performed on the structural plan.

Structural Detailing is assigned to Structural Designers by the Model Discipline Manager on a unit/module basis. ISPE supports the detailing process in the contract CAD system by providing a commodity parts library (implemented in STEP). As the CAD operators apply instances of commodity parts, ISPE composes a record of their use (i.e., type, location, orientation). Direct composition of geometry in detailing is tracked by ISPE and exported using the STEP export capabilities of the contract CAD system. As detailing proceeds the ISPE Neutral Design Model is updated. Once a unit/model is completed it is routed to the Model Discipline Manager for review and update of the configuration-controlled full-structural model and corresponding ISPE Neutral Design Model.

An *Intermediate Interference Check* is performed as unit/module detail designs are completed. The modules are checked against the distributive systems design to identify/resolve interferences and update/validate penetrations.

Shell Plate Development is performed using the available shell plate expansion capabilities of the contract CAD system, or the ISPE plate expansion application. The Loftsman extracts and reverse engineers curved shell plates into flat plate parts.

The *Yard-Neutral Manufacturing Model* is developed from data associated with individual parts extracted from the detailed structural model and the results of Plate Development. Plate parts edge-condition knowledge is embedded into their boundary representations to aid later application of yard-specific processes. Profile parts end-condition knowledge is embedded as appropriate to support application of yard-specific end-cuts/cutting processes.

The *Shipyard Manufacturing Model* is developed once the Yard-Neutral model is transferred to a building yard. Manufacturing engineers/loftsmen use the yard-local ISPE system to apply that yard's manufacturing rules and yard-specific processes to the parts and assembly definitions. The yard-local ISPE system provides viewing and data entry/editing tools to view parts and edge/end condition knowledge, query yard-specific knowledge bases for applicable rules and processes, and enter detailed process information.

Post Processing generates shipyard-specific artifacts. As driven by enterprise scheduling systems, ISPE adds enterprise management data to STEP AP 238 representation of nesting/profile cutting data as input to nesting or robot programming applications. The nesting/robot programming applications create NC programs and related drawings and reports for use in the yard. Manufacturing Engineers develop appropriate yard-specific manufacturing aids in accordance with prescribed assembly and quality control guidelines in the ISPE manufacturing model. ISPE will provide visualization and manufacturing aids knowledge base query tools.

4.4.4 Scenario: Late Breaking Planning Routing Changes Require Use of Alternate Yard Processes or External Yard Processes

In this scenario, the ISPE automated lofting capabilities are used to expedite change requirements that arise from re-routing steel work.

The scenario begins with a unit in production. Planning personnel have assigned routing to the parts and assemblies based on required processes and shop capabilities.

Planners are notified that the assigned shop cannot receive the Unit, possibly due to equipment or schedule issues. Planners wish to reroute the original Unit or assembly to another shop, or to another yard.

If the revised routing requires implementing an updated set of manufacturing rules, the manufacturing engineers retrieve the neutral manufacturing model for the unit, and apply the rules and constraints corresponding to the alternative shop or yard.

The scenario ends when the updated routing is forwarded to the alternative shop or yard.

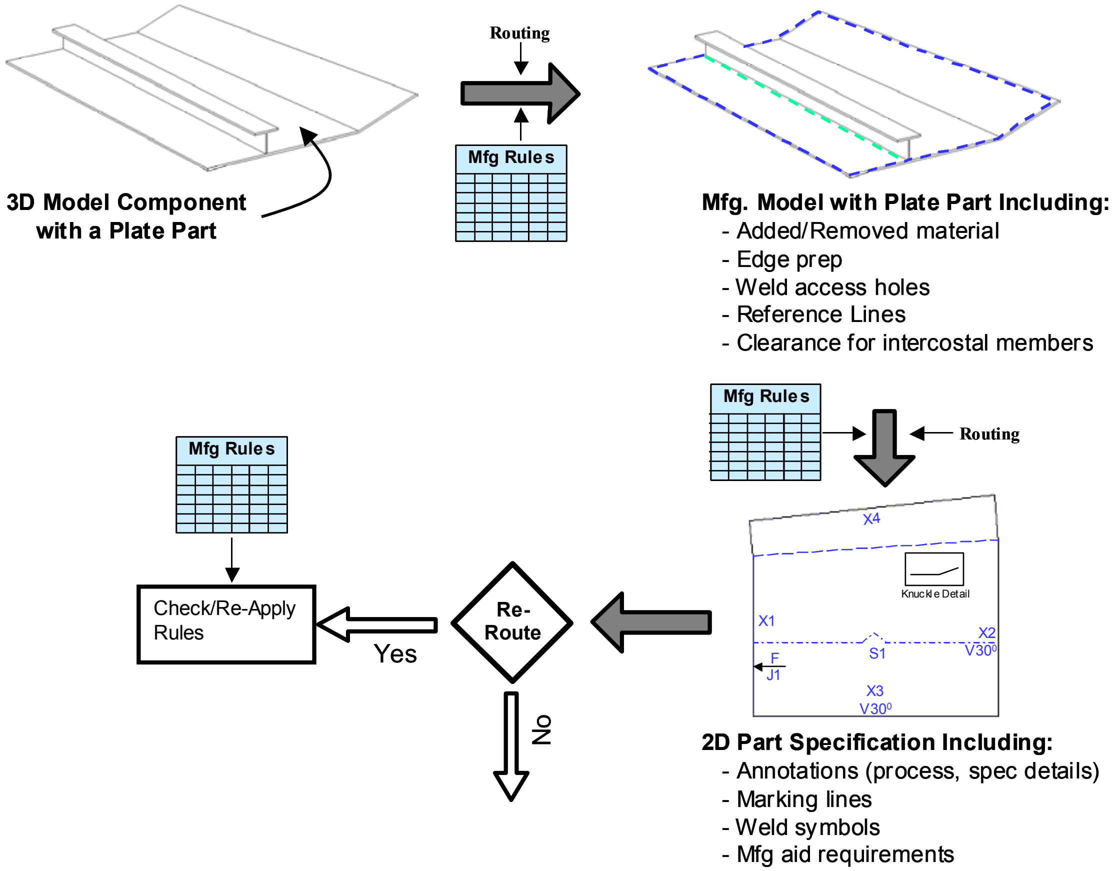


Figure 14 ISPE Process Flow For Addressing Routing Changes

5. ISPE Development Strategy

5.1 Overview

The development effort for the ISPE pilot will be separated into two phases, each with a 12-month duration. Allocating development work to multiple phases provides the opportunity to demonstrate the ISPE functionality earlier in the development lifecycle so feedback can be applied to follow-on work. The goal of phase 1 will be to produce a pilot system that will create an initial, end-to-end connection between Detailed Design and Manufacturing as well as developing the detailed requirements for the entire ISPE system. Phase 1 functionality will use the ISE TWR detailed design product model as input and provide tools to automate the creation of various yard-specific manufacturing data based on actual manufacturing processes and requirements. Phase 2 will expand upon the baseline created in phase 1 with the addition of more sophisticated manufacturing functions.

This section provides an overview of the proposed ISPE products, their interrelationships, and the phase in which each will be developed. The ISPE system can be described within the following, general areas:

- Ingesting data from CAD systems
- Manufacturability analysis
- ISPE repository
- Automated lofting
- Generation of CAM products

Refer to Figure 15 for a description of how each ISPE product is allocated within each phase.

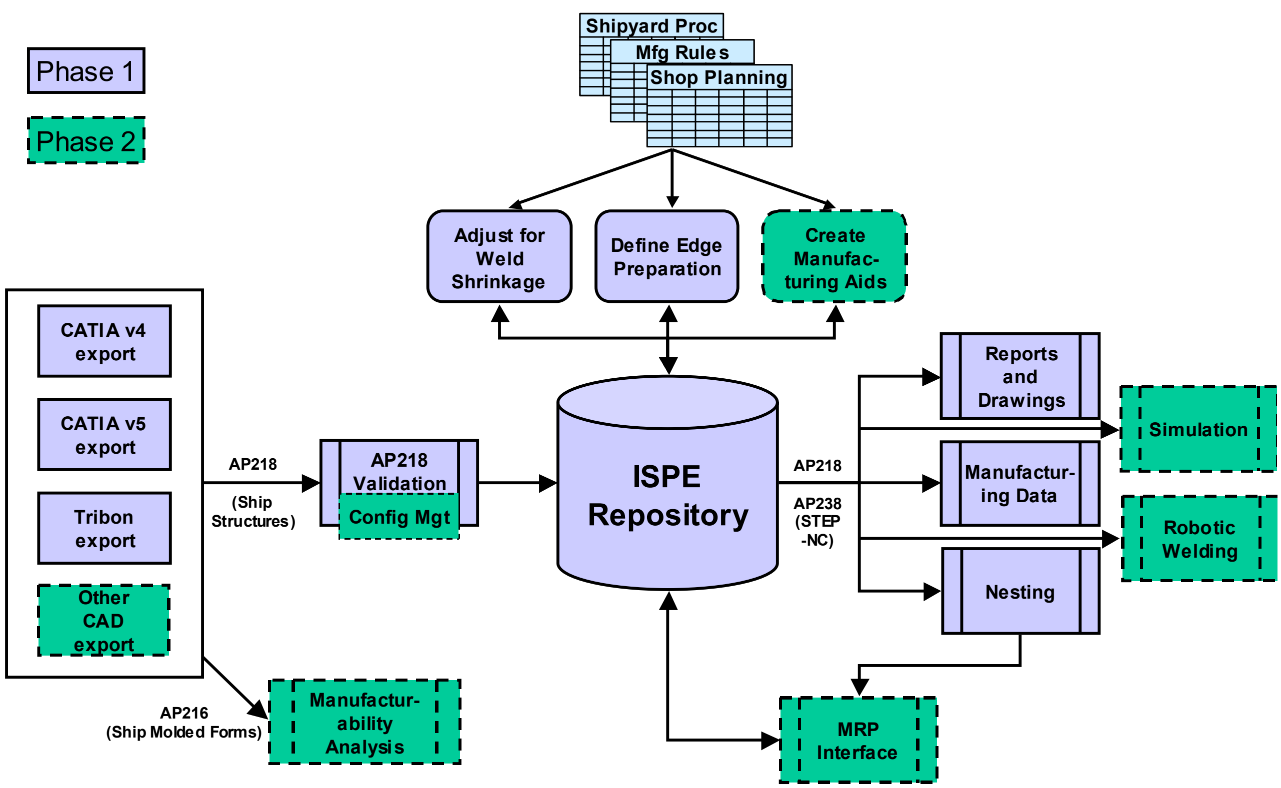
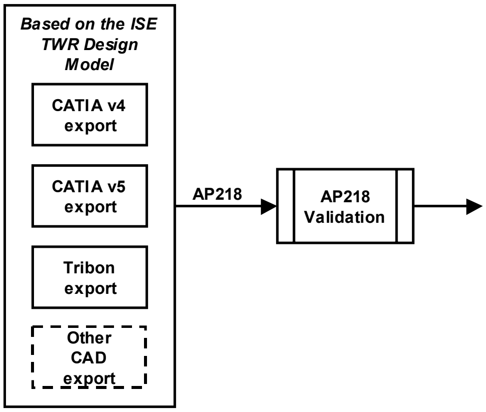


Figure 15: ISPE Products by Phase

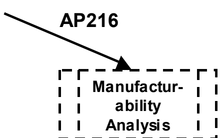
5.2 Ingesting Data From CAD Systems



The primary input into the ISPE will be the detailed design product model as generated from various CAD systems using STEP AP218 as the exchange medium. Accepting data from varied sources, even when based on an established standard, requires the need for validation for both structure and content. The rationale for this was explained in Section 4.3.2. The AP218 validation product will ensure that all data, that has been deemed necessary for the ISPE, exists and is in proper form. The capability will be provided to highlight discrepancies, either graphically or in report form, and provide a means for modification. In addition, this product will check the version of input design entities against an existing manufacturing product model to support configuration management. The ISPE team plans to work closely with the ISE team to resolve any issues concerning data format and content.

AP218 data validation will be included as part of the development of phase 1. A Configuration Management capability will be added in phase 2.

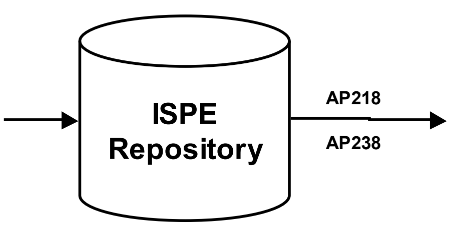
5.3 Manufacturability Analysis



Manufacturability analysis is applied prior to the generation of the detailed design product model to ensure that the ship's design, as provided by the hullform and general arrangements does not conflict with the processes and capabilities of the intended production area. It, in essence, raises manufacturability awareness into the design realm to avoid downstream issues with respect to manufacturing.

The manufacturing analysis product consists of a suite of tools that allow an operator to evaluate surface data, as ingested via STEP AP216, against the ISPE manufacturing rule base. Details of this function are included in Section 4.3.1. The functionality for this product will be defined based on phase 1 research and the TWR design data. However, executing this functionality requires an established manufacturing rule base and interface, which will be developed during phase 1. This product will therefore be piloted as part of phase 2.

5.4 ISPE Repository

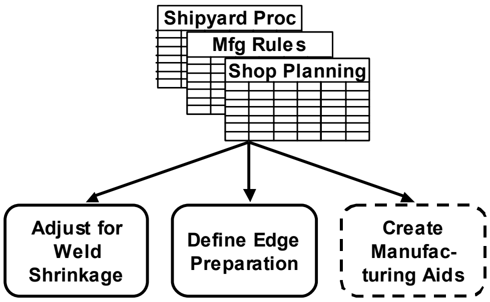


The ISPE data store represents the heart of the ISPE system. It is where the manufacturing product model, the manufacturing rule base, and other associated products generated by the ISPE are stored and maintained. The format of the data, its interface, and whether or not it will be hosted on an existing COTS database are yet to be determined.

Included in the development of the ISPE repository will be a set of STEP usage guides that detail the meaning of STEP data entities (as they are applied to the ISPE), the lifecycle of the data including where various entities and their content should be produced, and the format of the AP218 and AP238 exports. These usage guides will provide additional information on the format and structure of the ISPE data (beyond what is provided in the AP standard documents) and assist future ISPE integrators/developers in extending the system.

The ISPE repository will be designed and developed in phase 1, with continual additions and improvement as necessary in phase 2.

5.5 Automated Lofting



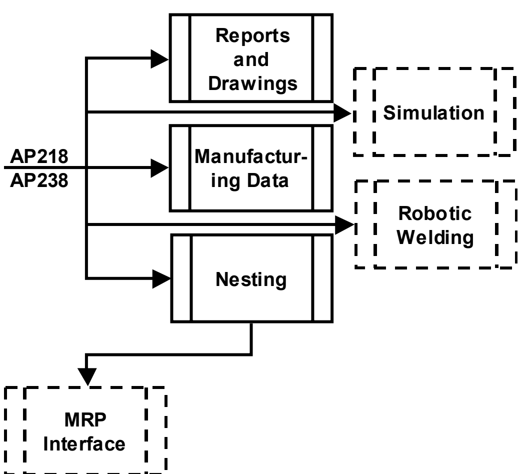
The ISPE team will develop a suite of products to be used in the automation of various lofting functions. A description and rationale for each are provided in Sections 4.3.4 & 4.3.5.

These products are all based on the content and interface to the manufacturing rule base which includes the capability of capturing a yard's/shop's processes, rules, and planning information. Developing this rule base will proceed after the formal definition of a sample set of manufacturing processes and rules for each shipyard. The gathered data will help drive the design and required interface. The requirements data collected as part of phase 0 will be extended to delve deeper into the detailed requirements of several candidate production shops to acquire a broad range of data to ensure that the rule base can accommodate various production needs.

In order to prove the concept and test the initial design of the manufacturing rule base, two specific lofting products will be created in phase 1: adjusting for weld shrinkage and edge preparation definition. These products will be used with the graphical geometry interface to allow a CAD operator to validate the processes performed on parts within the ISPE database based on the applied rule set. The adjustment for weld shrinkage will apply additional material to the plate boundaries based on the orientation and position of surrounding plates, attached stiffeners, and the manufacturing/welding processes performed on the plate. Edge preparation will specify the proper part edge treatments based on attached parts and other planned processes for the target shop including the weld position and processes, and joint fatigue requirements.

The ability to generate manufacturing aids will be added in phase 2. The manufacturing aids may be in the form of pin height tables for pin jigs to support one or more assemblies, design aids for creating templates and molds, girth tape length values for checking manufacturing accuracy, and annotations to be added to various parts.

5.6 Generation of CAM Products



The output of the ISPE ultimately results in fabrication work packages that get sent to the shop floor to be interpreted by production personnel and machinery. These include shop reports and drawings that detail the required production processes to be applied to parts and assemblies, nesting and NC data to drive the cutting machines, macros for programming robotic welders, and simulation data to aid in the planning process.

The reporting product will be based on the query interface to the ISPE repository and will allow a system administrator to generate custom reports that can be tailored to the needs of a target production shop. The ISPE will also be capable of printing 2D and 3D drawings that are composed using the geometry editor. Report and drawings functionality will be included as part of phase 1 and will be based on existing STEP geometry editors.

SigmaNEST will provide nesting functionality for the ISPE. Using AP238 as an exchange medium, data from within the ISPE repository will be extracted to SigmaNEST where nesting and NC data are generated. Existing reporting functionality from SigmaNEST will be exploited as well. The SigmaNEST interface will be developed in phase 1.

The ISPE will pilot the generation of macros that are used to run welding robots by incorporating the automated welding system (AutoGEN) coupled with the geometry and intelligence stored within the ISPE repository and manufacturing rule base. An interface will be developed to extract knowledge within the ISPE manufacturing product model regarding part geometry, the relationships and juxtaposition of attached parts, and welding requirements, to provide the required input to AutoGEN. This functionality will be designed in phase 1 and piloted in phase 2.

Finally, phase 2 will add simulation capability by incorporating a combination of existing software tools and new development to provide the ability to verify the build sequence by simulating fabrication steps. Planning data will be incorporated by means of the interface with MRP systems. Simulation requirements, candidate COTS tools for simulation and MRP, and the required interface to and from the ISPE will be explored as part of the detailed requirements gathering effort in phase 1.

6. Appendix

Common Process Model

ISPE Common Functions.xls
This spreadsheet was generated based on the comparison of yard process/function data received from each team yard as part of the Phase 0 requirements collection effort. The result is a description of each common function with associated input and output data.

There are two worksheets within the spreadsheet:

- *Common Input-Output* – Describes the input/output artifacts for each common function
- *Common Functions* – Maps the common function list, together with the common input/output artifacts, with the data received from a yard

Accessing the Common Process Model HTML Pages

All data regarding the derived common functions, including the common process model diagram, has been organized within a series of linked HTML pages. To access the main page, double click on the `default.htm` page within the `common html` directory[7] to launch the system's default browser. The web page displayed in the browser will contain three frames: a title/navigation frame at the top and two lower frames with a link to the common process diagram page (displayed in Figure 5).

[7] The `common html` sub-directory, along with other supporting documents, was delivered with this document within a `.zip` file. This directory will exist in the location where the contents of the `.zip` file were extracted.

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[KR1]Data should be validated as it is input making outgoing validation superfluous