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IPPD - The Concurrent Approach To Integrating Ship Design, Construction And Operation

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ABSTRACT

This concept of concurrent engineering is a philosophy widely accepted as the correct approach to considering all disciplines in the course of a design. The methods that are used to solicit and incorporate the input are not so widely accepted. Integrated Product and Process Development (IPPD) is a technique that has been successfully applied to the Engine Room Arrangement Modeling (ERAM) project.

The paper addresses the experience of the ERAM team, which is an element of the US Navy's Mid-Term Sealift Ship Technology Development Program and will focus on issues that may be experienced in a US shipyard environment when applying IPPD. The IPPD process will be discussed from two perspectives. First the team formation, training and operation will be addressed. The team issues include such elements as team formation, requirements for collocation, project pre-planning, team training, team member development, integration of new team members, maintaining team work including peer review, establishment of norms and consensus building. In general, issues differing from current practices will be addressed. Next, the application of the approach to ship design while considering cradle to grave costs will be addressed from a technical standpoint. The technical approach will provide a general outline of the steps followed in developing the engine room arrangement models, using the IPPD approach. This outline reflects both the initial development and the evolution over several engine room designs. The conclusion of the paper will define what steps the ERAM team recommends US shipbuilders should implement in adopting the IPPD process.

NOMENCLATURE

AutoCAD®

AutoCAD is a general purpose Computer-Aided Design/Drafting design package for computers.

COMPUTER AIDED DESIGN (CAD)

Computer aided design is the use of computers to aid system engineers and designers in the design of the end product.

COMPUTER AIDED DESIGN/COMPUTER AIDED MANUFACTURING (CAD/CAM)

The process of creating a direct link between the design developed on the computer to the machine manufacturing the product.

CONCURRENT ENGINEERING (CE)

Concurrent Engineering is a systematic approach to the integrated, concurrent design of products and their related processes, including manufacturing and support. This approach

drives the designers to consider all elements of the product life cycle from conception through eventual disposal. (1)

INTEGRATED PRODUCT AND PROCESS DEVELOPMENT (IPPD)

The Integrated Product/Process Development technique proposes using TEAM involvement and TEAM 'ownership' of the development process for a given product. Fundamental concepts underlying this technique include a strong emphasis on customer satisfaction compared to the more conventional approaches, and the use of multi-functional teams. The TEAM is guided by a Steering Committee composed of upper level management who are 'champions' of the project. (2)

STRATEGIC DESIGN METHOD (SDM)

The Strategic Design Method is based on the concept of IPPD, with the multi-functional members of a design team empowered to address the total business product strategy. Using SDM, a road map is developed to provide team members with a route through the Strategic Design Processes. A key element of SDM is that metrics are used to access the direction

the team is headed and adjust the focus of the team's activities as necessary. Although metrics would appear to be a simple process, the development and application will be one of the team's biggest challenges. (3)

QUALITY FUNCTIONAL DEPLOYMENT (QFD)

QFD is a tool for formulating strategic plans of action by consolidating the inputs of numerous participants. These participants, or stakeholders, should represent a broad variety of perspectives on the subject being planned, to assure that all viewpoints are considered. The tool provides a way to impose discipline on brainstorming sessions which can otherwise tend to lose direction and focus. (2)

INTRODUCTION

This paper describes the Integrated Product/Process Design (IPPD) processes developed by the Engine Room Arrangement Modeling (ERAM) Team under a project initiated by NAVSEA under the Midterm SEALIFT Program. The objective of the project was to identify a specific set of design processes, using IPPD technique, which would lead to cost and schedule improvements for engine room design and construction over traditional shipyard practices. The team was guided by a Steering Committee consisting of representatives from academia, three shipyards, two ship owners, a design agent and NAVSEA. Guidance was provided via the 'ERAM Requirements Document' which contained the following 'Vision Statement':

A customer-focused process that enables the U.S. shipbuilding industry to design and build engine rooms which promote internationally competitive commercial ships.

This vision statement was accompanied by seven (7) objectives.

1. Provide a forum for U. S. shipbuilders to present views and needs for product and process design.
2. Within 12 months develop a process for marine industry use to design internationally competitive commercial ships.
3. Within 24 months demonstrate the process by designing four (4) world class engine room arrangements.
4. Achieve customer-focus and buy-in of product design (4 Engine Room Arrangements).
5. Achieve U. S. shipbuilding industry-focus and buy-in of the design process.
6. Establish baseline commercial ship engine room designs for evaluation of future government initiated changes.
7. Document both the product and process design with rationale for use and future refinement by other users.

The initial set of design processes were identified during the design of a Sealift ship engine room fitted with a slow-speed diesel engine power plant. These processes were then applied to a medium-speed diesel and an additional slow speed diesel plant design, and were continuously improved as the project's participants gained more experience.

To arrive at the recommended design processes, a course of

action was set at the beginning of the project to identify baseline processes. Careful monitoring was continually performed to identify both positive and negative aspects of these baseline processes. Based on the lessons learned in executing each iteration, the processes were refined.

The lessons learned include lessons related to IPPD, SDM, and QFD techniques which were applied throughout this project. The resulting refinements were based on careful observation of which aspects were found to be effective, and which were found to be ineffective.

The IPPD processes are divided into six major topics:

- Team Selection
- Team Development
- Design Product Development
- Product Model Development
- Build Strategy Development
- Metrics Development

The design process described herein assumes that; the shipyard designers are relatively inexperienced in the design and arrangement of commercial ship engine rooms; available baseline or reference ships are out-dated, non-competitive or require extensive modification to suit current requirements; and few or no commercial standards are in place. As experience is gained and more suitable baseline ships become available, many of the recommended design process steps may be abbreviated or converted to shipyard standards which do not have to be redeveloped for each successive contract.

IPPD TEAM SELECTION AND DEVELOPMENT

This section provides a detailed description of the recommended approach for assembling and training an IPPD team. The start-up of any project requires a 'champion' to sell the project to company management. Once the project has been endorsed the following steps in selecting the team members are recommended.

Team Selection Process Development

The first and most important step is to establish a clear task definition, Figure 1, prior to team selection so that the team can be customized to the task. (4)

A well defined task is one with a clear vision statement, a clear set of objectives and a clearly defined set of strategies. These elements are essential to a project's success.

As a first step in clearly defining the task, the Quality Function Deployment (QFD) tool (Reference 2) should be utilized to identify the 8 or 10 top

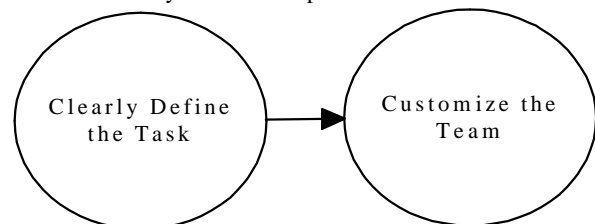


Figure 1. Customizing the Team to the Task

customer required characteristics for the product. These 8 or 10

characteristics should then be used to identify the skills required. See Figure 2 for the recommended procedure for identifying team member skill requirements. Other synergistic methods, such as, early customer involvement in determining customer requirements can also be used. It is strongly recommended that individual opinion approaches to identifying skill requirements be avoided.

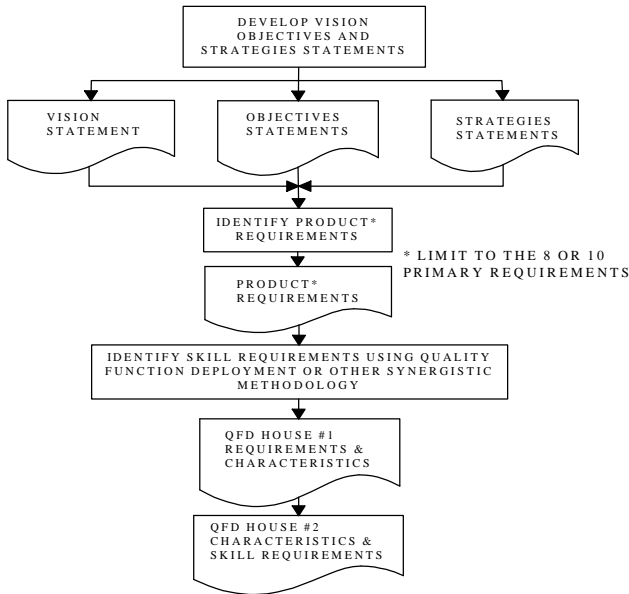


Figure 2. Identify Team Member Skills Process Flowchart

The selection of team members, in many ways, is similar to normal hiring procedures in that skill requirements vs. cost must be a factor. It is essential that the required skills to provide the characteristics identified in Figure 2 be provided. Hence, it may be necessary to acquire support sources other than those directly available sources within the company. Not all team members will be required full time. It is recommended that the core team/resource team concept be adopted. The part time resource team personnel should participate fully in the team training and development process. See Figure 3 for the recommended selection process.

The following is the recommended team composition for an engine room conceptual design team:

Core Team Permanently At Design Site

- Team Leader
- Design Engineers - 8
 1. Hull/Structural - 1
 2. Piping System - 3
 3. Machinery Engineer - 1
 4. Outfitting/HVAC/Arrangements - 1
 5. Electrical (Control & Monitoring) - 1
 6. Production (T & E/ Construction/Build Strategy) - 1
- Computer-aided Design Team Leader - 1*

Resource Team Permanently At Design Site

- Computer-aided Designers (Including Team Leader) - 8
- (One Designer skilled to support each

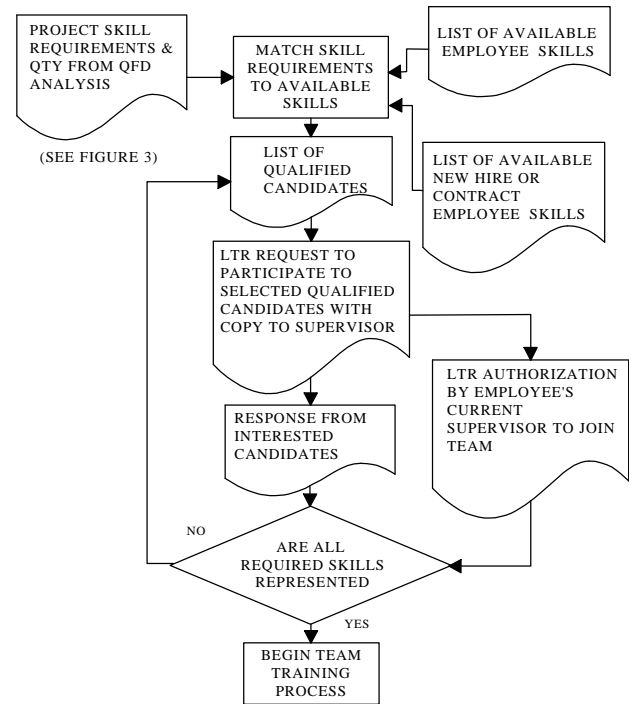


Figure 3. Team Selection Process Flowchart Design Engineer)

- Design Site Administrative Support - 1

Resource Team Periodically At Design Site (2 - 3 Weeks in Duration)

- Propulsion Equipment Vendor Applications Engineer - 1 (Diesel, Reduction Gear, and Propeller Representative as needed)
- Ship Owner/Operator Representative - 1

* This position may be eliminated if the Core team has sufficient computer knowledge.

Design Project Teambuilding/Training Program

A summary of the teambuilding approach is presented as Figure 4. The steps are further elaborated in the text following.

Step 1 - Design team developments should start with an orientation kick-off meeting which outlines the goals and objectives of the selected design team. These goals and

objectives of the selected design team. These goals and objectives should be developed by a Management team such as a Steering Committee. All goals and objectives should have the approval and buy-in of top management before they are presented to the design team. It is essential to have all goals and objectives developed before the training of the team begins, this promotes a better understanding of the overall project from the start.

Step 2 - Cross functional team training (5) should consist of the following:

- Preliminary Team Building Activity
- Skills and Techniques of a team Player
- Success Strategies for Cross-Functional Teams:
- Concerns and Questions Meeting the Steering Committee Outline
- Cross-Functional Team Simulation
- Review of Key Success Factors
- Developing Operating Agreements for Design Team
- Tools and Techniques for Effective Team Meetings
- Stages of Team Performance: Forming, Storming, Norming and Performing (2)
- Team Environment (Collocation)

Step 3 - Team meeting training should be provided to the entire design team which should include formal training in the following skills:

- Facilitation (controlling a meeting),
- Process Observation (reviewing the process followed and presenting positive and negative aspects of the meeting, referred to as plus and deltas) and
- Scribing (the art of taking notes on flip charts or view graphs).

Everyone on the team must understand the importance of these three factors in any meeting and be able to conduct themselves in a manner which will allow all three skills to be practiced most efficiently.

Step 4 - Practice working as a team by applying the training concepts in a team setting.. It is recommended that the core team be collocated adjacent to a large dedicated meeting room where information/development data can be posted for the team's constant review. Excellent resources for team related problem solving are references (6) and (7). It is recommended that references (8) through (15) be required reading for this step.

Step 5 - IPPD training should consist of the following.

- Team Management Practices
- Team Planning Session: Norms, Mission, Organization
- Communication Planning
- Team Planning Session: Communication Plan
- Customer Focus
- Team Planning Session: Customer Requirements
- Project Management for IPPD: Core Team and Support Ring
- Team Planning Session: Evaluation of Architecture

- Team Planning Session: Task Plan and Subteam Assignment
- Performance-Based Measurement (Metrics)
- Partnership Agreement, Next Steps Team Planning Session

At this point of team development it is imperative that the team develop a team dynamics measurement tool. This tool should be designed to help the team improve their performance in the areas that are considered important to the team development process. The focus of this tool is to build on successes and to identify and correct specific problems based on the team's norms.

Step 6 - Practice as a team by developing the following major subteams.

- Core Team
- Communication
- Team Agreements
- Training
- Resource Management
- Technology Management
- Vendor Furnished Information (VFI)

Step 7 - Strategic Design method training (4) must consist of the following.

- Why Concurrent Engineering Works
- Process-Based Design: A Concurrent Engineering Methodology

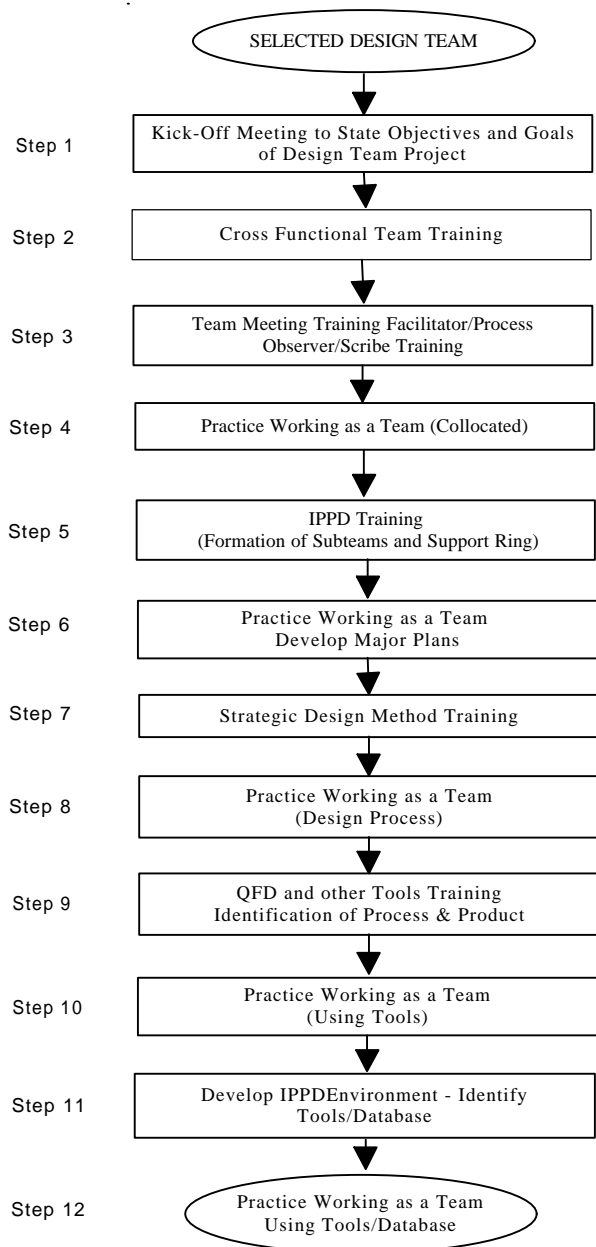


Figure 4. Teambuilding/Training Process Flowchart

- The Six Concurrent Engineering Skills
 - How to Analyze Product Requirements
 - How to Build A Winning Strategy
 - How to Create Competitive Designs
 - How to Rate Designs
 - How to Reduce Design Cycle Time
 - How to Build Team Success
- Best Practices of Winning Teams
- Case Studies

- The Teamwork Approach to Product Development
- Guidelines for Concurrent Product Development

All of the above are necessary skills the team must learn to successfully complete the concurrent engineering design process. This concurrent engineering process should bring the following to the team.

- Put Process and Product in Perspective
- Emphasis on Problem Seeking
- Excellent first step in design process
- Systematic approach to any design process

Step 8 - The team as a team, or several smaller teams, must practice the necessary skills on a small design project to gain experience in these methods. After several iterations of the Strategic Design road map; the design team should be able to develop a Strategic Design Brief in a three day period. First time development is best achieved with the assistance of a professional coach. (4) The intent of this Strategic Design Brief is to outline the design team's direction in developing the project, and gain management's (Steering Committee) buy-in.

Step 9 - The team must be trained in the use of design tools such as QFD. This tool is designed to focus on customer requirements, product and process characteristics and tasks. QFD is a fairly complicated process and should be taught by a qualified professional instructor.(5) This tool can be used to identify all process and product tasks needed to complete a detailed design process. The effort should focus on the critical points e.g. the team has to go deep into the build strategy and just superficially into sewage and drainage system concepts.

Step 10 - The team must practice using design tools. It is suggested the team develop QFD subteams to develop process and product houses. This exercise should produce a complete set of design tasks.

Step 11 - Establish a subteam, including computer support experts, to identify, implement, and support the computer applications required for all process and product activities for team members and external resources (Steering Committee, shipyards, owners, vendors etc.). The subteam must use advanced communication software between external resources to keep the record and maximize cooperation with external resources.

Step 12 - The computer applications subteam should develop "Computer Applications User's Guide" and a training program to allow the implementation without interruption of team member's daily project activities. An adequate amount of time must be provided for every team member to practice using these tools.

It is suggested that a professional IPPD/Concurrent Engineering coach be present with the team throughout the development of the team to give guidance and support in the development of individual teaming skills.

The team should devote as much time as possible to understanding the objectives of the training, especially team building. This will create a greater feeling of comfort with the IPPD process and tools.

The design team must understand that there is no "perfect ship", but just a full integration between shipbuilders and shipowners, which allows for sacrifice of some aspects to increase others, depending on priorities of both sides to reach an

agreement. Shipbuilders and shipowners should be partners, not rivals.

Pitfalls

The following pitfalls must be eliminated to have a successful team environment.

- Management expecting product output during the three to six month team development period.
- External management allowing team members to bring team problems outside the team for resolution.
- Not empowering the team to remove ineffective team members.

ENGINE ROOM DESIGN PRODUCT DEVELOPMENT

This section provides a description of the recommended approach for the design of an engine room.

Product QFD Development Process

This section is written assuming the reader has a basic knowledge of QFD, QFD houses, house rotation, and QFD house interaction scoring and weighting. See Reference (5) for detailed information on QFD.

By having a product sub-team composed of customers, operators, engineers, designers, production representatives who know how to use the QFD tool, a Product QFD House can be developed using the process described in Figure 5. Working groups for QFD houses should be no larger than eight and the participants should be committed to completing the task. Individuals should refrain from coming and going at will as continuity is not maintained. During this session the customer requirements are identified and prioritized by the customer and the characteristics of the product are identified by the customer and the

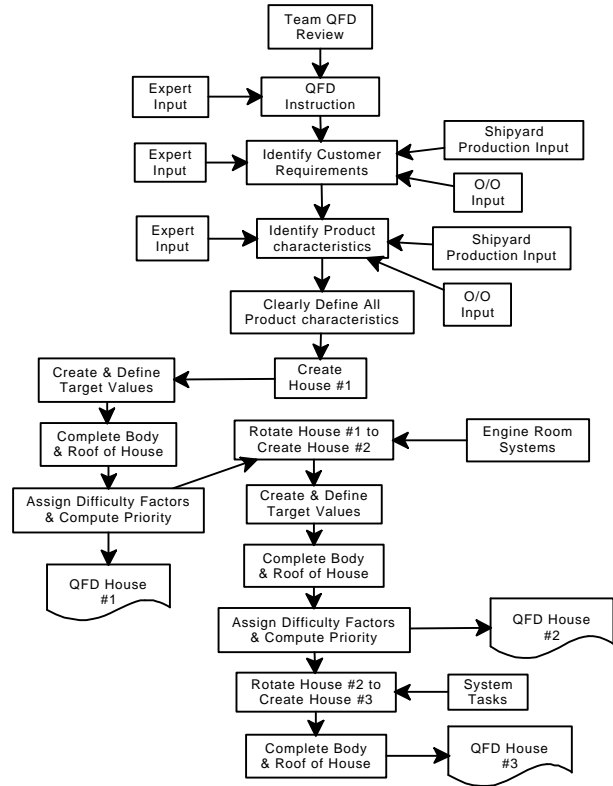


Figure 5. Product QFD/Task Development Process Flowchart

QFD subteam. It is very important to get customer input during the analysis to help answer any questions or uncertainties that arise regarding owner requirements.

Prioritization of the product characteristics is accomplished by identifying the interactions between the requirements and the characteristics and the level of importance of each interaction. All items on the house axes need to be clearly defined and agreed upon prior to doing the QFD analysis. This will help in resolving possible disputes and misunderstandings later on in the analysis. Participants should endeavor to keep the number of items on any single axis as low as possible. The addition of a single item requires a significant amount of time. Items may be deleted or combined to simplify the QFD house or the house may be split into smaller houses. The systems to be included are brainstormed by the team and listed on the horizontal axis. Interactions between the systems and product characteristics are then rated and prioritized.

QFD Completion

The QFD houses are reevaluated based on the Strategic Design Brief results to ensure that the focus of the QFD houses is in line with the SDB. QFD House 3 is developed to identify the technical design tasks required to meet the requirements and to prioritize those tasks.

A complete list of subtasks is then created based on the third QFD House. This is accomplished by comparing each of the

systems to the technical design tasks. For example, Table 1 is an excerpt from a fuel (purification) system comparison.

<u>System</u>	<u>Technical Design Task</u>	<u>Design Subtasks</u>
Fuel (Purification)	ER Arrangement	Locate all equipment within the engine room
	Master Equipment List (MEL)	Develop MEL for fuel purification equipment
	System Diagram	Develop System Diagram for fuel oil purification system

Table 1 Fuel Purification System Design Tasks

Each engineer is then assigned cognizance over one or more engine room systems and one or more technical design tasks. System cognizance typically requires developing calculations, diagrams, specifications, and selecting equipment for that system. Task cognizance requires completion of the administrative jobs associated with each task. These might include developing drawing formats, numbering schemes, and a list of standard symbols. The assignments are made based on interviews and discussions conducted with each team member to determine their capabilities and preferences while attempting to maintain a level work load. A typical member's work load might be Table II.

Changes to the tasking may occur as some individuals pass portions of their system responsibilities to others. Many of the task responsibilities may prove to be far too large to be accomplished by a single individual so subteams must be created to further reduce the time requirements for

<u>Systems</u>	<u>Design Tasks</u>
High Temperature Central Freshwater Cooling System	System Diagrams
Low Temperature Central Freshwater Cooling System	Component List
Potable/Drinking Water	System Diagrams
	Component List
Steam	System Diagrams
	Component List
Fire (Non-seawater)	System Diagrams
	Component List

Table II Typical Team Member s Work Load

the participants.

Project Schedule Development

The schedule development should be based on the QFD product house. The resulting task list should be as detailed as possible, presenting every task and sub-tasks for every system.

Project and task completion dates, vacations and holidays, as well as the availability of core team and resource team personnel should be known.

The phases of the design development should be defined with at least the following three phases identified:

- Conceptual Phase (Phase 1), where the concepts are established and settled, based on the main requirements, kept as short as possible;
- Development Phase (Phase 2), where the design is developed based on the definitions of the first phase and where the main equipment and associated technical data should be carried out; and
- Refinement phase (Phase 3), where the design incorporates additional internal improvements and refinements as well as external comments.

The duration of each design phase is based on the available baseline design documentation, and level of skill and experience of the participants. The schedule should include a time tolerance.

The schedule should be available to all team members for tracking tasks and early identification of the areas requiring assistance.

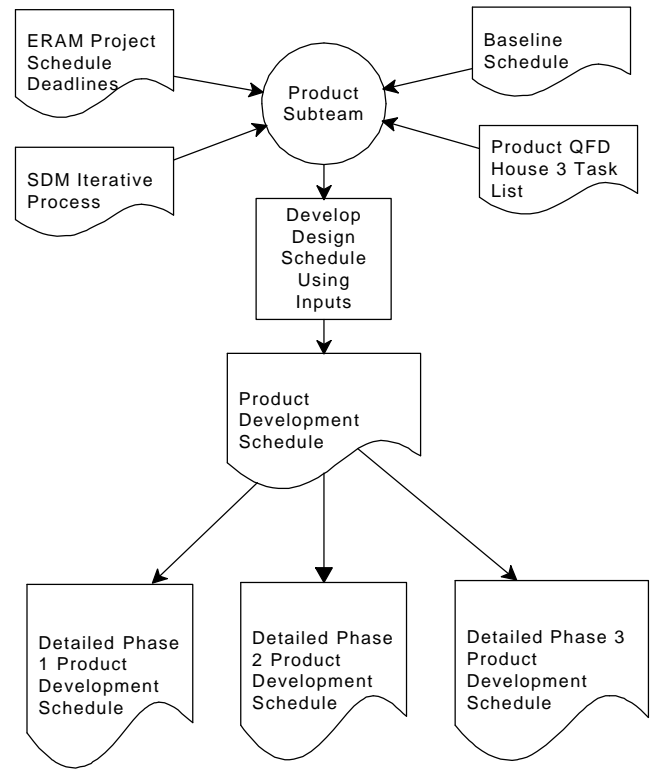


Figure 6. Product Schedule Development Flowchart

3-D PRODUCT MODEL DATA DEVELOPMENT PROCESS

In order for the product model to be integrated into the design, construction, and business practices employed at the shipyard, it must have sufficient detail to be useful in making design decisions. The type of data and level of detail available in the product model needs to be correlated to the various stages

in the design process. The product model development scenario is based on the following assumptions:

- During the conceptual design stage, the product model is extremely dynamic but the level of detail is low.
- Early stage design is concentrated on system diagrams.
- During detail design, the product model is less dynamic, but the level of detail increases greatly, and configuration management becomes complicated.
- During the construction phase, configuration management is the most difficult due to the introduction of the many dissimilar systems required to support the manufacturing processes.
- The majority of engineers/designers do not have access to the CAD system.
- Many engineers/designers supply data to one CAD technician.

The product model development process can be summarized as follows.

- Define library parts
- Hull Definition
- Locate Decks/Major Bulkheads
- Define Major Structure
- Locate Major Equipment
- Locate Tanks
- Arrange remaining equipment
- Define Deck and Bulkhead structure
- Define distributed systems lanes
- Locate major piping
- Optimize equipment location
- Organize equipment into units
- Structural details
- Optimize unit location
- Define foundations
- Arrange minor piping
- Optimize distributive systems

In addition, for the product model to be useful it must support the development of the documentation required for periodic design reviews and the development of the traditional drawings at the completion of the design.

Software Selection

Software has to be obtained to create and access the product model data. There are no commercial off the shelf systems which can adequately support ship design and construction within a specific business context without being customized. The development effort required to integrate the software, ease of use, and reliability, should be a significant consideration in the selection process.

One of the most important steps in the selection of commercial software is the evaluation. Software must be evaluated in the context it will be used in the shipyard. The evaluation should include at least a prototype implementation in which interfaces are developed to all major shipyard processes. The implementation should be phased, based upon the

requirements of existing and planned projects.

Personnel Selection and Training

An ideal CAD user is an experienced designer and engineer with an expert understanding of the application software. The user needs to be trained not only in the use of the system, but must be familiar with the design and construction processes as well. It is very important to integrate actual examples of shipyard processes into the training process in order to reinforce the theory as well as to prepare the user for actual tasks. The CAD team should consist of a core of application experts who can provide some guidance in addition to performing their own tasks. Initially, inexperienced users should develop library parts and assist the application experts. As they gain experience they will require less guidance and can be assigned more difficult tasks. Cross training should be performed where practical in order to provide awareness of the overall product model as well as to develop a reserve of users to accommodate a shifting workload.

Other resources required to support product model development include system support, application programming, and library part development. The system support role does not really require knowledge or experience with the application software. The application programmers should have a great deal of knowledge and experience with the software. Experience and knowledge of the ship design and construction processes is highly desirable. Library part modelers should have an expert understanding of the CAD application and an understanding of the level of detail required to represent a component. Experience and knowledge of the ship design and construction process is not necessary. Notice the level of experience for the application programmers and library part modelers are opposite of the ideal CAD user. Additional training is required for non CAD users who require access to the product model. This training should consist of visualization and redlining techniques in order to review and comment on the work in progress. Application of IPPD process by the CAD sub team is critical due to the close interaction between all the roles involved in product model development.

Product Model Preparation

Before a product model can be developed, an infrastructure must exist which includes configuration management, procedures, components and commodity items, and system support. The process of developing the product model requires the identification and modeling of equipment, outfit, and furnishings before these items can be inserted into the model. The product model is highly dependent upon the availability of commodity parts such as structural steel shapes, major equipment, outfit and furnishings, valves, fittings, etc. The first ship designed using the system is generally the hardest because in addition to design and construction, the infrastructure is under development.

Library Parts and Commodity Parts

Since commercial CAD/CAM systems are used to develop

arrangements, structural, and distributed systems models it is highly desirable that this data be provided in a digital format. This data consists of the information required to represent the as-built geometric definition of the component as well as the attributes required to convey non-graphic information. The vendor files should be accessible to all CAD workstations for reviewing, printing and referencing as a “footprint” for modeling. A database should be developed which provides information about the availability of the data and the developmental status of the library parts. It is recommended that a group be established to support the product model library consisting of CAD users and personnel who can obtain and document the data required to build the equipment. The best practice is to receive the data formatted specifically for the product modeling system. This will require a partnership between the shipyard and suppliers.

Product Model Procedures

Due to the complexity and the all encompassing scope of the product model, a set of procedures and guidelines must be established to ensure that the product model will be developed in a consistent fashion. There should be a general set of guidelines which pertain across all applications as well as application specific guidelines. For example, configuration management, general model organization, product work breakdown system, and component modeling procedures will probably be the same across applications because they affect the product model globally. Value added modifications to the product model such as manufacturing data or engineering analysis data, which have a local effect between a limited number of groups, require unique procedures. The procedures need to consider not only how the product model will be used to perform a specific task, but the effects on other users as well.

Product Model Usage

In general it is best to have a single product model which can be accessed in a distributed environment by all ‘electronic’ design and construction processes (e.g. arrangements, distributed system layout, structural design, pipe flow analysis, structural analysis, naval architecture, plate nesting, pipe bending, etc.). This means the sophistication of the product model varies among the shipyards. The uses of the product model must be known in advance. For instance if the end product of the product model is the creation of drawings, a radically different approach will be undertaken than if the product model will be used directly to support ship construction. A process must also be developed for product model development. The definition of the product model as well as its development and implementation necessitates the involvement of all groups which will be creating as well as accessing product model data. The sequencing of access to the model must also be determined, including the output products required to facilitate communication of the information. Currently, access to the product model by others than CAD users are through annotated sketches generated from the product model. This is also the predominant methodology used for design review. Anyone who has input into the design must be trained and given

access to the product model. Design reviews should be facilitated using electronic mockups.

Product Model Development

The product model can be initiated from many different sources, including existing product models, CAD drawings, and paper sketches/drawings. Also in the conceptual phases, much of the 3-D layout is unknown. The system must be able to accommodate new ideas and scanned images. The first iteration of a new design can manifest in any of the three formats. As the arrangements evolve, the CAD technician populates the product model and generates models and sketches as defined in the product model development procedures. The next step is the definition of pipe lanes. As the model becomes more mature, it becomes suitable for providing the documentation required for the design review. Once the piping lanes have been identified the distributive systems can be defined in more detail in the product model. This more complete product model would be used to optimize equipment arrangement and begin the grouping of equipment into units. As the units evolve, the foundations can be modeled, and structural details can be designed. Although product model development lags slightly behind the optima time in which data should be provided to the designer, the data can be delivered in time to have a positive influence on the design. This cycle is repeated until the design phase has been completed.

Product Model Output Products

Output products are used to provide information to downstream processes and interim documentation and may be the final end products as well. For example, graphics files required by a visualization system for design reviews is an end product. Work packages generated from the product model in a paper format may be required on the waterfront by the trades. Final drawings are still a requirement in most applications. In-process output products include finite element models, equipment lists, and numerical control instructions. Sketches generated from the model may be required to convey information to the system engineer who does not have product model access.

- Design Documents (released continuously)
 - Sketches
 - Reports
 - Visualization files (shaded images, hidden line)
 - Manually created 2-D Schematics (provided upon request)
- Design Review Documentation (released periodically)
 - Annotated drawings required to communicate system diagrams and arrangements
- Visualization files (Documentation (released semi-weekly))
 - Product Model Review files downloaded
- Product model neutral databases (as requested)

This data will initially be provided in the format as defined in digital data exchange procedures. Long term plans are to

provide the data in Standard Technical Exchange Program (STEP) format conforming to the ship design and construction application protocols:

- Arrangement;
- Structure;
- Distributed systems; and
- Library parts.
- Final Drawings (end of project)
This requires major rework of the latest design documentation. These drawings shall be developed explicitly from the product model and annotation added manually as required. Editing of line style shall be performed as required. This process is developed after the product model has been completed, and will be non-associative to the product model.
 - Paper drawings
 - Raster images
 - Drawing Interchange File (DXF) files (2-D)
 - Initial Graphics Exchange Specification (IGES) files (2-D)

Hierarchy for the Acquisition of Commodity and Library Part Data

1. Provide digital data in native format in conformance to product modeling library development guidelines. Basically, this data consists of geometry for the various representations of the part (e.g. detail, 2-D symbolic, envelope, etc.) and the non-graphic attributes for the required level of intelligence.
2. Provide the geometry and attributes using the appropriate National Shipbuilding Research Program (NSRP) specification for the definition of STEP application protocol for shipbuilding.
3. Provide the geometry and attributes using the Initial Graphics Exchange Specification Version 5.2 or greater. Multiple formats are available within IGES to represent this data. The preferred method would be to use CSG and Brep solids to represent the geometry and the attribute table and instance entity to represent attributes. In the event the preprocessor is not robust enough to handle solids, then surfaces or wireframe geometry would be used. If the preprocessor is not robust enough to handle the attribute table and instance entities then a text file would be used.
4. Provide the geometry using DXF, and the attributes using a text file. The preferred DXF geometry type would be surfaces, however wireframe is acceptable if surfaces are not available.
5. Provide the data in native format AutoCAD or Microstation.
6. A scanned image of the applicable technical publication describing the component would be used and the attribute data would be provided in a text file. Regardless of the methodology used to represent the vendor data, it is highly desirable for a raster image of the technical documentation be provided.

7. Provide sufficient technical documentation to develop a CAD model of the exterior of the component, including the location and orientations of connections (structural, fluid, electrical).

SHIP S SYSTEMS DEVELOPMENT

The System Development Process is shown on the flowchart of Figure 7. Development of systems starts when the systems are identified in the QFD product house and ranked according to how difficult they are to implement and how they interact with other systems. After the systems are identified, the product subteam assigns the systems to individual core team engineers. System assignment is based on the time required to develop each system and core team knowledge. At this point, each engineer develops his system concurrently with all of the other systems. System concepts can be refined throughout the conceptual and development phases along with trade-off studies, equipment selection, owner/operator input, build strategy and during the level of unitization defined during Phase 2.

The core team defines, selects or adopts a proven baseline for all systems before the start of a design. This will pay off downstream with regard to minimizing the time spent in discussion within the team about content. It also supports the team by reducing the 'blank sheet of start-up time. Systems such as the following are to be considered.

- Exhaust Gas
- HVAC
- Sounding/Venting & Overflow
- Structure
- Fuel Oil Supply and Purification
- Sea water
- Propulsion
- etc.

Systems specifications need to be defined at the start of the project. System requirements should be changed to match commercial practice on world class ships as defined by the core team and owner/operators.

Diagrams

A diagram subteam can be established early in Phase 1 to create rules and guidelines for system diagrams and to select the 2D CAD software for engineers to create the system diagrams. It is necessary to agree to use only one type of software for these diagrams. Also, a universal list of equipment symbols and valve symbols must be used to promote consistency amongst the system diagrams.

The level of detail listed on the diagrams must be agreed upon for all system oriented diagrams. This level should require clear presentation of system

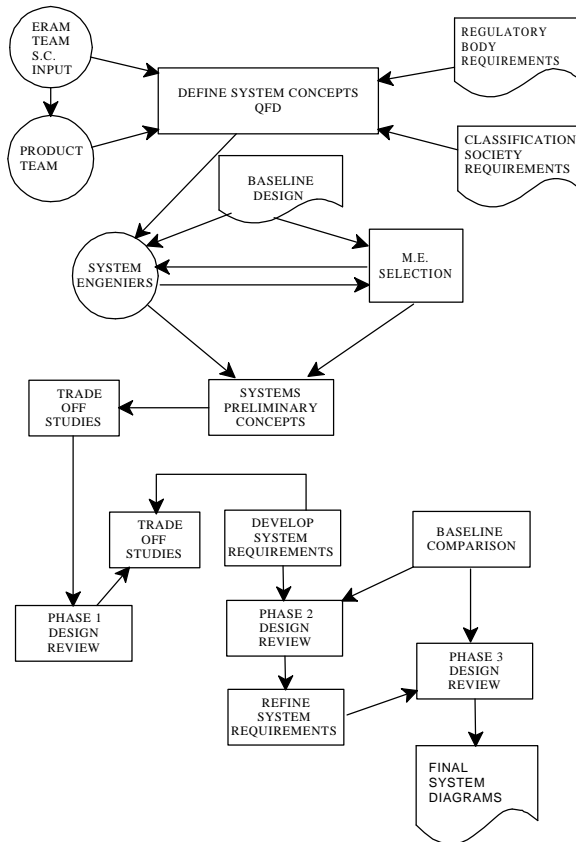


Figure 7. System Development Flowchart

function, ease of understanding, and system interaction must be identifiable with references to other diagrams where needed. The equipment on the diagrams should be positioned similar to the actual room arrangement to later simplify the unitization breakdown process.

The revision and approval process of the diagrams and drawings need to be properly defined prior to the completion of the first diagram.

Trade-Off Studies

Trade-off studies on system design philosophies and equipment selection should be done throughout Phase 1 and Phase 2. The initial system concepts can be based on the following items.

- The system concept to be commercially viable
- The baseline ship
- The eight key 'Illities' listed in the SDB
- Ship rider reports
- Owner/Operator written comments
- Core team input/evaluation

Goals for the trade-off studies are as follows:

- Create a simple, but efficient system that is commercially viable, a proven concept, easy and

economical to build and operate that provides high reliability.

- Reduce in number of equipment, thereby minimizing the equipment to be maintained
- Reduce the amount of sea-water piping to reduce problems as the ship ages and the sea water piping corrodes

Equipment Selection

The equipment selection process must be defined for the project. The vendor furnished information library needs to support the equipment selection process and allow access for engineers to look for equipment and vendors. In many cases that the support from vendors takes too much time and is a constraint for the engineers and the schedule. The need for drawings and information will be a great concern for the team if the vendors are not as willing to provide information.

Project Database

A project database must be able to manage conceptual design and formation in a central manner. From this database, reports covering design information, master equipment list, parts list, list of units and blocks could be generated. Other uses included capturing data for the electric load analysis and automation and signal list. Several examples of the database content can be found in the ERAM design package.

PRELIMINARY DEVELOPMENT OF ENGINE ROOM ARRANGEMENT

This initial step of engine room arrangement involves propulsion unit identification and integration within the engine room envelope. Additional studies can be performed to specify:

- Tank top, main grating and intermediate flat levels;
- Main engine foundation;
- Height of the shaftline;
- Location of the engine room bulkheads;
- Location of the fuel oil tanks; and
- Location of stack/casing.

This development of this step is done using 2-D drawings derived from the 3-D model.

The main items of the preliminary engine room arrangement identified in the first step are presented to the team. During this discussion the main drivers for spatial relationships can be identified.

Development Of Engine Room Arrangement Options

Engine room arrangements can now be developed by individual team members or subteams to provide several options. Affinity diagrams and the "QFD" house matrix, Figure 5, are valuable tools at this stage. Concurrently a preliminary pipeline arrangement study can be performed.

These arrangements are now presented to the team with an explanation of each concept and configuration.

Selection Of One Option For The Engine Room Arrangement

For each option “plus & deltas” and “QFD” analysis are applied to validate and select the preferred option.

The preferred option selected by the team can now be optimized to further improve the arrangement and incorporate the best features from the discarded options if necessary.

ENGINE ROOM ARRANGEMENT DEVELOPMENT

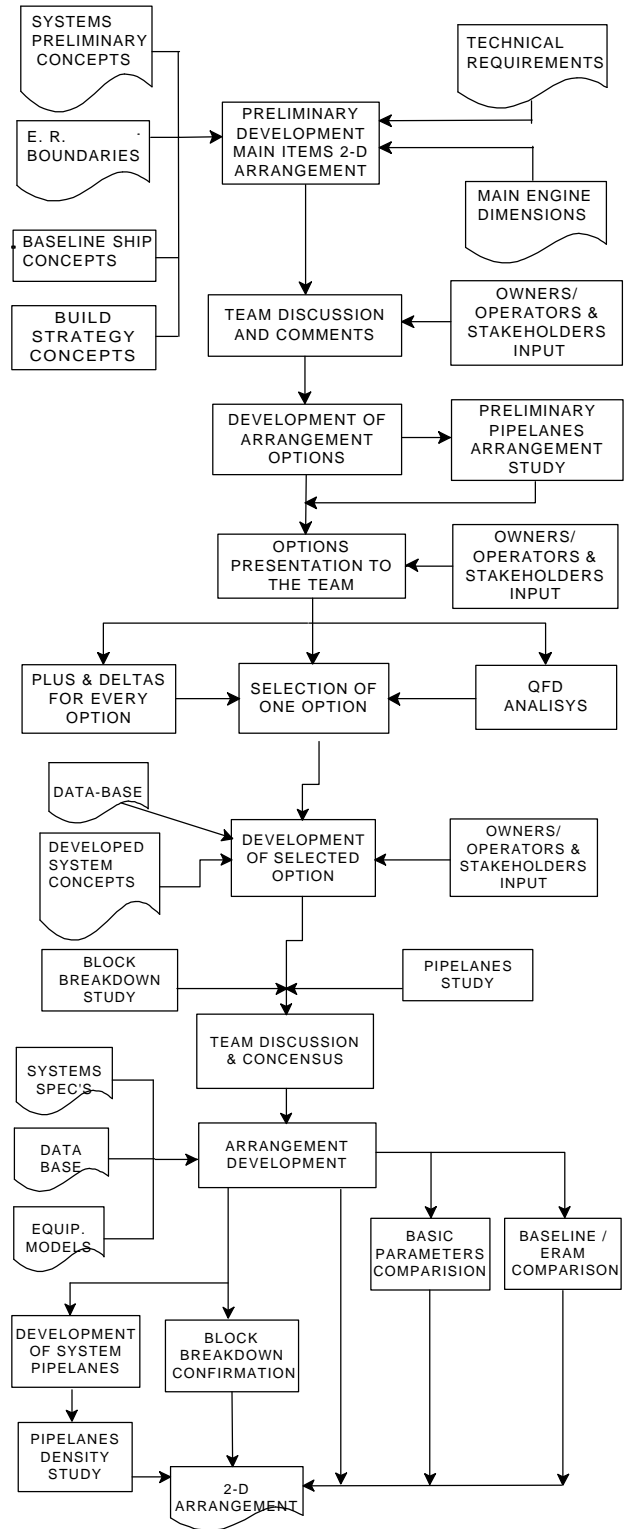


Figure 8. Engine Room Arrangement Process Flowchart

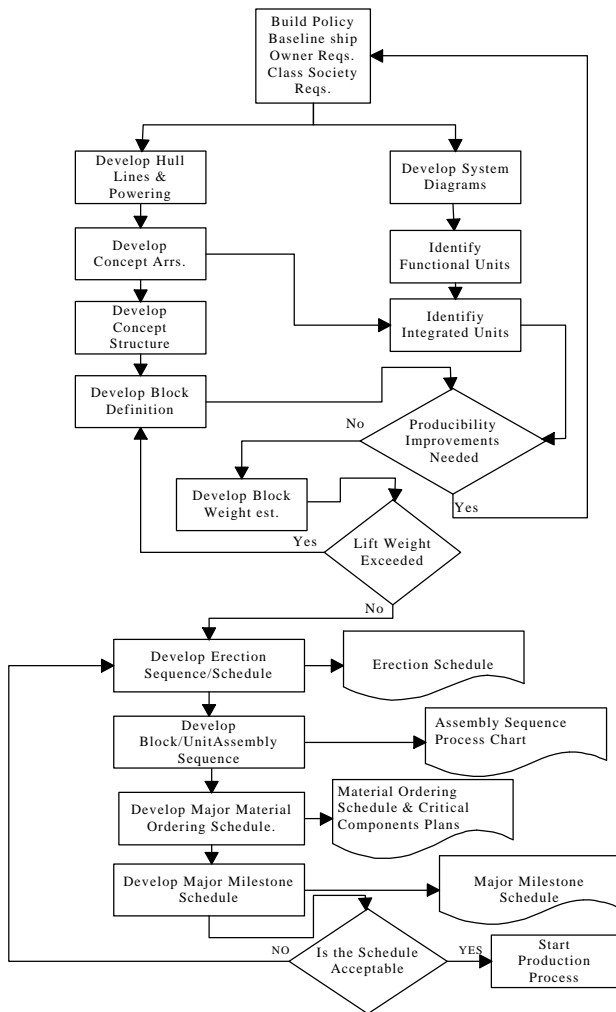


Figure 9. Build Strategy Development Flowchart

The arrangement can now be populated using the 3D model and data base. Development of system pipelines from earlier studies can now be included in the 3D model. As the 3D model is developed detailed arrangements can be accurately produced at any time with minimal effort. Final arrangements are a feature of the completed 3D model.

BUILD STRATEGY DEVELOPMENT

Build strategy development is initiated in parallel with the engine room arrangement studies and system diagram

development. See Figure 9.

This process includes initial system design steps to:

- Simplify systems;
- Combine system functions;
- Minimize number of components;
- Define intersystem relationships; and
- Define system level units

using such tools as affinity diagrams (See Figure 10), equipment association tables, networks, and analysis of system schematics.

Development of the build strategy begins with the provisional establishment of block boundaries, in accordance with the following principles

Program Considerations

Interim products must fit the characteristics of the shipyard and block breaks and erection sequences should be compatible with the production strategy developed during GBS Phase II for the total ship. The overall production strategy must support the goals of the Strategic Design Brief and the Requirements Document, including:

- Ship delivery schedule after contract award;
- Engine room cost;
- Latest feasible delivery/installation of main engine; and
- Minimum design/marketing cost and no financial commitments (e.g. for long lead material) prior to contract award.

Logic and Criteria

Favor outfitting in any tradeoff between structural and outfit production and maximize interim product size within the facility constraints. Standardize components, arrangements and interim product configurations. Other factors to consider include:

- Move work to the earliest feasible stage
- Installation

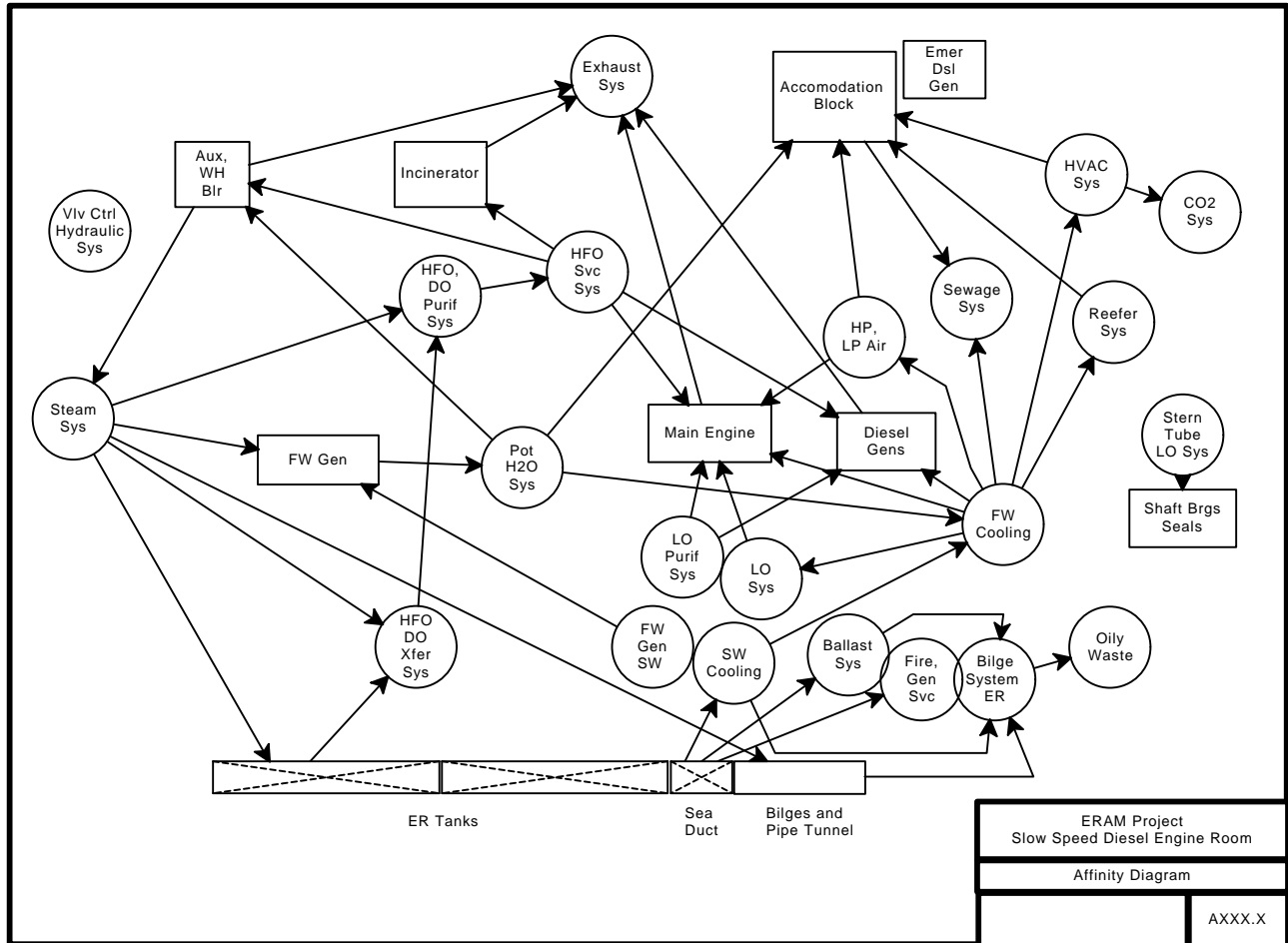


Figure 10 Engine Room Systems Affinity Diagram

- Testing;
- Minimize joint (weld) length; and
- Provide flexibility to allow for the unexpected.

Production Process and Sequence

Assemble blocks on flat surfaces (usually decks) on the assembly floor (no pylons, minimize use of pin jigs). Provide for parallel processing of interim products and install all possible components on unit. Install units on-block wherever weight limits permit, otherwise on-berth and use grand blocks/units to increase the efficiency of the on-berth erection process. Maintain open access to all blocks containing outfitting, including a window for blue sky outfitting on-berth. Include the following items in the development of the build strategy.

- Minimize time between material delivery and ship delivery (“just in time”)

- Install main engine as close to launch as possible (late installation)

- Minimize time between keel and delivery
- Load hook up (free ride) material on-block
- Complete test and paint structural tanks prior to block erection. Use free standing tanks where feasible.
- Complete block painting in paint facility prior to erection

Interim Products

Configure blocks with at least one flat surface wherever feasible, to facilitate assembly and to provide enclosed spaces for functions not amenable to unitization, such as workshops and stores. Maximize the use of outfit units by incorporating the following.

- System units which can be standardized, vendor furnished
- Large integrated units, possibly integrated with ship structure at the assembly stage

Having defined the major interim products, the next priority is the assembly and erection sequence. An erection sequence and schedule is created, based on the baseline erection schedule. This schedule, represents the current capability of a shipyard. In the engine room area, adjustments are made to provide for:

- Provision of open (“blue sky”) time for unit the erection schedule and assembly sequences loading;
- Opportunity for joining blocks into grand blocks;
- Acceleration of Zone 4 erection schedule to support shaft installation & alignment; and
- Late installation of the main engine.

Supporting the erection sequence, the following approach is recommended for the assembly of interim products in preparation for erection on berth.

- a) Block assembly and installation of in-tank piping, structural attachments and foundations,
- b) Grand block assembly of two or more blocks, outfitting of grating/pipe lane units, selected pipe assemblies and foundations, loading pallets for later installation,
- c) Erection on-berth,
- d) Loading of any remaining outfit material during the open period prior to erection of the next block. This includes major components and units which are costly, have a critically long lead time, or are too large or heavy to load on-block.

The engine room block/grand block erection sequence are shown in an erection schedule. For each block, the sequence and schedule allowed for one week of open time to permit on-berth installation of outfit units and pallets. In addition, the machinery casing area is kept open to allow two weeks for main engine installation starting ten weeks after keel, completing just prior to deck house erection.

The erection sequence and schedule is followed by development of interim product assembly sequences which define how these products are combined prior to erection on berth. The logic and criteria used included:

- Assembly of subunits and units within the unit shop, including the integration of vendor furnished units where appropriate;
- Assembly of grand units wherever feasible, breaking these units for loadout where necessary;
- Installation of grand units/units on grand blocks prior to erection on-berth. It is assumed that on-berth material pallets will also be loaded on the blocks prior to erection; and
- Units too large or heavy to load at this stage will be loaded on berth.

The results are recorded in a series of process flow charts, one for each grand block involved.

Finally, using the erection schedule and assembly sequence described above, material required dates, defined in terms of weeks before or after keel, are determined. Using material lead times, the required time for order placement for critical material is determined. It is found that a minimum interval of 12 months is required between contract award and keel to allow for the timely receipt of long lead material in support of the production strategy. With this minimum time established, the remaining 6 months in the target 18 month schedule are divided between the on-berth and overboard periods.

DESIGN REVIEW PROCESS

The design review process should be as open and objective as possible, giving the opportunity of discussions between the design team and the steering committee or its spokesperson.

The design team should present the design development, detailing the relevant points such as build strategy and metrics. Then the steering committee, together with the team, must spend the necessary time in analysis, discussion and clarification of design issues. This is best done on a one on one basis. This allows individual interface between steering committee and team members as each steering committee member reviews each system design storyboard.

In the end of the this analysis phase, the team and the committee should meet to discuss the results and to capture comments and action items.

A single list of comments requiring action should be developed and agreed upon. The team answers should be addressed as soon as possible in order to incorporate the comments into the design.

Figure 11 provides the recommended in-process design review process.

UNIT DEVELOPMENT

The following definitions are applied to unit levels.

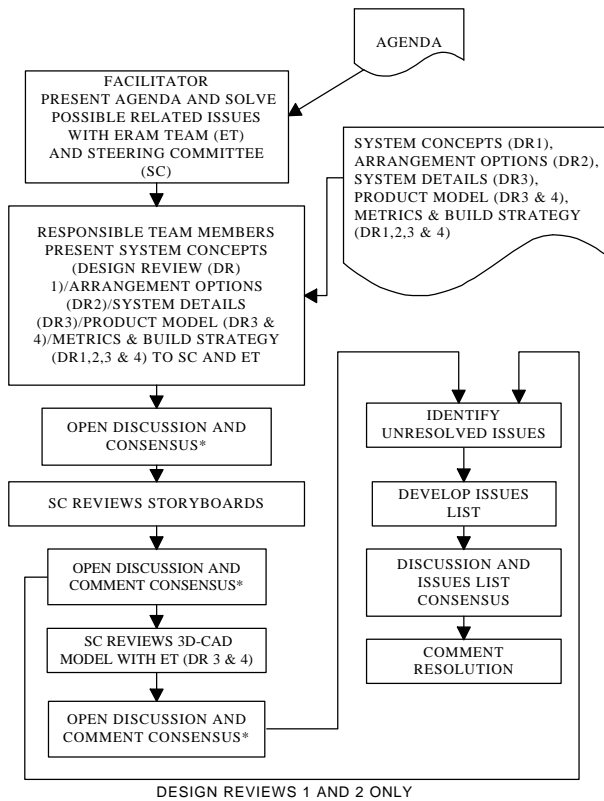


Figure 11 Design Review Process Flowchart

Level 1 - On-Block Outfit

The installation of individual components and systems on hull structural blocks. This approach minimizes miscellaneous steel but requires heavy-lift capability (600-800 tons) to avoid extensive on-board construction.

Level 2 - Functional Units

The integration of functional pipe and machinery skids normally dealing with major sub-elements of individual functional systems. This approach moves significant complex piping and machinery installation from on-board to on-unit but requires more secondary structure and design integration.

Level 3 - Large Integrated Units

The integration of large machinery units including all pipe, machinery and electrical components and systems in a geographical area of an the engine room. This approach effectively moves the majority of piping, machinery and electrical work from on-board to on-unit, but it requires a higher level of design integration and more secondary steel work than Level 2 as the units are larger and require additional support structure for lifting and handling..

Level 4 - Standard Machinery Units

Similar to the integrated machinery units described above, these units include pipe, machinery and electrical work in a given geographical zone of the ship. In addition, through the use of parametric design and a high level of planning prior to developing the machinery arrangement, some foreign yards have been able to standardize the structural framework and system interfaces such that all machinery units across a series of ship types and sizes utilize standard structural and system interfaces. This approach requires the highest level of pre-planning and design integration. Secondary steel work requirements are similar to Level 3.

The build strategy concepts and the level 2 units should be identified in the early stages of the design development. See Figure 12 The logical grouping of distributive system runs must also be considered in the

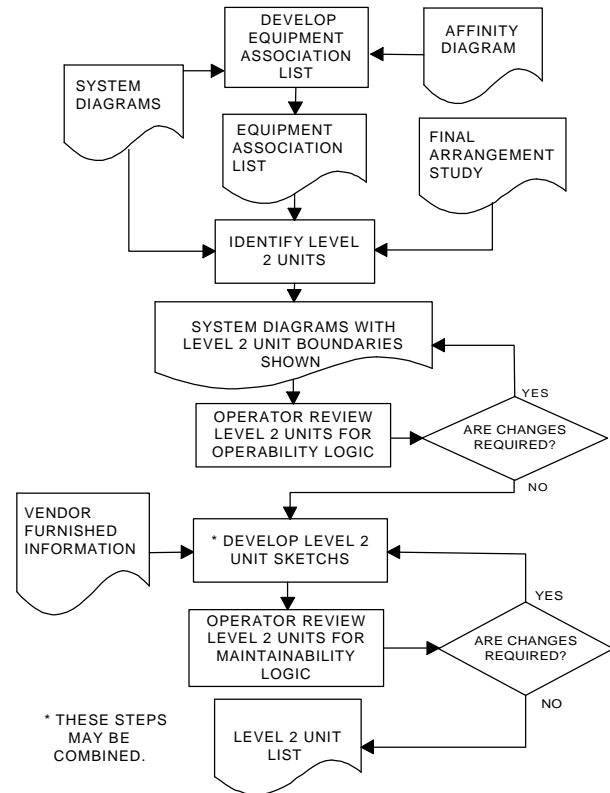


Figure 11. Level 2 Unit Development Flowchart early stages.

Tools such as affinity diagrams, Figure 10, or equipment association tables should be used to guide unit definition. The engine room arrangement should be developed trying to place the potential level 2 units in suitable locations, taking into consideration the block breakdown and pipeline positions. Based on the tools used for system development, a list of level 2 units should be developed.

Parallel to the arrangement development, level 3 units should be identified (See Figure 13) and the component locations should be adjusted in order to accomplish this level of unitization.

Finally a complete list of units should be developed, presenting what components are included on level 2 units, level 3 units and block assemblies.

The following unitization concepts should be applied to the engine room design development:

- Maximize level of unitization, thereby avoiding work onboard;
- Maximize the use of pipelines and cablelanes, to minimize work onboard; and

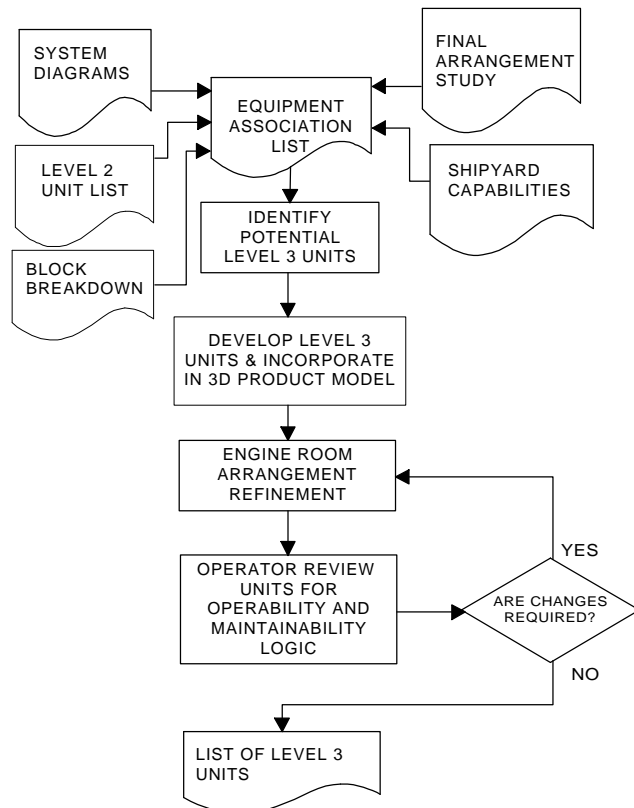


Figure 13 Level 3 Unit Development Flowchart

- Avoid the use of ship structure as a part of any unit.

METRICS DEVELOPMENT

The use of metrics is a key element of the Strategic Design Method and the development of metrics are an integral part of the development of the Strategic Design Brief. The process for metric development and its integration into the Strategic Design Brief is shown on Figure 14.

Strategic Design Brief

The Strategic Design Brief is a document which is created in an intensive 24 hour (3 working days) period to accomplish the following:

- Define the design problem with the agreement of all,

including management;

- Shape a strategy framework to guide the design thinking;
- Generate creative design solutions;
- Develop a design measurement system; and
- Create a “next steps” action plan.

The basic concept of strategic design method is to identify, at the start of a project, the desirable

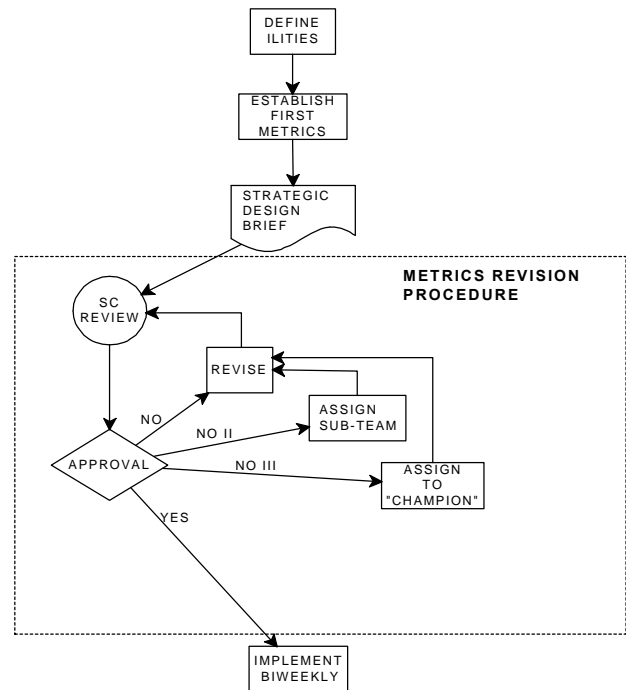


Figure 14. Metrics Development Process Flowchart

properties (“ilities”) of the final product and design process, set goals for each property, innovate solutions strong points in both the design process and in the final product. They keep the design team and management in touch with the original concepts of the project, and indicate where more work is needed to achieve project goals. With buy-in, they are an agreed upon method between the team and management for measuring project success in-process. Post process, it is ultimately the customer that measures this success.

The design process is the most critical element to drive to consensus in the early stages of the project. All of the “ilities” of the process must be considered while innovating solutions. Attention must be paid to minimizing expenditures of effort (“ings”) which achieve little progress towards the goals.

Metrics Concepts and Objectives Definitions

For the achievement of these goals, and set up a measuring system (the metrics) which will indicate whether the goals are being approached and where effort must be focused to achieve the project objectives.

Metrics are essential for indicating weak and the basic

method for establishing a metric is to look at the intent of the metric, brainstorm all of the major influences (the ilities) for that metric, and select 5 to 8 key drivers for that metric that are measurable. Then compare those 5 to 8 key drivers to the baseline to establish a reference. The normalized 'baseline ratio' has a goal, boundary and start value based on these values of the drivers compared to the baseline. Team progress is always tracked against these values. The concept of the boundary value is the minimum required to break into the market.

Brainstorming and selection of key drivers is conducted by the team. This session is lead by the most skilled or knowledgeable people of the team in each of the metrics. The open discussion within the team will ensure quicker team buy-in than forming a subteam to develop recommendations for team buy-in.

Buy-in of the metric is essential to the success of the team, if the Steering committee has rejected a metric recommendation for a second time, it may be necessary for a subteam to review metric basics. A quick review of these basics will indicate which metrics are in need of revision, this may include a redefinition of the 'ility'. The likelihood of metric buy-in is increased if the complexity and time required to calculate the metric values are reduced by remembering that team buy-in does not mean 100% satisfaction of all the stakeholders. Once Steering Committee buy-in has been achieved, subteams or individuals are assigned to develop the measurement tool for each metric. This tool is submitted to the team for buy-in and then the Steering Committee again following the process outlined in Figure 14.

CONCLUSION

The application of the IPPD processes to the ship design process at U.S. shipyards can significantly reduce the man-hours and duration to design commercial engine rooms. This concept can be effectively applied to the entire ship design process if shipyard management fully endorses and supports a corporate wide IPPD training program. In addition the concurrent incorporation of customer requirements can enhance customer satisfaction and lead to repeat orders.

The processes that each team should develop to enhance their success in an IPPD environment, listed in descending order of importance, follow.

Consensus Agreement Process

Consensus basically means the team is in agreement on an issue. This process should be the very first process invoked by a new team because it allows the team to make decisions. Having this agreement defined in writing is absolutely necessary to enable a team to function.

Team Norms Development Process

Team norms must be developed to insure that all team members follow certain standards that each team member has agreed upon. The standards will range from how work should be presented to mutual respect for each other. The amount of

importance that the team places on how they treat each other as individuals can directly affect the output of a team. Norms are created to address member's concerns at the onset of team building so that all team members are assured of "riding the same bus down the same road to reach the same goal".

Meeting Management Process

A meeting management process is necessary in order to efficiently utilize the attendees time and capture and disseminate the results of the meeting. There are three basic types of meetings used to manage an IPPD team. The general meeting attended by all team members is used to discuss team issues. The Core Team meeting is used to discuss technical issues and major operating decisions. The Week In Review Meeting (WIRM) is used to manage the team and maintain focus of the overall objectives and goals of the project. This WIRM is the most important meeting tool used to manage the team.

Peer Review Process

The Peer Review is a tool that gives the team members a chance to confidentially evaluate their peers performance and make comments in a positive manner. When constructively done this is an excellent self improvement tool. This is an essential element to a successful team approach but one that must be owned by the team and properly conducted to be beneficial. The process could be modified to include sharing each individuals results with the team.

Team Member Performance Appraisal Process

The team member performance appraisal is a tool that is used to provide feedback on a team member's "TEAM" performance to his/her supervisor. Many team members will no longer have daily or even weekly contact with their actual supervisors due to their presence on a team. This process is created to fill that communication gap. It is very important that the team own/develop and update this tool.

Personal Conflict Resolution

Personal conflicts within the team is one of the most disruptive elements of the team process. They cause communication shutdown and team polarization resulting in loss productivity. It is essential that conflicts between team members remain within the team. Team members who take personal conflicts with other team members to persons outside the team should be subject to disciplinary measures that will be determined by the team as appropriate to the occasion.

Subteam Assignment Process

In order to improve team efficiency a process must be in place to prevent lengthy discussions. The subteam assignment process appoints a subteam (or expert) to develop a strawman or make a decision to be presented to the team for buy-in.

Action Item List Process

The action item process identifies new tasks that are not addressed in the schedule. These new additional tasks are one of the primary reasons schedules are slipped. The action item list serves three purposes:

It tracks the status of the new items

It provides a simple method to prioritize new tasks and

It provides the basis for schedule changes or requests for additional support is such action becomes necessary.

Internal Approval Process

Throughout each of the design phases, team members who identify improvements to the current process or design must be given the chance to present their ideas to the team. A procedure for internal approval to allow all team members to have a chance to convey their thoughts and ideas to the rest of the team is an important tool. Using this tool not only increases awareness within the team but also promotes synergism and helps produce a better process and product.

Product Design Milestones Identification and Change Procedure

The milestones and principal dates are identified in order to develop the project schedule. The milestones to be identified are those related to the process design development as well as those related to the product design.

The milestones and principal dates initially identified may have to be revised due to issues not included in the initial schedule. A task to be included in the schedule is "schedule up-dating", which should be provided at regular intervals.

Owner/Operator Participation Procedures

In order to effectively integrate the voice of the customer through the design process it is recommended to have participation from an owner/operator in the form of a chief engineer. The process can effectively utilize this valuable resource and ensure that a dynamic partnership is created between shipyard and customer.

Process and Product Metrics

The use of metrics is a key element of the IPPD process. Metrics can be a powerful tool to improve both the product and a team's social behavior. The concept of process and product metrics is to set goals and use an in-process measuring system (metrics) which will indicate whether the goals are being approached and where effort must be focused to achieve the project objectives. Metrics are essential for indicating weak and strong points in both the design process and in the final product. They keep the design team and management in touch with the original concepts of the project, and indicate where more work is needed to achieve project goals. With buy-in, they are an agreed upon method between the team and management for measuring project success in-process. Post process, it is ultimately the customer that measures this success. The in-process measurement system should go beyond the traditional methods of measurement for the common three - Schedule, Performance and Direct Cost. Therefore the

understanding of metrics and the effect of such on both process and product, along with the conclusions that are drawn are difficult to agree upon. Especially for those persons outside of the team. To this end it is important that metrics be used only to show direction and guide a team towards success.

Cad Subteam/System Engineer Interface Process

The CAD designers and the CORE Team must develop a process to facilitate the exchange of information between system engineers and the CAD subteam. This process should be developed to reduce confusion between team members, eliminate duplicated information being submitted to the CAD designers and to document the information being transferred between the system engineers and the CAD designers.

Vendor Information Management Procedure

This procedure provides a method by which Vendor Furnished Information (VFI) is requested, received, controlled and reviewed for conformity to specific project requirements. Each project may be set up in a different environment and requirements should be established to meet the shipowner needs. Some VFI can be available immediately from shipyard files or system engineers. Other VFI, shipowner specific vendor requirements, may be very difficult to obtain. This can be easily resolved through a close working relationship with the customer. Vendor Furnished Information must be provided concurrently with the engineering work during Phase 1.

Design Review Process

The design reviews shall be conducted in compliance with the IPPD approach of in-process review, evaluation, and approval. The design reviews shall be limited to the current phase of the project that is being addressed.

The goals of the design review process are as follows:

- Time Phase the Buy-In Process
- Promote Concurrent Incorporation of Comments
- Maximize the Development of the Project Final Report Elements

Ship's Systems Integration Process

In the design of the ship's systems there are many interface points that must be addressed. The identification of these points of interface and the proper integration of them is essential to the design process.

Information Storage/Back-Up/Retrieval Procedures

All enterprises require a plan for managing all technical and business data in order to design, build, and support a product through its life cycle. The implementation should be distributed in order to take full advantage of the networking and processing capabilities of the enterprise and to accommodate the possibility of participating within a virtual enterprise. Backups should be performed on a daily basis. The relational database used to support the product model should be unloaded nightly to text

files. All files which have been accessed in the previous days should be written to tape. At the end of the week and the month, and all files on the system should be written to tape. Monthly tapes should be archived.

Visit Process

Team visits to ships, vendors and related facilities to gather information, learn operational and maintenance characteristics of various equipment, and increase the shipboard knowledge of the team are essential. The visit process is created to increase the effectiveness and document the results of the visits.

Capture Lessons Learned

As part of the IPPD design process there is a need to capture any lessons learned in either resolving a problem, achieving a goal or finding a short cut to a solution. By recording the process, team members can refer back to it for answers or to avoid past problems.

User s Guide Editing Process

The 'User's Guide' is the **product** of the process. In order to improve the process, the process itself must be documented and a means to rapidly incorporate such improvements and disseminate them to all team members must be in place. This Guide should be a "living document" with "continuous improvement" of the document occurring as lessons are learned.

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