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Reducing the Construction Contract Cycle for Naval Auxiliary Ships

No. 7B-1

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ABSTRACT

A Mid-Term Fast Sealift Technology Development Program producibility study was undertaken by the Manufacturing Systems Division (Code 125) of the Naval Surface Warfare Center, Carderock Division (NSWC) for the Naval Sea Systems Command Computer Aided Engineering Division, Ship Design and Engineering Directorate, SEA 507. The producibility project team was initially tasked to identify and evaluate possible design improvements with regard to their potential impact upon the cost of construction for the Baseline (BL) Oa rough order of magnitude (ROM) geared-diesel option. This particular design variant is a 30 kt twin screw, 289 m (948 ft.) roll-on/roll-off (RO/RO) vessel with four 18 PC4.2V medium speed diesels producing 85,619 kilowatts (114,817 h.p.) of installed power. The construction cost estimate developed by NAVSEA for this particular design variant is \$385 million per ship (1). In addition to the NAVSEA-assigned task, the team reviewed the producibility aspects of the Navy auxiliary ship procurement process with regard to finding methods that would facilitate major reductions in the construction contract cycle, as time is now recognized as a major cost driver in ship procurement (2). The construction contract cycle is defined as the amount of time from construction contract award to delivery, and was estimated by NAVSEA to be 42 months for this particular design variant (3).

ACRONYMS

AII - Avondale Industries, Inc.
BL - Baseline.
CAD - Computer-aided design.
COR - Circular of requirements.
FSS - Fast Sealift Ship.
GBS - Generic build strategy.
GT - Group technology.

NASSCO - National Steel and Shipbuilding Company.

NAVSEA - Naval Sea Systems Command.

NSRP - National Shipbuilding Research Program.

NSWC - Naval Surface Warfare Center, Carderock Division.

PBI - Peterson Builders, Inc.

PODAC - Product oriented design and construction.

PWBS - Product-based work breakdown structure.

ROM - Rough order of magnitude.

RO/RO - Roll-on/roll-off.

SWBS - Ship system-based work breakdown structure.

UMTRI - University of Michigan Transportation Research Institute.

VFI - Vendor-furnished information.

INTRODUCTION

The purpose of the Mid-Term Fast Sealift producibility task was initially to examine the Mid-Term Fast Sealift Baseline (BL) Oa rough order of magnitude (ROM) geared-diesel design option to identifying alternative product characteristics that could reduce construction costs. The NAVSEA estimated construction duration for these ships was 42 months at a cost of \$385M per ship (1,3).

The Computer Aided Engineering Division, Ship Design and Engineering Directorate, SEA 507, tasked the Naval Surface Warfare Center, Carderock Division, Code 1253, with creating a team to address producibility issues. The Naval Surface Warfare Center, Carderock Division, used an existing National Shipbuilding Research Program (NSRP) contract vehicle with Peterson Builders, Inc. (PBI) to place PBI, Avondale Industries, Inc. (AII), National Steel & Shipbuilding Company (NASSCO), and the University of Michigan Transportation Research Institute (UMTRI) under subcontract for this task.

The participating shipyards were selected based on their size and experience in designing and building naval auxiliaries. PBI is a small shipyard with considerable experience in designing and building small naval auxiliary vessels. Their role in this task was to provide contract management and to provide some technical input from the perspective of a smaller shipbuilder. Both AII and NASSCO were selected for their considerable experience in designing and building large naval auxiliary vessels. The Marine Systems Division of UMTRI was asked to participate because of their knowledge of ship production methods and technologies, and because of their perspective on the implications of the sealift program for the domestic shipbuilding industry.

This project team examined the producibility of the Mid-Term Fast Sealift BLOa ROM geared-diesel option as originally tasked. In addition, the team identified procurement policy and process improvements, and design and production technologies that could potentially reduce the construction contract cycle for the Mid-Term Fast Sealift ship, as time is now recognized as a major cost driver in ship procurement (2). The construction contract cycle was defined as the amount of time from construction contract award to delivery.

Producibility, also known as design for production, was defined to include the following processes:

- rationalization of the ship acquisition/procurement process;
- organization of design and production in accordance with a product-based build strategy;
- development of an understanding of the limitations of existing ship production technology;
- continuous scrutinization of the product, and the design, procurement and production processes to simplify them; and
- continuous scrutinization of the product, and the design, procurement and production processes to create standards.

Rationalization of the ship acquisition process results in a thorough understanding of all aspects of the procurement process as it presently exists. This rationalization results from the detailed description of individual process functions and their relationships, along with the

identification of the time and resources required to perform these functions. Upon completion of this rationalization, intelligent choices can be made as to where within the process improvements are possible (4). The Mid-Term Fast Sealift Producibility team worked from an assumed understanding of the present Navy and commercial procurement processes. However, the team believes that a formal and detailed analysis of these procurement processes would be beneficial.

A build strategy is a basic construction plan (5). This plan describes how the ship will be manufactured and also specifies the types of engineering and design deliverables required to build the ship efficiently. Modern build strategies are based upon product-oriented design and construction (PODAC) methods which, in turn, are based upon group technology (GT) and product work breakdown structure (PWBS) (6). A detailed definition of the "generic build strategy" (GBS) concept is provided in the "Goals and Definitions" section below.

The build strategy should reflect an understanding of how best to manufacture the ship within the existing and expected future capabilities of the industrial base. This requires a thorough knowledge of the current manufacturing capabilities of all major domestic shipbuilders. Shipbuilder participation in build strategy development will assure that the build strategy takes into account the production capabilities of the industry. Shipbuilder participation should be augmented with studies of worldwide state-of-the-art ship production methods and technologies. A build strategy is considered "generic" when it facilitates the construction of the ship at all shipyards with certain minimum capabilities.

Design for production also requires continuous scrutinization of the product, and procurement and production processes in order to simplify and improve them, and to create product and process standards. The continuous simplification, minimization, and standardization of interim products and components is essential to improving the production process. In addition, it is important to assess the applicability of existing commercial standards and standardized interim products and processes already developed for other naval ships.

This paper addresses producibility in the context provided above. The remainder of the paper describes the goals and further definitions underlying the Mid-Term Fast Sealift producibility project, presents the specific producibility task achievements, and then provides conclusions and recommended actions in the areas of "product," "policy," "process,"

and “technology” which would support more cost-effective procurement of the Mid-Term Fast Sealift ships.

GOALS AND DEFINITIONS

Several additional goals and definitions were established at the outset of the project to provide direction for the team. The overriding goal of the producibility project was to document how the adoption of modern ship construction and procurement methods can benefit the Navy and the industrial base. NAVSEA’s own process improvement efforts have identified that “the U.S. Navy is not fully realizing the significant benefits which could accrue from modern shipbuilding methods. These benefits include reduced construction cost, improved quality, and reduced construction time” (7). Specific producibility project goals and definitions are described in detail below.

Justification of Time as the Dominant of Performance

Time was selected as the dominant metric of performance for the procurement of all naval vessels. NAVSEA has identified through its own process improvement efforts that too much time is required in the present design and procurement environment to take a ship from concept through construction, and that this excessive time drives up procurement costs significantly (7). Therefore, a primary task of the producibility team was to identify and examine product characteristics, procurement policy and process improvements, and technologies that might reduce the construction contract cycle for these ships.

Navy studies aimed at lowering costs and improving productivity have traditionally been based on the identification of ship system work breakdown structure (SWBS) -based cost drivers. However, in a product-oriented environment new metrics must be found in lieu of these traditional methods. Modern commercial manufacturers focus upon metrics such as “time to market,” and “throughput coefficients” to quickly respond to changing customer requirements, maintain market share, and drive costs per unit of production lower. These metrics use the component of time to measure effectiveness; emphasis is placed on identifying throughput inhibitors rather than cost drivers. Japanese shipyards invest significantly in reducing cycle time through continuous rationalization and improvement of products and production techniques; this type of investment has a higher priority than investment in capital improvements because the potential payback is considered much greater (8).

Recent international trade negotiations attempting to “level the playing field” with regard to subsidies on behalf of the U.S. shipbuilding industry are only addressing part of the problem. Even if these negotiations are successful in eliminating foreign shipbuilding subsidies, the fact still remains that it would take up to twice as long to build a particular ship (from construction contract award to delivery) in the United States as it would take elsewhere in the world (4). Current data shows construction contract cycles for large foreign-built commercial ships of various complexities to be 12-24 months in length (9). The most recent construction contract cycle performance for the construction of a moderately complex commercial container ship in the U.S. is approximately 28 months.¹² If the U.S. Navy wants to maintain a viable shipbuilding industrial base, it must find ways help U.S. shipbuilders address the “time to market” issue through improved procurement practices, contract policies, product development processes, and product and manufacturing technologies.

Definition of the Present Construction Contract Responsibilities

When a construction contract is awarded for a naval auxiliary ship within the present procurement environment (see Figure 1), NAVSEA provides the contracted shipbuilder(s) with Navy/design agent-developed functional (system) guidance drawings and specifications. The information and drawings provided are usually unsized and/or incomplete, and are almost never certified correct. Some material procurement is done by the Navy prior to

1 Source: Matson Navigation Co., San Francisco, for vessel presently under construction at NASSCO.

2 The inability of the U.S. shipbuilding industry to build ships within a competitive time frame places the United States at both a strategic and competitive disadvantage. A future would-be adversary might exploit this weakness in U.S. shipyards’ ability to replace shipping assets in a timely manner. In a commercial venue, customers usually want their ships as quickly as possible. Late delivery of a new ship may represent lost revenue while loan payments are being made. Also, a longer construction contract cycle drives up the time-related portions of construction costs making a ship more expensive to acquire. Owner/operators are likely to take their business elsewhere if a shipbuilder is incapable of supporting a competitive construction contract timetable.

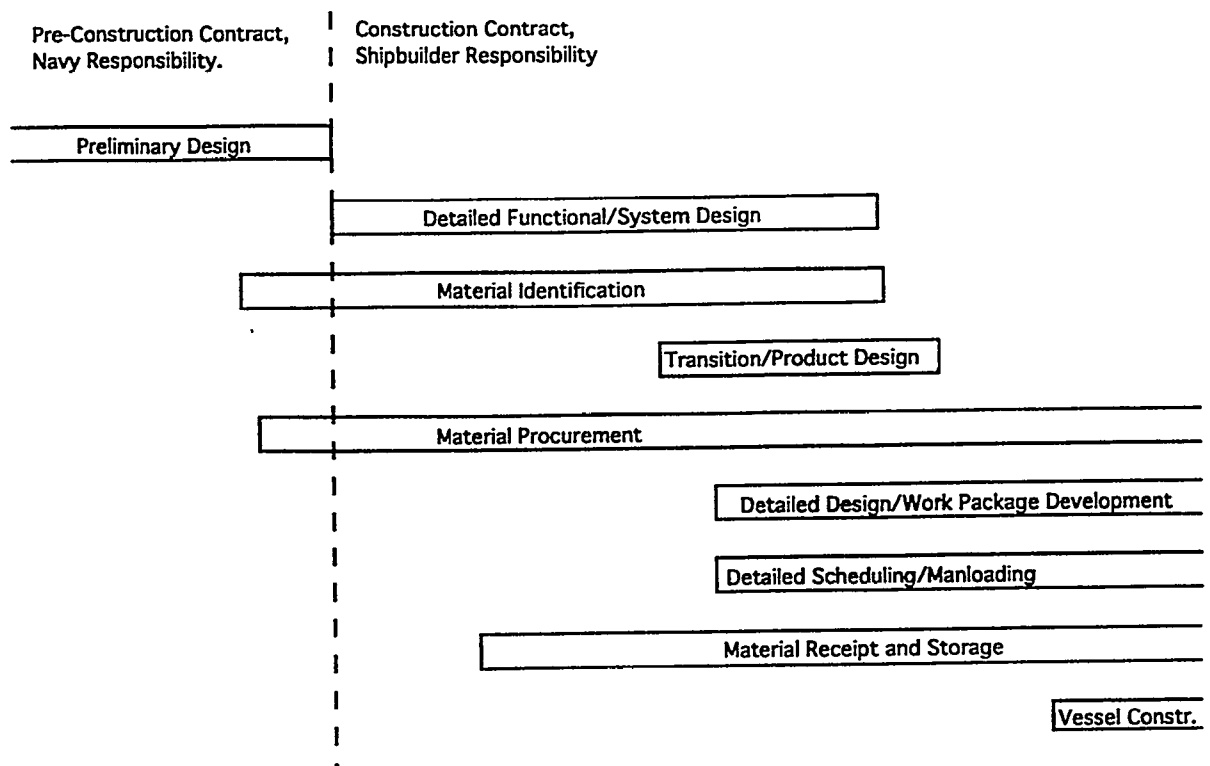


Figure 1. Present Procurement Environment Responsibilities.

construction contract award. As part of the construction contract, each shipbuilder is then responsible for completing and checking functional design, and for accomplishing any transition and detailed design work they require to support their way of doing business, developing system-based and product-based bills of material, procuring most material, and finally building and testing the ship. Transition design includes the development of multi-system composites and the definition of the ship's product structure. Detailed design includes the development of shipyard-specific plans, production documentation and drawings, and schedules supporting construction.

Development of FSS Construction Contract Targets

Recent naval auxiliary construction contract durations contrast sharply with construction contract durations associated with commercial procurement of similar ships. The best recent performance for a U.S. Navy auxiliary lead ship construction contract was 46 months on a naval fleet oiler program (TAO-187) (10). A commercial variant of this ship was acquired in the United States in 30 months during the early 1980s (4). That same commercial variant can be acquired on the world market in

20 months.³ Reference is also made to past domestic design and construction performance on RO/RO ships at Sun Shipbuilding and Dry Dock Co.: these vessels required one year to design and one year to build (11). The producibility team chose 24 months as its initial construction contract cycle target for the Mid-Term Fast Sealift ship because this cycle time lies between the best current domestic and foreign construction contract cycle times. A secondary target of 18 months was identified to account for the potential development and adoption of future productivity-enhancing design and production technologies, and the potential adoption of procurement policies which support continuous production from ship to ship in a shipyard.

Estimation of Potential Cost Savings Resulting From Shorter Construction Contract Cycles

NSWC, Code 1253, conducted a basic cost analysis to estimate what a 24-month construction contract cycle could save in dollars. In support of this analysis, construction cost return information from the Cost Assessment Office, Code 1210, was reviewed for a recent naval

³ Source: Bremer-Vulkan AG, Bremen, Germany.

auxiliary in the LSD-41 (Dock Landing Ship) class. This review lead to the identification of six cost categories. These categories, along with their respective percentages of total cost, are listed below.

LSD-41 Cost Breakdown

1. Direct Labor - Work related	14%
2. Direct Labor - Time related	2%
3. Variable Overhead	7%
4. Fixed Overhead	15%
5. Material	55%
6. Profit	7%

These categories and their respective cost percentages were then applied to the estimated construction cost of the Baseline Oa design, assuming a 42-month construction contract cycle and a \$385M price as estimated by NAVSEA (1, 2).

42-month Construction Contract Cycle Cost Breakdown

	<u>% Total Cost</u>	<u>\$ (Mil.)</u>
Dir. Labor-Work rel.		54
Dir. Labor-Time rel.	2.0	8
Variable Overhead	7.0	26
Fixed Overhead	15.0	58
Material	55.0	212
Profit	<u>7.0</u>	<u>27</u>
Total	100%	\$385

In estimating costs for a 24-months construction contract cycle, the "direct labor, time-related" cost category was reduced proportionally to the overall schedule reduction of 43 percent. Both the "variable overhead" and "fixed overhead" cost categories were also reduced proportionally to the overall schedule reduction resulting in a 43 percent savings. For the purposes of this exercise, material escalation was estimated at 5 percent per annum; the 18-month time reduction translated into a 7.5 percent reduction in "material" cost category. The "profit" cost category remained at 7 percent of the total cost. However, due to the overall cost reduction, the dollar value for the profit would be reduced by approximately 15 percent. The "direct labor-work related" cost category remained at \$54.0M meaning that the direct labor work content was assumed to remain constant. The following table shows the resulting cost figures for a 24-month construction contract cycle.

24-month Construction Cycle Cost Breakdown

	<u>% Total Cost</u>	<u>\$ (Mil.)</u>
Dir. Labor-Work rel.		54
Dir. Labor-Time rel.	1.4	5
Variable Overhead	4.6	15
Fixed Overhead	10.2	33
Material	60.2	196
Profit	<u>7.0</u>	<u>23</u>
Total	100%	\$326

The resulting estimated cost savings for a 24-month construction contract cycle are approximately \$59M per ship, or 16 percent, while holding the direct labor work content constant. However, it is important to recognize that a traditional procurement represented by the 42-month construction contract cycle includes a considerable amount of functional and transition design, material and vendor-furnished information (VFI) procurement, and test planning that would have to be done prior to construction contract award to support a 24-month construction contract cycle. If it is assumed that this work costs 2.5 percent⁴ of the NAVSEA procurement cost estimate of \$385M, or about \$10M, and that the cost of this work will not change when it is conducted prior to the award of the construction contract, the savings will still be about \$49M per ship, or 13 percent, while holding the direct labor work content constant.

The development and adoption of advanced design and production technologies, and the use of procurement policies which support continuous production from ship to ship could, over time, help reduce construction contract duration and direct labor man-hours. Following is a NSWC-developed cost analysis for an 18-month construction contract cycle.

18-month Construction Contract Cycle Cost Breakdown

<u>Cost Category</u>	<u>Total Cost</u>	<u>\$ (Mil.)</u>
Dir. Labor-Work rel.	14.7	43
Dir. Labor-Time rel.	1.2	3
Variable Overhead	3.8	11
Fixed Overhead	8.5	25
Material	64.8	191
Profit	<u>7.0</u>	<u>21</u>
Total	100%	\$294

4 UMTRI estimate based on shipyard-provided information.

The additional cost savings resulting from an 18-month construction contract cycle (beyond those savings already realized from a 24-month construction contract cycle) is 8 percent, or \$32M per ship. This 8 percent savings includes a conservative 20 percent estimate of the reduction of direct labor costs resulting from the use of new production technologies. These savings when added to the savings already obtained from reducing the construction contract cycle to 24 months (and taking into account the design, procurement, and test planning costs shifted prior to construction contract award) would result in a cumulative savings of approximately \$81M per ship. This cumulative savings translates to 21 percent of the NAVSEA acquisition cost estimate for the BLOa design.

Definition of the "Generic Build Strategy" Concept

The generic build strategy (GBS) was identified by the team as being a tool that could play a significant role in reducing the construction contract cycle to 24 months by serving as a focal point for overall procurement process improvement. A generic build strategy is a basic plan for the construction of the ship based on the proven principles of group technology (GT) and product-oriented design and construction (PODAC) (5). One objective of GT and PODAC is to design the ship so that it can be broken into groups or families of similar component parts, or interim products, based upon their manufacturing characteristics. A manufacturer can then optimize the application of his manufacturing resources to produce each of these product families. Another objective of PODAC is to outfit and test on-unit and on-block to the greatest extent possible, and to outfit on-board by zone (6). The development and use of its well defined product work breakdown structure (PWBS) in lieu of the traditional ship system work breakdown structure (SWBS) is essential to support GT and PODAC principles.

A GBS serves as a guide for all product development and production work, including all SWBS-based system/functional design work. The GBS also identifies all information content and formats required for production. The GBS for the mid-term fast sealift ships would encourage the incorporation of producible product attributes and globally accepted commercial standards during product development.

L i s t O f

- a. Assessment of industrial base capabilities (vendors, shipbuilders)
- b. Hull block definition
- c. Zone definition
- d. Dimensional reference system
- e. Alignment procedures for propulsion equipment
- f. Molded lines definition
- g. Accuracy control plan
- h. Required tolerances
- i. Mat'l & design selections for hull structure
- j. Mat'l & design selections for deckhouse structure
- k. Hull outfitting schemes
 1. Deckhouse outfitting schemes
- m. Machinery space outfitting schemes
- n. Definitions of design and production information requirements
- o. Assessment of existing industrial base work load
- p. Basic high level schedules (material, information, production)

The shipbuilders on the producibility team have emphasized that the Navy and shipbuilders must work together to define a meaningful GBS which supports a 24-month construction contract cycle. The level of cooperation required between the Navy and shipbuilders during all stages of product development to support a meaningful GBS will, in turn, require that significant changes be made to existing product development policies and processes. Traditionally, functional/system design, and any transition and detailed design considered necessary to support the shipbuilder's construction methods have been completed by the shipbuilder as part of the construction contract, as shown in Figure 1 above. In contrast, Figure 2 shows that some of this work would have to be done prior to construction contract award as part of a GBS which supports a 24-month construction contract cycle. Some of the specific activities which would have to be much more complete prior to construction contract award are: 1) functional and transition design (this includes all composite drawings and product definition), 2) identification of nearly all of the material, equipment, and supporting VFI, and ordering of all schedule-critical material, equipment, and supporting VFI, 3) development of much test planning and some supporting documentation, and 4) development of cost estimating tools which accurately assess the cost of PODAC-based ship construction.

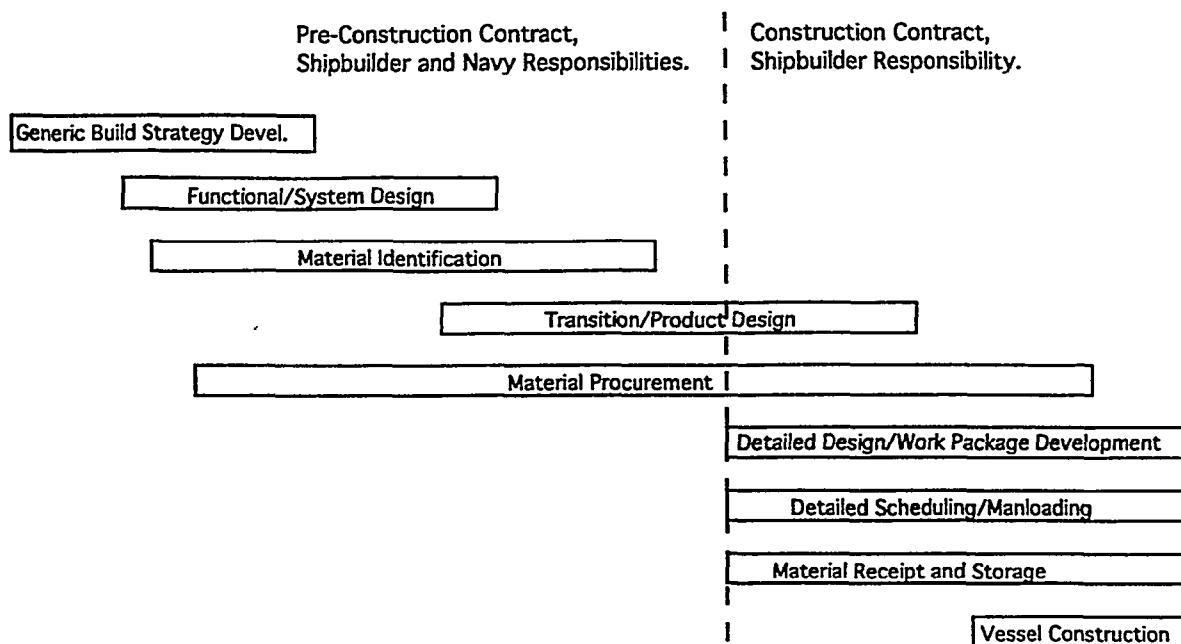


Figure 2. Possible Procurement Responsibilities.

The content and format of each of the elements of the GBS must be defined such that the information provided by the GBS is useful for detailed product development and construction. Each shipbuilder would agree to use the GBS as a construction guideline if they were to win a construction contract. In this regard, the GBS must be useful for contractors without intruding upon the detailed management of their manufacturing operations. The purpose of the build strategy is to establish the direct linkages needed between design and manufacturing so as to optimize the overall ship acquisition process, and to facilitate the organization of production work by a variety of individual U.S. shipyards to suit their individual needs. The GBS is not intended to dictate how contractors and vendors manage their people and facilities.

HIGH-LEVEL BUILD STRATEGIES FOR THE FSS BLOa

Both of the larger shipyards on the producibility team produced high-level build strategies for the BLOa design based on their experience with designing and building similar vessels. In the following discussions of build strategy these shipyards are referred to as "Shipyard A" and "Shipyard B."

Structural Build Strategies

Both Shipyard A and Shipyard B would use 15.24 m (50 ft.) long structural erection blocks. Both shipyards indicated that there would be a need to expand their present pin jig/curved block assembly areas to accommodate the large percentage of curved structural units/blocks associated with this hull shape. Both shipyards would define the innerbottom blocks to extend to where the innerbottom meets the side shell, and would choose to erect innerbottoms without side shell attached.

Shipyard A would define other structural blocks to include a single deck and the single-level shell and bulkhead adjacent and below. These structural blocks would be approximately half-breadth with erection breaks defined just to one side of centerline (see Figure 3). Shipyard A

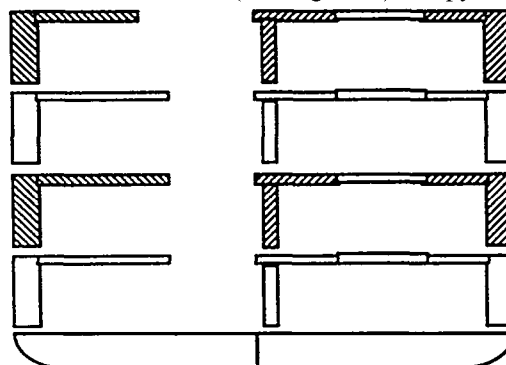


Figure 3. Shipyard A Erection Units With Modified Hatch Openings.

assumed that there would be centerline columns in the holds. Shipyard A moved the hatch openings toward centerline to decrease the number of erection units (see "Structural Product Considerations" section below). This product structure resulted in 199 structural erection blocks including stem ramp, rudders, and cranes.

Shipyard B would define side shell blocks two decks high, and each individual 15.24 m (50 ft.) section of deck and each bulkhead would be a separate erection block. The transverse structural blocks would be approximately half-breadth with erection breaks defined just to one side of centerline (see Figure 4). Shipyard B also assumed that there would be centerline columns in the holds. Shipyard B assumed that a skeg would be part of this baseline design. Shipyard B's structural product structure definition resulted in 263 structural erection units/blocks including stem ramp, rudders, cranes, and skeg.

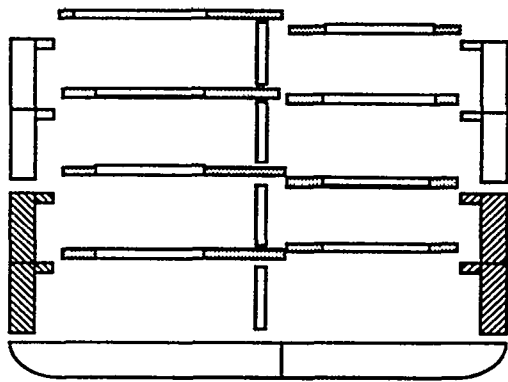


Figure 4. Shipyard B erection units.

Outfitting Build Strategies

Both shipyards expect that this ship's, or any other sealift ship's, product structure would be based on a product/zone oriented work breakdown structure which would facilitate pre-outfitting to the maximum extent possible.

Both shipyards would pre-outfit as many moveable ramps, hatches, and watertight doors as possible to their respective decks and bulkheads before these decks and bulkheads are erected. Because of the dimensional criticality of these components, final alignment, fitting, and welding of these ramps, hatches, and doors would be completed after erection.

Both shipyards would pre-outfit and test distributive system piping, hydraulic power units for ramps and doors, ventilation systems, light fixtures, local junction boxes and wiring, etc. to the maximum extent possible prior to erection.

Both shipyards expect that pre-assembled and tested outfitting components would be specified to the maximum extent possible. These components would include cranes, mooring winches, anchor windlass, etc.

Shipyard B defined its engine room around the machinery arrangement provided by NAVSEA for this study. Following are the important characteristics of Shipyard B's main machinery space:

- 1) The equipment on the 3.96 m (13 ft.) level would be broken into 9 outfit package-units/assemblies which would fit around the main engine, the reduction gears, and the SSDG's (see Figure 5).
- 2) Equipment on each upper level would be divided into 4 to 6 outfit package-units/assemblies which would cover most of each level.
- 3) All of these outfit package-units/assemblies would be pre-assembled and tested to the maximum extent possible prior to erection.

Shipyard A has proposed an alternative engine room arrangement which could greatly enhance the producibility of this ship. This arrangement differs from the NAVSEA-provided arrangement in the following ways.

- 1) The main engines and reduction gears are moved aft in the main machinery space as far as possible while maintaining reasonable access to the aft side of the gears.
- 2) The uptakes/stack(s) are moved aft of the deckhouse rather than being integral to the deckhouse. This arrangement would, to some extent, remove ship accommodations work from the critical path associated with main machinery space outfitting and testing. This arrangement would have the additional benefits of simplifying the paths for exhaust uptakes and air intakes, and removing a major source of noise and vibration from the middle of the accommodations spaces.
- 3) Most other main outfit components, and the machinery control room (MCR) are incorporated within three "cores" arranged transversely forward of the main engines. These "cores" are multi-level assemblies of outfit package-

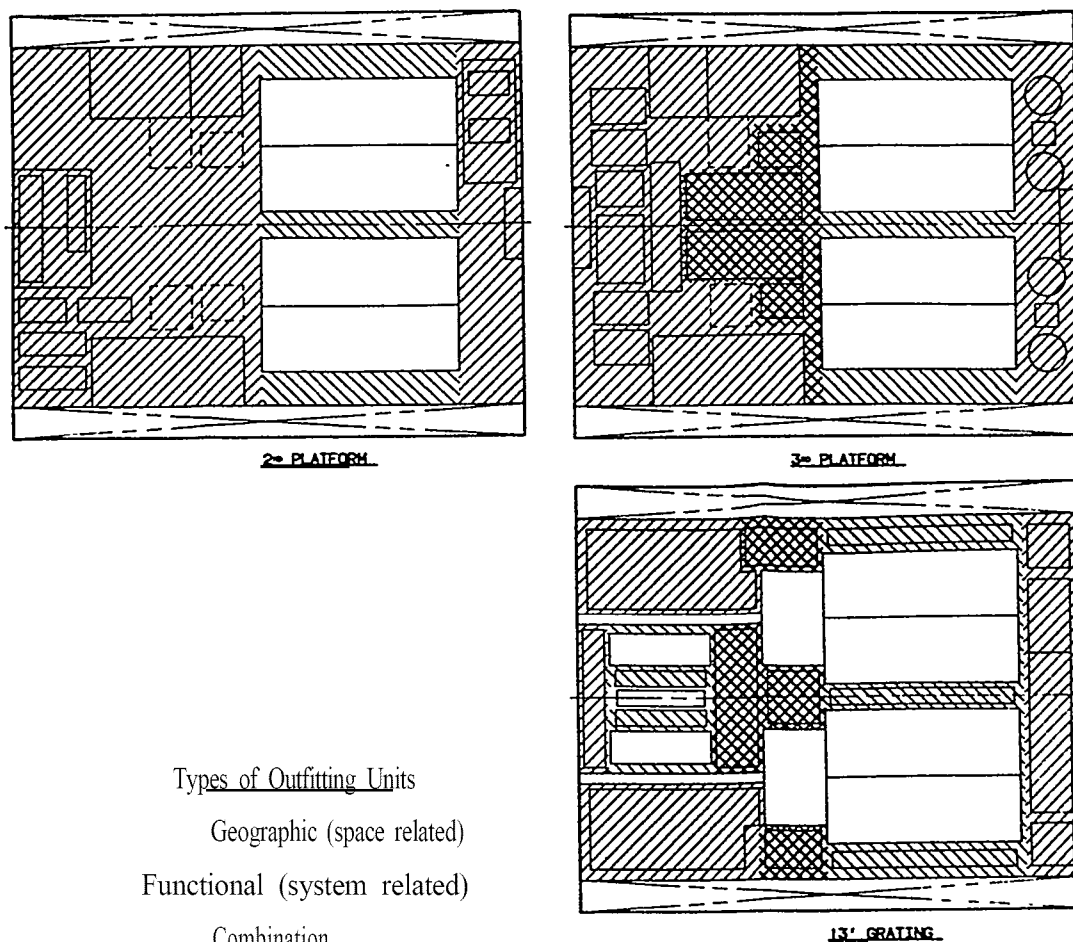


Figure 5. Shipyard B Outfit Unit Definition and Layout.

units/assemblies with their associated support structure, foundations, wireways, catwalks, etc. (see Figure 6). The cores would weigh 100-200 tons complete and could be erected either as singular erection lifts, level by level, one outfit unit at a time, or component by component depending on the capabilities of the shipyard erecting the ship. This arrangement would provide maximum flexibility for the shipbuilder to conduct outfitting work and testing on-unit and on-block either at the shipyard or at subcontractors, and would also provide maximum access around and above the main engines and reduction gears. The MCR would also be moved from above the main engines and reduction gears which would prevent the MCR from restricting uptake routing, and would significantly reduce noise and vibration within the MCR.

- 4) Long-lead auxiliary equipment such as SSDG's, auxiliary boiler, HVAC units, etc. are arranged on upper levels making this arrangement less schedule-critical (see Figure 7). Being able to erect the cores complete, level-by-level, one outfit unit at a time, or component-by-component provides some schedule flexibility for late components. This arrangement would have the additional benefits of preventing auxiliary system failure due to lower-level flooding of the engine room, and also moving these systems closer to air intakes and exhaust uptakes.
- 5) Main wireways and junction boxes are located on the forward engine room bulkhead to allow easy access.

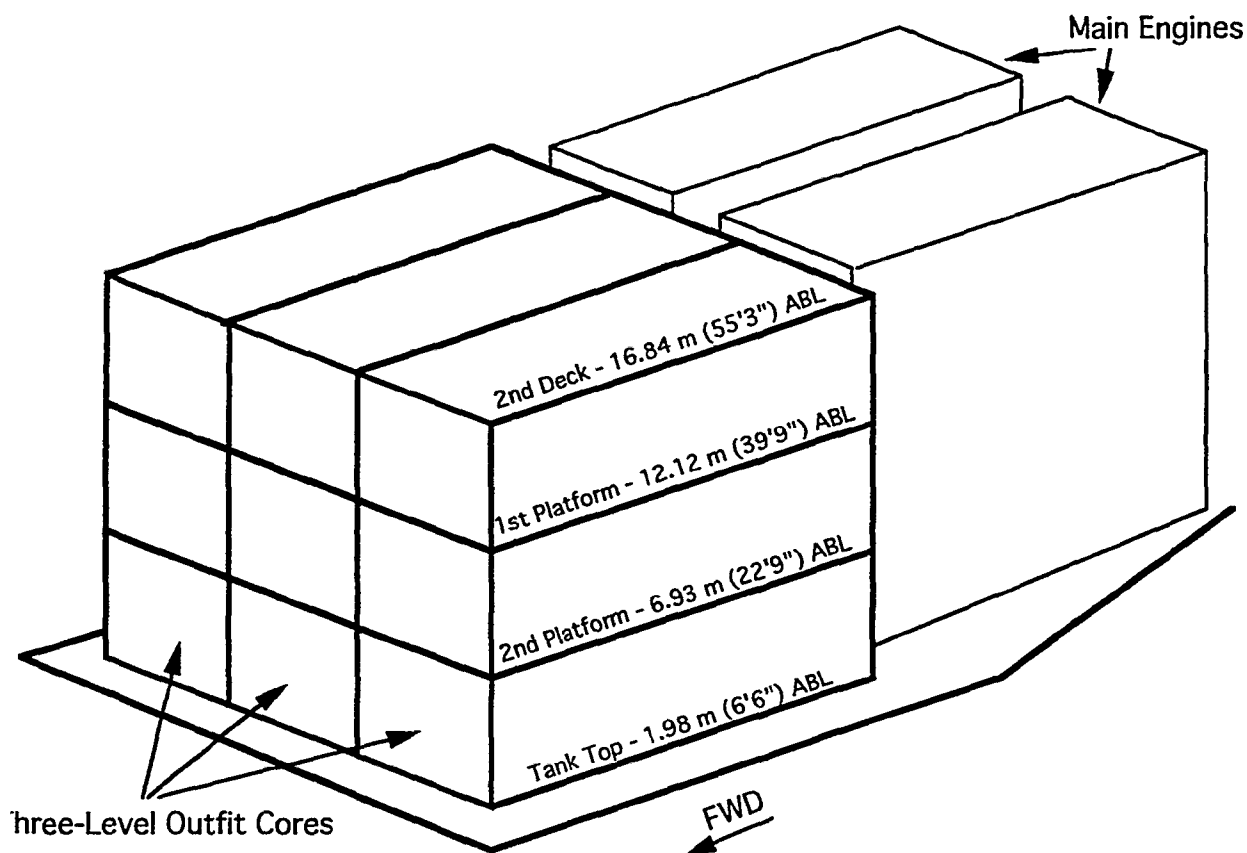


Figure 6. Re-Arranged Engine Room With Outfit Cores.

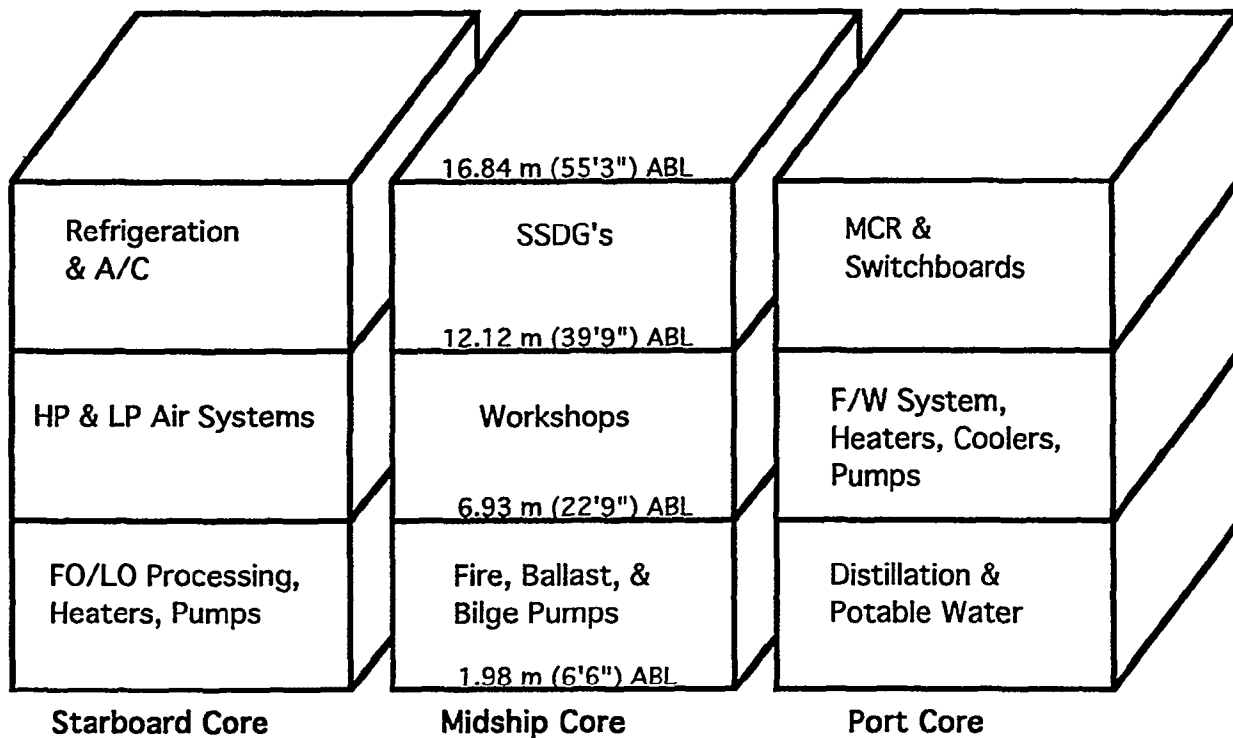


Figure 7. Possible System Arrangement Within Outfit Cores.

PRODUCT-RELATED RECOMMENDATIONS

Improving the producibility of the product itself would contribute significantly to the reduction of the construction contract cycle to 24 months. Following are the results of the producibility critique of the FSS BLOa ROM design as it existed in September 1991._

Structural Product Considerations

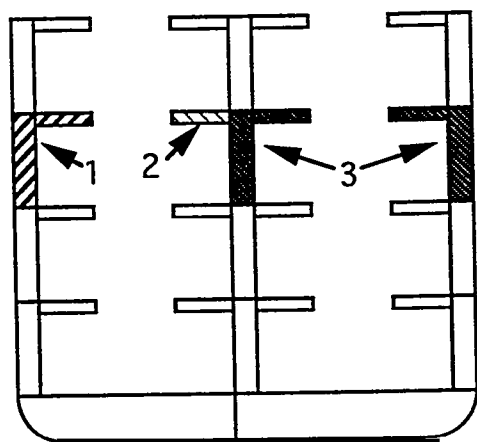
Hull Shape. The BLOa design has a significant amount of complex hull shape and no parallel mid-body. For this baseline design, NAVSEA should consider altering the shape of the hull near and above the design waterline to provide more flat and simple curved structure. The labor hours per ton cost difference is significant between flat/simple curved blocks and complex curved blocks. Flat shell plate and associated structure require no forming and shell plate with simple curvature and associated structure can be easily machine formed. Complex curved shell plate and associated structure require a combination of more difficult machine forming and heat forming. Flat and simple curved blocks can be welded using mostly automatic and semi-automatic methods. Complex curved blocks require much more manual welding. Also, the labor hours required for layout, fitting, and accuracy control are significantly higher for complex curved blocks. Finally, complex curved blocks are not repetitive and require either unique fixtures or pin jigs for assembly at a substantial capital cost. The hull shape may not be as much of a problem for other baseline designs.

Hatch Position and Number of Erection Units. Careful consideration should be given to the position of hatches as hatch placement might have an effect on the number of erection lifts-required (see Figure 8).

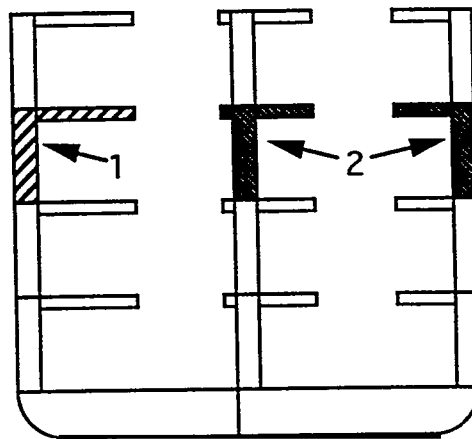
Innerbottom and Adjacent Bulkhead

In sections of the ship where there are outboard longitudinal bulkheads and an innerbottom, the innerbottom should be designed with the tank top extending to the side shell, and the longitudinal bulkheads should end at the tank top. This innerbottom configuration will provide a convenient platform onto which vertical structural units can be erected.

Alternative Structural Details. NAVSEA's own process improvement effort has identified that "(the) Navy should get familiar with shipyard standards and standard details" (7). All structural details should be examined for improving ship producibility. As an example, existing vehicle tie-downs are castings that must be welded into the deck from both above and below. These castings are expensive long-lead items, and their installation is labor intensive and requires early access to both sides of each deck. This additional access requires additional repositioning of each deck over and above the repositioning already required for other outfitting. The installation of these castings and their supporting structure make the assembly of the decks much more schedule-critical with the possibility of their effecting overall construction duration. A possible alternative might be that the clover-leaf openings could be automatically (NC)



Hatch Arrangement As Specified,
14 Erection Units Per Section.



Alternative Hatch Arrangement,
10 Erection Units Per Section.

Figure 8. Hatch Arrangement vs. Number of Erection Units.

cut in the deck plate, and pipe caps could be welded from the back side to serve as reinforcement and as watertight seals between decks. Uncoped flat bar could be used to back these caps. The more standard the structural configuration and the positioning of these tie-downs, the more amenable this installation work is to automated/robotic fitting and welding. Another structural detail producibility example is the potential for use of bulb plate rather than angles and T's in some ship structure.

Drive-Through Passageway Arrangement.

Main deck drive-through passageways should be positioned so as not to interfere with engine room casing(s)/uptakes, and such that they complement second deck structure. For example, port and starboard main deck passageways could be positioned similarly to passageways on second deck - this would simplify deck structure.

Deck Height and Structural Design Deck heights and/or beam depths should be designed to allow the running of as many distributive and service systems as possible without having to penetrate structural members. This would apply in accommodations and other spaces.

Shipbuilder Involvement In Design

Shipbuilders should be involved in conceptual, preliminary, and functional design to help identify and develop the type of ideas discussed above.

Outfitting Product Consideration

PODAC Compatibility of Design The FSS design must be completely compatible with product/zone oriented work breakdown structure to facilitate maximum pre-outfitting, early testing, and aggressive construction schedules. The earlier outfitting work and testing can be completed in the construction process, the less time it will take and the less it will cost (6). There is a substantial increase in the time and cost required for work from one construction stage to the next (on-unit to on-block to on-board) (see Figure 9).

Alternative Engine Room Arrangement

NAVSEA should carefully consider the potential benefits of alternative engine room

arrangements. Both shipyards agree that an alternative arrangement such as that proposed by Shipyard A could reduce construction duration and cost. The development of a producible machinery arrangement would be greatly facilitated by the development of physical and/or CAD design models.

Major Equipment Decisions. Both shipyards expressed significant concern over seemingly premature and/or ill-considered NAVSEA decisions on major propulsion equipment for the FSS BLOa design variant. Both shipyards feel that these type of decisions can jeopardize any attempt to improve the efficiency of construction and operation of any ship. This is particularly true when unproved major equipment has been specified.

In the case of the BLOa, only one of the 18 PC4.2V Colt-Pielstick engines specified has ever been built. In addition, there are no build/test beds in this country capable of accommodating these engines. This makes the delivery of these engines to support aggressive construction schedules of the mid-term sealift ships a potentially serious problem, even at this early date. The reduction gears will also cause problems with regard to their development and delivery. To the shipyards' knowledge, no single-reduction gear has ever been built to accommodate two 22,000 kilowatt inputs and an almost 45,000 kilowatt output. Double reduction gears with this capability have been built, but have not yet been designed for a reduction from a 400 RPM input to a 120 RPM output.

Additionally, even if the specified equipment were available to support an aggressive multi-ship procurement schedule, sealift ships with these machinery specifications would be very complex and expensive to operate and maintain. This expense would remove such ships from the category of "commercially viable."

NAVSEA should be absolutely certain that equipment specified for these ships will be proven and available to support aggressive multi-ship build schedules. NAVSEA should also consider the impact that equipment decisions will have on operations complexity and expense, and on the resulting commercial viability of these ships.

Modularized Accommodations. NAVSEA should consider the use of modularized accommodations spaces similar to those used on cruise ships. These are pre-fabricated cabins which are installed and attached to the hotel services with flexible couplings.

5 Data provided in Figure 10 was confirmed by two shipyards on the team based upon their own experience.

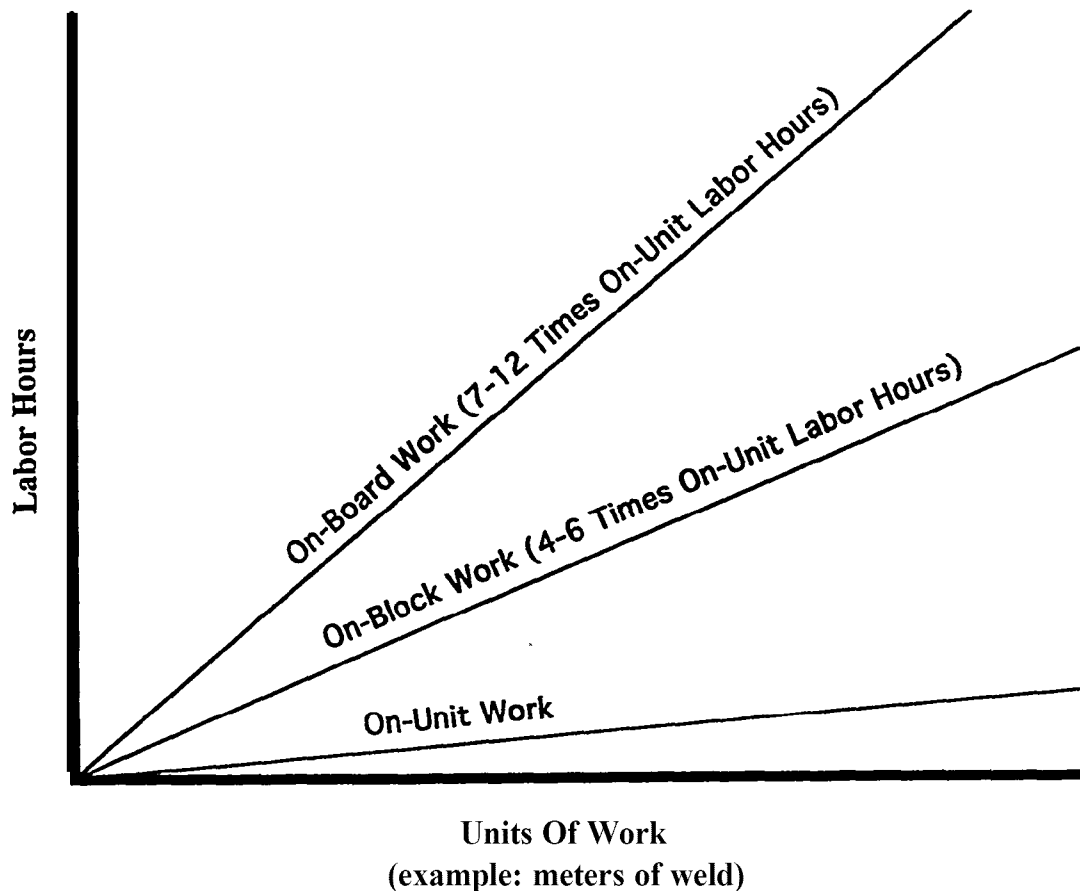


Figure 9. Productivity Versus Stage of Construction.

System Joining Technology. NAVSEA should consider the development and use of alternative systems joining technologies such as electrical splices, different couplings for pipe, etc. Present specifications related to system continuity and joining methods sometimes directly limit the amount of pre-outfitting and testing that can be completed on-unit and on-block.

Shipbuilder Involvement In Design. Shipbuilders should be involved in conceptual and preliminary design to help identify and develop the type of ideas discussed above.

Other Product Considerations

Commercial Standards. Navy auxiliary ship designs should be based on globally accepted commercial product and process standards to the greatest extent possible. Using commercial standards would allow both the Navy and the shipyards much greater flexibility in procurement, and would significantly reduce integrated logistics support (ILS) and contract

data requirements list (CDRL) requirements, and the inspection, testing, approval, and reporting requirements associated with the construction and maintenance of these ships. The shipyards identified that using commercial standard equipment, materials, and procedures could help reduce the time from launch to delivery, which averages 8-10 months on present Navy auxiliaries, by up to 3 months.

Metrification. Metrification is inevitable if U.S. shipbuilders wish to compete in the global shipbuilding market. In fact, both shipyards on the team are already using some metric-based material and equipment in their commercial work. Both shipyards feel that in spite of the considerable initial cost, the sooner the Navy supports the conversion to metric, the less costly and more beneficial the conversion will be in the longer term for the Navy, U.S. shipbuilders, and the supporting industrial base. In the short term, it is recommended that NAVSEA initiate cost/benefit analyses to determine the effects of implementing metrification over time.

Standardized Interim Product The development and use standard interim products, such as the fan room package produced by Avondale Industries for the LSD 41 and LSD 41 (CV) classes, could significantly reduce the duration and cost of follow-ship design, material identification and procurement, and construction, even for new and different classes of ships. The standardization of interim products would also reduce the cost of ship maintenance through reductions of spare-part inventories and custom-made components and systems. Standard outfitting units, such as chill water machinery units of various sizes/capacities, SSDG units of various sizes/capacities, fire pump units, etc. could be developed to globally accepted commercial specifications. This ties in directly with NAVSEA's "Affordability Through Commonality" initiative. NAVSEA should actively involve shipbuilders and the shipbuilding-related industrial base when developing standard interim products.

Existing Alternative Materials Existing alternative materials should be identified and evaluated for potential savings in construction duration and cost. NAVSEA's own process improvement effort has identified that the Navy should "...allow use of alternative materials, especially better ones" (7). Some of these materials are poured epoxy chocks, composites (piping, joiner bulkheads, etc.), spiral ducting, U-bolt pipe mounts, and bulb plate stiffeners.

POLICY-RELATED RECOMMENDATIONS

Following are procurement policy issues that would have to be addressed to support a construction contract cycle of 24 months.

Product Development Policy

Navy ship design-related and construction-related policies should be re-defined to clearly describe the various product development stages and the extent of shipyard involvement in each of the following:

- conceptual, preliminary, and functional design;
- material, equipment, and **VFI** procurement;
- transition design;
- detailed design and construction.

NAVSEA's own process improvement efforts have identified that "ship acquisition rules frequently inhibit incorporation of design changes by shipbuilders which could enhance producibility" (7). Both shipyards on the

producibility team strongly recommend that the Navy redefine its shipbuilding related contracting procedures to accommodate shipyard involvement throughout the procurement cycle, from conceptual and preliminary design through delivery. The Navy should obtain shipyard input to help define the product development process and associated contracts.

Commercial Standards Policy

Existing globally accepted commercial standards should be approved for incorporation into sealift design to the greatest extent possible.

Design Change Policy

A policy to eliminate, or at least significantly limit design changes after construction contract award must be established. NAVSEA's own process improvement efforts have identified that there are significant unnecessary costs associated with excessive design changes (7).

Vendor Approval Policy

A streamlined Navy approval process for vendors proposed by shipbuilders must be created, and/or vendor pre-selection should be supported.

Multiple Ship Procurement Policy

The Navy should consider using multi-ship procurements so that shipbuilders can take advantage of design and planning standards developed on earlier hulls and keep process lanes going continuously. Multi-ship procurement would also encourage investment in re-tooling and automation for repetitive work. Multi-ship procurement would have a significant positive impact on procurement duration and cost per ship.

PROCESS-RELATED RECOMMENDATIONS

All improvements in the product development process identified below are dependent upon satisfactory resolution of many policy issues identified above.

The Design Process Prior To Construction Contract Award

As identified in the "policy" section above, shipbuilders feel that they must be involved in every stage of product development to assure the producibility of the ship design. NAVSEA's own process improvement efforts have identified that

“potential cost savings (are) not being realized (with) producibility not part of early design stages. . . . NAVSEA ship designers are not sufficiently knowledgeable of the latest advances in ship construction technology to incorporate producibility features in the design. . . . NAVSEA design policies, procedures, and standards do not routinely address design trade-offs relative to ship production efficiency. . . . There is a lack of concurrent product and process design and an inconsistent approach to addressing producibility among ship designs” (7).

The ship design/product development process should focus upon the development of a generic build strategy for the ship, meeting the specified functional requirements, and incorporating producible characteristics into the design. The generic build strategy would support the incorporation of design-for-production attributes and globally accepted commercial standards to the greatest extent possible, and would facilitate the organization of production work by a variety of individual U.S. shipyards to suit their mutual and individual needs. The GBS would be used to guide product development and production planning.

In support of the GBS, all functional and much of transition design would be completed prior to construction contract award. Transition design is defined to include the development of all multi-system composites and the ship's product structure. Also, as part of the design process all material, components, and VFI would be identified prior to construction contract award, and all schedule-critical material, components, and VFI would be ordered prior to construction contract award to support design and construction schedules. All important testing requirements would be identified and some supporting documentation prepared prior to the construction contract award. The normally inactive period of time between submittal of shipyard quotations and construction contract award (6-18 months⁶) could be used by shipyards, perhaps working with NAVSEA, to complete some of the work identified above.

Cost Estimating Processes and Tools

The development of a GBS that is based on PODAC concepts would require the support of cost estimating methods and tools that accurately reflect the costs of building a product-oriented ship design in a modern ship construction environment. Some current NAVSEA cost

estimating algorithms may not accurately reflect the benefits that can accrue from the utilization of product-oriented design and construction methods, and from the incorporation of producibility-related characteristics into a design. Many existing NAVSEA algorithms are known to be system- and weight-based which sometimes drive reductions in steel weight at the expense of internal ship volume. These reductions in internal volume necessarily increase outfitting density and, in turn, drive up the cost of construction outfitting, maintenance, and overhaul, and may adversely impact the effective unitization of outfitting. NAVSEA's own process improvement efforts have identified that “the NAVSEA ship acquisition cost estimating process used in assessing the cost impacts of different design options is not adequately sensitive to producibility considerations in a ship design. . . . High cost drivers (are) not well understood; (there is a) lack of quantitative measures of producibility” (7). Current cost estimating algorithms should be critically examined and modified/replaced as necessary (perhaps with time- and/or density-based methods) to assure that they accurately reflect the costs/benefits of modern ship design and construction.

Material and VFI Procurement Processes

Procurement responsibility for material, equipment, and required VFI should be more clearly defined for each stage of product development. This would help streamline the procurement process by eliminating redundant administration and inspection requirements.

Detailed Design Process

Detailed design (which is defined to include the development of work instruction, construction drawing, and detailed/working schedule) should continue to be conducted by the shipbuilders after construction contract award as part of the construction contract.

Cost and Schedule Reporting Process

Cost and schedule reporting requirements outlined in the Department of Defense instruction DODI 7000.10 should be used for these ships (or something even less burdensome), rather than the full cost and schedule control requirements of DODI 7000.2.

⁶ Source: Shipyard experience with recent Naval auxiliary contracts.

Naval Auxiliary Ship Acquisition Process Model

A Navy auxiliary ship acquisition process model should be developed. It is important that all parties to the Navy auxiliary acquisition process clearly understand the process and agree where the greatest acquisition time reductions and savings could be gained for a given investment of resources. It is also important to have a tool that can be used to measure the effects of changes as they are implemented (4).

Shipyard Capabilities Survey and IMIP Information

A survey should be conducted to identify the facilities capabilities and construction philosophies of the different U.S. shipbuilders as related to Naval auxiliaries, and to use in determining the minimum level of facility and methods required to support future Navy auxiliary ship acquisition. This information would serve as a key starting element for the generic build strategy development process. It is also recommended that NAVSEA ensure that shipbuilders are made aware of these minimum requirements and that they are also made aware of the Industrial Modernization Incentives Program (IMIP).

Navy/Vendor "Tiger Teams." Complex Component Installation Processes

Technicians and specialists who are familiar with specific complex components and systems are expensive personnel for individual shipyards to keep on payroll full time so that they are available for relatively intermittent installation, testing and inspection work. The Navy, along with appropriate vendors, could maintain "tiger teams" for the installation, inspection, and testing of specific complex components and systems. These teams would rotate from shipyard to shipyard as needed, and thus would be kept busy on a full-time basis. This method of installation, inspection, and testing of complex outfitting would be worth investigating for potential savings.

SUPSHIP Construction Evaluation and Inspection Processes

As standards are developed and adopted more and more within the shipbuilding industry, the Navy's Supervisor of Shipbuilding (SUPSHIP) organizations at different shipyards should be trained to evaluate construction consistently according to these standards.

Circular of Requirements Process

A potentially more cost-effective method by which the Navy could procure fast sealift ships might be through a commercial-type procurement using a Circular Of Requirements. Both shipyards on the producibility team agree that the most cost-effective method by which they could produce these ships would be through the use of a commercial-type COR. Using a commercial-type procurement, shipyards would be responsible for all product development work including all design work, material procurement, VFI procurement, and construction. This type of procurement would help shipyards orient their operations more toward the commercial market. The potential cost savings associated with a commercial-type procurement can be demonstrated by comparing the NAVSEA-estimated \$385M price and the NSWC-estimated \$304M price to an estimated commercial market price of \$220-230M per ship.⁷ Container ships of similar size and with significantly less complex machinery arrangements are presently being built in Japan and Germany for about \$125M per ship (12). Adequate consideration should be given to commercial-type procurement methods which might reduce costs and result in ships which are more desirable for chartered commercial service.

TECHNOLOGY-RELATED RECOMMENDATIONS

Following are some technologies that could directly reduce, or facilitate the reduction of, the construction contract cycle if developed and implemented.

Modeling Tools

Physical and/or CAD design modeling capability could be developed for ship design and construction planning. Physical and CAD models of outfit-intensive areas within a ship, such as the

⁷ UMTRI estimate based on vessel complexity and current world market prices, and on information from a shipyard stating that a COR-type procurement for the BLOa ship would result in 20-25% cost and schedule savings at their facility over a traditional-type procurement. 75% of \$385M is \$289M; if the world's most productive shipyards are presently at least 20% more cost effective than any U.S. shipyard (an estimate that UMTRI feels is reasonable), then the current world market price would be less than \$231 M.

engine room, can be tremendously useful for identifying interferences and restricted accesses. Models can also be used to compare various product structure alternatives and associated erection plans for production and maintenance efficiency.

New Materials

Materials research should be conducted to identify and evaluate alternative materials or material applications which have not yet been used on ships of this type.

Producibility Guide For Design

A producibility guide for design could be developed to assure that designers and engineers (Navy, shipyard, design agent) have access to information that will support the incorporation of producible characteristics into ship designs. This producibility guide could be developed so that it could be accessed within the CAD environment. The guide would contain information from the numerous producibility studies that the Navy has funded over the last twenty years, as well as other information developed through the NSRP and by foreign shipbuilders. The available information would be maintained to represent the state of the art in naval ship construction.

Standard Materials Guide For Design

With increased use of standard interim products and components, a standard material guide could be developed for use by designers (Navy, shipyard, design agent). This guide could be developed so that it could be accessed within the CAD environment.

Automation in Production

With increased use of standard interim products, and, possibly, multiple-ship procurements, many production processes would be standardized and some could be automated. The assembly of structural panels is one example area where the associated production processes could potentially be automated, greatly reducing process variation and production cost.

Real-time Production Monitoring and Control

Improving shipbuilders' ability to monitor production in a realistic way and on a real-time basis could significantly improve their ability to identify and improve costly interim products and construction processes.

Electronic Data Transfer

Electronic data transfer could greatly enhance the efficiency of the ship acquisition process if the ship is being developed or built by multiple parties. Data requirements could be developed for in accordance with NIDDESC (Navy Industry Digital Data Exchange Standards Committee) guidelines.

Scaffolding Technology

Foreign shipbuilders use significantly more modular, moveable scaffolding than U.S. shipbuilders. Many U.S. shipbuilders continue to use old-fashioned pipe-and-plank scaffolding. The development of new scaffolding technology to coincide with the development of standard interim products would help reduce the difficulty of work on large units and on-board ship, improve safety, and reduce non-value-added labor hours associated with scaffolding set-up and tear down.

Jigs and Fixtures

The government and shipbuilders could work together to develop, build, and share jigs and fixtures for the fast sealift ships.

Test Equipment

The government and shipbuilders could work together to develop, build, and share test equipment for the fast sealift ships.

Welding and Heat-Forming Technology

Research should continue to be pursued in these areas to develop intelligent and automated systems for this work.

CONCLUSIONS

In determining what Mid-Term FSS research and development areas to support, the Navy must recognize that because the Ship Construction Navy (SCN) budget will not be capable of supporting the shipbuilding industrial base as it had during the 1980s, the survival of the industrial base is dependent upon becoming competitive in the world shipbuilding market. The Navy can support this objective by attempting to acquire auxiliaries that are as commercial in nature as possible. A determined effort must be made to increase the level of common types of hull, machinery, and electrical (HM&E) components that reside in commercial and defense-related ships. The Navy could also

modify its procurement practices to be more like commercial procurement practices. Failing to address these issues will result in a severely weakened and inefficient mobilization base by the end of this decade, as U.S. shipbuilders either go out of business or choose to compete only in the world market in order to maintain their commercial competitiveness.

In determining where to focus production-related RDT&E resources, it is also important to realize that a significant portion of the production technology needed to boost the industry's competitiveness already exists. Many U.S. shipbuilders have not implemented significant portions of this existing technology. For example, there are four prime components to product-oriented design and construction that have been documented within National Shipbuilding Research Program literature. These four components are the Hull Block Construction Method (HBCM) (6), Zone Outfitting Method (ZOFM) (6, 13,14), Zone Painting Method (ZPTM) (15), and Integrated Hull, Outfitting and Painting Method (IHOP) (16). To date, the Hull Block Construction Method is the only component that has been widely implemented by the U.S. shipbuilding industry. Some of the other components have been applied with varying degrees of success by some U.S. shipbuilders. The piece-meal application of PODAC concepts by most U.S. shipbuilders has not allowed them to realize the full potential of implementing all four components in an integrated fashion.

A major contributing factor to this lack of implementation has been the lack of incentives in past and existing Navy contracts. NAVSEA has already identified this as a problem through their process improvement efforts (7). A serious effort should be made to encourage and facilitate the implementation of existing fundamental ship production methods and technologies prior to Developing new technologies. The pursuit of contractual vehicles which can provide the incentive for full implementation of PODAC within the industrial base should be a top priority. The producibility team has identified the generic build strategy as a potential tool which, if properly executed, could provide the necessary focus for the Navy and the industrial base in this regard.

Recommendations which would support the successful implementation of a GBS and PODAC have been identified above. Most items requiring immediate action are associated with refining/changing existing design and procurement policies and processes, as these items are most critical to supporting GBS development and reducing procurement duration

and cost. Items requiring action in the longer term are primarily associated with the development of new shipbuilding technology as these items by themselves will have significantly less impact on reducing construction duration and cost.

It is impossible for the project team to estimate the cost of making the policy and process changes that will facilitate the development of a generic build strategy and the PODAC-based construction of the Mid-Term Fast Sealift ships. It is the team's belief, however, that the benefits that will result from such changes would far outweigh the associated Costs.

The Naval Surface Warfare Center, Carderock Division, has made some cost estimates for the development of a generic build strategy and for the development of some supporting product, policy, process, and technology areas. The project team is also analyzing many of the other product, policy, process, and technology areas identified in this paper to determine for each the time to develop, time to implement, cost to develop, cost to implement, potential time savings, and potential cost savings.

NSWC estimates that an investment of less than \$30M in the most critical producibility-related areas identified in this paper, if supported by necessary policy and process changes, will lead Mid-Term Fast Sealift development in a direction, as manifest in the development of a generic build strategy, that will result in significant savings over the NAVSEA estimated cost of \$385M per ship. The total estimated cost savings for a 24-month construction contract cycle are \$49M or 13 percent per ship. The total estimated cost savings resulting from an 18-month construction contract cycle are **\$81M** or 21 percent of the NAVSEA estimated initial acquisition cost for the BLOa design.

NAVSEA should continue its efforts related to improving product development and procurement policies and processes to create a more streamlined environment for the development and procurement of the Mid-Term Fast Sealift ships and all future Navy ships. The Navy should also begin to invest in the critical producibility research and development areas identified in this paper.

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