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Modular Payload Ships in the U. S. Navy

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This paper describes the results of intensive studies of a concept called SEAMOD which deliberately "decouples" payload and platform. It allows independent (and parallel) design and acquisition of payload and platform without taking the risk of perturbating the ship design after contract award. The potential payoff and problems associated with segregating the payload and platform into two distinct systems are discussed. The design impact on a typical 8000-ton destroyer (for example, arrangements, structures, displacement, stability, and support systems sizing) is presented. A conceptual version of a 4500-ton SEAMOD frigate is described. Finally, the impact on ship construction, ship modernization and the acquisition process is presented and analyzed. Conclusions reached point to SEAMOD as a way to simplify the design, development and acquisition of Navy surface combatant ships.

Introduction

CURRENTLY there are many problems which beset the Navy and the shipbuilding industry with regard to the design, development and acquisition of surface combatant ships. Control of acquisition cost and schedule is complex—partly because of changing interface requirements between payload and platform. The time and cost of ship construction are considerable—partly because of payload assembly/integration within a shipyard. Although replacement of payload is desired much sooner than replacement of platform, modernization and conversion during a ship's life cycle often requires a total "whole ship" redesign and is therefore done infrequently.

Under the current method of ship design and acquisition, new weapons systems developed by the Navy require almost 14 years before they can be introduced into the fleet; this includes seven years for the development of a new platform. Often weapons system development can exceed seven years, in which case the Navy is sometimes tempted to initiate platform development and construction before full service approval of weapon elements/systems is complete—bringing with it the risk that any change to the weapon/ship interface could impact the ship construction process. This approach, however, contributes to the difficulty in control of acquisition cost due to changing payload interface requirements and difficulties in shipyard integration, as summarized in a statement by Edwin M. Hood, President of the Shipbuilders Council of America:

> "Existing ship procurement practices and procedures, intensive competitive conditions, cyclical market opportunities, uncertain national policies, and uneconomical contract terms and conditions have contributed to a decline in profit margins. Particularly with regard to long-term Navy procurements, changes in vessel design imposed on the shipbuilder after the construction cycle has begun plus complexities of engineering approval procedures, and delays in the deliveries of major Government-furnished ship components, have caused, on many occasions, serious disruptions in shipyard operations, the full costs of which are never completely reimbursed or recovered." [1][2]

Thus it is seen that both the Navy and the shipbuilding industry are finding the job of efficiently producing a modern Navy combatant ship more and more difficult. It is the contention of the author that the foregoing symptoms are caused by a widening incompatibility in the rate and nature of technical evolutions between payload (weapon suite) and platform (ship). This is due to the following basic problems:

(*a*) A disparity in payload/platform development cycle.

(*b*) A disparity in payload/platform production technology.

(*c*) A disparity in payload/platform life cycle.

(*d*) A disparity in payload/threat matchup.

The first two problems are associated with the construction of new Navy ships. The last two problems are associated with the modernization and conversion of Navy ships. The first problem is caused by the fact that development of new weapons systems many times requires a technical breakthrough for advances in the state-of-the-art. Thus, allowance for seven years of development may be pessimistic or optimistic depending on the sophistication of the system to be developed. To plan a ship development in advance can become a risky approach, since, once basic platform sizing to accommodate the weapon suite takes place, pressures are brought to bear to "optimize" the ship and its internal support services (for example, electric plant) around the "frozen interface requirements of the weapon system." Any changes to the interface requirements can cause considerable perturbation to the ship platform.

The second problem is due to the change in the nature and level of sophistication between shipbuilding and modern weapons systems. Whereas during World War II most weapons systems were a combination of explosives and mechanical/manual methods to deliver them, we are now involved with super electronics/sensors, target/ballistic computation and supersonic missile delivery systems all requiring a computer

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[2] Numbers in brackets designate References at end of paper.

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SEAMOD "DECOUPLES" PAYLOAD AND PLATFORM THROUGH THE DEVELOPMENT OF PREPACKAGED MODULAR WEAPON SYSTEMS, WHICH CAN BE RAPIDLY INSTALLED IN SHIPS DESIGNED TO THE SAME INTERFACE

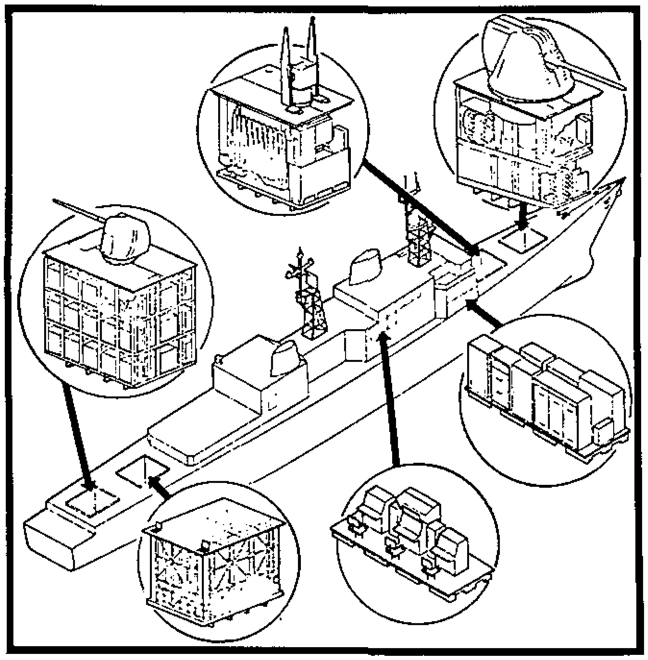

Fig. 1 The SEAMOD concept

to coordinate and initiate individual sequence actions in microseconds. The skills and technology required to design and manufacture weapons are different than those available in shipyards whose primary expertise is in welding, installation and alignment of large heavy-duty structures and equipment. That is not to say that certain aspects of weapon assembly are still not compatible, but so much of today's weapons system integration is connected with software integration and electronic calibration that the ability to "install the gun barrel" is not enough. Thus, where shipyards have gone into automation of steel construction and subassembly modularity, weapons systems have gone into electronics and missile fire controls systems.

Modernization of a Navy combatant is presently an expensive, lengthy affair. This is again due to the natural trend which combat systems have undergone over the past 30 years. Not only have they become complex, they have become a highly integrated system in which change to any element causes severe perturbations to the remaining system. This is particularly true when there is a large central computer controlling the total operation of the weapons system. Ironically, however, the "growth" of new weapon concepts has accelerated at such a maddening pace that the useful life of a specific weapon design (for example, Mark XX Mod X) becomes shorter and shorter. This is because technological advances cause the system to become obsolete in 5 to 10 years. Contrasted with this fact is the realization that the ship platform, usually due to seaworthiness and other safety factors, is built to last approximately 30 years (assuming no battle damage precludes its life as was common in World War II). Thus we have a rather expensive platform which will provide perfectly good service for 30 years, but which must undergo frequent weapons update if it is to be an effective element in the national defense.

Finally, there is the issue of type of weapon to be carried. Similar to the foregoing issue of having a useful platform for 30 years, there are times when the nature of the potential conflict may drastically change the "type" of weapon that is most effective. The most startling example in recent years was the modernization of the battleship *New Jersey* to fight in Viet Nam because most multipurpose ships did not have the extent or size of gun power to handle shore bombardment duties. Thus, the inability to quickly convert a ship from mission capability "A" to mission capability "B" can severely limit the Navy's ability to respond to change in world situations.

What can be done about these problems? Certainly they are not easy ones to address and they involve thousands of people in the Navy and the shipbuilding industry. However, it should be realized that, at the minimum, a reexamination is in order regarding the way we design ships and weapons systems and how it relates to the aforementioned disparities. The concept described in the remainder of this paper contends to be the answer, but the success of this hypothesis depends not so much on any technology breakthrough of one kind or another, but on the ability to manage and implement an entirely new philosophy in Navy ship design.

Concept definition

The concept presented within this paper is called SEAMOD, which stands for *Sea* Systems *Mod*ification and *Mod*ernization by *Mod*ularity. SEAMOD is a new concept for designing and constructing Navy surface combatants. It allows the independent (and parallel) design, development and acquisition of weapons systems payloads and platforms and permits interchangeability between the two. It achieves this capability through the establishment of comprehensive interface design standards which allow "decoupling" of payload and platform to occur but which insure their ultimate successful integration into an effective Navy ship. Figure 1 displays this modular payload approach. It is important to realize from the onset that the SEAMOD concept is not a system itself but a "philosophy of design" which affects both payload and platform.

The technical aspects of this concept include the use of standard-size and configured weapon system stations on ships to accommodate the rapid installation and removal of combat weapons system payload modules. Weapons system payloads under consideration for modularization include offensive and defensive armament, all sensors, and all combat direction system hardware and software. Under the SEAMOD concept, the ship platform is designed to receive its payloads as complete modules that can be installed after the basic ship platform construction has been completed.

Payload modules can be replaced by similar or entirely different payload modules, as operational circumstances dictate, without major structural changes to the ship platform or alteration of the ship services. The ship platform weapons system stations will be of adequate structural strength and size to meet the requirements of current and projected system payloads.

A word of caution is in order, however, when describing the SEAMOD concept. At first glance the approach may seem rather simplistic. That is, the mechanical interfaces associated with "plug in" modules seem easy to achieve. Certainly this has been done in the commercial world with the advent of containers. Upon closer inspection, however, there comes the realization that the payload of a Navy surface combatant carries with it certain demands that far exceed that of containerized cargo. First of all it must function as an integrated combat system, that is, all the elements serve a purpose to each other and correct information must flow between them. This is, of course, the world of combat systems software that has caused so many headaches for both Navy program managers and shipbuilders alike. Thus, the SEAMOD concept does not (and cannot) limit its approach to functional/physical segregation of the ship platform only, but includes the necessary partitioning of the payload into decentralized generic elements such as weapon launchers, target sensors, target analysis and display, and data transmissions. This involves design requirements which reflect use of microprocessors, multiplexing and other technologies that can best implement the philosophy of SEAMOD. Thus, we will see that SEAMOD does not inhibit future technology and innovation adoption but, on the contrary, will enhance it. The reason for this is that by achieving the decoupling of payload elements from the platform (and each other), changes within each module which could reflect improvements brought on by future technologies can be implemented with minimum perturbation to the rest of the system, *as long as the basic interface standards are met.* Thus SEAMOD produces a synergistic effect through decentralization and will allow flexibility in the design, procurement, and operation of the surface combatant fleet. The remaining portion of this paper presents the translation of the SEAMOD concept into design solutions and an analysis of the impact such an approach would have for both the Navy and the shipbuilding industry.

Ship design feasibility studies

The SEAMOD concept began in 1972 as an overall proposal to consider generic modularity by the Combat System Advisory Group (CSAG) within the Navy Material Command (NAVMAT). Until 1975, however, most studies concentrated on where modularity should be applied and a survey of modularity approaches by various navies within the world. Any design efforts were very conceptual in nature and, therefore, a frequent criticism of past studies of the SEAMOD concept has been that SEAMOD proponents expressed their evaluations of the concept in subjective terms rather than quantifiable units such as time, dollars, and man-hours. Consequently, in 1975, a study was begun to derive measurable operational, technical, and economic values of SEAMOD by analyzing actual weapons systems hardware, in the SEAMOD environment, throughout a representative portion of the ship's life cycle. To accomplish this, a fleet unit was selected as a baseline ship, and actual combat weapons systems were selected for which there were adequate design and cost data. Comparisons were made based on actual engineering solutions in the design of a SEAMOD ship.

The overall approach taken to investigate the technical feasibility and measures of benefit (MOB) and penalty of the SEAMOD concept was through the following steps:

1. *Select a conventionally configured ship:* An existing modern surface combatant ship was chosen as a baseline for the study. The ship was capable of carrying and supporting current weapons system payloads and incorporated up-to-date ship design criteria. Adequate actual cost and planning data were available for the ship.
2. *Select weapons system payloads:* A number of payloads were selected that could reasonably be expected to replace installed payloads during modernization and conversion periods of the baseline ship.
3. *Complete design/construction data for a Conventional Ship:* Data on the actual design and construction requirements of the baseline ship were compiled in terms of man-hours, cost, and elapsed time.
4. *Develop a SEAMOD-configured ship design:* A design for a ship platform capable of carrying the selected weapons system payloads as modules (a SEAMOD-configured ship platform) was developed. The development of this design included engineering solutions to the payload/platform interface so that modules could be rapidly removed and installed.

Table 1 General characteristics, DD 963

LENGTH OVERALL	563'-3 13/16"
LENGTH BETWEEN PERPENDICULARS	529' - 0"
BEAM, MLD	55' - 0"
DEPTH TO 01 LEVEL AMIDSHIP, MLD	42' - 0"
DEPTH TO MAIN DECK AMIDSHIP, MLD	33' - 0"
DRAFT, FULL LOAD, TO LOWEST PROJECTION BELOW KEEL	29' - 5"
DISPLACEMENT, FULL LOAD	7840 L. TONS
LIGHTSHIP	5799 L. TONS
COMPLEMENT, APPROX. (18 OFFICES, 232 ENLISTED MEN)	250
GUNS	TWO 5"/54 MARK 45
MISSILE LAUNCHERS: ONE NATO SEA SPARROW MISSILE LAUNCHER MK 29 (PLANNED)	
ASW WEAPONS: ONE SH-3 SEA KING OR TWO SH-2D LAMPS HELICOPTERS	
ONE ASROC 8-TUBE LAUNCHER	
TWO TRIPLE TORPEDO TUBES (MK 32)	
MAIN ENGINES: FOUR GAS TURBINES (GENERAL ELECTRIC), 80,000 SHP, TWO SHAFTS	
ELECTRONICS: SQS-53 SONAR	
SPS-40B AND SPS-55 RADAR ANTENNAS	
ADVANCED ELECTRONIC COUNTERMEASURE (ECM) EQUIPMENT	
MK 86 FIRE CONTROL SYSTEM	

5. *Design modular weapons system payloads:* Each payload element involved in modernization and conversion was designed in modular form suitable for rapid removal and installation in the SEAMOD-configured ship platform.
6. *Develop 30-year scenarios:* A realistic, operational, 30-year scenario for the SEAMOD-configured ship was developed in parallel with the basic requirements of a scenario similarly developed for a conventionally configured baseline ship.
7. *Determine modernization and conversion requirements:* The requirements of simulated modernization and conversion periods of the baseline ship were studied and man-hours, costs, and elapsed times were computed. Then man-hours, costs, and elapsed times required to install the same weapons system for modernization and conversion of the SEAMOD-configured ship were computed.
8. *Determine technical and operational MOBs through life-cycle comparisons:* Technical and operational analyses of the SEAMOD-configured ship, in comparison with a ship having its payloads installed in a conventional manner, were conducted. This included comparisons in cost and time for construction, modernization and conversion.

The following discussion concentrates on how the foregoing steps were implemented for an 8000-ton [8128 t (metric tons)] destroyer, and then presents a conceptual design of a 4500-ton (4572 t) SEAMOD frigate which incorporates the same design criteria.

SEAMOD destroyer (8000-ton) (8128 t)

Specific life-cycle ship configurations:

The conventional ship selected for comparison with a SEAMOD version of itself was the DD 963. The general characteristics of the ship are given in Table 1. The DD 963 was selected because it represented the Navy's most recent destroyer design and ample data were available from which quantitative comparisons could be made.

The weapons system payloads on the DD 963 at commissioning were designated at the baseline payload for the study. The conventional ship scenario contains a 12-month moder-

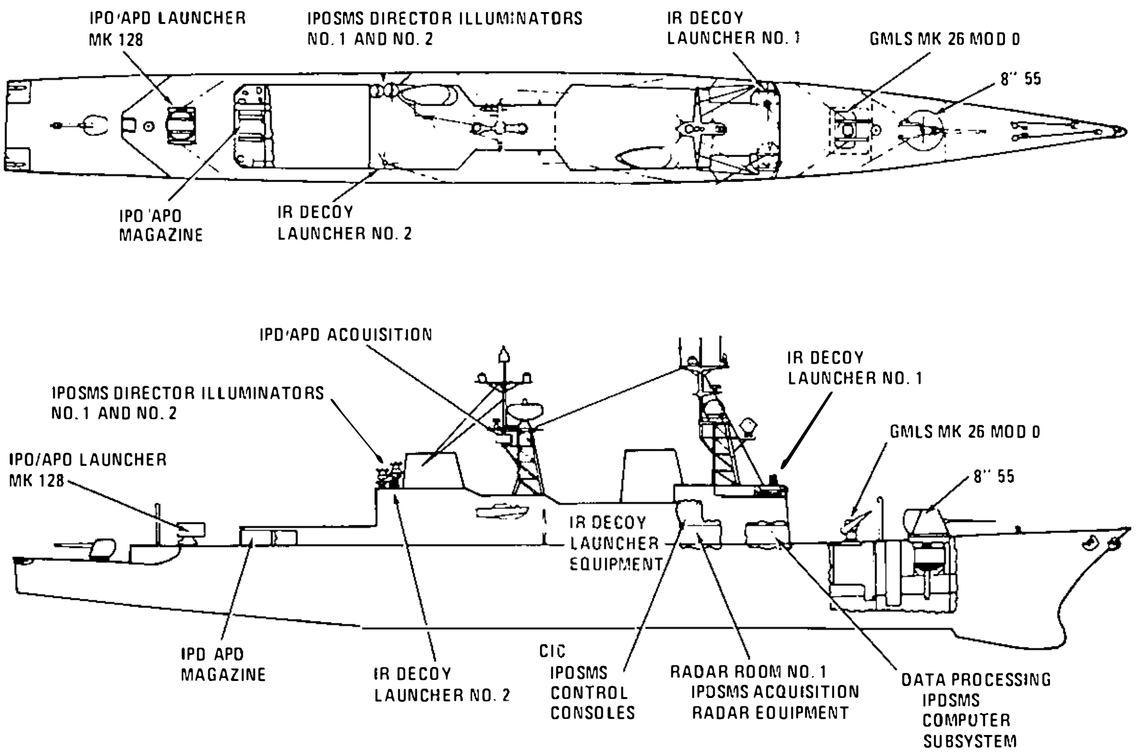

Fig. 2 Modernized configuration

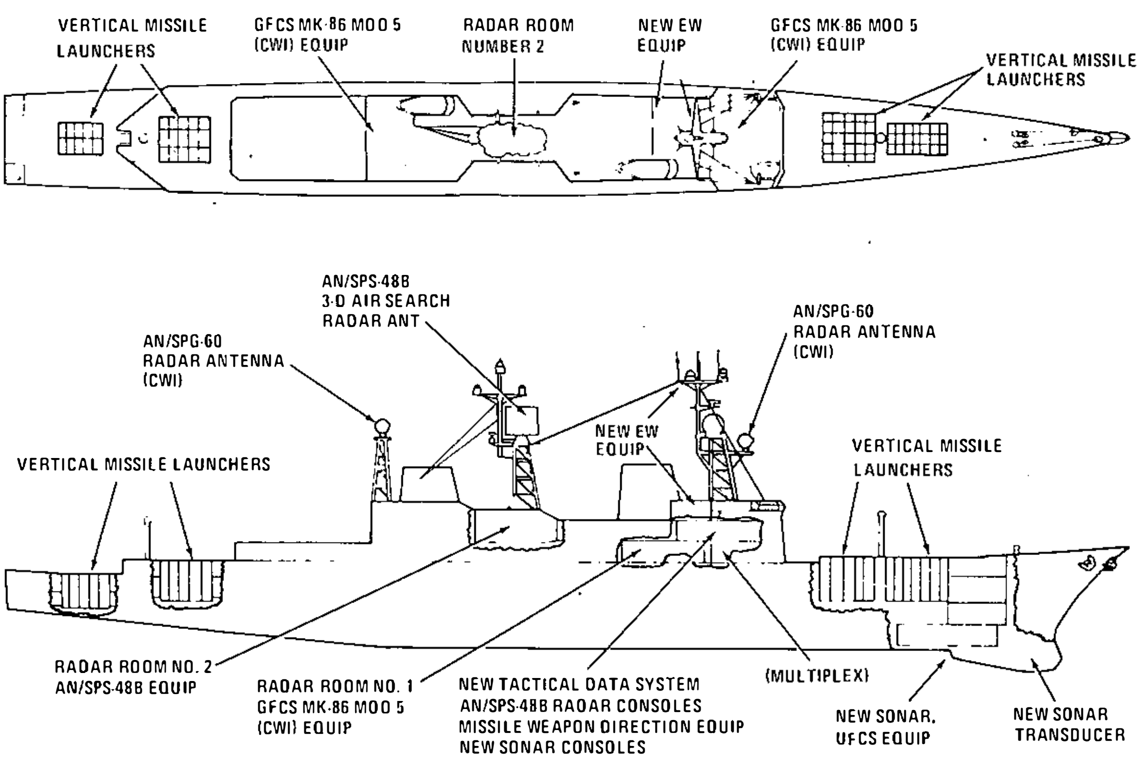

Fig. 3 Converted configuration

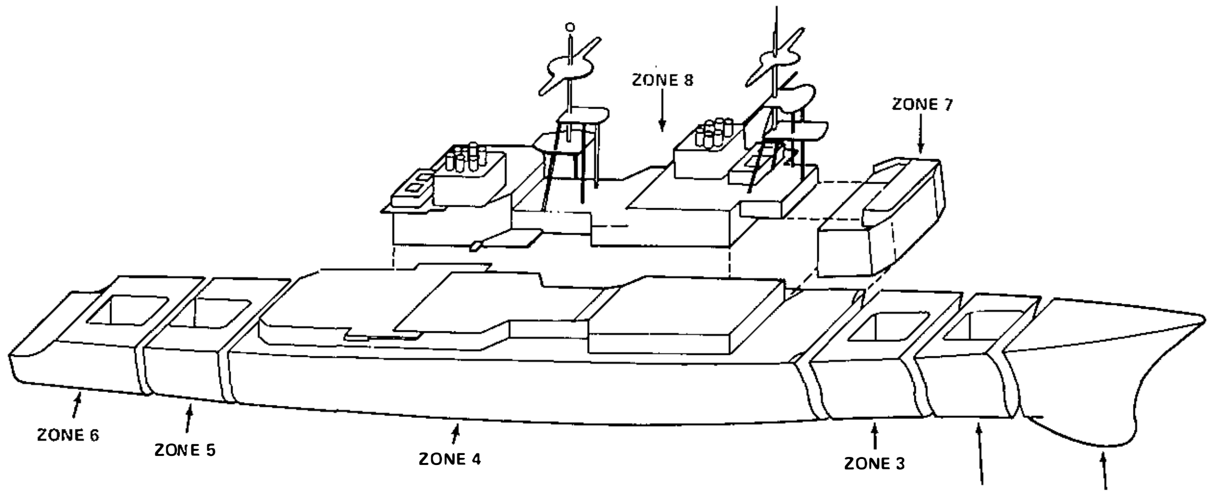

Fig. 4 The zone concept

nization period in the 9th year of the life cycle and an 8-month conversion period in the 18th year.

The goal of the modernization period was to upgrade the general-purpose capabilities of the baseline ship and improve the ship's self-defense capabilities. Specific readiness criteria considered in the selection of weapons system changeouts during modernization included improved antiaircraft warfare (AAW) capabilities to engage high-speed aircraft with short-range missiles, and to engage incoming air-to-surface and surface-to-surface missiles. An improved surface warfare (SUW) capability included an ability to engage surface targets with 6-in. (152 mm) or larger gunfire or missiles, or both, and to conduct direct and indirect fire and shore bombardment.

The goal of the conversion period was to change the ship's basic mission from a general-purpose destroyer to a guided-missile destroyer with an AAW area defense capability. Criteria considered in the selection of weapons system changeouts during conversion included improved AAW capabilities to engage low-, medium-, and high-altitude high-speed aircraft with short- and long-range missiles; engage incoming air-to-surface and surface-to-surface missiles; and provide antiair defense for a convoy, task force, amphibious operation, or geographical area.

Based upon the foregoing, combat system payloads were selected for analysis as being most representative of the wide span of payloads which could be exchanged during typical modernization and conversion periods of a conventionally configured platform. The arrangements of these combat system payloads are shown in Figs. 2 and 3.

Platform design criteria:

The zone concept—As noted in the foregoing discussion, the SEAMOD platform must be able to readily accept varying combat systems. For the case study, each of the combat systems included a varying mix of sensors and four major weapons systems.

The objective which formed the basis for development of all SEAMOD design criteria as documented in references [2-6] was to establish a set of requirements so that *interchangeability of any or all of the payload elements could take place with a minimum impact on the remaining system(s).* To achieve this objective, a "zone modularity" concept was utilized for the ship configuration.

In this concept, the overall ship is divided into zones as shown in Fig. 4. Each payload zone is provided with margins of volume and weight and is dedicated to a particular payload function (for example, launchers). Furthermore, each payload zone is also provided with support systems (electrical power, etc.) anticipated to be required after either conversion or modification. Thus, within the zones there remains flexibility of arrangements, allowing changes to be readily accomplished locally without severe impact elsewhere in the ship.

Zones had to be selected with consideration given to overall ship arrangement, vulnerability, damaged stability and control, and subsystem demand requirements.

The existing DD 963 lends itself to simple zone subdivision. The hull was configured to accept four major weapons systems, two forward and two aft, and has a large central area largely oriented toward provision of hotel and machinery services. Furthermore the Combat Information Center (CIC), data-handling center, and pilothouse (that is, control spaces) are concentrated forward in the superstructure, while the remaining superstructure contains the uptakes and intake for the main propulsion machinery and the hangar and other secondary payload spaces for detection and tracking.

Ship arrangements—The SEAMOD arrangement requirements may be subdivided as follows:

- Module size and location.
- Access and interface areas.
- Space allocation.

• Module size and location—Although, at first thought, module size selection may appear to be an overwhelming decision (that is, How do we know what the future will bring?), it can be approached in a logical and realistic manner. For the study case, a semistatistical comparison was made of the various weapon modules to be installed to see if there was any significant deviation from one to another. As shown in Fig. 5, this was not the case, although the 8-in. (203 mm) gun drove the volume selection. At this point, however, some discussion should be presented on how the SEAMOD design concept differs from the conventional approach to ship design.

Whereas the usual process is to define each combat system element (payload) and then optimize the platform around it so as to minimize cost, displacement, etc., the SEAMOD approach is to arrive at a set of standard interface constraints which allocate certain areas of the platform to payload functions. This may appear to present a risk of either "oversizing" or "undersizing" the platform for certain weapon suites. It is contended, however, that this will not be the case. All that is really happening by the establishment of a set of predetermined constraints *within the platform* is that the weapons manufacturer must optimize his module design within these constraints.

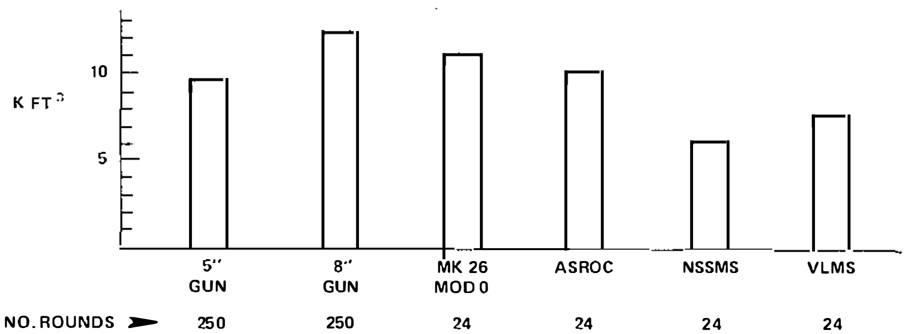

Fig. 5 Volumes of various weapon modules

Thus, the weapons manufacturer will maximize his performance (for example, size of projectile/missile, range of projectiles/missiles, number of rounds, rate of fire) within an allocated amount of space, weight and support services. The SEAMOD concept does *not* tell him *how* to do it, but allows for technology change over a period of years. Thus, the choice shifts from building a variety of platforms for various increments of weapon sizes to standard platform sizes within which a variety of weapon sizes and types, rounds and ranges can be fitted (for example, an 8-in. (203 mm) gun with 250 rounds or a 5-in. (127 mm) gun with 400 rounds, etc.). The ability to adjust control of the combat system to perform in these various modes is not a simple matter and should not be construed as such. However, the SEAMOD program has addressed this problem, a part of which will be discussed in the section on payload design criteria.

SEAMOD does not claim it will standardize all weapons hardware in the future, but only that *the interface between payload and platform will be standardized.* The feasibility will be proven when such design standards can be shown to accommodate all *major* armament installed on frigates, destroyers and cruisers.

From the studies conducted to date, the weapon envelope dimensions that meet this criterion are:

Length, ft-in. 29–0 (8.8 m)
Width, ft-in. 20–0 (6.0 m)
Height, ft-in. 26–0 (7.9 m)

Length refers to the maximum allowable fore-and-aft dimension inclusive of all structure and all projections, while width is the maximum transverse dimension inclusive of all projections. The depth quoted refers to the distance between the bottom of the module's foundation to the top of the hatch coaming.

As part of the SEAMOD concept, the weapon modules must be capable of being lowered into place within a SEAMOD platform. To allow for manufacturing tolerances, deflection, rounded corners in deck penetrations, alignment procedures and swinging while installing, clearances between the module and the weapon station were established. A large clearance would simplify the installation of the module but would penalize the ship by creating an unutilized void. Six inches (15.24 cm) was selected as representing the minimum clearance for fitting the module. This margin was provided on all faces of the module. The resulting required deck cut on the SEAMOD ship was 30 by 21 ft (9.1 by 6.4 m).

The vertical module dimension was determined considering the following factors:

(i) Minimize vertical center of gravity.
(ii) Minimize interference with RAS replenishment at sea, field of view, etc.
(iii) Provide adequate clearance for a deck coaming.
(iv) Provide an adequate foundation with a minimum of interference.
(v) Allow access under module.

To provide structural integrity and a watertight seal, a deck coaming is provided on the weather deck in way of each deck cut. To permit fabrication, 6 in. (15.24 cm) was established as the minimum coaming height above the deck.

The foregoing factors combined to give an allocated weapon station size of:

Length, ft-in. 30–0 (9.1 m)
Width, ft-in. 21–0 (6.4 m)
Height, ft-in. 28–0 (8.6 m)

The transverse location of the weapon module was assumed to be on the centerline of the ship. The longitudinal position of the weapon module within each zone is dependent on the desired weapon position and the SEAMOD ship web spacing. Although these factors were primarily fixed on the DD 963 study, a new ship design would consider such factors as insensitivity to weight change (list and trim) at weapon station location.

• Access and interface areas—Access must be provided to weapon modules in the event of casualty, emergency repairs, and for installation. Furthermore, access is required for the personnel manning a mount or control room contained within a weapon module. The ease of access into a weapon module is vital from a ship mission standpoint and the entry point should be integral with the ship personnel traffic patterns.

For security reasons it was felt desirable to provide a single entry point into the weapon module for all types of potential payload. The port and starboard fore-and-aft passageways of naval combatants are usually located on the first deck below the weather deck. Below this level there is no fore-and-aft access between spaces in order to maximize watertight integrity of the platform in the event of flooding. If the module access were located below the first enclosed deck, personnel would have to decend to a lower level before gaining entrance to the weapon module. If the point of entry were located on the end of a module, then SEAMOD would establish the requirement that platforms provide a transverse passageway at the end of a weapon module. Therefore, the entry point(s) should not be located on the ends of a weapon module and a single entry point should be located on the weapon module such that the same point could be utilized for all weapons and in all weapon zones on the SEAMOD platform. The point of entry location selected was the first deck below the weather on the forward side of the module.

In establishing the location of a weapon module in a zone, consideration was given to requirements for connecting interface service piping, cable and ducts from the platform to the module. In conventional ship practice, the service connection locations associated with the weapons systems are usually fixed with the result that extensive system modifications are required to facilitate a changeout. This contributes to the time required for modernization and conversion.

One of the objectives of the study was to assess the feasibility of providing centrally distributive systems which are configured to provide services to a weapon zone to support a changeout with a minimum disruption of the services. Discussion with the weapons system manufacturers indicated that it would be possible to standardize the location of module service connections (as well as access point) with minimum impact on module design.

• Space allocation—Using the foregoing criteria, actual ship arrangements were developed which allowed satisfactory installation of the weapon modules. A representative arrangement for Zone 3 is shown in Fig. 6.

The original DD 963 was not, of course, arranged using the zone concept. As a result, the reconfiguration into the SEAMOD design necessitated rearrangement of "nonpayload function spaces" within the newly dedicated zone to be reassigned to a different part of the ship. This realignment caused certain changes in space allocations as shown in Table 2. Given the constraint of a fixed hull form, these changes were felt to be acceptable for purposes of the study. Development of a "from scratch" SEAMOD ship would insure that adequate space per function would be allocated in the "nonweapon zone" portions of the ship.

Structural approach—One of the key factors in the development of a platform responsive to the SEAMOD objectives is that the structure of the ship must be designed to facilitate the exchange of payload without major reconfiguration. This section presents a discussion of the structural approach to the SEAMOD platform with particular emphasis focused on the structure in way of the large weapon modules.

The loads imposed on the SEAMOD platform structure can be divided into four categories summarized as follows:

(i) Basic loads. These are loads which act on structure independent of environmental, operational, or combat influences. Contained within this group are live loads, dead loads, and liquid/tank loads.

(ii) Sea environment loads. Included in this group are hull girder loading, sea loads, weather loads and ship motion loads.

(iii) Operational environment loads. In this category are included loads which result from slamming, flooding, aircraft landing, tank overfill, docking and UNREP (underway replenishment) operations.

(iv) Combat environment loads. The loads which result from the combat environment include shock, air blast, fragment protection, gun blast, and missile blast and accidental ignition.

The development of the structural configuration of the platform considered each of these load categories only in the context of determining the differences between SEAMOD and conventional configurations. Preliminary studies revealed that because of the module weights, shown in Fig. 7, the loads located at the ends of the hull girder exceeded the 9.5-ton (HTS) hogging wave bending stress at certain locations. In order to maintain an allowable stress level, the hull girder strength of the SEAMOD platform was therefore slightly increased. Analysis of the various loads just described demonstrated that the shock load factor exceeded by far all other defined load categories. The magnitude of the shock factor was established as:

Vertical:	18 g's
Transverse:	11 g's
Longitudinal:	7 g's

These factors were multiplied by the mass of the weapon modules and accordingly formed the basis for the development of the SEAMOD local structural design.

• Weapon module structural support concepts. Analysis of the configuration of the weapon modules and the structural configuration of the DD 963 established that there are two methods available to support a module. One method is to hang the module from a coaming around the deck opening and prevent the lower portion from swaying. The alternative method is to support the weight of the module from below and absorb only the lateral loads at the deck.

Both methods were considered and a study was undertaken to ascertain the advantages and disadvantages of each method. Although both concepts had advantages and disadvantages, the basic advantage of the bottom-supported concept was that the structure around the module did not carry vertical loads and therefore could be light, often consisting only of pillars. This would result in unrestricted access and service interface areas. The weight savings amounted to nearly 25 tons (25.4 t). Considering the importance of minimizing weight and maximizing the access to the module, the bottom supported concept was selected. A representative drawing of the developed structural concept is shown in Fig. 8.

• Longitudinal strength. The longitudinal strength of the SEAMOD platform was developed based on DD 963 information. Since the varying payloads tended to load the ends of the ship, the longitudinal strength was checked with all three payloads embarked.

Three weight curves were developed by adding the three different payload weights. Each weight curve was then used as input to generate the shear and bending curves. The conventional Navy standards were used for wave height and wave length, namely wave height (H) = 1.1 × length between perpendiculars (LBP) and wave length (L) = LBP. Representative results for the modernized configuration are presented in Table 3.

From the bending moment and the DD 963's curve of section modulus, the stress level was determined for each of the three payloads. The stress level exceeded the design stress by 6 percent or 0.5 tons/in.^{2} (7.7 MPa).

Two methods to correct the apparent deficiency in longitudinal strength were possible. The tankage of the ship could be altered to reduce the bending moment and therefore reduce the stress. However, this solution would require additional tankage in the midlength, an area where there is no available cube. The second option was to increase the section modulus. The increase required amounted to increasing the thickness of one strake of plating about ⅛ in. (3.2 mm). The net effect of this change would be less than 20 LT (20.3 t) to the Group 1 weight.

Therefore, it was decided that the section modulus be slightly increased and that the impact of the additional 20 tons (20.3 t) be considered in the MOB comparison.

Ship support services—The potential variation in auxiliary support services for various payloads could provide a major obstacle to implementation of the SEAMOD concept. There are two alternatives available to meet the SEAMOD objectives with regard to establishing support service requirements:

• Permit payload manufacturers to establish requirements for their payload as they wish and force ship designers to provide for these requirements.

• Establish a standardized set of reasonable requirement constraints for payloads, based on a careful study of a broad spectrum of payloads, and simplify the overall design.

The first alternative provides great latitude for the payload manufacturer but significant problems for the ship designer who must configure the platform to accommodate potential fluctuations in requirements over the ship's life cycle. Such

ITEM	DESCRIPTION
1	ASROC DIST. WTR/GLYCOL HEATING COOLING/PUMPING MODULE
2	F.W. TANK & AIR ACCUMULATOR MODULE MISSILE SPRINKLER SYS. STATIC CHARGE
3	F.W. TANK & AIR ACCUMULATOR MODULE MISSILE MOTIVE SUPPRESS. SYS. STATIC CHARGE
4	CONTROL VALVE - DRAINAGE EDUCTOR MOTIVE WATER
5	CONTROL VALVE - MISSILE MOTOR SUPPRESSION
6	CONTROL VALVE - MISSILE SPRINKLING
7	SPRINKLING CONTROLS
8	MISSILE SPRINKLING INTERFACE CONNECTION
9	MISSILE MOTOR SUPPRESSION INTERFACE CONNECTION

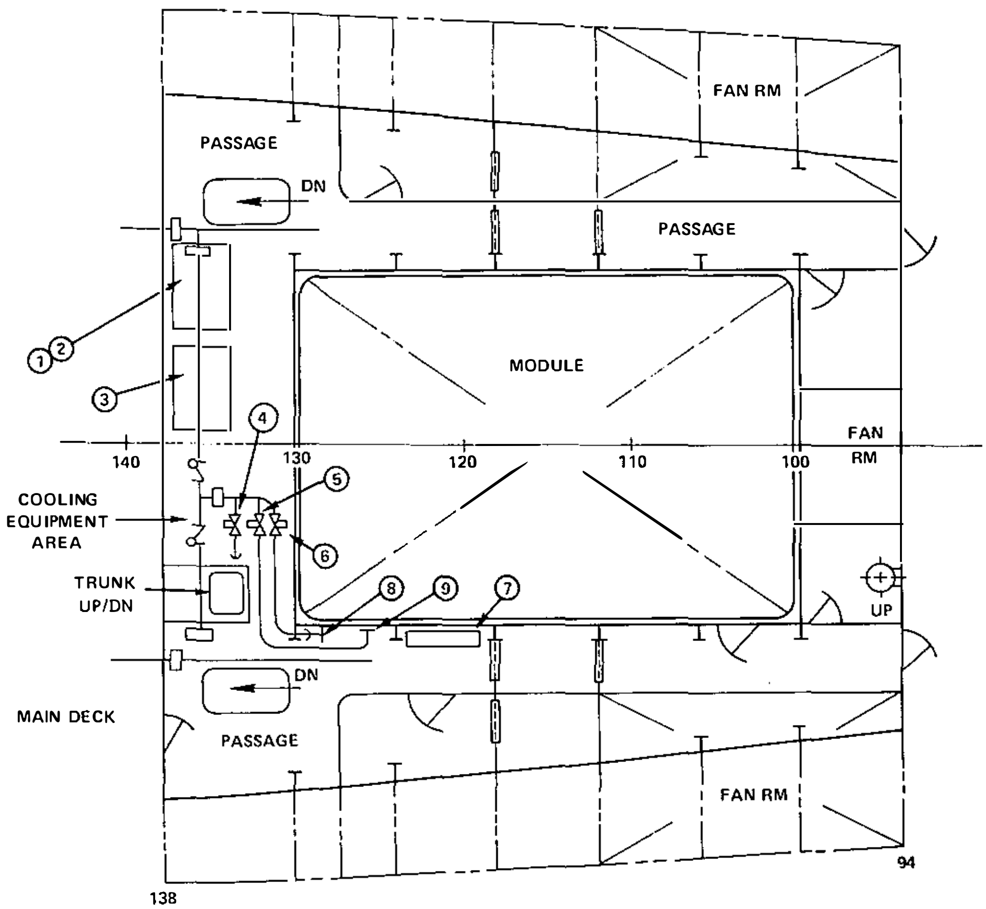

Fig. 6 Arrangements, main deck—Zone 3

fluctuations introduce a conflict between meeting the SEA-MOD objectives and meeting design constraints on cost, weight, and space. The second alternative significantly simplifies the ship designer's task, but unless careful consideration is made of its potential impact on payload design it introduces the risk of impairing payload effectiveness.

In determining what constraints can or should be imposed it becomes apparent that a further analysis is needed to determine if the generation or conversion function for the service in a question should be centralized or decentralized based on comparative cost, weight and space characteristics, as well as technical feasibility.

The following discussion will describe two representative cases—one in which the decision was to centralize services, the other in which it was decided to decentralize services. Finally, a discussion of margin development for all support services will be described and the design criteria used for the destroyer study presented.

• Electrical power generation and distribution. In order to determine the impact of the SEAMOD concept on the configuration of the electrical generation and distribution system, a load analysis which establishes the connected load within each of the SEAMOD zones was developed. Investigation of all available DD 963 information reveals that the following load groups would undergo relatively insignificant load changes when the ship is modernized and subsequently converted:

Propulsion auxiliaries
Deck machinery
Interior communication
Lighting
Control systems
Shops and miscellaneous
Hotel

Available information on the SEAMOD weapons/electronics suites was reviewed to determine the electrical requirements for each configuration.

Results of the load analysis confirmed that the present generating plant capacity (6000 KW) on the DD 963 was adequate for the baseline, modernized, and converted configurations of the ship. However, it must be remembered that for purposes of this study, a *specific* group of weapons systems was selected to provide a data base representative of current weapons systems and likely candidates for future conversions. Thus, though the study of electrical power requirements based on data for these specific weapons systems determined plant adequacy, and though this was utilized in the MOB comparisons, the ultimate goal is the development of general rules applicable to all future SEAMOD systems. Studies were conducted toward this objective and are presented in the section on margins.

Based on the foregoing analysis, it was determined that the power-generating approach should be centralized with a standard connecting interface between the module and the platform.

• Heating, ventilation, and air-conditioning (HVAC). In determining the HVAC system requirements and design, investigations were initiated in the following areas:

(i) Method for sizing and locating HVAC equipment.
(ii) Configuration of zones to be served (space types).
(iii) Preferred fan room locations and associated ductwork routing.
(iv) System impact on air-conditioning machinery plant, chilled water system, heating system, electrical plant, etc.

Table 2

A. MODIFIED SPACES. ZONE 2 & 3

SPACE	DD 963 ORIGINAL AREA, FT^2	SEAMOD PLATFORM AREA, FT^2
FORWARD REPAIR	171	72
POST OFFICE	87	72
ASROC SECURITY	18	36
GYRO ROOM #1	142	149
DIVING GEAR LOCKER	77	70
CREW BAGGAGE	117	159
I.C. ROOM #1	278	232
BOSUN STORES TOTAL	512	417

B. MODIFIED SPACES ZONE 5 & 6

SPACE	DD 963 ORIGINAL AREA, FT^2	SEAMOD PLATFORM AREA, FT^2
ACCESS DECONTAMINATION	144	187
PAINT MIXING & ISSUE ROOM	90	96
INERT GAS STRM	70	166
PLENUM	140	166
ORDNANCE WORKSHOP	145	157
AFT REPAIR STATION	162	166
SPECIAL CLOTHING	224	166
BATTERY SHOP	127	125
ARMOR	216	204
VDS NIXIE ELECTRONICS ROOM AND PAINT SHOP	235	260
FLAMMABLE LIQUID STRM TOTAL	217	159
ORDNANCE EQUIPMENT STOREROOM	103	86
SMALL ARMS MAGAZINE	300	297
CHEM. WARFARE DEFENSES EQUIP.	146	166
LANDING FORCE EQUIP. STRM.	220	228
COMPRESSOR ROOM	108	132
REEL STOREROOM NO. 1	153	162

For the SEAMOD study, the HVAC equipment requirements had to accommodate the basic problem of satisfying the large variance in load possible for each particular zone due to future change. Consequently, heating and cooling loads were determined for each zone based on initial (baseline) outfitting

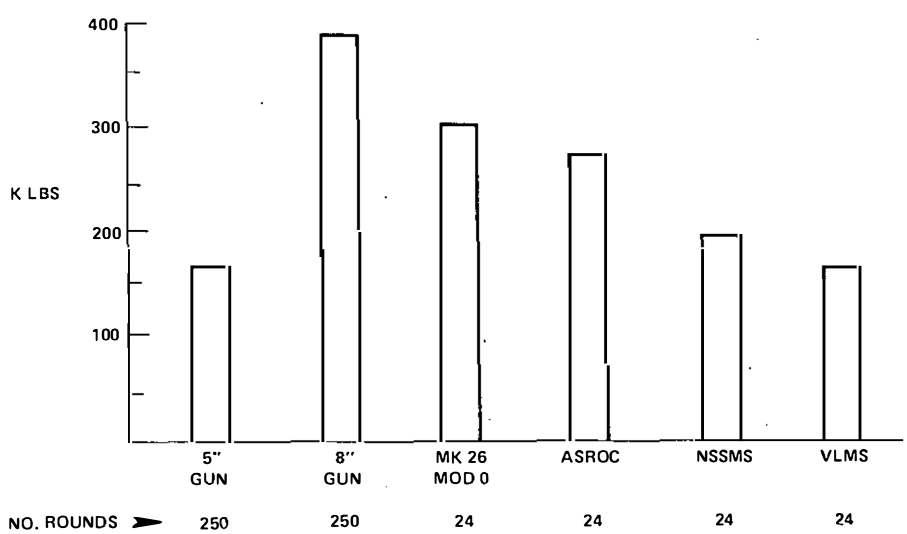

Fig. 7 Module weight

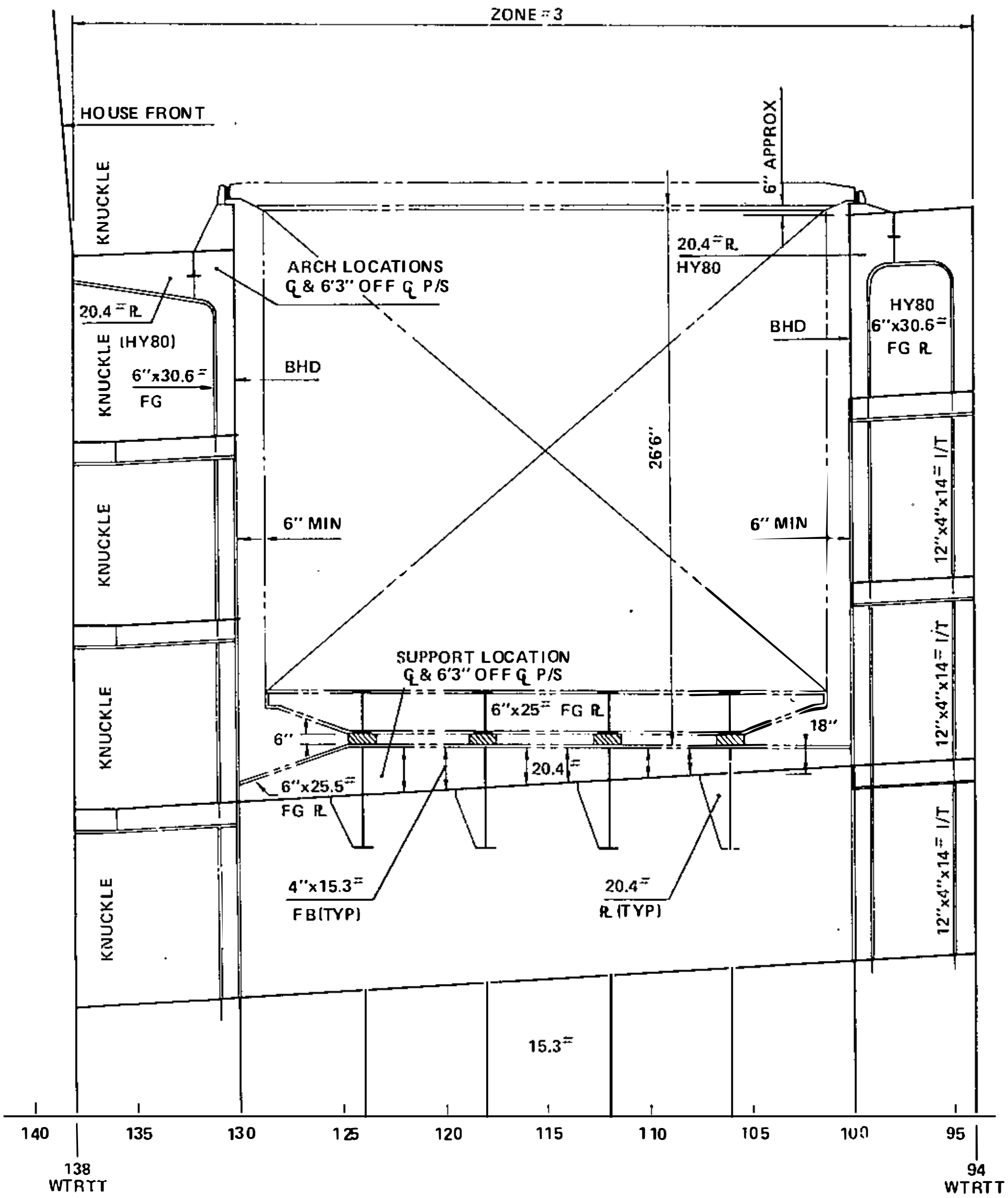

Fig. 8(a) Structural concept—Zone 3

of the area, as well as prospective future requirements (modernization and conversion). This resulted in upper and lower limits for all zones to be considered. The HVAC system equipment was sized for the maximum condition with suitable measures incorporated to include the capability to satisfy minimum conditions, such as dampers, bypass, inactive systems, and blanked-off ducts.

These primary calculations established approximate HVAC requirements on a per-zone basis and are given in Table 4. All specific payload (5-in. (127 mm) gun, 8-in. (203 mm) gun, MK 26 Launcher, etc.) requirements relating to HVAC were provided by and discussed with the weapons manufacturers.

Based on the above analysis, it was determined that an additional 150 ton/540 gpm air-conditioning plant must be provided to satisfy the requirements of SEAMOD since only 450 tons are presently installed. (This requirement was accounted for in the electric load analysis.)

With regard to fan rooms, ductwork and coils, consideration had to be kept in mind that the design of the SEAMOD ship was to assure quick payload removal and replacement with minimum support system revision.

However, HVAC systems will interface with each specific weapons package, with penetrations required for air-conditioning supply and return ductwork, supply, exhaust and blowout ventilation, etc. It appears that there will be some degree of duct size and location modifications required to suit each payload.

Thus, for the HVAC system (with the exception of the air-conditioning plant) it was decided that the heaters, coil fans and ductwork should be decentralized in the weapon zone area.

• Margins. Margins for ship support services (beyond future load determination) could be selected by using a probabilistic approach to minimize the sum of support system initial cost and the "expected value" of subsequent modification cost. Such costs can be determined for various levels of margin allocation. In other words, the margin level for supplying the requirement should be that which is a compromise between:

(*a*) incurring excessive initial costs for a level of supply so high it is unlikely to ever be needed, and

(*b*) incurring excessive modification costs for an initial level

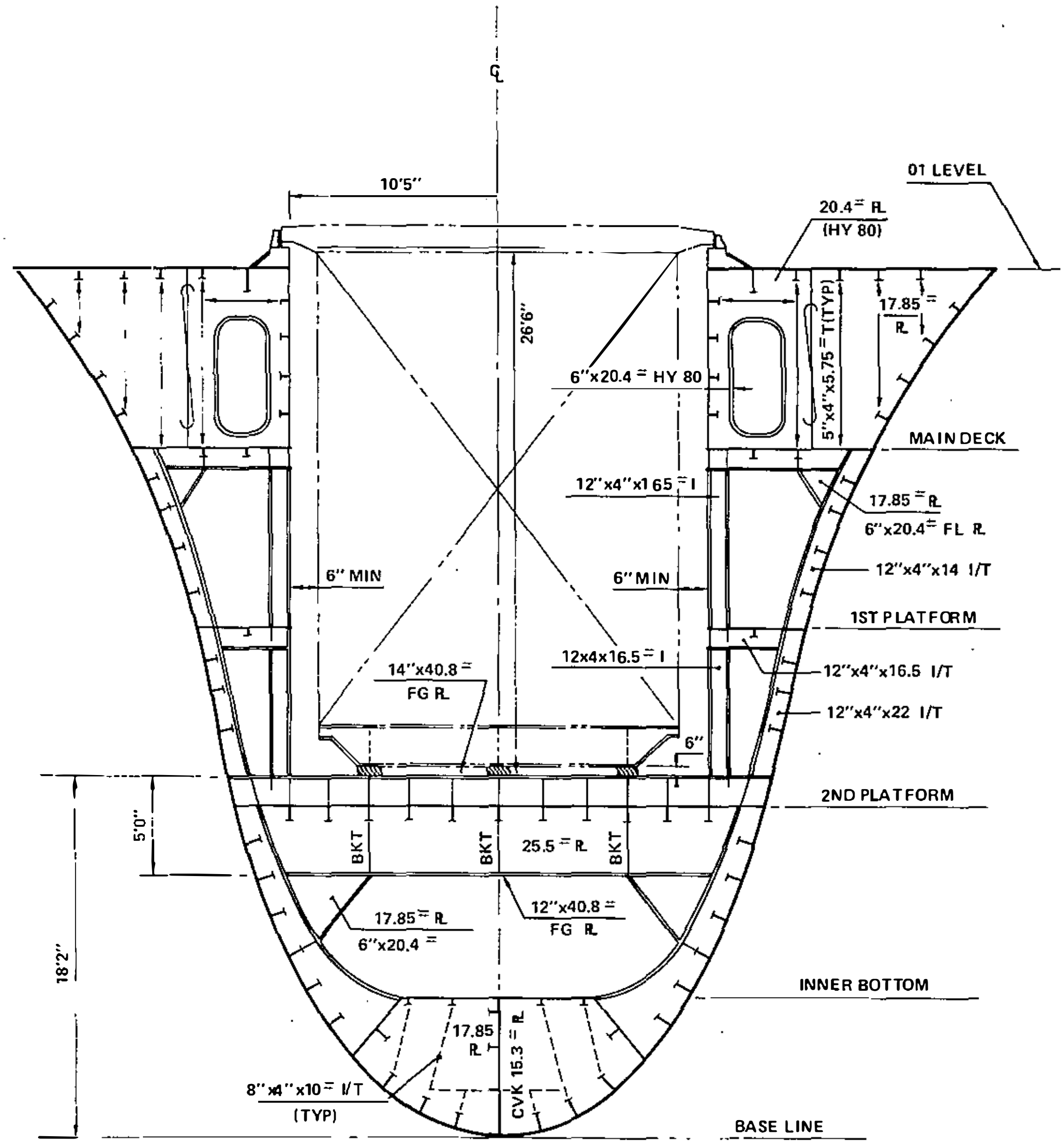

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Fig. 8(*b*) Structural concept—Zone 3

of supply so low that it is likely to be exceeded by demand at some point during the ship's life cycle.

A study was undertaken to attempt to quantify this compromise even though it was recognized that the simplifying assumptions restricted the validity of the final quantitative results. These assumptions were:

(i) Module demand for a particular service will grow linearly over time.

(ii) Projected demand is normally distributed about a mean defined by a least-squares linear fit and a standard deviation based on sample dispersion about the mean demand line over time.

For each service requirement the following parameters are determined and plotted:

$\overline{D}(t)$ = mean demand as a linear function of time, established by least-squares fit of sample data points

$\overline{D}_p$ = projected mean demand, that point on $\overline{D}(t)$ in the year 2010, or the 30th year of a ship built in 1980

D_r = reference demand, or worst case of known data points, from which various levels of supply margin are considered

σ = standard deviation of projected demand, established from dispersion of sample data points about $\overline{D}(t)$

$P[D > S]$ = probability of demand exceeding supply, based on distribution of projected demand and various levels of supply

C_i = initial cost of providing various levels of supply including labor and material

C_m = cost of modification to increase supply, including labor and material

$E[C_m]$ = expected value of cost of modification, $P[D > S] \times C_m$

Table 3 Shear and bending moment modernization

STATION	SHEER, L.T. HOGGING	SAGGING	MOMENT, FT-T HOGGING	SAGGING
0,FP	0	0	0	0
1	246	32	3523	416
2	382	-157	11608	-1207
3	641	-309	25209	-7197
4	862	-516	45240	-18039
5	1089	-645	71301	-33415
6	1130	-806	101024	-52672
7	1137	-773	131470	-73656
8	1147	-481	162157	-90348
9	723	-370	187327	-101700
10	294	-88	201015	-107800
11	224	156	201928	-106884
12	-582	501	191060	-98164
13	-942	691	170496	-82354
14	-1250	704	140977	-63857
15	-1370	654	105813	-45808
16	-1323	515	69743	-30260
17	-1024	422	38391	-17786
18	-672	279	15946	-8468
19	-267	187	3532	-2326
20,AP	0	0	0	13

1. MAXIMUM SAGGING MOMENT= 108218 FT TON AT 273.96 FT AFT F.P.

2. MAXIMUM HOGGING MOMENT - 203220 FT TON AT 279.46 FT AFT F.P.

r = time correlation coefficient, from basic statistics. An index of the degree of correlation of demand with time, $r = 1$ indicates perfect correlation, $r = 0$ indicates no correlation

Without devoting a detailed description to the approach, the results of such an approach are reflected in Figs. 9 and 10 for the seawater system. Figure 9 shows the linear projection of demand by which the statistical distribution of demand in the ship's 30th year may be estimated. The probability that projected demand will exceed supply can then be determined for various levels of supply. Figure 10 shows the details of a probabilistic cost minimization analysis. From this analysis, a margin for allocating supply is selected to be 50 percent above the reference.

Such a margin requires that the platform provide up to 10 000 gpm (7580 l/s) and constraints each module to a demand of no more than 2500 gpm (1895 l/s).

• Summary of support services design criteria. The design criteria developed for the SEAMOD destroyer study are given in Tables 5 and 6. The effect these requirements had on modifications to the DD 963 were reflected in the impact on platform characteristics and the concept analysis.

Payload design criteria:

Although certain aspects of the payload/(platform interface have been discussed as part of the platform design criteria development (for example, module size, weight, and services), this section briefly discusses the impact that SEAMOD will have on the payload itself. For as significant as SEAMOD would be on the platform design, it will have equal (and some say

Table 4 Air-conditioning tonnage and chilled water requirements

ZONE	DAMAGE CONTROL CLASSIFICATION	SERVES	BASELINE TONS	GPM	MODERNIZATION TONS	GPM	CONVERSION TONS	GPM
1	W	PAYLOAD (ELECTRONICS)	7.8	28.1	7.8	28.1	7.8	28.1
2	Z	PLATFORM	3.5	13	3.5	13	3.5	13
	W	PAYLOAD (WEAPONS)	6.5	23.5	23	83	5.5	19.7
	W	PAYLOAD (MAGAZINES)	1.1	5.6	1.1	5.6	—	—
3	Z	PLATFORM	5	18	5	18	5	18
	W	PLATFORM	3.5	13	3.5	13	3.5	13
	W	PAYLOAD (WEAPONS)	5	18	19.5	79	5.5	19.7
	W	PAYLOAD (MAGAZINES)	2.4	21	—	—	—	—
4	W	PALTFORM	50	180	50	180	50	180
	Z	PLATFORM	210	756	210	756	210	756
5	W	PAYLOAD (WEAPONS)	4.8	17.3	4.8	17.3	5.5	19.7
	W	PLATFORM	5	18	5	18	5	18
	2	PLATFORM	5	18	5	18	5	18
6	W	PAYLOAD (WEAPONS)	6.5	23.5	6.5	23.5	5.5	19.7
	W	PAYLOAD (MAGAZINES)	1.1	5.6	1.1	5.6	—	—
	Z	PLATFORM	5	18	5	18	5	18
7	W	PAYLOAD (ELECTRONICS)	44	158.4	44	158.4	52.8	190.1
	W	PLATFORM	5	18	5	18	5	18
	Z	PLATFORM	5	18	5	18	5	18
8	W	PAYLOAD (ELECTRONICS)	54.4	196	54.4	196	71	255.5
	W	PLATFORM	10	36	10	36	10	36
	Z	PLATFORM	5	18	5	18	5	18
SUMMARY	W	PAYLOAD	133.6	497	162.2	596.5	153.6	552.5
	W	PLATFORM	73.5	265	73.5	265	73.5	265
	Z	PLATFORM	238.5	859	238.5	859	238.5	859
TOTALS			445.6	1621	474.2	1720.5	465.6	1676.5

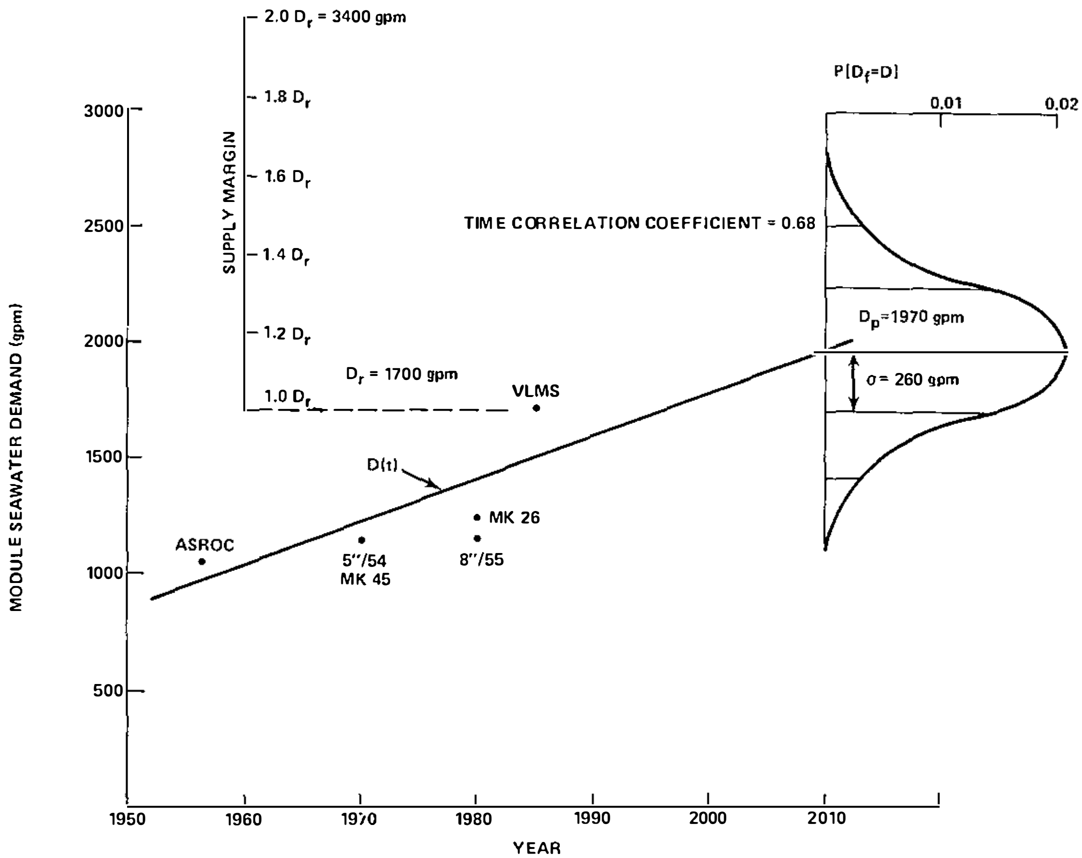


Fig. 9 Projection of module seawater demand

greater) impact on the combat system design and manufacture. The design criteria for the payload must allow the objectives of SEAMOD to be implemented yet be realistic with regard to state-of-the-art capabilities in technology and producibility.

Combat Direction System. One of the most significant impacts on payload design will be in the command and control system—now referred to as the Combat Direction System (CDS). The reason is that up until recently, the trend in design was toward heavy centralization and integration. With the initial adoption of computers, such an approach was felt necessary to achieve suitable capacity and redundancy at reasonable costs. Since the desire was to handle more and more sophisticated sensors and weapons (and manual response was literally "out of the question" for rapid computation) the trend was understandable.

The result of this trend (highly centralized and integrated), however, is that it greatly inhibites any changes to the combat system (payload). This is the reason that for every change in a hardware element, there is currently a requirement to change the software. And, as most program managers of recent conversions are aware, this can be more expensive and time-consuming (for checkout) than the hardware change. This statement is understandable when observing all the current interdependencies and shared functions as shown in Fig. 11.

It was quickly realized, that if the objectives of SEAMOD were to be reached, a redesign of the CDS would be necessary to allow individual interchange of payload elements without major perturbation to the remaining system. To do this required decentralization of functions and removal of interdependencies that currently exist. Thus, the study that was conducted addressed two issues:

- The feasibility of distributing (partitioning) CDS functions.
- The development of the distributed model.
- System level CDS partitioning. The approach to development of CDS partitioning is reflected in Fig. 12. It is composed of a number of highly "intelligent" sensor and weapons control subsystems which mask all of the peculiarities and dependencies of their internal technology, timing, and configuration from the central display, decision, and control functions of the system. The external interfaces to these subsystems would be functionally standardized to such a degree that broad classes of subsystems will be largely interchangeable in terms of functional integration into the combat system. Thus, for example, an SPS-49 radar (sensor) and a SPY-1 radar (sensor) would have a highly similar interface in which all dependencies were either masked or forwarded to the system as a part of the interface. A similar set of generic standards would apply to the weapons and weapons control subsystems, so that an "intelligent" vertical launcher and fire control system could become a direct functional replacement for an "intelligent" MK 26 launcher and fire control system.

The combat system suite of intelligent SEAMOD payloads would be electrically and functionally integrated by their standard interfaces. Operational integration is achieved by the existence of a number of system level functions to coordinate and direct activities of the sensor/weapon resources. These "system services control points" can operate independently of the subsystem peculiarities masked by the standard interfaces, and as such will be impacted minimally by any change in subsystem payload.

Two architectural observations are immediately apparent from Fig. 12. The first is that many functions formerly centralized in CDS computers have been disbursed throughout the subsystems. The second is that the interconnection of subsystem elements via a data bus network implies ease of recon-

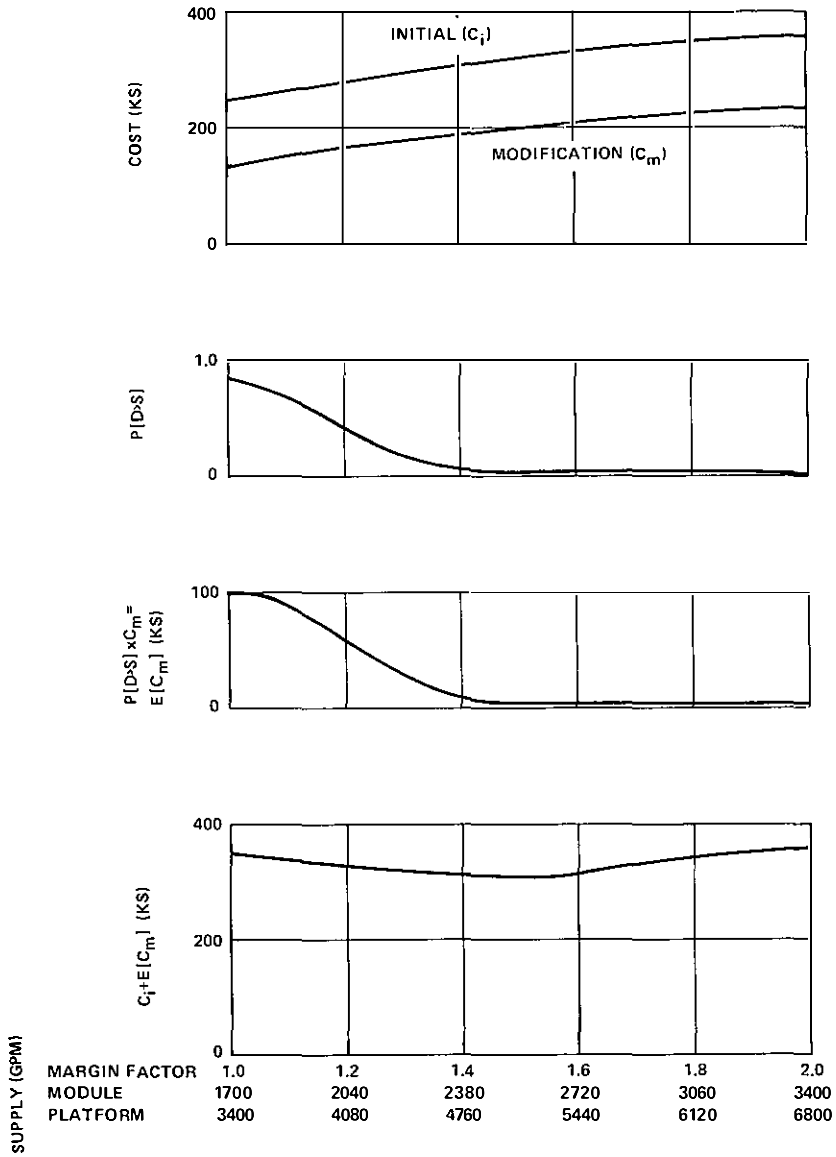


Fig. 10 Seawater margin selection

figuration, considerable capacity for functional and physical expansion, and the ability for direct intercommunication between subsystem elements. With these combined features, the potential for fallback and survivability in the event of loss of one or more subsystems is very high.

While the logical and physical functions of the sensor and weapons control subsystems are co-located, the central services control functions can be relocated or duplicated as necessary to ensure adequate recovery. While the track management function is valuable in coordinating sensor inputs, the outputs of intelligent sensors are sophisticated enough to be used directly by weapons control functions. In vital areas such as command and decision, the manual and automatic engagement control functions provide an overlap which allows each to serve as a backup for the other. The key to simplified system fallback is the processing, smoothing and refinement of information within each subsystem and the continuous availability of this information to all other subsystems via shared memory and the data bus network.

The availability of minicomputers and multiplexing for data bus transmission make this redistribution not only feasible but attractive on a cost-and-weight basis.

• Distributed CDS architecture. In accordance with the above model, a distributed version of the DD 963 Combat Direction System would appear as in Fig. 13.

Interfunction interconnects for the distributed architecture are shown by lines (or dotted intersections of lines) between the 27 processors or function groups of the system. Each control function block in the figure represents a combined set of hardware/software functions to support the unique processing for the subsystem in which it resides.

Comparing Fig. 11 with Fig. 13 reveals that the haphazard and irregular data flow structure between functions of the centralized structure is replaced by an orderly and symmetrical intercommunication structure in the distributed case. Although the same functions are processed by the latter system, they are partitioned into the subsystem they support. The result is a level of intelligent interface which can be more easily standardized, rather than a variety of levels of raw data and unique information signals which interface with specific hardware. Thus, the myriad of irregular signals reduces to a few standard signals between each subsystem and the central system. The impact on configuration management of a data bus system or dedicated cabling is obvious.

Table 5 **Weapon module support service constraints**

ITEM CONSTRAINED	QUANTITATIVE CONSTRAINT	WORST CASE IN SAMPLE POPULATION	MARGIN ALLOWANCE
SEA WATER	2,500 gpm	1,700 gpm	50%
VENTILATION	8,500 cfm	5,000 cfm	70%
CHILLED WATER	200 gpm	90 gpm	100%
COMPRESSED AIR	25 cfm/250 psi	12 cfm/250 psi	100%
ELECTRICAL POWER (AVERAGE OPERATING)			
60 Hz	500 KW	270 KW	90%

Table 6 **Support system design criteria for SEAMOD destroyer**

SYSTEM	LOCATION	CAPACTIY*	RATIO OF WEAPONS LOAD TO SHIP LOAD
SEA WATER (FIREMAIN/ SPRINKLING)	CENTRALIZED	10000 gpm	0.2
VENTILATION (EXCLUDING ZONE 4)	DE-CENTRALIZED	115,000 cfm	0.3
AIR CONDITIONING	CENTRALIZED	600 TONS	0.3
CHILLED WATER	CENTRALIZED	2300 gpm	0.3
COMPRESSED AIR	CENTRALIZED	200 cfm @ 250 psi	0.5
ELECTRICAL POWER (60 Hz)	CENTRALIZED	10,000 KW**	0.2
NITROGEN/HYDRAULICS	DE-CENTRALIZED, PROVIDED WITH MODULE		

* IN TERMS OF HARDWARE, INITIAL DISTRIBUTIVE SYSTEM MUST BE CAPABLE OF CARRYING INDICATED CAPACITY. HOWEVER, GENERATION COMPONENTS (PUMPS, CHILLERS, GENERATORS) MAY BE SIZED TO INITIAL NEEDS WITH SPACE/WEIGHT RESERVATION FOR UPGRADED COMPONENTS.

** RECOMMENDED PLANT FOR KEEL-UP DESIGN OF SEAMOD PLATFORM. FOR SEAMOD ADAPTATION OF THE DD 963 DESIGN, 6000 KW WAS DEEMED ADEQUATE FOR THE SPECIFIED PAYLOADS, WITHOUT CONSIDERATION OF UNCERTAINTY.

The distributed configuration retains exactly the same operational capabilities as the centralized CDS, but the interfaces permit expansion to more easily incorporate future automated capabilities as they develop.

The Combat Information Center (CIC) remains centralized on the distributed ship where the central tactical display control function drives the display console arrangement for that particular ship. However, since the subsystem-dependent displays and mode processing are either provided by the distributed processors (via the standard interface) or by prestored high-order language routines and display skeletons stored on disk or other mass-memory devices in the display subsystem, there is no reason why a second tactical display control subsystem capability could not be provided elsewhere on the ship for activation in the event of casualty in the primary CIC. In fact, with the high degree of decentralized *processing*, it appears very feasible that backup local operation of sensor/weapons subsystems could retain intersubsystem coordination via the track management and engagement direction subsystem even if CIC were disabled altogether.

The configuration of a distributed CDS as it might appear on a SEAMOD destroyer is shown in Fig. 14.

Weapons. Extensive discussion and design effort was conducted with various weapons manufacturers. In particular, the physical and functional constraints discussed above were developed in cooperation with the producer/designers of the Mark 26 Guided Missile Launching System, the 5-in. (127 mm)/54 and 8-in. (203 mm)/55 guns and a proposed Vertical Launch Module System.

It was determined that modularizing the gun mounts and launching systems would not degrade the units. Their performance remained the same. The gun mount basic units remain intact; the platforms and support posts were built around existing assemblies. The gun mount module ammo elevator, stowage bins, and handling equipment have the same requirements as similar equipment for a conventional system. Where the launching system module is concerned, the basic units also remained intact; the only addition is the mounting platform which serves as a foundation for the entire module. The mounting platform would rest on and be secured to the ship structure.

As discussed earlier, in all modules the entire vertical load would be distributed to the ship structure under the module. The lateral loads for the upper part of the module would be distributed to the ship's structure at the 01 level. The vertical and lateral support surfaces, the module access, and the ship service connections would be in the same location; thus, there would be commonality among modules.

The Mark 26 Mod 1 type Missile Launching System module was designed to fit into the envelope dimensions as shown in

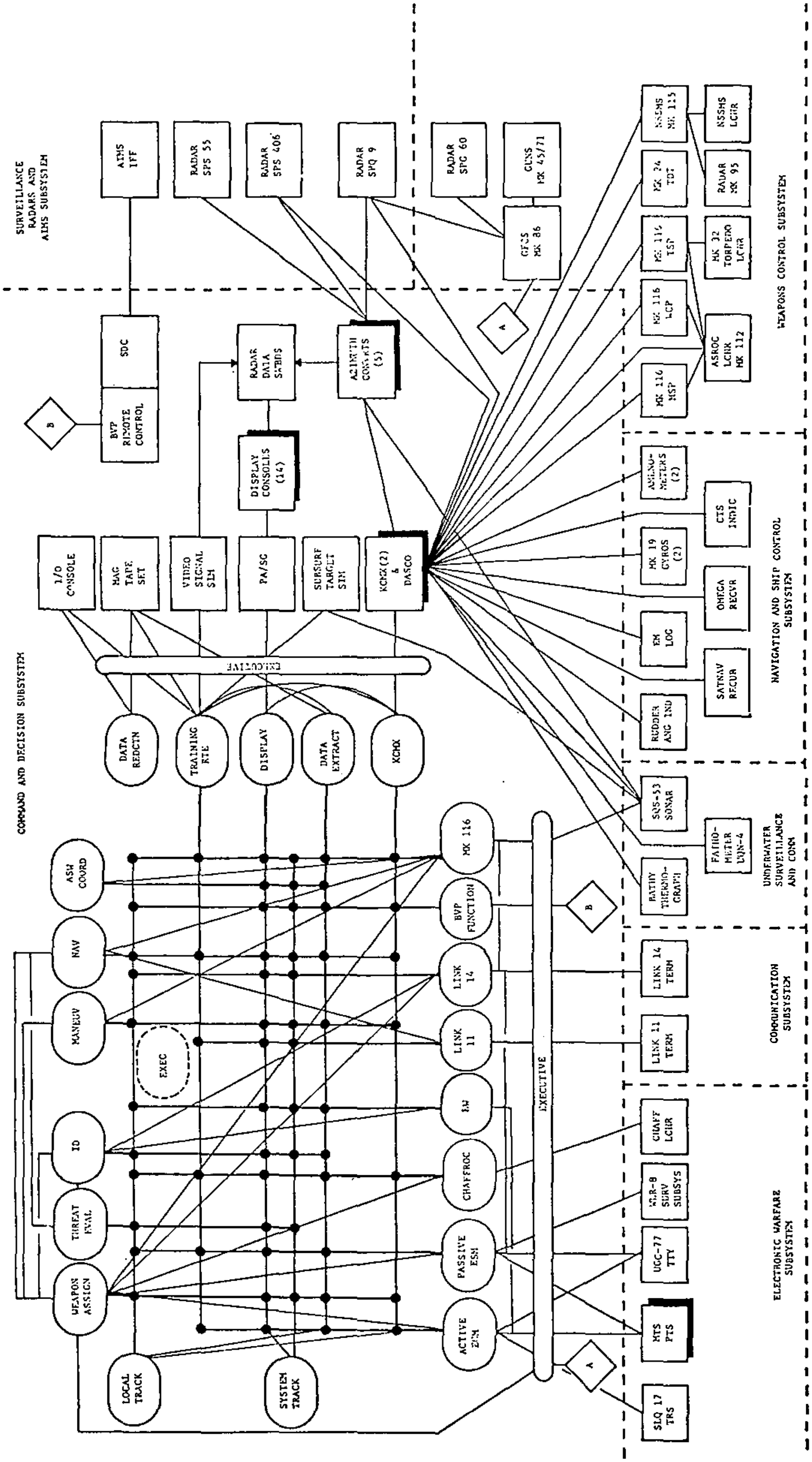


Fig. 11 CDS functional interactions for conventional destroyer

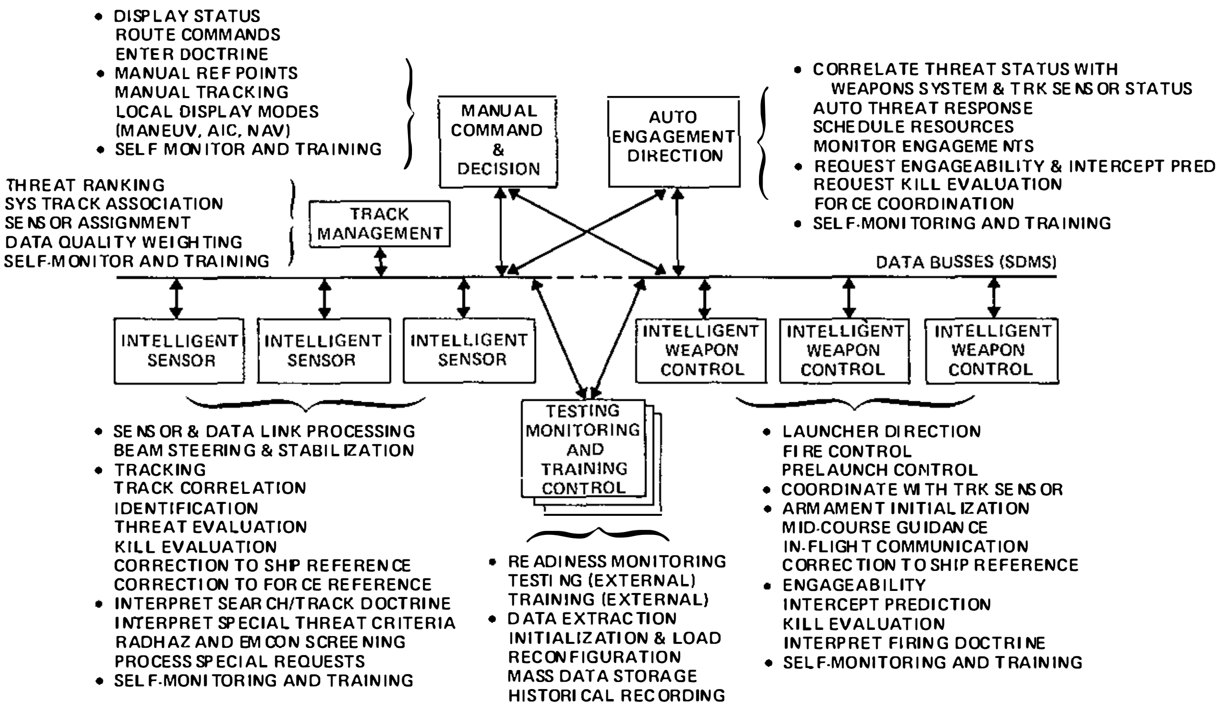


Fig. 12 SEAMOD CDS model

Fig. 15. All the launcher assemblies are basic. The deck platform would be supported through the ready service ring and launcher platform structure.

Strikedown would be accomplished via the guide arm. This is a variation from the existing Mark 26 Mod 1 but is a proposed change for all systems. Also, access to the control room would be from the side of rather than from behind the control room. The change in access location was made to accommodate the ship interface discussed earlier.

The 8-in. (203 mm)/55 Caliber Gun Mount Mark 71 module was also designed to fit into the designated envelope. The gun mount and its loader are basic units, the loader carrying 75 rounds in ready service. The module consists of a structure incorporating three platforms which are separated by seven vertical support posts. A flanged ring on the top or deck platform supports the basic gun mount. The control room would be secured to the underside of the deck platform.

No additional equipment beyond what exists for a conventional system was required. Replenishing would be accomplished in much the same manner for both modular and conventional; therefore, replenishing time requirements would be the same.

The total number of rounds in stowage and ready service was 250. The 8-in. (203 mm) gun module, as installed, is shown on Fig. 16. A similar design approach was taken with the Mark 45 Mod 0 5-in. (127 mm)/54 Caliber. Although many more rounds could be stored with the 5-in. (127 mm) gun, 250 rounds were used for purposes of the study.

Design of a Vertical Launch Missile System was developed for the converted version of the SEAMOD ship. Sufficient engineering effort was undertaken so that definition of the module could be achieved to a level indicated in Fig. 17.

The encouraging results from the above weapon module studies was that the participating manufacturers felt very positive about adhering to a set of Design standards—*assuming they had sufficient time to design new weapons against them.* For the dimensions developed, repackaging of existing weapons was no problem.

Impact on ship characteristics:

Weight comparison. Data from the DD 963 was used extensively in determining the weight of the SEAMOD platform. The methodology used was a weight-off/weight-on approach. Only those areas affected by SEAMOD were analyzed. It was assumed that all other areas would be the same as the DD 963. The resulting weight comparison is given in Table 7.

In order to establish the light ship weight condition of the SEAMOD platform without payload, it was necessary to depart from standard weight groups. This is because of the nature of the modular "payload" now treated as an independent weight group.

In addition to the payload items normally contained in Navy Weight Groups 4 and 7, this specialized load category includes ammunition stowed within the weapon modules and the ballistic plate, usually a Group 1 item, used to protect missile magazines. The weight used for various payload modules was provided by weapon manufacturers participating in the study.

The change in hull structure reflects the addition of structure required to extend the 01 level aft, removing structure to form the weapon module location, the installation of transverse foundations, the use of HY 80 steel in lieu of HTS in reinforcement areas, and the addition of solid ballast to meet stability requirements.

The estimated increase of 3.5 tons under "Electrical" reflects the addition of power distribution panels and cable in each weapon zone.

An increase of 37 tons (37.6 t) was estimated for the auxiliary group. This increase was attributed to the increased size of the firemain/sprinkling system, the addition of a 150-ton air-conditioning plant and increased distribution and the installation of dedicated HVAC systems for each weapon zone. The increase under the new group "payload" was due to the need for additional structure necessary to modularize the weapon systems.

Stability. Intact and damage stability investigations were analyzed for two ship conditions for each of the three SEAMOD

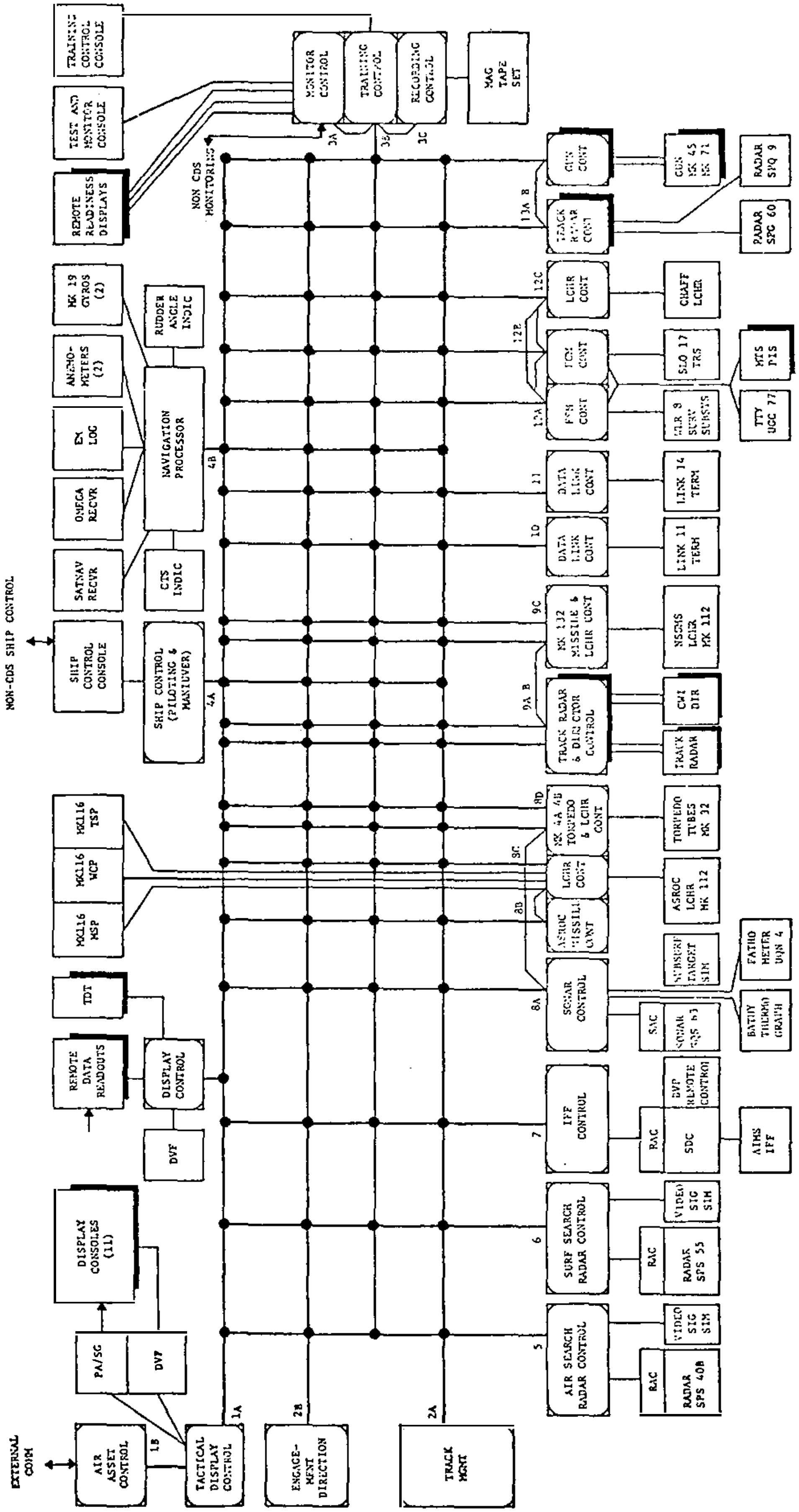


Fig. 13 Functional interactions for distributed CDS architecture

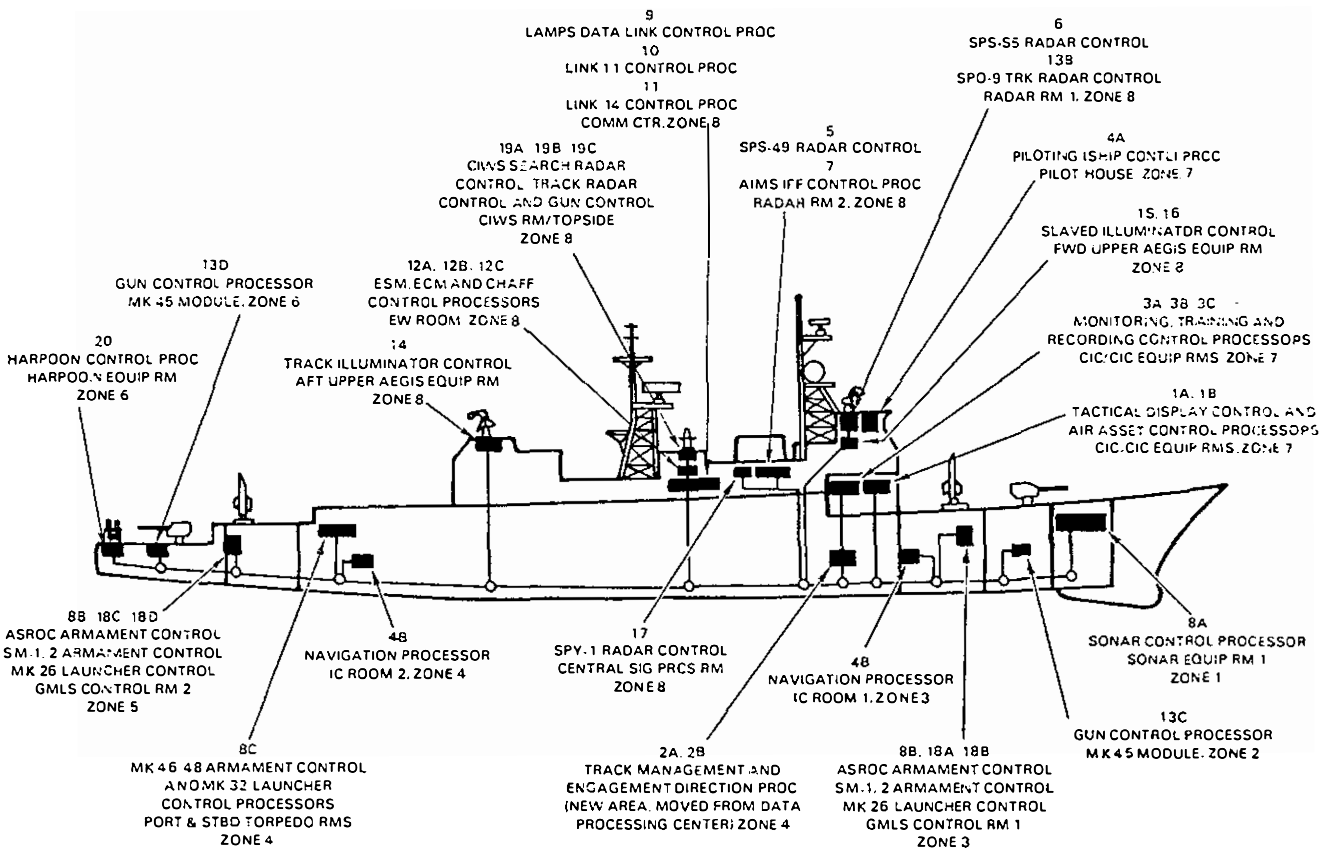


Fig. 14 Distributed CDS configuration

ship configurations (that is, baseline, modernization, and conversion). It was determined that there was a rise in $\overline{KG}$ due to the reconfiguration of the weapon modules/stations.

The results of the *intact stability* investigations shows that the high-speed turn criterion was the most critical case for determining the allowable $\overline{KG}$ for the intact condition. All three SEAMOD ship concepts had adequate $\overline{KG}$ margins for Case I (inclining experiment margin of 0.25 ft (7.62 cm) rise in KG) as given in Table 8. However, when the service life growth margin, Case II [350 tons (355.6 t) and 0.50 ft (15.24 cm] rise in $\overline{KG}$) is included, the SEAMOD Modernization and Conversion ship concepts were unacceptable (negative $\overline{KG}$ margin).

Using the standard practice within the Navy for determining *damage stability*, the SEAMOD Modernization and Conversion ship concepts were found to be initially unsatisfactory as shown in Table 8.

The stability characteristics may be improved by one or more of the three methods below:

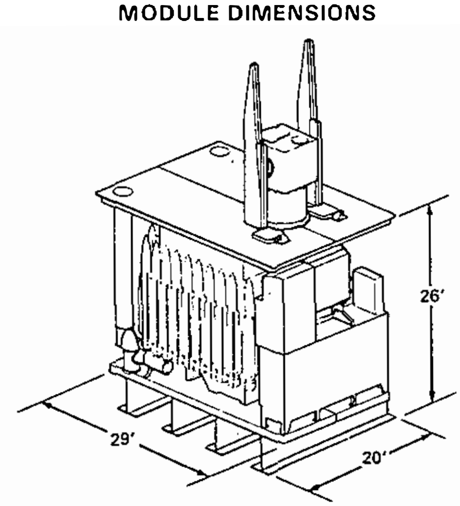
(i) Add solid ballast to inner bottom.
(ii) Raise bulkhead deck to 01 level.
(iii) Change major hull dimensions.

Of these three options, it was decided to add solid ballast to simplify the comparison in the study. [Approximately 65 tons (66 t) of ballast with a vertical center of gravity 6 ft (1.8 m) above the keel were required to sufficiently lower the $\overline{KG}$, and this was reflected in the weight comparison.]

For future designs, the rise in $\overline{KG}$ caused by the SEAMOD configuration could be easily adjusted for by adequate hull form and weight distribution.

Trim. The trim was also analyzed for each of the ship configuration conditions. The trim with the conversion payload is excellent and with the baseline payload acceptable, but the trim as calculated with the modernized payload was ex-

MODULE DIMENSIONS



WEIGHT CONSTRAINTS
400K LBS WITH SHOCK FACTORS:
VERTICAL: 18G
TRANSVERSE: 11G
LONGITUDINAL: 7G

LIFT CAPACITY:
150 TONS WITHOUT AMMUNITION

SUPPORT REQUIREMENT CONSTRAINTS
800KW ELECTRICAL POWER (PEAK)
2500GPM SEA WATER
200GPM CHILLED WATER
25CFM (AT 250PSI) COMPRESSED AIR

Fig. 15 The MK26 module

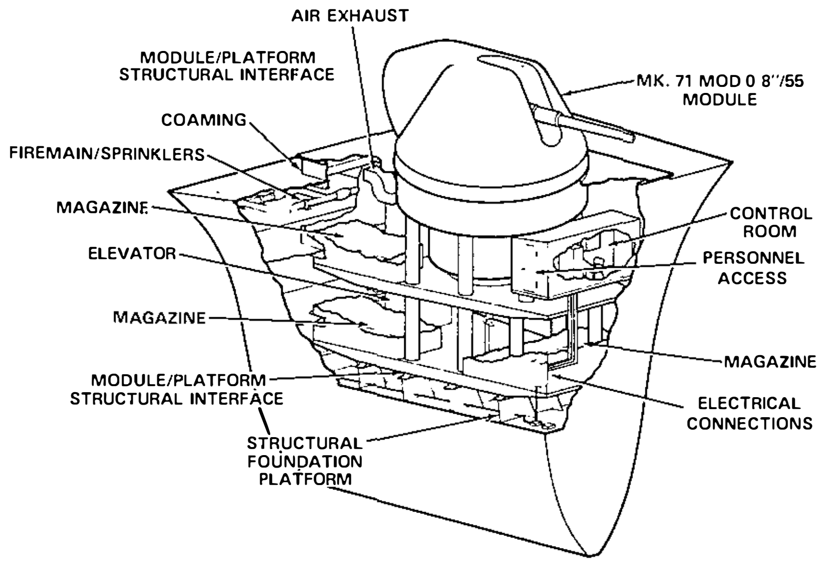


Fig. 16 8-in. (203 mm)/55 gun module installation

Table 7 Weight comparisons

A. BASELINE COMPARISON

WEIGHT GROUP	DD 963 WEIGHT (TONS)	SEAMOD WEIGHT (TONS)	Δ(TONS)
HULL STRUCTURE	3106	3162	+57
PROPULSION	760	760	–
ELECTRICAL	284	287	+3
AUXILIARY	723	760	+37
OUTFIT/ FURNISHINGS	451	451	–
PAYLOADS	506	684	+178
LOADS	2040	2040	–
FULL LOAD	7870	8144	+274

B. MODERNIZED AND CONVERTED FULL LOAD COMPARISON

	CONVENTIONAL WEIGHT (TONS)	SEAMOD WEIGHT (TONS)	(TONS)
MODERNIZED	8083	8264	+181
CONVERTED	8194	8299	+105

Table 8 $\overline{KG}$ margins

A. $\overline{KG}$ MARGINS FOR CASE I

ITEM	BASELINE	MODERNIZATION	CONVERSION
INTACT STABILITY	0.74	0.46	0.51
DAMAGE STABILITY	0.14	−0.13	−.015

MARGINS INCLUDE: 0.25 FT $\overline{KG}$ INCLINING EXPERIMENT

MARGIN: POSITIVE VALUE IS SATISFACTORY.
NEGATIVE VALUE IS UNSATISFACTORY.

B. $\overline{KG}$ MARGINS FOR CASE II

ITEM	BASELINE	MODERNIZATION	CONVERSION
INTACT STABILITY	0.24	−0.04	−0.09
DAMAGE STABILITY	−0.48	−0.75	−0.75

MARGINS INCLUDE: 0.25 FT $\overline{KG}$ INCLINING EXPERIMENT
0.50 FT $\overline{KG}$ SERVICE LIFE GROWTH
350 TONS SERVICE LIFE GROWTH

MARGIN: POSITIVE VALUE IS SATISFACTORY.
NEGATIVE VALUE IS UNSATISFACTORY.

cessive [1.63 ft (0.5 m) forward]. This condition was attributable to the heavier payload [8-in. (203 mm) gun] being added to the forward portion of the ship without any change aft. The destroyer study did not include analyzing all possible solutions for this condition; however, in order to further establish the characteristics of the SEAMOD concept, additional studies were conducted to ascertain the trim and stability characteristics of the platform with one weapon module removed.

The significance of the trim and stability analysis was that future designs must choose weapon station locations which desensitize trim and stability changes as a function of module weight and CG change.

Survivability. Design of Navy surface combatants must consider the issues related to survivability in a wartime environment.

The SEAMOD concept proposes the placement of standard-size modules within previously prepared standard cavities of similar but slightly larger proportions. Because of the required horizontal clearances between the module boundary and the module cavity structure, there is a decision that must be made with regard to damage control and ship protection. For example: Which should be made watertight—the module or the hole? or neither? or both? The same question can be raised with regard to ballistic protection and where and when it is attached.

The following issues were considered when evaluating the impact of SEAMOD on ship design:

Watertight damage control deck.

Watertight boundary for vital spaces.

Nuclear security requirements.

Ballistic protection for missile magazines.

Figure 18 shows four means of meeting the above requirements.

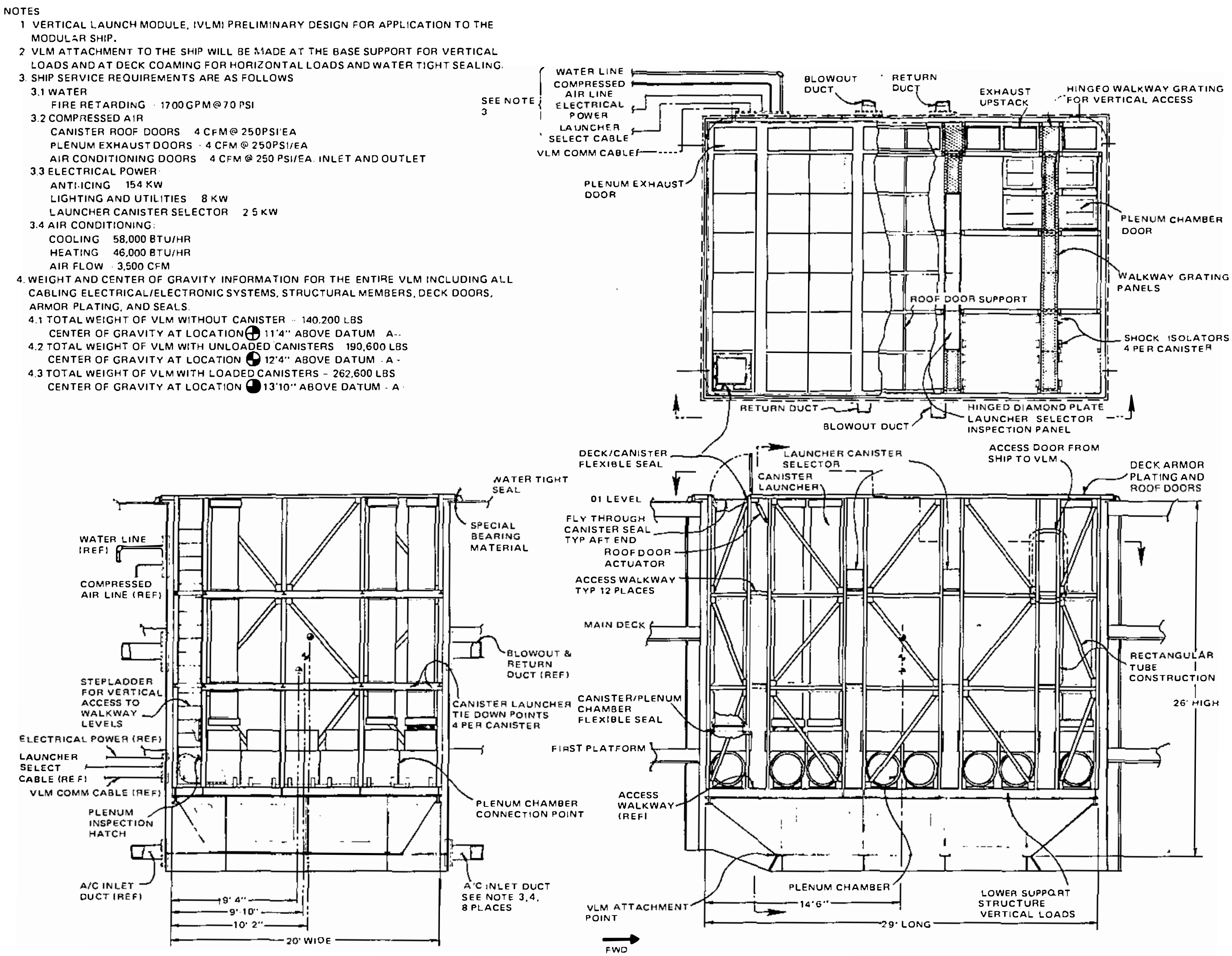


Fig. 17 Vertical launch missile system (VLMS) module

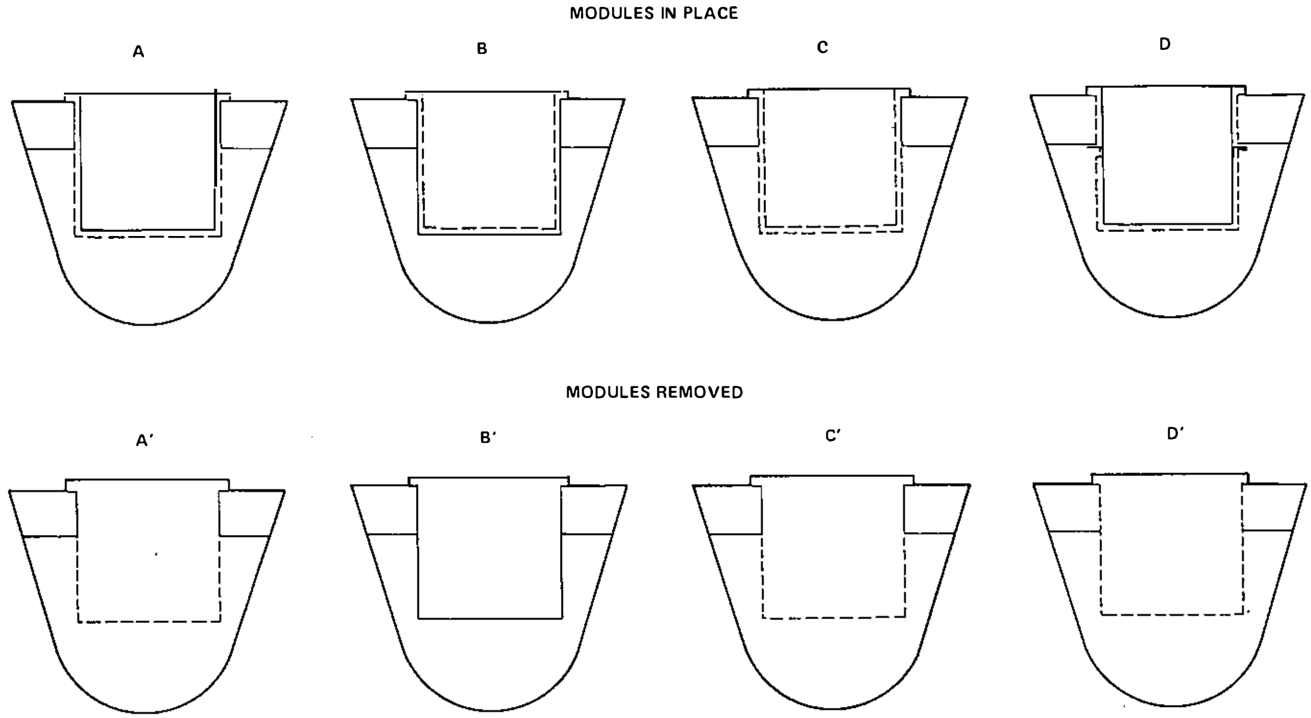


Fig. 18 Subdivision configuration options

For missile modules (vertical stowage), Schemes A and B meet the GEN SPECS and are appropriate for use. Scheme B leaves watertight integrity intact when the module is removed. Scheme C provides no protection for vital spaces and Scheme D requires a DC deck bulkhead to be installed if a module is not present. Horizontal missile stowage modules were not contemplated.

For gun modules, Scheme B would require more extensive subdivision than Scheme A because of double walls being a necessity for sealing individual magazines. In Scheme A the module shell could serve to isolate the magazines. Scheme C would be valid for a gun module but would most likely end up looking like Scheme A because of all the various magazines.

Since it would be a rare time when a ship would operate with empty module spaces (probably only when going from building yard to integration facility), it seems that Schemes A and D have the most universal application (both guns and missiles). An additional benefit is that where armor is required (for missile magazines), this armor can also serve the purpose of a watertight envelope.

SEAMOD frigate (4500 ton) (4572 t)

Having analyzed the SEAMOD concept as it would apply to an 8000-ton (8128 t) destroyer, the next logical step was to review the developed design criteria against other sizes of surface combatants. Review of the FFG-7 was made and it was determined that only two standard modules (developed from the DD 963 study) could be fitted with considerable redesign of the basic ship. The FFG-7 design is much more integrated (compact) than the DD 963, making the application of the zone concept very difficult.

Therefore, a study recently began to develop the design of a SEAMOD frigate which would be:

- Approximately half the displacement of the DD 963.
- Carry three quarters of the major armament weapons.

In achieving these objectives, it was felt that such a ship would be most competitive in "specific" acquisition cost (re: payload carried/ship costs) and at the same time provide the Navy with extreme flexibility for changing or upgrading mission capabilities, or both.

In the development of the SEAMOD frigate, retention of the same major armament module size as the destroyer was desired, so that weapons modules could be interchanged between the two ships. To meet the payload allocation of three quarters of the destroyer, a three-weapon-zone ship would have to evolve. Furthermore, it was felt that criteria should be applied in selecting weapon station location which incorporated "lessons learned" from the destroyer study as well as compatibility with other platform systems. Some of these criteria are listed below:

(*a*) Modules should be oriented longitudinally on the centerline to avoid list problems caused by variable module weights as well as heel and fire control problems.

(*b*) Modules should be located as close as possible to the LCB in order to minimize trim problems, also caused by interchanging modules of different weight.

(*c*) Reasonable separation (three watertight bulkheads) should be made between the forward and aft modules for survivability reasons.

(*d*) Compatibility with other platform systems or arrangements must be considered (for example, masts, intake/exhaust stack and helicopter pad locations).

Facilities capable of handling two helicopters were considered a requirement in order to provide the vessel with adequate ASW capability.

A displacement of 4500 LT (4572 t) was chosen as a starting point by which vessel dimensions could be obtained. This displacement is about 1000 tons greater than the FFG-7's displacement and should be sufficient to allow for the required increase in vessel capability. The following vessel dimensions were obtained by using a geosim hull of the FFG-7 at a displacement of 4500 LT (4572 t) and keeping block coefficient (C_B), length-over-beam (L/B) and beam-over-draft (B/T) ratios constant:

LBP: 450.43 ft (137.29 m)
Beam: 49.83 ft (15.19 m)
Draft: 15.84 ft (4.82 m)

A detailed vessel design would dictate how much the estimated displacement and dimensions would have to be adjusted.

The inboard profile is shown in Fig. 19 and conforms to the general requirements discussed above as well as providing the following specific features:

(i) The modules are standard (not tapered for hull form). As a result, only one zone was possible forward, so two zones were located aft.

(ii) The superstructure is located enough aft of the forward module location to provide adequate clearance.

(iii) The helicopter landing pad and hangars are located aft to allow unobstructed helicopter operations.

(iv) The exhaust stack is located at the forward end of the indicated machinery room to keep hot exhaust gases from interferring with helicopter operations or the aft weapons systems.

(v) The indicated height of the stack is to allow for good exhaust flow away from the ship.

(vi) The masts shown are only possible locations; good topside arrangement for compatibility with exhaust gases, electromagnetic interference (EMI), etc. would have to be determined.

Although the aft two modules are somewhat elevated, stability requirements can be met with proper weight distribution or beam selection, or both.

To demonstrate the flexibility of this design, Fig. 20 shows the ship with three different payload configurations. The time to change from one configuration to another (as will be discussed later) is less than six weeks.

Concept analysis

Having developed design solutions for implementation of the SEAMOD philosophy the next question is what impact would it have on the Navy shipbuilding industry? This section will attempt to provide insight to answering such a question, particularly as it relates to comparison with current practices and problems.

Impact on the ship construction process

Planning and scheduling analysis.

In order to define the possible impact caused by implementation of SEAMOD, it was necessary to define those changes within each zone that would be required by installation of the SEAMOD modules. This would include equipment or compartments, or both, that would be relocated or removed from the conventional ship configuration and replaced as part of the weapon module, or any modifications necessary to accommodate palletization of weapons system electronics.

By progressively eliminating areas within the DD 963 baseline ship, it was possible to extract increments of the total fabrication, preassembly, preoutfitting, erection, and post-launch outfitting from the total construction process.

The analysis contained in reference [7] identified the DD baseline compartments that were affected by modifications in the SEAMOD zone areas as shown in Fig. 21.

The impact analysis was based on Stationized Construction Planning presently employed in construction of the DD 963. Stationized Construction utilizes a system in which the fabrication units are moved to stations where crews that perform specified operations are located. By this method preoutfitted assemblies are combined and erected to form ship "modules" whieh are then aligned and welded to form the complete hull. Through the analysis it was determined that SEAMOD had the following impact:

(*a*) Preassembly activity would be reduced by 12 percent.

(*b*) Preoutfitting and outfitting in the superstructure and in Ship Modules 1 and 3 (Fig. 21) would be reduced by 22 percent.

(*c*) Preliminary testing and installation checkout of weapons and associated electrical, pipe, vent and machinery within the weapons module would reduce on-ship testing by 20 percent. It is also possible that physical integration and test of components within the module off-ship would reduce time required for system debugging and grooming prior to performance and operational testing on ship.

(*d*) Compartment completion is usually a critical-path effort constraining builder's trials. Early compartment closure in the weapons modules prior to "land on ship" (LOS) would reduce overall compartment completion.

The impact that this has on the key event schedule of destroyer construction is shown in Fig. 22. The rationale for reduction in time to construct the SEAMOD destroyer includes some of the following specific impact areas:

1. Precision alignment and testing requirements for weapons/magazines would be eliminated.
2. Fabrication, preassembly, erection and assembly integration schedule would change due to structural redesign. Manufacturing requirements for platework, shapes and formed steelwork in the affected areas would be reduced.
3. Piping, electric cabling, vent ducts, etc. in the direct area of the module holds would be reduced. Ship services would terminate at the module interface.
4. Joiner work, insulation, deck covering, etc., would be eliminated in the module area.
5. Increased use of HY-80 will require modification of assembly and nondestructive testing procedures.
6. Planning and structural provisions of superstructure access must be made for installation of palletized electronic components.

As shown in Fig. 22, a comparison of DD 963 key events to SEAMOD platform key events indicates an estimated reduction in construction time of approximately 16 weeks. As will be presented in the following section, the SEAMOD concept allows installation and exchange of payload within six weeks; therefore the net savings would be 10 weeks.

Labor/material cost analysis.

The major impact to the shipyard would be the 16-week reduction in construction time. This reduction in time may be expressed in the following approximate man-hours:

	man-hours
Start fabrication to keel laying	2 500
Keel laying to float-off (launch)	28 000
Float-off to builder's trial	84 000
Total reduction	114 500

Using rates indicated, the cost would be:

(*a*) Labor: 14 312 × \$120 = \$1 717 500
(*b*) Services: \$2000 (per day) × 112 days = \$224 000
(*c*) Total savings: \$1 941 500

For the purpose of determining the reduction in manning requirements the following percentages were used:

	percent
Fabricate ship	10
Erection and platens	11
Chippers	2
Hull erection	8
Rigging	7
Paint	10

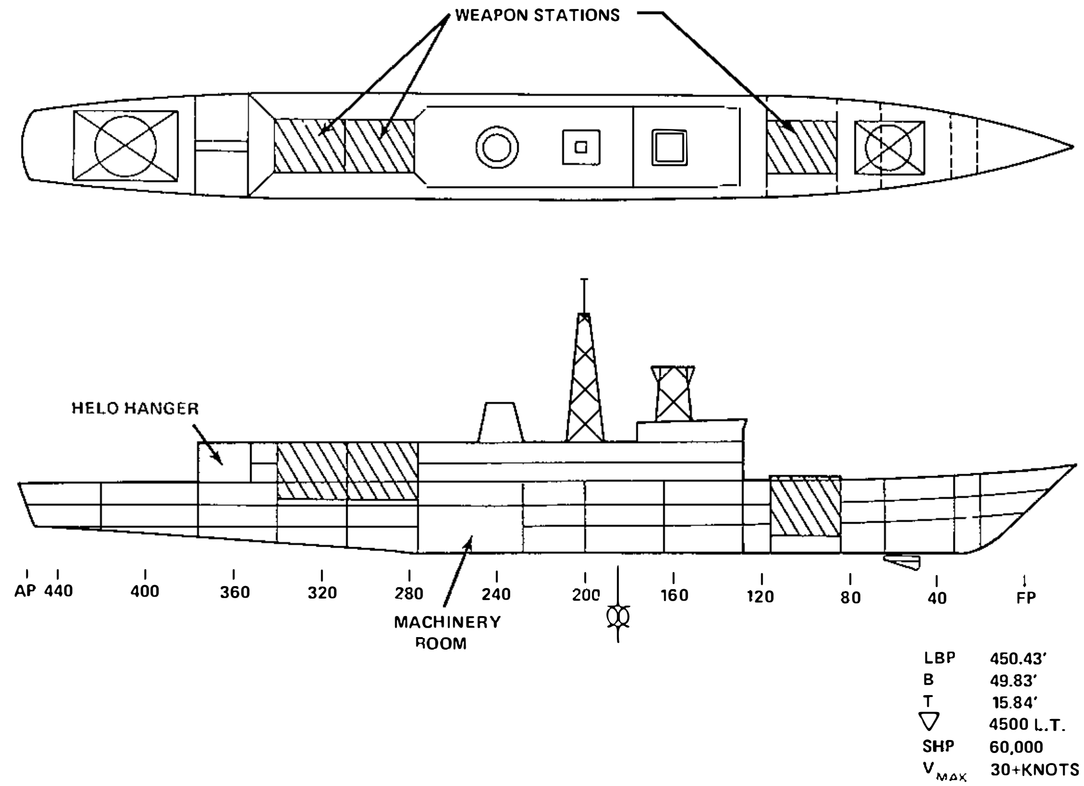


Fig. 19 SEAMOD frigate

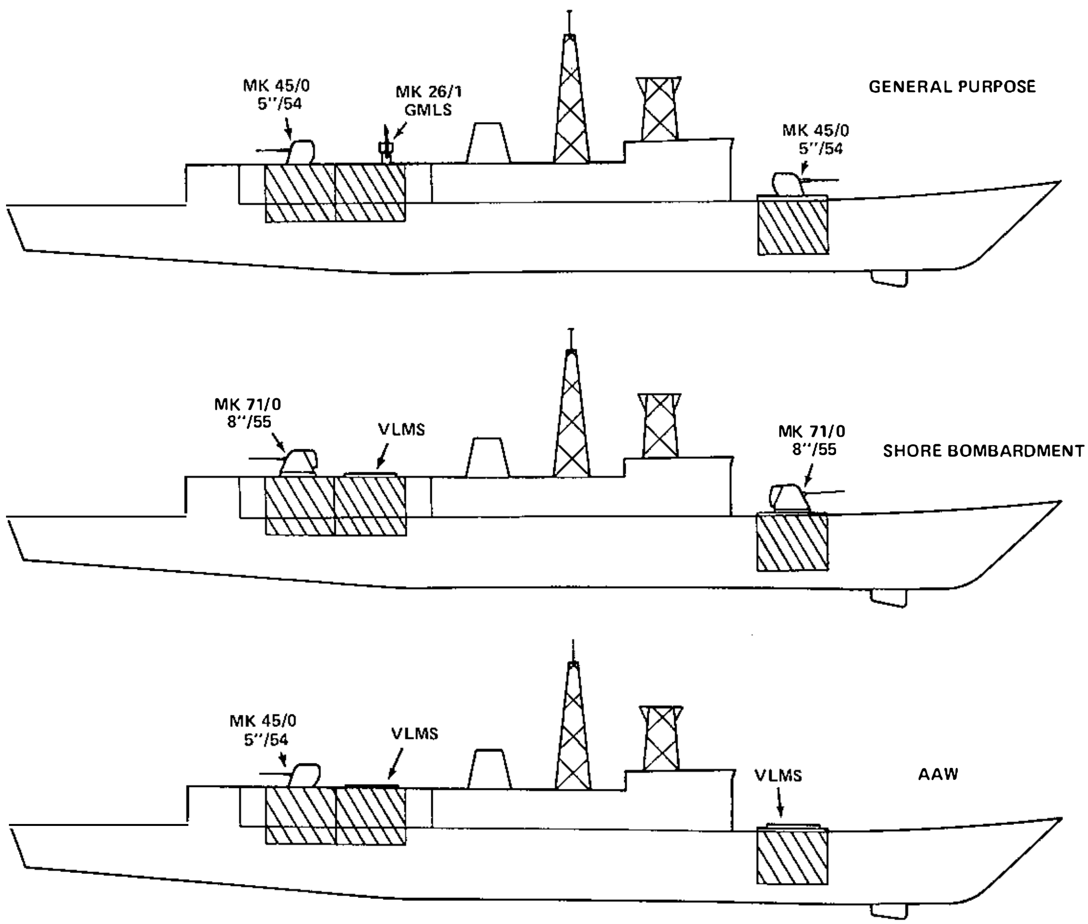


Fig. 20 Various configurations of SEAMOD frigate

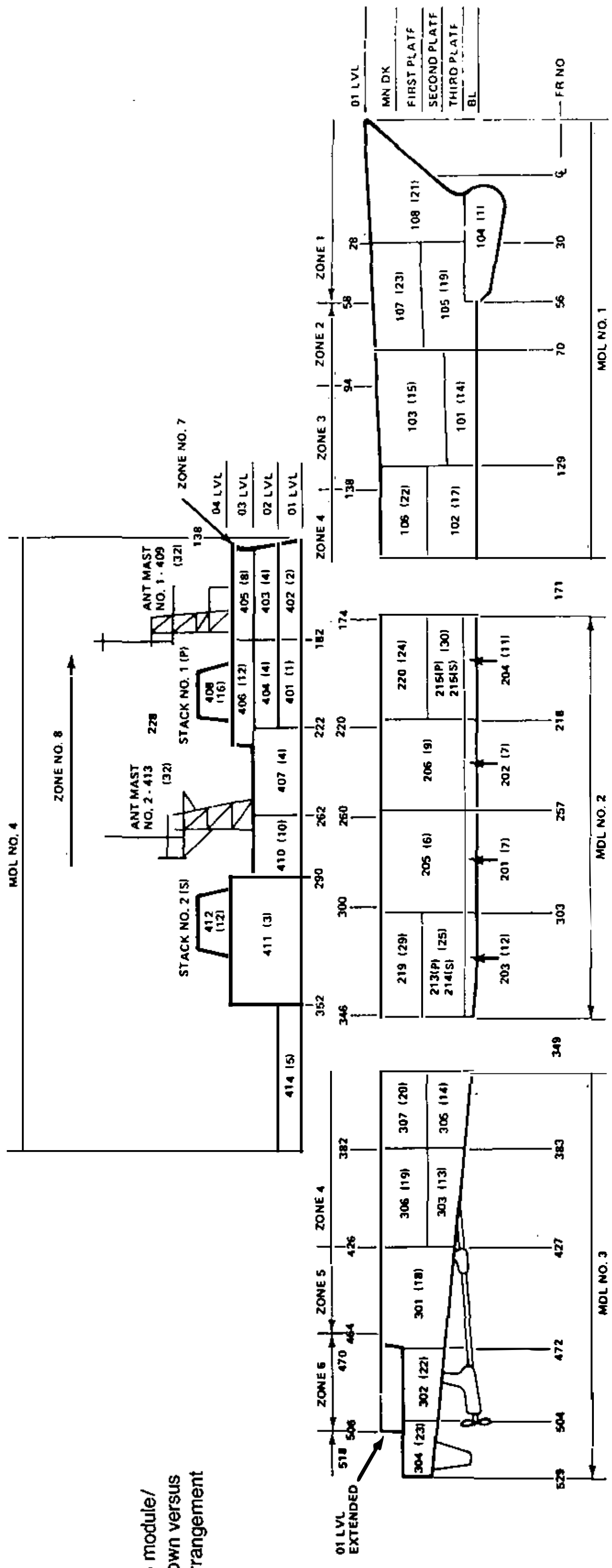


Fig. 21 DD 963 module/assembly breakdown versus SEAMOD zone arrangement

Sheet metal (ship and shop)	7
Pipe (ship and shop)	14
Electrical (ship and shop)	24
Miscellaneous crafts	7

When the increased cost to modularize and install the weapon payload was accounted for, the savings in total construction costs was still over $1 million per ship.

Impact on the modernization and conversion process

One of the reasons for specifying the weapon changeout scenario in the case study was so quantitative cost comparisons could be made between conventional and SEAMOD destroyers for modernization and conversion evolutions.

Since the overall evolution of updating a naval combat system is quite complex, great care was taken in identifying all of the cost factors in the required chain of events. In addition, the span of the chronology had to be carefully defined because costs can occur at various stages of the evolution. For example, consideration of too brief a time span, such as the shipyard phase only, could bias the analysis unfavorably by completely omitting a significant cost factor, such as acquisition of the system, which could be quite different for the two configurations. These considerations were incorporated in a detailed analysis of the modernization and conversion process as documented in reference [8].

It was recognized from the onset that:

- The number of discrete factors required for "complete" analysis was staggering.
- Quantitative estimates of these factors would span several orders of magnitude, as well as several levels of confidence and precision.
- Estimates of some factors could show negligible difference between SEAMOD and conventional approaches.
- Certain quantitative results obtained for one system could be generalized to apply to other similar systems.

Accordingly, it was intended to distinguish between significant and negligible factors and differences as early in the procedure as possible, with reasonable justification. Likewise, it was felt that selected data could be extrapolated to cover systems for which little or no data were available.

This permitted what was felt to be a meaningful analysis to be carried to completion within the allotted time and labor constraints, by avoiding overconcentration in inappropriate areas.

The combat systems considered were those affected by two groups of "scenario events" or combat system changeouts to be accomplished during the life cycles of the two platforms.

Four scenario events comprised the modernization evolution. These included:

1. Replacement of the forward 5-in. (127 mm)/54 gun system with an 8-in. (203 mm)/55 gun system.
2. Replacement of the ASROC system with the MK 26 MOD 1 Guided Missile Launcher System.
3. Installation of the Improved Point Defense Surface Missile System, with its associated detection and fire control systems.
4. Replacement of the 20-mm Close-In Weapon System with Infrared Decoy Launcher System.

Four scenario events comprised the conversion evolution. These included:

1. Replacement of the forward 8-in. (203 mm)/55 and after 5-in. (127 mm)/54 gun systems, as well as the forward MK 26 and after IPDSMS guided missile systems, with a Vertically Launched Missile System.
2. Replacement of the AN/SPS 40B air search radar with the AN/SPS 48C.
3. Modification of the MK 86 MOD 3 Gun Fire Control System to a MOD 5 configuration.

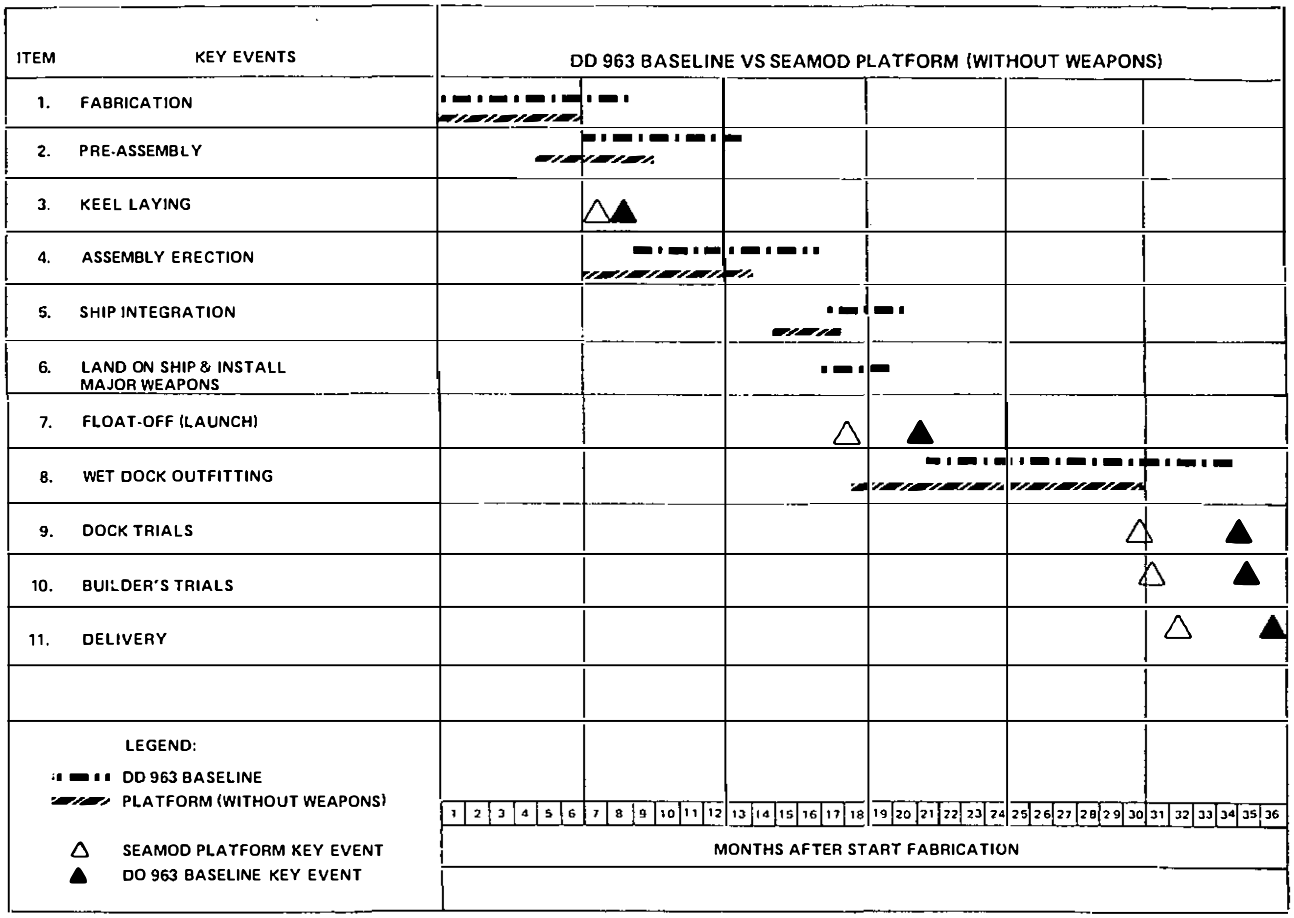


Fig. 22 Production—key event schedule

4. Replacement of the AN/WLR 1C Passive Electronic Warfare System by the Design to Price Electronic Warfare System 3.

To quantify the comparison for each modernization and conversion, Pert networks were established for each event. Figure 23 is a representative example for the installation of the 8-in. (203 mm)/55 gun. These Pert networks were developed using a very detailed breakdown of the hundreds of steps required.

The result of this very complex analysis showed significant reduction in total time to modernize and convert the ship as shown in Fig. 24. When the savings in software reconfiguration were taken into account [6], modernized and converted scenarios indicated a $9.3 million advantage for SEAMOD.

Impact on acquisition process

As a concept which could modify the procedures and contractual interfaces in the procurement of ships, SEAMOD was analyzed for both government and industry impact. This section will summarize those findings.

Government impact.

There are several planning systems which ultimately affect the design and procurement of Navy ships. However, the discussion will concentrate on the Planning, Programming and Budget System (PPBS) and the impact on ship design and production documents.

SEAMOD will have several impacts on the PPBS cycle. One of the most obvious is the reorientation of strategic thinking and planning. The broad strategic guidance for force planning and programming formulated by the Secretary of Defense, on the one hand, and the force and resource recommendations developed by the Joint Chiefs of Staff and the Navy, on the other hand, *must take into account the SEAMOD ship's ability to perform a number of different missions and counteract a wide range of threats at different times through rapid reconfiguration for specific missions.* This is in contrast to a conventional ship class which is designed for multiple missions and is armed with some weapons systems unrelated to the particular mission in which the ship might be engaged. Furthermore, traditional assumptions about force sizing must be altered in that reduced out-of-service time will permit a smaller SEAMOD force to accomplish the same tasks a larger conventional force did in the past.

Another impact will depend on the way the Navy decides to program resources and fund SEAMOD ships. If the Navy chooses to program and request funding for a total ship buy (platform and payload) each time, then SEAMOD will have no effect on these aspects of the PPBS Cycle. However, *should the Navy decide to request funding for the ship platform in one fiscal year and separate funding for payload in another, SEAMOD will undoubtedly change the nature of resource programming, the establishment of time-phased financial requirements, and the preparation and approval of the Navy Budget Estimate.* Although this latter type of funding request for SEAMOD could provide a more constant level of platform procurement, it might also present the Navy with a problem in justifying and selling the program during Congressional hearings. The only means for the Secretary of Defense and the Navy to put SEAMOD ship procurement into perspective will

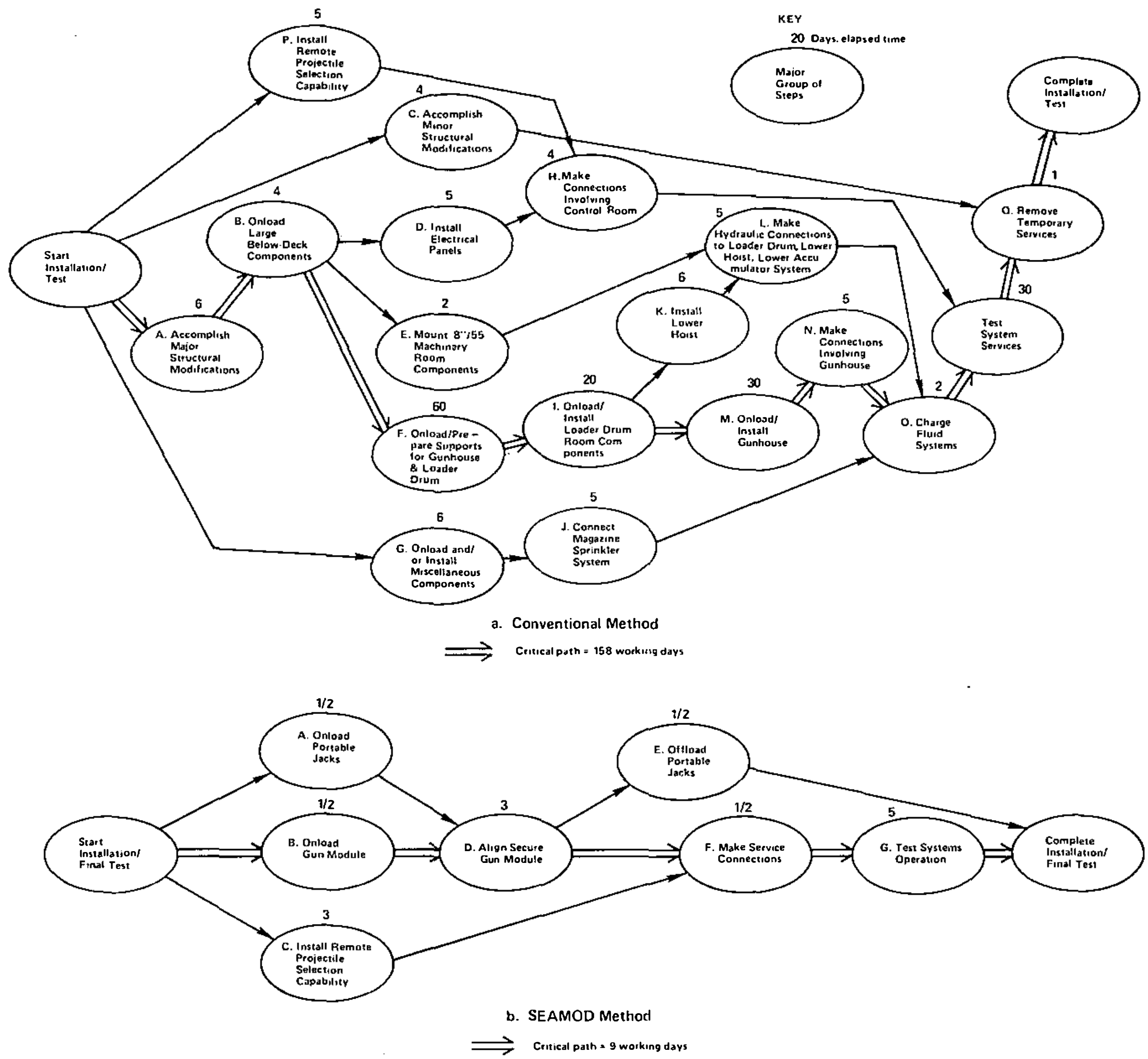


Fig. 23 Installation/final test of 8-in. (203 mm)/55 gun system

be detailed use of the Five Year Defense Program to show total fleet strategy.

As described in reference [9], implementation of SEAMOD can have an impact on the Navy's technical requirements, namely, the Top Level Requirements (TLR), and the Top Level Specifications (TLS). A summary of projected impact to these and other requirements documents is given in the Appendix.

Industry impact:

As the first phases of the SEAMOD analysis effort were completed, it became increasingly apparent that the SEAMOD vessels would require a different configuration and operating profile for vessel construction and repair facilities. The important questions raised by this realization were:

- What type of impact will the shipbuilding industry be likely to experience?
- How severe will these impacts be, should they occur?
- How can the Navy minimize these potential impacts?
- What effect will unavoidable impact have on the direction and implementation of the SEAMOD program?

The following discussion presents a summary of a study [10] undertaken to answer the foregoing questions.

Implementation options. The effect of implementing a SEAMOD program on commercial U.S. shipbuilders would vary widely depending on the implementation options selected by the Navy. Recognizing this wide range of impacts, the options which might have a major effect on the shipyards were identified in order to narrow the parameters of an impact analysis. They considered the three basic construction steps of platform construction, payload module construction, and module integration from the point of view of what facility will be used and who will do it, and they assumed program implementation on a DD 963 class of vessels. Also considered was the financial and contractual impact of the cost of shipyard operational and facility changes in relation to the size of the ship series order.

Not only were a large number of implementation options

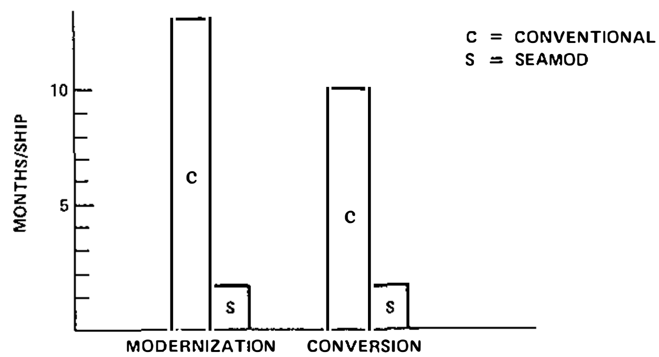


Fig. 24 Comparison of modernization and conversion time

which could significantly impact commercial shipyards identified, but the ways in which these options could be combined with varying effect were seen to be even larger. To analyze the relationships between the identified options, an option tree was constructed as shown in Fig. 25. This tree was laid out to show only the principal relationships between categories, since it is a simple two-dimensional tree. A multidimensional tree would be capable of expressing more complex combinations, but was beyond the scope of the study.

If all the alternative paths through the tree were considered, there would be 5400 different combinations to evaluate. To reduce this requirement as much as possible, some path lines were eliminated.

The paths eliminated were those which were very unlikely no matter what value index was being analyzed. This is due primarily to the fact that the reason for including one node in an alternate path would exclude a following node. For instance, in establishing the economic viability of SEAMOD to commercial shipyards, if the Navy elects to build the payload modules at a commercial shipyard, it is highly unlikely that they would use Government personnel to do it.

It was also obvious that some alternative paths would contain mutually excluding nodes which were not in sequence and, therefore, could not be eliminated by removal of a path line in the tree. As these false paths were identified, they were automatically excluded from the analysis results.

To handle the multivariables of the tree and to permit easy sensitivity analysis of the tree's elements, a simple computer program was developed. This program was designed to allow a variety of values to be placed on the option which would evaluate such comparative categories as:

(1) Index of Economic Viability to the Navy
(2) Index of Military Responsiveness
(3) Index of Minimum Change/Impact to the Navy
(4) Index of Political Acceptability
(5) Index of Economic Viability to the Commercial Shipbuilder
(6) Index of Minimum Change/Impact to the Commercial Shipbuilder
(7) Index of Economic Viability to the Payload Manufacturer
(8) Index of Minimum Change/Impact to the Payload Manufacturer

The basic approach was to subjectively assign weighting values to the pathline groups between option categories which were indicative of their relative importance to the particular value analysis. Guiding rationales for the assignment of weighting values to the path-line groups are presented in reference [10]. The pathline group weighting values were fractions whose sum was one except in value analyses where some pathlines groups were not applicable and were given a weight of zero so they could not affect final full path values.

Within each pathline group, the individual pathlines were also assigned relative values of importance to the particular value analysis, where the sum of pathlines within the group totaled one.

In calculating the full path values, the computer program multiplies the pathline value times its pathline group weight to arrive at a weighted pathline value. These weighted pathline values are then added for each possible alternative path. A simple sort of routine then arranges the final full path values in descending order.

An example of an option tree with weighting factors filled in for "Index of Economic Viability to the Commercial Shipyard" is shown in Fig. 26.

The eight option trees and assigned values were manipulated by the previously discussed computer program with the output consisting of a descending value list of all the possible paths through the tree.

The outputs were carefully analyzed to determine the best paths in each category. This involved discarding any false or self-contradicting paths, characterizing groups of paths, and selecting a reasonable number of options representing a truly major difference between each other.

The analysis of the computer runs showed a strong tendency for polarization of results in favor of the principal (Navy, commercial shipbuilder, payload manufacturer) being characterized by the analysis. This situation indicated, as expected, that no single option existed which would be optimal for all the principals and that an acceptable compromise must be sought. Accordingly, the groupings of favorable options were carefully analyzed and reduced to the 40 options presented in Fig. 27. Each of these options was then analyzed in depth to determine the number, nature, and size of its potential impact on the shipbuilding industry.

Impact, analysis. The methodology used in the impact analysis developed directly from the available data, and identified potential impacts.

It was decided to assess impacts by operational areas. The areas selected for analysis were:

- Material procurement
- Material storage
- Manufacturing
- Assembly
- Erection
- Outfitting
- Integration
- Testing

In determining the proper approach for evaluating the eight operational areas, it became apparent that an impact in any of these areas could be characterized as affecting cost, schedule, and shipyard flexibility.

To enhance impact characterization, each of the three types of impacts were given two sub-categories as follows:

COST { INITIAL CAPITALIZATION / ONGOING PRODUCTION
SCHEDULE { PROGRAM IMPLEMENTATION / VESSEL CONSTRUCTION
SHIPYARD FLEXIBILITY { PRODUCT LINE / MANAGEMENT AND LABOR

This additional breakdown brought the number of evaluations to 1920, which were made as the first level of impact analysis.

With the types of necessary evaluations identified, the mechanics of the evaluation remained to be specified. The large number of separate evaluations that must be made suggested the use of a matrix approach. Several matrix arrangements were examined and the selected coordinates were "Operational

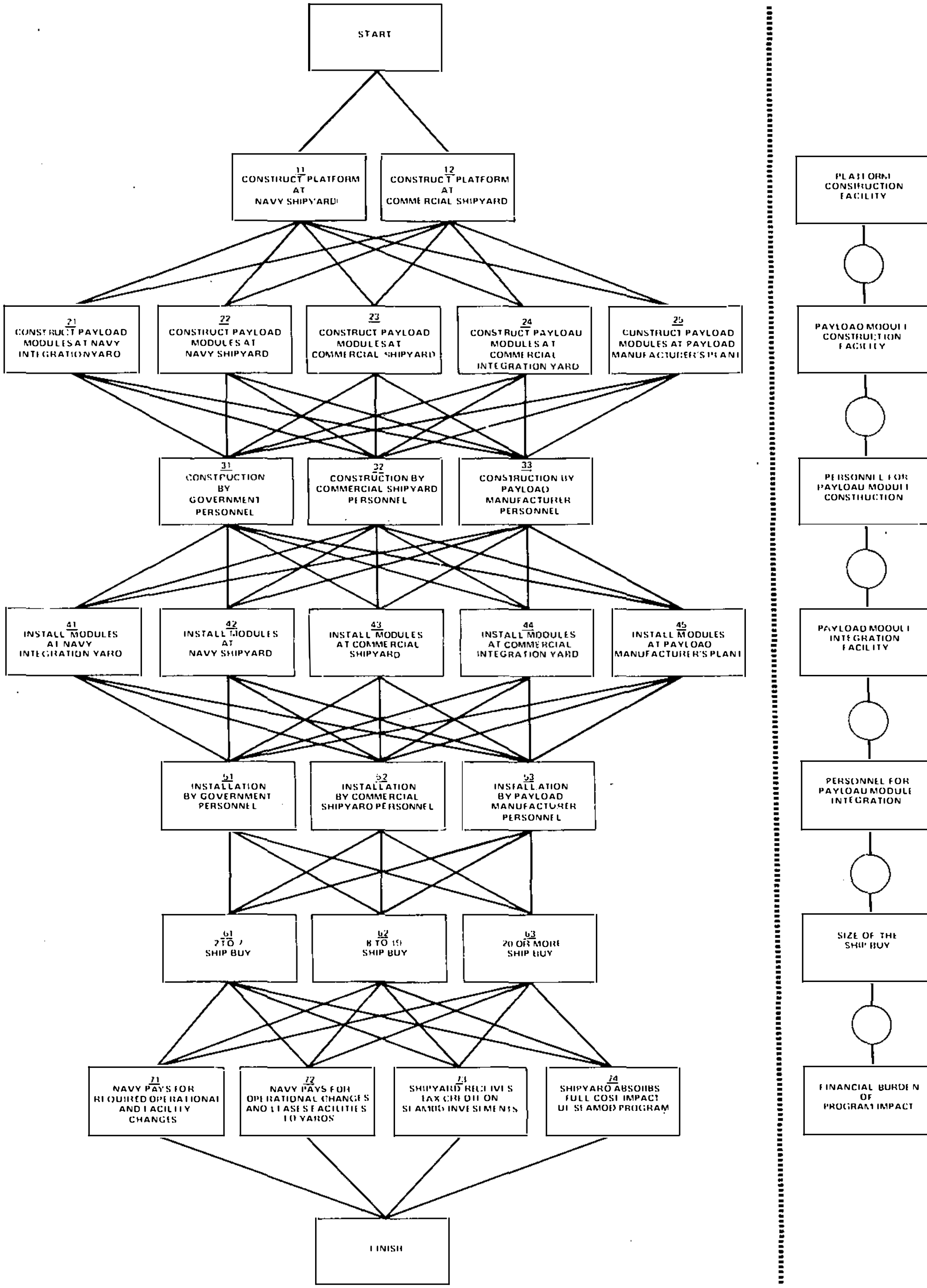


Fig. 25 Option tree

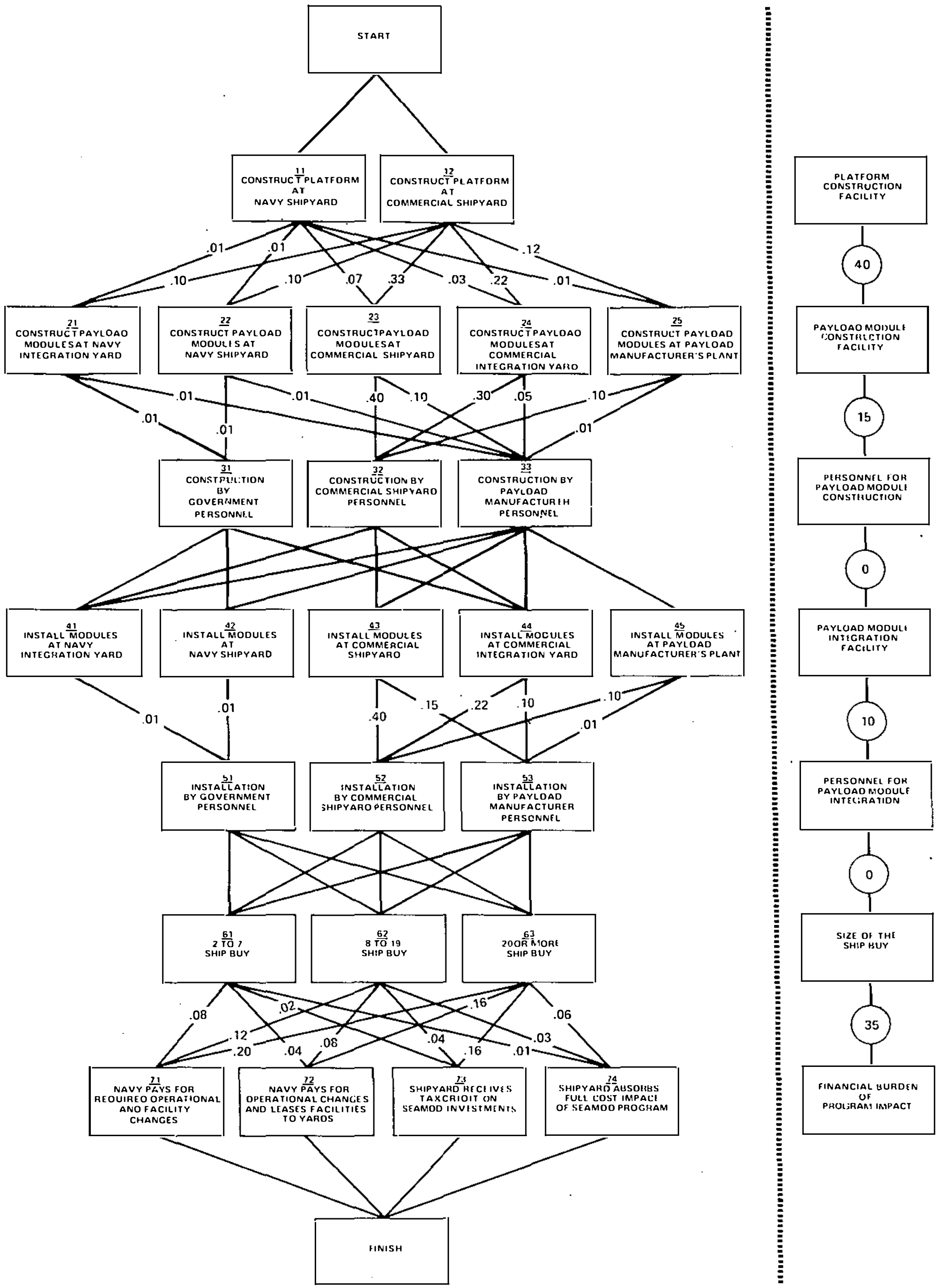


Fig. 26 Navy implementation options which could affect shipyards—economic viability to commercial shipyards

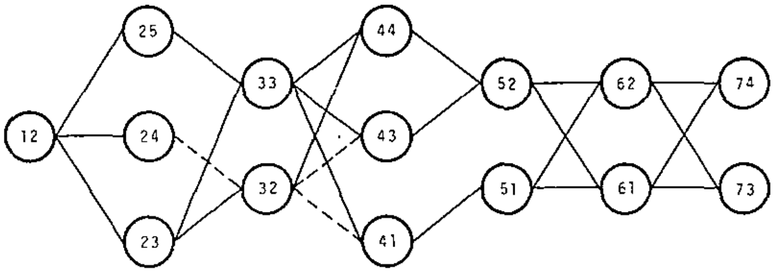


Fig. 27 Most probable options. Note: where line is dotted, options containing 24–32–43 and 24–32–41 are not included

OPERATIONAL AREAS OF IMPACT	IMPACT CHARACTERIZATION																		TOTAL AREA IMPACT
	COST						SCHEDULE						SHIPYARD FLEXIBILITY						
	INITIAL CAPITALIZATION			ONGOING PRODUCTION			PROGRAM IMPLEMENTATION			VESSEL CONSTRUCTION			PRODUCT LINE			MANAGEMENT AND LABOR			
	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	
MATERIAL PROCUREMENT	0.01			0.05			0.10			0.15			0.02			0.05			
MATERIAL STORAGE	0.13			0.10			0.20			0.02			0.15			0.02			
MANUFACTURING	0.17			0.12			0.25			0.14			0.23			0.12			
ASSEMBLY	0.10			0.25			0.15			0.18			0.10			0.17			
ERECTION	0.22			0.16			0.15			0.20			0.21			0.21			
OUTFITTING	0.10			0.20			0.05			0.14			0.12			0.14			
INTEGRATION	0.22			0.05			0.05			0.05			0.13			0.12			
TESTING	0.05			0.07			0.05			0.12			0.04			0.17			
TOTAL CATEGORY IMPACT																			

KEY: A - CATEGORY WEIGHT, B - IMPACT VALUE, C - WEIGHT IMPACT

Fig. 28 SEAMOD shipbuilding cross-impact matrix

Areas of Impact" down, "Impact Characterization" across, as shown in Fig. 28.

Since the potential impacts identified could be either adverse or beneficial, any numerical system of subjective evaluation must be capable of reflecting this situation. Accordingly, both positive and negative numbers were used with zero reflecting no impact, positive numbers reflecting an adverse impact, and negative numbers reflecting a beneficial impact. The following list shows the assignment of numerical values to the subjective impact graduations selected for the impact analysis:

0, no impact
1 or −1, negligible impact
2 or −2, minor impact
3 or −3, moderate impact
4 or −4, significant impact
5 or −5, major impact

In examining the boxes requiring value assignments, it was apparent that a simple addition of assigned values by characterization or area categories would yield a number reflecting an equal value to the shipyard for each cross-category. This does not reflect the real situation and, as a result, weights were assigned to each cross-category to reflect its relative importance to the shipyard as a business entity. The assigned cross-category weights are shown in Fig. 28.

The magnitude of the impact analysis requiring a separate evaluation of 40 different implementation options, coupled with the complexity of the selected cross-correlation output, dictated the need for an evaluation guide to insure uniformity and completeness of the individual assessments.

The desired commonality of cross-impact matrix results was approached by first defining the subcategories of impact and the factors to be considered when assessing the potential impact of SEAMOD implementation within the various areas of shipyard operations. Next, a simple evaluation worksheet was developed to serve as a guide for the actual impact assessment.

The subcategories within each of the three types of impact noted on the cross-impact matrix form were defined as follows:

- Initial Capitalization—The effect of SEAMOD upon the one-time costs incurred to institute the required changes in the shipyard facility and operation.
- Ongoing Production—The effect of SEAMOD upon vessel

IMPLEMENTATION OPTION:

COST

How would the subject SEAMOD option affect the shipyard with respect to initial implementation or start-up outlays for

Capitalization

	Required	Not Required
• Additional dredging, cut and fill, or bulkheading?		
• Additional roads, railways, or craneways?		
• New buildings, structures, or platens?		
• Additional utilities?		
• Modification or renovation of structures or platens?		
• New equipment?		
• New or additional fixtures and tools?		
• Modifications to equipment?		
• Changes in facility or work center layout?		
• Changes in personnel or training		

How would the subject implementation option affect on-going production costs through changes in:

Production Costs

	Increases	Would Not Change	Decrease
• Utilities and yard services?			
• Maintenance requirements?			
• Training requirements?			
• Skill mix/grade/level needs?			
• Productivity due to standardization and specialization?			

SCHEDULE

How would the subject implementation option affect vessel construction time requirements, as compared to a conventional design, due to:

Construction Schedule

	Increase	Would Not Change	Decrease
• Construction planning?			
• Labor availability and mobility?			
• Facility limitations?			
• Subcontractor interface?			
• Customer interface (GFE/GFI)?			

How would the subject SEAMOD option affect the initial time requirements or implementation schedule, as compared to a comparable conventional new construction program, for:

Time Requirements

	Increase	Would Not Change	Decrease
• Facility planning and design?			
• Process and industrial engineering?			
• Facility construction or modification?			
• Facility equipment procurement?			
• Equipment installation and check-out?			

SHIPYARD FLEXIBILITY

How would the subject implementation option affect a shipyard's capability to participate in other shipbuilding programs, due to:

Production Flexibility

	Decreases	Would Not Change	Increases
• Facility limitations?			
• Facility or equipment dedication?			
• Skill level/grade/mix changes?			
• Supervisory capacity changes?			

How would the subject implementation option affect the yard's production and support staffing plan and its operational response flexibility, due to changes in:

Manning Flexibility

	Decrease	Would Not Change	Increase
• Employment level?			
• Skill level/mix/grade?			
• Supervisory/trades retio?			
• Training requirements?			

Fig. 29 SEAMOD shipbuilding impact evaluation

production costs as compared with conventional construction costs.

- Program Implementation—The effect of SEAMOD implementation upon the time requirements for change and startup of initial production operations.
- Vessel Construction—The effect of SEAMOD upon the schedule requirements of ongoing vessel production as compared with comparable requirements for conventional construction.
- Product Line—The effect of SEAMOD implementation upon a shipyard's ability to participate in other shipbuilding programs.
- Management and Labor—The effect of SEAMOD implementation upon a shipyard's production and support staffing plan as compared with a conventional construction program of comparable ship size.

The impact evaluation worksheet that was developed, Fig. 29, contains a question structured around each of these impact category definitions and notes the various factors to be considered in evaluating potential impact on the "average" shipyard. It was recognized that the use of the "average" shipyard concept brought with it certain limitations. However, the purpose was to assess industry-wide impact, and the worksheet forced the individual performing the impact assessment to examine the potential effects in greater depth than might occur without the prompter, and, more importantly, to insure that the different implementation options are evaluated on an equivalent basis against an "average" shipyard.

After completing the 40 different matrixes, it was then necessary to analyze the results to determine significant patterns and sensitivities. Two basic tabulations of the data were made—one vertical and one horizontal. The vertical and horizontal sums were then listed and summed for each of the 40 options. For brevity, the options were numbered as given in Table 9.

For the eight operational areas evaluated, a summary table of impact values was compiled and is presented as Table 10. A similar table was constructed of the three different characterizations of impact, but analysis of the table led to an expansion of the table to emphasize the relationships between the individual values. This expanded table is presented as Table 11. A sensitivity analysis, which changed the weighted value of cost, schedule and flexibility to 3, 2, and 1, respectively, did not change the results given in Table 11.

In analyzing the expanded table of characterization values (Table 11), it was apparent that the 40 options could be more conveniently treated as ten groups of four options each. The ten option groups differ from each other in where and by whom work would be done, while the four options within each group vary only in contractual and financial factors.

Several significant conclusions can be drawn from the expanded summary table:

- The majority of the four-option groups respond directly to the size of the buy, reflecting a more beneficial impact with an increase in the size of the buy. The relationship was completely expected as it reflects the well-accepted application of learning curves and other economies of series production.
- The option group most beneficial to the shipyard is composed of Options 29, 30, 31 and 32. This group has the shipyard constructing only the platforms, which leads to low capitalization and production costs, and significantly reduces the chance of schedule-delaying interface problems with subcontractors and the Navy.
- The group having the most adverse impact on the shipyard is composed of Options 17, 18, 19 and 20. This group has the shipyard constructing and integrating all the pieces at its yard but using the payload manufacturer's personnel to construct the modules. This group has the highest combination of capitalization and production costs, which could only partially offset by flexibility gains due to the use of subcontracted labor for module construction.

Table 9 Sequence of evaluated options

(1)	12--23--32--41--51--61--73	(21)	12--23--33--44--52--61--73
(2)	12--23--32--41--51--61--74	(22)	12--23--33--44--52--61--74
(3)	12--23--32--41--51--62--73	(23)	12--23--33--44--52--62--73
(4)	12--23--32--41--51--62--74	(24)	12--23--33--44--52--62--74
(5)	12--23--32--43--52--61--73	(25)	12--24--32--44--52--61--73
(6)	12--23--32--43--52--61--74	(26)	12--24--32--44--52--61--74
(7)	12--23--32--43--52--62--73	(27)	12--24--32--44--52--62--73
(8)	12--23--32--43--52--62--74	(28)	12--24--32--44--52--62--74
(9)	12--23--32--44--52--61--73	(29)	12--25--33--41--51--61--73
(10)	12--23--32--44--52--61--74	(30)	12--25--33--41--51--61--74
(11)	12--23--32--44--52--62--73	(31)	12--25--33--41--51--62--73
(12)	12--23--32--44--52--62--74	(32)	12--25--33--41--51--62--74
(13)	12--23--33--41--51--61--73	(33)	12--25--33--43--52--61--73
(14)	12--23--33--41--51--61--74	(34)	12--25--33--43--52--61--74
(15)	12--23--33--41--51--62--73	(35)	12--25--33--43--52--62--73
(16)	12--23--33--41--51--62--74	(36)	12--25--33--43--52--62--74
(17)	12--23--33--43--52--61--73	(37)	12--25--33--44--52--61--73
(18)	12--23--33--43--52--61--74	(38)	12--25--33--44--52--61--74
(19)	12--23--33--43--52--62--73	(39)	12--25--33--44--52--62--73
(20)	12--23--33--43--52--62--74	(40)	12--25--33--44--52--62--74

Requirements for implementation

If SEAMOD is to be successful, the requirements for defining a standard interface become essential. There are several key elements which must, in all cases, be specified if significant disruption to the ship (platform) is to be avoided during module changeout.

There has always been great difficulty in obtaining agreement among various entities as to standardization. However, SEAMOD can be implemented only if agreement on interface standardization can be achieved. Consider the maritime industry with respect to containers. Agreement had to be reached by ship designers, crane manufacturers, freight terminal activities, trucking companies, and others, on a standard set of container configurations in order for the intermodel container shipping system to be workable.

Careful consideration of all aspects must be made in order that definition of interfaces is not so restrictive that it limits development or raises the cost to a considerable degree. Also, if the definition is too loose, severe problems can be imposed on the industrial activity performing a module interchange in order to accommodate the new module in the way of support, services, etc.

The impact on module design may be very significant. For many years there has been a constant effort to legislate the definition of data interchange, use standard equipment modules, and so forth. The problem which arises is that if one is not careful, the development of a new system may be severely hampered by the limitations imposed by the interfaces definition. As an example, if the data rate capability of the prescribed data interface is not sufficient to service the requirements of a new undeveloped system, that system could possibly be restricted to a lesser degree of capability or the system cost considerably increased. On the other hand, if the equipment designer is presented with this restriction at the outset, he can probably design around it and produce the desired capability at the same or lower cost.

In order to achieve standardization with the least risk to all concerned, the interface definition would have to be carefully constructed to neither overspecify nor underspecify. *Industry participation in this definition effort would be mandatory to*

Table 10 Summary of operational impact values

OPTION NUMBER	MATERIAL PROCUREMENT	MATERIAL STORAGE	MANUFACTURING	ASSEMBLY	ERECTION	OUTFITTING	INTEGRATION	TESTING	TOTAL IMPACT INDEX
1	0	.61	.12	.65	.31	−.17	NA	−.16	1.36
2	0	.74	.12	.65	.31	−.17	NA	−.16	1.49
3	.10	.93	.12	.07	.34	.12	NA	−.73	.95
4	.10	1.06	.12	.17	.56	.22	NA	−.68	1.55
5	0	1.49	.12	.65	.31	−.17	.69	−.12	2.97
6	0	1.62	.12	.65	.31	−.17	.91	−.12	3.32
7	0	1.03	.12	.43	.08	.22	.58	−.47	1.13
8	0	1.16	.12	−.33	.30	.32	.80	−.42	1.95
9	0	.67	.12	.65	.31	−.17	.69	−.02	2.25
10	0	.80	.12	.65	.31	−.17	.91	.03	2.65
11	0	1.01	.12	−.43	.08	−.56	−.05	−.87	−.70
12	0	1.14	.12	−.33	.30	−.46	−.05	−.82	−.10
13	0	.61	.12	.98	.63	.43	NA	−.12	2.65
14	0	.74	.12	.98	.63	.43	NA	−.12	2.78
15	.10	.93	.12	.75	.60	.26	NA	.09	2.85
16	.10	1.06	.12	.85	.82	.36	NA	.14	3.45
17	0	1.49	.12	.98	.63	.43	.69	.02	4.36
18	0	1.62	.12	.98	.63	.43	.91	.02	4.71
19	0	1.03	.12	.75	.82	.08	.48	−.47	2.81
20	0	1.16	.12	.85	1.04	.18	.70	−.42	3.63
21	0	.67	.12	.98	.63	.43	.69	.12	3.64
22	0	.80	.12	.98	.63	.43	.91	.17	4.04
23	0	1.01	.12	.75	.82	−.52	−.15	−.87	1.16
24	0	1.14	.12	.85	1.04	−.42	−.15	−.82	1.76
25	.10	.67	.64	−.16	.23	−.16	.20	−.15	1.37
26	.10	.80	.64	−.06	.45	−.06	.42	−.10	2.19
27	.10	.97	.90	−.86	−.34	−.81	.02	−1.13	−1.15
28	.10	1.10	.90	−.76	−.12	−.71	.02	−.108	−.55
29	−.22	−.77	−.38	−2.28	−.36	−.60	NA	−.96	−5.57
30	−.22	−.77	−.38	−2.28	−.36	−.60	NA	−.96	−5.57
31	−.27	−1.33	−.50	−2.10	−.74	−.50	NA	−.28	−5.72
32	−.27	−1.33	−.50	−2.10	−.74	−.50	NA	−.28	−5.72
33	−.22	−.34	−.38	−2.28	−.36	−.60	.69	−.61	−4.10
34	−.22	−.21	−.38	−2.28	−.36	−.60	.91	−.61	−3.75
35	−.27	.30	−.50	−2.00	−.74	−.38	.48	−.46	−3.57
36	−.27	.43	−.50	−2.00	−.74	−.38	.70	−.41	−3.17
37	−.22	.29	−.38	−2.28	−.36	−.60	.45	−.67	−3.77
38	−.22	.42	−.38	−2.28	−.36	−.60	.67	−.62	−3.37
39	−.22	.46	−.50	−1.65	−.52	−.08	.03	−1.15	−3.63
40	−.22	.59	−.50	−1.65	−.52	−.08	.25	−1.10	−3.23

Table 11 Summary of impact characterization values

	COST				SCHEDULE			FLEXIBILITY		INDEX
OPTION NUMBER	PRODUCTION	INITIAL CAPITALIZATION	% CHANGE	COST INDEX	SCHEDULE INDEX	% CHANGE	COST + SCHEDULE INDEX	FLEXIBILITY INDEX	% CHANGE	TOTAL IMPACT INDEX
1	.63	.56	89	1.19	.50	42	1.69	−.33	−20	1.36
2	.63	.69	110	1.32	.50	38	1.82	−.33	−18	1.49
3	1.56	1.48	95	3.04	.20	7	3.24	−2.29	−71	.95
4	1.56	2.08	133	3.64	.20	5	3.84	−2.29	−60	1.55
5	1.02	1.35	132	2.37	1.19	50	3.56	−.59	−17	2.97
6	1.02	1.70	167	2.72	1.19	44	3.91	−.59	−15	3.32
7	1.02	2.86	280	3.88	.61	16	4.49	−3.36	−94	1.13
8	1.02	3.68	361	4.70	.61	13	5.31	−3.36	−63	1.95
9	.87	1.67	192	2.54	.92	36	3.46	−1.21	−35	2.25
10	.87	2.07	238	2.94	.92	31	3.86	−1.21	−31	2.65
11	.40	3.08	770	3.48	.08	2	3.56	−4.26	−120	−.70
12	.40	3.68	920	4.08	.08	2	4.16	−4.26	−102	−.10
13	2.26	.56	25	2.82	.50	18	3.32	−.67	−20	2.65
14	2.26	.69	31	2.95	.50	17	3.45	−.67	−19	2.78
15	1.54	1.48	96	3.02	.20	7	3.22	−.37	−11	2.85
16	1.54	2.08	135	3.62	.20	6	3.82	−.37	−10	3.45
17	2.58	1.35	52	3.93	1.19	30	5.12	−.76	−15	4.36
18	2.58	1.70	66	4.28	1.19	28	5.47	−.76	−14	4.71
19	1.74	2.86	164	4.60	.61	13	5.21	−2.40	−46	2.81
20	1.74	3.68	211	5.42	.61	11	6.03	−2.40	−40	3.63
21	2.43	1.67	69	4.10	.92	22	5.02	−1.38	−27	3.64
22	2.43	2.07	85	4.50	.92	20	5.42	−1.38	−25	4.04
23	1.12	3.08	275	4.20	.08	2	4.28	−3.12	−37	1.16
24	1.12	3.68	329	4.80	.08	2	4.22	−3.12	−74	1.76
25	1.11	2.36	213	3.47	.42	12	3.89	−2.52	−65	1.37
26	1.11	3.18	286	4.29	.42	10	4.71	−2.52	−54	2.19
27	−.39	3.18	815	2.79	.35	13	3.14	−4.29	−137	−1.15
28	−.39	3.78	969	3.39	.35	10	3.74	−4.29	−115	−.55
29	−2.01	0	0	−2.01	−1.32	−66	−3.33	−2.24	−67	−5.57
30	−2.01	0	0	−2.01	−1.32	−66	−3.33	−2.24	−67	−5.57
31	−2.83	−.98	−35	−3.81	−1.91	−50	−5.72	0	0	−5.72
32	−2.83	−.98	−35	−3.81	−1.91	−50	−5.72	0	0	−5.72
33	−1.42	.92	65	−.50	−1.07	−214	−1.57	−2.53	−161	−4.10
34	−1.42	1.27	89	−.15	−1.07	−713	−1.22	−2.53	−207	−3.75
35	−2.09	.52	25	−1.57	−1.19	−76	−2.76	−.81	−29	−3.57
36	−2.09	.92	44	−1.17	−1.19	−102	−2.36	−.81	−34	−3.17
37	−1.51	1.47	97	−.04	−.94	−2350	−.98	−2.79	−285	−3.77
38	−1.51	1.87	124	.36	−.94	−261	−.58	−2.79	−481	−3.37
39	−2.31	1.47	64	−.94	−1.28	−136	−2.22	−1.51	−68	−3.63
40	−2.31	1.87	81	−.44	−1.28	−291	−1.72	−1.51	−88	−3.23

ensure both cooperation and producibility of the end products.

To insure that the standards will be developed such as to achieve the objectives of SEAMOD without jeopardizing the performance capabilities of the combat system (payload), a development program is being proposed within the Navy.

The purpose of the SEAMOD Program would be: (1) *the development and validation of the SEAMOD Design Standards* (*SDS*) to be imposed on ship and combat system designers, and (2) *the development of a realistic implementation plan* to ensure proper introduction of the concept into the Navy acquisition and operating practices. Also, in conjunction with the assigned SHAPM, the SEAMOD Program would help develop the first ship application through contract design.

The *SEAMOD Design Standards* would consist of overall general standards, specifications and procedures. Essentially, they would be broken into four major groups with general headings of *Physical, Functional, Performance,* and *Computer Software* SEAMOD Design Standards.

- The *Physical* SDS would include size, weight, material, structural cabling, etc., of all interfaces relating to payload and platform and the requirements for supporting activities such as the Module Installation Facility (MIF).
- The *Functional* SDS would provide requirements that govern electrical power, cooling air/water, etc., to ensure compatibility between ship platform and module interfaces.
- The *Performance* SDS would consist of requirements covering noise, vibration, Integrated Logistic Support, documentation, safety, etc., as they relate to SEAMOD modules.
- The *Computer Software* SDS would cover message formats, timing, communications, EMI/EMC, electronic function requirements, etc., to ensure compatibility.

The SEAMOD program would provide the basic management and technical structure needed to coordinate the program. The primary management areas are Program Management, Concept Integration, Configuration Control, Special Studies and Implementation. Although all four areas are of primary interest to the program, it is probably the latter of these that is most often neglected. The SEAMOD implementation considerations would form the adhesive that binds the program together to facilitate a realistic approach to design as well as implementation. The formation and development of the *Implementation Plan* is necessary to assure a smooth efficient transition from the conceptual phase through program validation/demonstration, engineering and development to finally culminate in design and acquisition practices and procedures.

The Implementation Plan must include careful analysis and action with respect to the following Integrated Logistic Support (ILS) elements:

- Maintenance planning
- Supply support
- Technical data
- Facilities
- Personnel and training
- Support and test equipment
- Packaging, handling, storage and transportation

Initial studies have already been completed, the details of which are contained in reference [11]. Conclusions reached to date have been that the greatest impact of SEAMOD will be in supply support, facilities, and personnel and training areas. The impact on facilities involves consideration of a Module Installation Facility (MIF).

The MIF is a facility in which the various weapon system modules would be assembled, tested and checked out prior to either being stored in a rotatable pool or installed on the platform. To accomplish this the MIF must be organized consistent with Navy regulations and DOD directives. The organizational structure must also be compatible with the required technical functions, which are summarized in the following:

1. *Module assembly, installation, test and checkout.* This function would be to assemble the modules and install them on board ship. Testing would be performed to verify conformance to specification prior to the module being installed or stored. This function would also include responsibility for testing on board ship to verify proper installation.

2. *Module changeout refurbishment and overhaul.* This function would be to remove and replace modules for the purpose of incorporating changes, refurbishment and equipment overhaul.

3. *Module rotatable pool.* This function would be to store various combinations of completed modules. Preventative maintenance such as cleaning and liquid level checks would be performed on the modules on a continuous basis.

4. *Module system level maintenance.* This function would be to perform maintenance at a module level on a continuous level. Performance checks would be performed and equipment replaced or repaired as necessary.

5. *Module system level training.* This function would be to train engineers and technicians on the operation and onboard maintenance of the various modules. Training would cover in-plant operation and maintenance primarily at the engineering level.

6. *Module equipment level maintenance.* This function would be to perform only the necessary equipment level maintenance that would not require the equipment to be sent to the manufacturers. This would be replacing wires, connectors, light bulbs, etc. and cleaning contacts, pins, replace PC (printed circuit) boards, power-supplies, etc. that were found defective during routine maintenance testing.

The development and incorporation of SEAMOD design standards into a set of Government policy and contractual documents plus establishment of Module Installation Facilities are considered minimum requirements for successful implementation of the SEAMOD concept.

Conclusions

SEAMOD (*Sea* Systems *Mod*ification and *Mod*ernization by *Mod*ularity) is a departure from present methods and policies for ship and combat system acquisition. SEAMOD facilitates rapid installation or exchange or both of combat system elements through the deliberate decoupling of the design/construction interdependencies of payload and platform. The SEAMOD concept contemplates design and construction of ship platforms capable of receiving all of their combat system payloads (major armament system, sensor systems, and electronics) as modules. Included in the concept are hardware and software design considerations to facilitate the physical, functional and electronic integration of the payload modules. This modularization capability will allow the Navy to:

(*a*) Simplify the acquisition, construction, and modernization of ship platforms and payloads.

(*b*) Hasten the introduction of new-technology weapons systems (payloads) into the fleet.

(*c*) Quickly convert the type and mix of combat system elements to counter new and changing threats.

The ability to achieve the first capability has been the main subject of this paper. The payoff from this capability has been shown to yield:

- Reduced construction time.
- Reduced construction cost.
- Reduced modernization/conversion time.
- Reduced modernization/conversion costs.

The purpose of presenting this paper at this time is to solicit response from those in industry and Government responsible for the construction and modernization of Naval ships. Although the analysis presented herein concludes that the SEAMOD concept would be welcome by the U. S. shipyards, it is only the result of initial studies. It is realized that much yet remains to be done before full evaluation by shipyards can take place (such as impact on contractual format). However, the SEAMOD concept depends on complete cooperation between (and among) government and industry if it is to succeed.

The author believes SEAMOD is technically feasible. It can be done. The question is, Will it be done?

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9 John J. McMullen Associates, *SEAMOD Implementation Analysis,* SEAMOD Final Technical Report, Nov. 1976.

10 John J. McMullen Associates, *Potential Impact of SEAMOD on the Shipbuilding Industry,* SEAMOD Final Tecnnical Report, Oct. 1976.

11 George G. Sharp, Inc., *SEAMOD Logistics Support Study,* Initial Report, 13 Jan. 1977.

(Appendix follows: pages 36–40)

Appendix

Acquisition document matrix—ship and equipment design and production

TITLE	DESCRIPTION	PREPARED BY	SOURCE DOCUMENT(S)/INPUT	SEAMOD IMPACT
Science and Technology Objectives [S&TO]	"...describe in broad terms the Navy's needs and problems requiring R&D solutions and are based on the Navy's role, objectives and threat anticipated in 10-20 year future time frame."[1]	Director of Research, Development, Test and Evaluation [DRDT&E]	CNO Policy and Planning Guidance [CPPG]; CNO Program Analysis Memorandum [CPAM]; Extended Planning Guidance [EPG]; Force and Mission Sponsor Plans [FMSP]. The S&TO is part of the ROP and is input to Advanced Systems Concepts [ASCs].	Will remain an important R&D document. No change in format is perceived.
Research and Development Plan [RDP]	"...serves as the primary guide to the research and development community for the establishment of projects which are responsive to operational needs"[1]	DRDT&E	Consistent with the CPPG, EPG and PPGM updated by Operational Requirements [OR] and Science & Technology Objectives [ST&O]. Developed using Force and Mission Sponsor Plans [FMSP]	Will remain an important R&D document. No change in format is perceived.
Advanced Systems Concepts [ASC]	"...propose future concepts emphasizing Navy ....operational needs"[2]	Systems Command [SYSCOM]	Science and Technology Objectives [S&TO]. The ASCs are input to Navy Advanced Concepts [NAC] and Operational Requirements [OR].	Will remain an important R&D document. SEAMOD may affect the Navy's perception of possible solutions to operational problems. No change in format is perceived.
Navy Advanced Concepts [NAC]	"...provides a compendium of selected ASC.s ready for transition to advanced Development within five years."[2]	Chief of Naval Development [CND]	Advanced Systems Concepts [ASC]. The NAC is input to the Operational Requirements [OR].	Will remain an important R&D document. SEAMOD may affect the Navy's perception of proposed solutions to operational problems. No change in format is perceived.

Footnotes: 1 OPNAVINST 5000.42: Subj: Weapon System Selection and Planning

2 NAVMATINST 3910.10C; Subj.: Implementation Procedures for the Navy Advanced Concepts [NAC].

Acquisition document matrix—ship and equipment design and production

TITLE	DESCRIPTION	PREPARED BY	SOURCE DOCUMENT(S)/INPUT	SEAMOD IMPACT
Operational Requirement [OR]	"...provides concise statements of operational needs."[1]	Force & Mission [F & M] Sponsor	Navy Advanced Concepts [NAC] and indirectly, Advanced Systems Concepts [ASC]. The OR solicits Development Proposals [DP] from NAVMAT or Bureaus as appropriate.	Will remain an important R&D document. SEAMOD will have an impact on the Navy's perception of technical requirements. No change in format is perceived.
Feasibility Study Report	Includes a Class E [or F] Cost Estimate and the results of Cost/Characteristics trade-offs	Ship Design Manager [SDM]	Not based on any formal source document. The Feasibility Study Report is input to the ship Development Proposal [DP].	Will remain an important Technical document. No change in format is perceived.
Development Proposal [DP]	"...presents a range of alternatives and trade-offs to achieve a particular range of capabilities", in response to the OR[1]	Ship Acquisition Project Manager [SHAPM] [Ship] Development Proposal Manager [DPM] [Equipment]	Operational Requirements [OR] and the Feasibility Study Report. The DP is input to the Navy Decision Coordinating Paper.	Will remain an important Technical document. No change in format is perceived.
Concept Design Report Package	Provides a summary physical description of the ship, i.e., its principal characteristics and combat systems selections.	SDM	Not based on any formal source document. The Concept Design Report is input to the Top Level Requirements [TLR]	Will remain an important technical document. SEAMOD will impact this document in situations where weapons suites are undefined and mission performance requirements are not provided but no. of standard weapon stations are specified.
Top Level Requirements [TLR]	As a technical acquisition document, amplifies the OR and provides constraints and guidance for ship design. Developed in parallel with Top Level Specifications. [TLS][3]	Program Co-Ordinating Group [PCG] with inputs from CNO and CNM	Operational Requirements [OR] and Concept Design Report. The TLR is input to a draft Decision Coordinating Paper [DCP].	Will remain an important technical document. SEAMOD will impact the Navy's perception of technical requirements depending on whether or not weapon suites are defined and mission performance requirements are provided. No change in format is perceived.

Footnotes: [1]OPNAVINST 5000.42: Subj: Weapon System Selection and Planning

[3]OPNAVINST 9010.300; Subj: Top Level Requirements and Top Level Specifications for the Development of Naval Ships; also, Top Level Specifications Handbook, NAVSEC, April 1975

(continued)

Appendix ***(continued)*** **Acquisition document matrix—ship and equipment design and production**

TITLE	DESCRIPTION	PREPARED BY	SOURCE DOCUMENT(S)/INPUT	SEAMOD IMPACT
Navy Decision Coordinating Paper [NDCP].	"...defines program issues, the considerations which support the operational need, program plans, performance parameters, areas of risk, development alternatives, level of logistic support and relationship to logistic capabilities."[1] It is a document which supports, authorizes and promulgates CNO/SECNAV decisions on an acquisition program.	PCG	Operational Requirements [OR] and the ship Development Proposal [DP]. The NDCP is input to a draft Decision Coordinating Paper [DCP].	Will remain an important decision document. No change in format is perceived.
Decision Coordinating Paper [DCP]	"...a summary document...that provides management with a broad overview of a major defense system program."[4] Developed in "For Comments" and "For Coordination" drafts before it is approved by SECDEF.	Program Coordinator [PC] and Office of Secretary of Defense [OSD]	Concept Baseline [CB] package, Top Level Requirements [TLR], and Navy Decision Coordinating Paper [NDCP]. The DCP is input to the Five Year Defense Program [FYDP] and the Navy Five Year Program [DNFYP].	Will remain an important decision document. No change in format is perceived.

Footnotes: [1] OPNAVINST 5000.42, Subj: Weapon System Selection and Planning

[4] OPNAV 9 OP-1D; Subj.: Department of Navy Programming Manual

Acquisition document matrix—ship and equipment design and production

TITLE	DESCRIPTION	PREPARED BY	SOURCE DOCUMENT(S)/INPUT	SEAMOD IMPACT
Top Level Specifications [TLS]	Translates TLR into a physical ship description by acting as a bridge between this requirements document and ship procurement specifications. Presents the technical baseline on which choices can be made to produce an optimum design within constraints. It is responsive to the TLR and developed in parallel with it.[3]	SHAPM/PCG	Top Level Requirements. The TLS is input to the Decision Coordinating Paper [DCP]	Will remain an important technical document. SEAMOD will impact the Navy's perception of technical requirements depending on whether or not weapon suites are defined and mission performance requirements are provided. Content will reflect SEAMOD design criteria. No change in format is perceived.
Preliminary Design Package	Includes TLR revision and TLS, GFE/GFI Schedule, and subsystem design and engineering preliminary design documentation.	SDM	Top Level Requirements [TLR], Top Level Specifications [TLS] and design documentation. The Preliminary Design Package is input to the Navy Decision Coordinating Paper [NDCP]	Will remain an important technical document. Content will reflect SEAMOD design criteria. No change in format is perceived.
Contract Design Package	Includes approved drawings, and ship specifications.	SDM	Not based on any formal source document. The Contract Design Package is input to the Request For Proposal [RFP]	Will be affected by shipbuilder/payload manufacturer involvement in the design process in that the required interface data must be spelled out in greater detail. This will be the place in which SEAMOD Design Standards are invoked.
Request For Proposal [RFP]	Provides Contractors with a comprehensive insight into the technical factors, criteria and/or problems which they must consider in drawing up their proposals and which the government will use in proposal evaluation.	SHAPM [ship] Project Manager [PM] [Equipment]	Procurement Request [PR], a Project Master Plan [PMP] and other technical documentation. The RFP is submitted to contractors as part of the bid package.	Will be affected by the earlier detail interface definition. This definition will be included in the bid package and allow contractors to prepare more accurate bids and proposals.

Footnotes: 3OPNAVINST 9010.300; Subj: Top Level Requirements and Top Level Specifications for the Development of Naval Ships; also, Top Level Specifications Handbook, NAVSEC, April 1975

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Appendix *(continued)* Acquisition document matrix—ship and equipment design and production

TITLE	DESCRIPTION	PREPARED BY	SOURCE DOCUMENT(S)/INPUT	SEAMOD IMPACT
Product Baseline [PBL] Package	Consists of formal working drawings developed during Detail Design from ship specifications and drawings in the bid package.	Contractor	Not based on any formal source document. The PBL is input to the decision Coordinating Paper [DCP].	Will remain an important technical document. No change in format is perceived will reflect SEAMOD Design criteria.
Ship Project Directives [SPD]	Transmits the plans and requirements of a Participating Manager [PARM] and reaches and documents agreements on the tasks, schedule and financial resources to be assigned to the PARM.[5]	SHAPM	Not based on any formal source document.	Will remain an important management document. No change in format is perceived.
Test and Evaluation Master Plan [TEMP]	"...is the controlling management document which defines the test and evaulation for each acquisition program. As such, it contains the integrated requirements of the DA [for DT&E] and COMOPTEVFOR [for OT&E], and the schedule and resources required for accomplishment"[6]	SHAPM in Cooperation with the Development Agency [DA] and Commander Operational Test and Evaluation Force [COMOPTEVFOR]	Not based on any formal source document.	Will remain an important management document. SEAMOD will impact the testing schedule for ships and weapon suites and necessitate the inclusion of sections on different testing sites and integration facilities.
Project Master Plan [PMP]	"...provides uniform guidance for work planning and scheduling and provides basic documentation which coordinates NAVMAT effort for a specific project."[7]	PM	Operational Requirement [OR]; Development Proposal [DP]; Advanced Procurement Plan [APP]. The PMP is input to the Request for Proposal [RFP].	Will remain in important management document. No change in format is perceived. Will reflect SEAMOD impact on construction modernization process.
Advanced Procurement Plan [APP]	Details the long range contractual methods which will be used for the procurement by contract of both the development and production of an individual item or system.[8]	PM	Decision Coordinating Paper [DCP].	Will remain an important procurement document. SEAMOD may impact content depending on whether or not the Navy decides to fund and construct platforms and payloads separately in different years.
Selected Acquisition Report [SAR]	Summarizes current estimates of technical, schedule, quantity and cost information for submission to higher levels of DOD, GAO and Congress.[9]	PM	Not based on any formal source document.	Will remain an important management document. SEAMOD may impact content depending on whether or not the Navy decides to fund and construct platforms and payloads separately in different years.

Footnotes: [5]NAVSHIPSINST 7000.29C; Subj.: Implementation of Ship Project Directive System

[6]OPNAVINST 3960.10; Subj.: Test and Evaluation. Also, NAVMATINST 3960.7; Subj.: Test and Evaluation of Ship Acquisition.

[7]NAVMATINST 5200.11B; Subj: Project Master Plan

[8]SECNAVINST 5000.1; Subj.: System Acquisition in the Department of the Navy

[9]SECNAVINST 77-0.5C; Subj.: Selected Acquisition Reports [SAR]