# AN APPROACH TO STANDARDIZATION OF NAVAL EQUIPMENT AND COMPONENTS

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## ABSTRACT

The objective of this study was to research the potential of standardization of equipment, components and modules as a means for reducing the costs associated with shipbuilding, particularly the costs associated with Navy acquisition and construction. This study built upon both prior and contemporary research into standardization within the Navy, other military activities and commercial industry. The potential impacts of standardization upon acquisition costs, life cycle costs, construction costs, time to delivery, and the U.S. shipbuilding industrial base were studied. Methods for determining the appropriate degree of standardization (within a ship, a class or the fleet) and the type of standard (equipment, component or large module) were analyzed. Means for identifying and prioritizing standardization candidates were presented and discussed.

Standardization was found to have considerable potential for reducing the costs associated with Navy acquistion and construction. Maximizing the use of common structure and components throughout a ship's architecture and within a class were found to be potentially very effective. Many of the benefits of standardization could be achieved by utilizing standard interfaces for mounting equipment and by placing constraints on equipment geometries and dimensions. Standardization decisions and policies require several challenges to be met. Among these are the development of a set of criteria by which to judge the merits of standardization projects, the development of a detailed database of statistics regarding naval equipment and components, the development of flexible designs, detailed up front production planning, and a detailed understanding of legal and contractual roadblocks.

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| | |
|---|---|
| ABS | American Bureau of Shipping |
| AHP | Analytical Hierarchical Process |
| AIAA | Aerospace Industries Association of America |
| ANSI | American Standards Association |
| APL | Allowance Parts List (number) |
| ASTM | American Society for Testing Materials |
| ATC | Affordability Through Commonaility |
| BOSS | Buy Our Spares Smart |
| CASA | Cost Analysis Strategy Assesment |
| CCF | Component Characteristics File |
| CDRL | Contract Deliverables Requirements List |
| CD - ROM | Compact Disc Read Only Memory |
| CFE | Contractor Furnished Equipment |
| CNC | Computerized Numerical Control |
| COSAL | Consolidated Shipboard Allowance List |
| DDS | Design Data Sheet |
| DepSO | Departmental Standardization Office |
| DESC | Defense Electronic Supply Center |
| DTRC | David Taylor Research Center |
| DOD | Department of Defense |
| EC | Equipment Code |
| ESC | Engineering Support Code |
| ESWBS | Expanded Ship Work Breakdown Structure |
| FAR | Federal Acquisition Regulations |

| | |
|---|---|
| FEA | Front End Analysis |
| FRESCO | Future-Oriented Refined Engineering System for Shipbuilding Aided By Computer |
| GFE | Government Furnished Equipment |
| GT | Group Technology |
| HEDRS | Hull, Mechanical and Electrical Data Research System |
| HM&E | Hull, Mechanical and Electrical |
| ILS | Integrated Logistics Support |
| JIT | Just In Time |
| LAPL | Lead Allowance Parts List (number) |
| LBP | Length Between Perpendiculars |
| LCC | Life Cycle Cost |
| LOA | Length Over All |
| MILSTD | Military Standard |
| MLT | Manufacturing Lead Time |
| MPCAGS | Military Parts Control Advisory Groups |
| MRC | Maintenance Requirement Cards |
| NAS | National Aerospace Standard |
| NASC | National Aerospace Standards Committee |
| NAVMAT | Naval Material Command |
| NAVSEA | Naval Sea Systems Command |
| NAVSEALOGCEN | Naval Sea Logistics Center |
| NAVSHIPSO | NAVSEA Shipbuilding Support Office |
| NPV | Net Present Value |
| NSN | National Stock Number |
| NSRP | National Ship research Program |
| NSWC | Naval Surface Warfare Center |

| | |
|---|---|
| RFP | Request For Proposals |
| SAC | Service Application Code |
| SCSC | Standardization Candidate Selection Criteria |
| SNAME | Society of Naval Architects and Marine Engineers |
| SPC | Statistical Process Control |
| SPCC | Ship Parts Control Center |
| SWAB | Ship Work Authorization Boundery |
| TRACE | Total resource and Cost Evaluation |
| TQM | Total Quality Management |
| VFI | Vendor Furnished Information |
| VPS | Variable Payload Ships |

# CHAPTER 1: INTRODUCTION

Today the Navy is faced with a budget which is decreasing, costs which are increasing and a diminishing U.S. industrial base. The Navy must strive harder than ever before to reduce the costs associated with naval ship design, production, acquisition and operation. Methods to reduce the total cost of ownership must be developed and implemented. Figures 1.0, 1.1, 1.2 and 1.3 illustrate some alarming U.S. shipbuilding trends. As Navy construction slows down and commercial work continues to be nearly non-existent, the situation could get considerably worse without successful efforts to improve the ship design, acquisition and production processes.

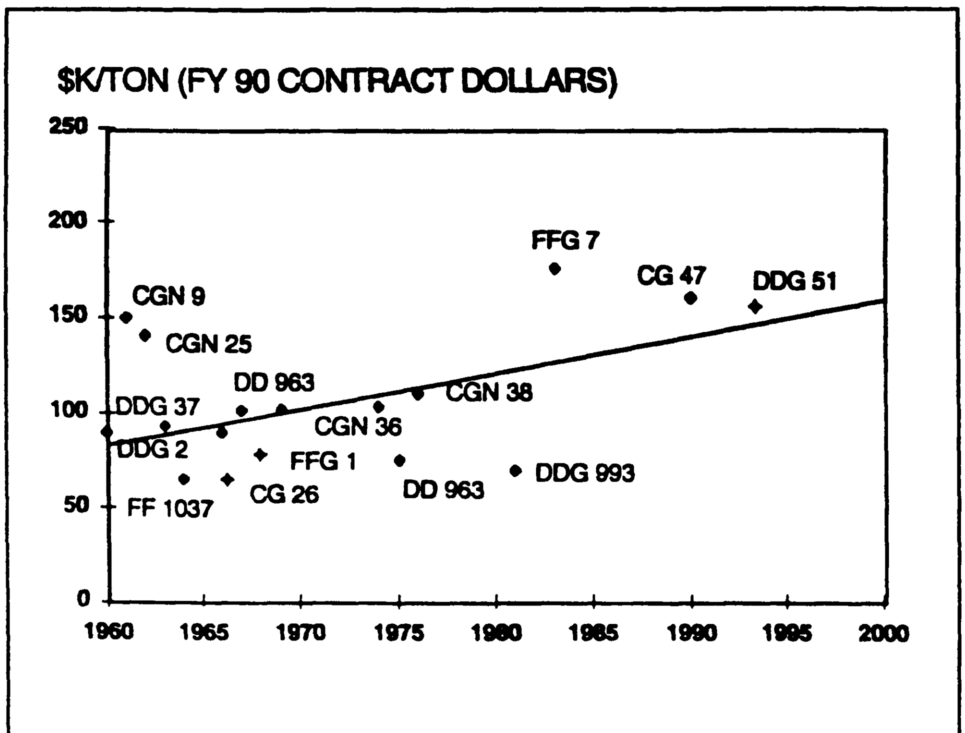


Figure 1.0 - The Increasing Costs of Surface Combatants[1]

1 Figure from NAVSEA 070-05R-TN-004, May 1993

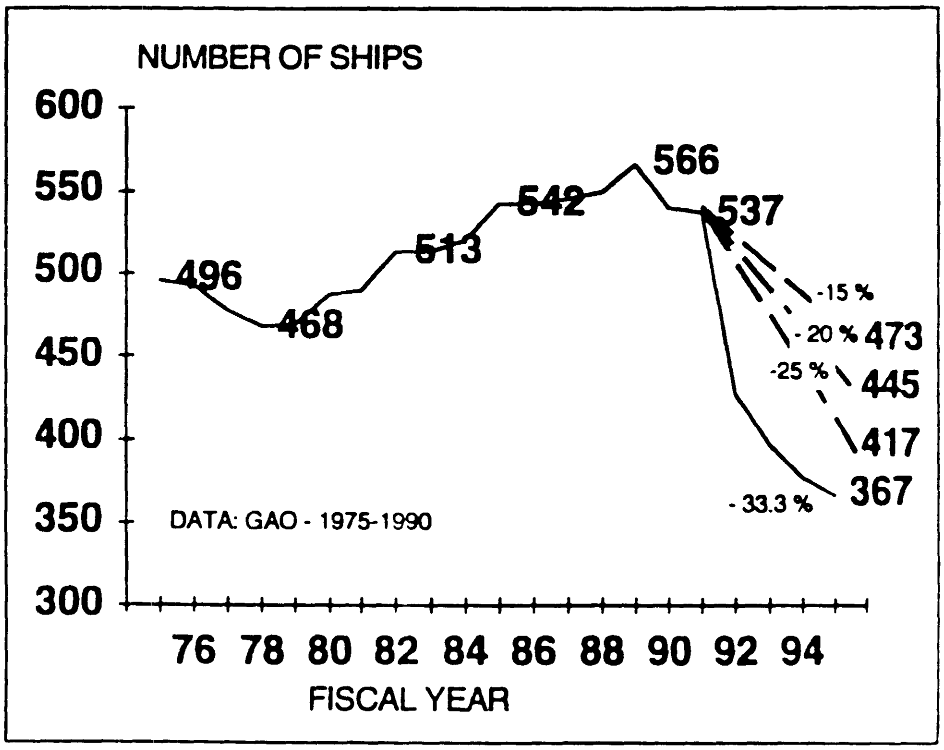


Figure 1.1 - A Shrinking Navy[2]

2 Figure from NAVSEA #004, May 1993

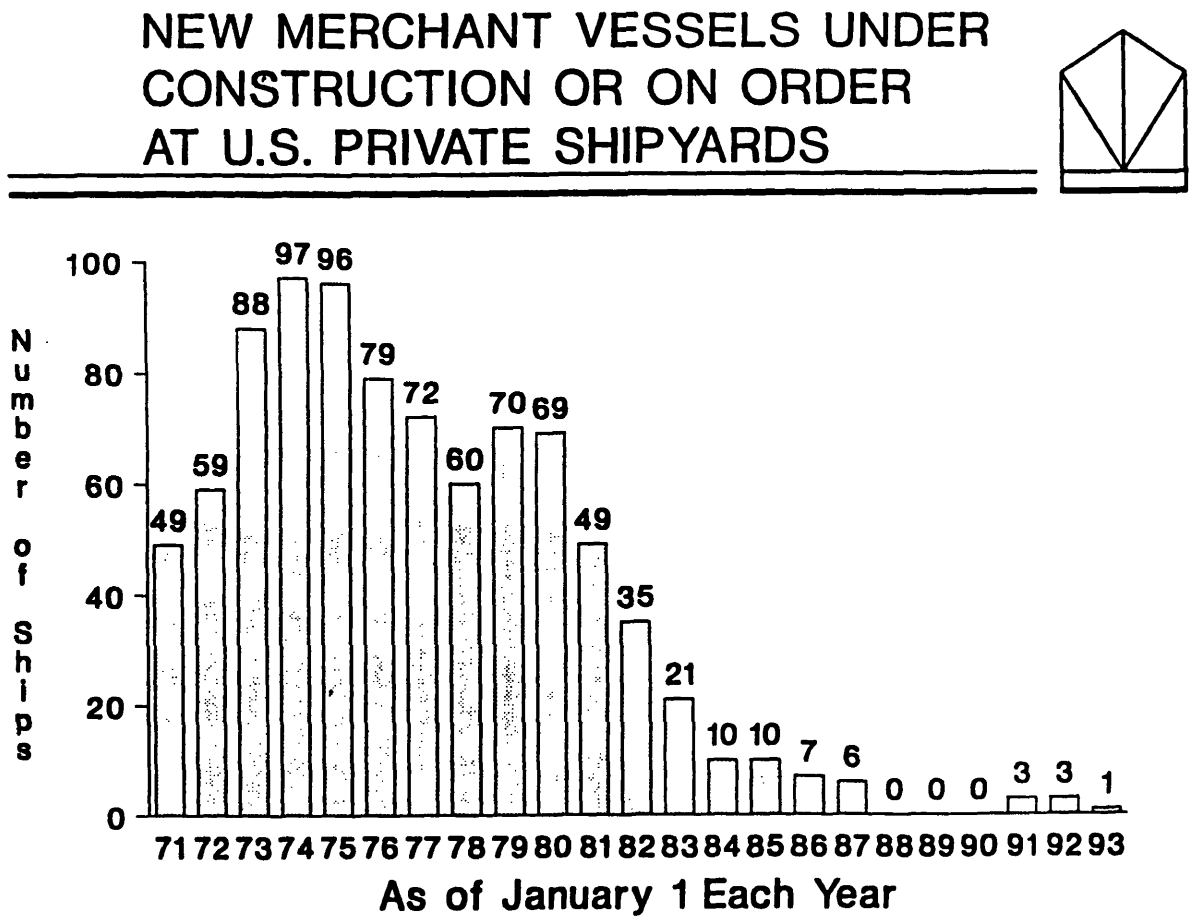


Figure 1.2 - Low Commercial Orders[3]

3 Figure supplied by the Shipbuilder's Council of America

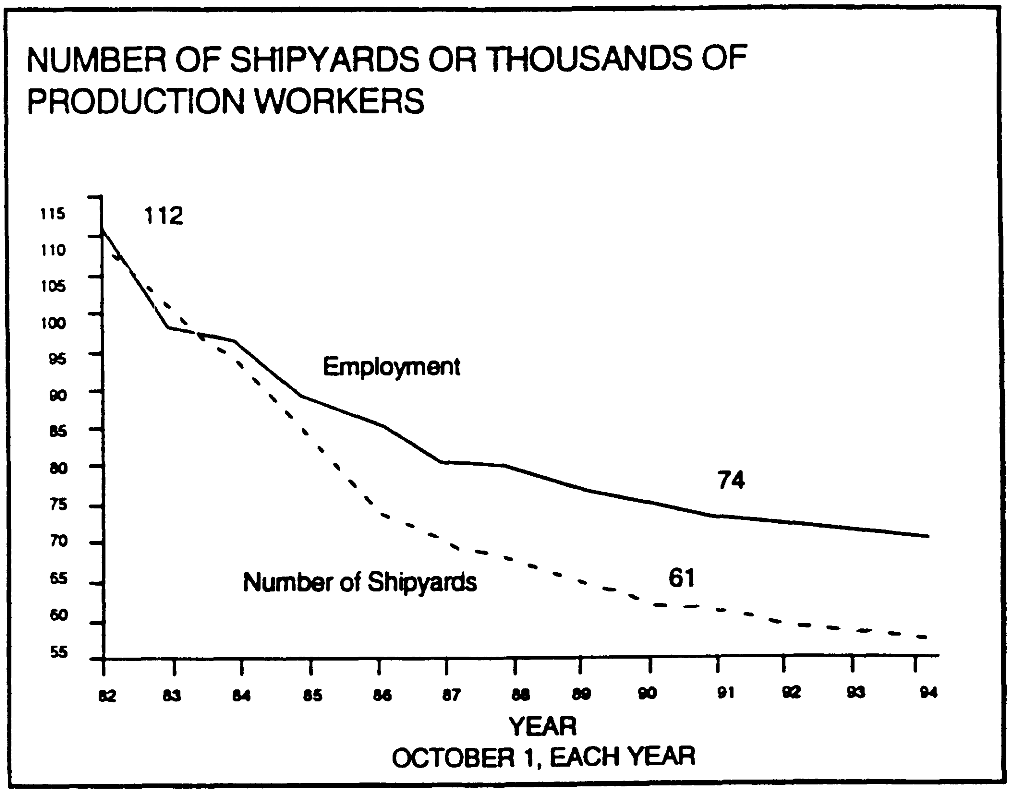


Figure 1.3 - A Diminishing Shipbuilding Industrial Base[4]

4 Figure from NAVSEA #004, May 1993

As the title of this thesis suggests, the objective of this study was to research the role of standardization in shipbuilding, particularly the role of naval equipment and component standardization in naval shipbuilding and acquisition. In 1952, Congress enacted the Defense Cataloging and Standardization Act. The language of the law reads as follows:

> *"It shall be the duty of each military department to achieve the highest practicable degree possible in the standardization of items used throughout the Department of Defense through the reduction of the number of sizes, kinds or types of generally similar items."*

This law remains the statutory charter of the DOD Standardization program. High level interest in affordability has focused attention upon the standardization effort as a means to achieve significant cost savings, and efforts are underway to review and improve this process. The Secretary of Defense intensified interest in the standardization program by proliferating the "Defense Management Report" in 1989.

This report sets forth a plan in response to the President's directive to improve the acquisition system and effectively manage defense resources. Three broad recommendations came out of that process improvement study:

1. *The preferred procurement of previously developed items currently in use by the government.*
2. *Systematically reduce DOD inventories by minimizing new item entries and reducing the number of items in the system.*
3. *Strengthen the defense industrial base by drawing upon established product lines of marine equipment manufacturers to encourage their continued participation in the market.*

The Department of Defense defines standardization as:

*"...the process by which the DOD achieves the closest cooperation among services and agencies for the most effective use of research, development and production resources and agrees to adopt on the broadest possible basis the use of:*

*a. common or comparable operational, administrative and logistical procedures*

*b. common or compatible technical procedures and criteria*

*c. common, compatible or interchangeable supplies, components, weapons or equipment.*

*d. common or compatible tactical doctrine with corresponding organizational compatibility."*

This thesis is most concerned with C, and related issues regarding A&B. There should be four broad elements to a program aimed at improving the Naval Acquisition process. These elements include:

- Reducing Acquisition Costs
- Reducing Life Cycle Costs
- Reducing time to delivery
- Bolstering the U.S. Shipbuilding Industrial Base

This study will review the role of standardization in shipbuilding. The ways in which standardization of naval equipment and components at both the equipment and ship module levels can be beneficial in these four areas will be explored. The principal objective of this research was to examine the appropriate degree of, and approach to, standardization as well as to develop criteria for prioritizing candidates for standardization. Processes and approaches which may prove effective in dealing with the standardization function will be studied and suggested. Tools for trade-off studies, candidate selection and implementing standardization towards these ends will be reviewed and proposed.

This research has not been conducted in a vacuum, and builds upon previous and current work in this area. Many industries and organizations, including the Navy, have conducted research and developed tools for the application of standards and standard equipment and components. The Naval Sea Logistics Center (NAVSEALOGCEN) has done a great deal of work in this area which serves as an excellent starting point. Among the tools they have developed are:

- ILS Cost Algorithm - a cost estimating technique for use in trade-off studies
- Data Ownership Analysis - a trade-off methodology to help determine when there is value to purchase data ownership rights for equipment.
- Standardization Candidate Criteria Model - a methodology for selecting equipment to be standardized.
- HM&E Data Research System - a database of equipment supported in the Navy fleet
- 3M database - database of maintenance records and information

The utility of these and other tools will be discussed. Prior successes in standardization of naval equipment and other industries will be studied. A broad review across equipment categories will be conducted to demonstrate that opportunities for savings through standardization exist. Modularity will be studied as a means of reducing construction costs and time to delivery. The integration of standard components and modules will be discussed. Many of the design constraints which must be considered in developing these modules will be presented. The impact of standardization and modularity upon design and the acquisition process will be reviewed.

# CHAPTER 2: AN OVERVIEW OF STANDARDIZATION IN SHIPBUILDING

Standardization, with regard to shipbuilding, is the broad term used to describe a methodology by which the number of unique guidelines, procedures, processes, drawings, documents or physical parts, components and equipment necessary to manufacture, operate and maintain a vessel is minimized. The principal objective is to reduce Acquisition Costs, Production Costs, Life Cycle Costs, and Time to Delivery. It is also hoped that the wise application of standards would help bolster the U.S. shipbuilding industrial base. The benefits of standardization programs are numerous and documented in many industries such as the automotive, electronics and aerospace industries. Standards are used successfully in foreign shipbuilding, particularly in Japan and Germany. The Aerospace Industries Association of America, in its National Aerospace Standard 1524, identifies savings attributable to engineering, procurement, quality control, inventory management, production, maintenance and general improvements. These savings are applicable to ship systems as well. Some benefits may be quantified with hard data, others are more intangible benefits. Some benefits which may be attributable to standardization include[5]:

## ENGINEERING

- Reduce technical time in processing product design
- Reuse known items improves reliability and reduces "debugging"
- Reduce hazard of technical error in judgment
- Increase time available for work requiring special design or handling
- Reduce errors arising from miscommunication between engineers, draftsmen, production etc.

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5 List compiled from NAS 1524 and other sources

- Reduce "break-in" time for new technical personnel
- Reduce the need for minor supervisory decisions
- Reduce the need for waivers and non-standard part testing and approval
- Reduce redesign and redrafting effort
- Improve interchangeability of parts, designs, packages etc.
- Promote the use of improved methods and products
- Help eliminate unsound practices based on prejudice, tradition, advertising etc.
- Facilitate the development of cost estimating techniques
- Facilitate and speed the delivery of critical information

PROCUREMENT

- Increase purchasing power through procurement of larger quantities of fewer items
- Reduce the number of purchase orders, receipts and payments
- Reduce lead time
- Provide a common language between buyer and seller reducing time required for negotiations
- Facilitate the formation of quality partnerships with vendors which lead to just in time delivery
- Use standard dimensions, interfaces and design requirements to help put all suppliers on a fair competitive basis
- Promote purchase by intrinsic value rather than sales-pitch
- Facilitate more rapid acceptance of designs which meet a particular standard

QUALITY CONTROL

- Facilitate quality control through th euse of standard designs of known quality and specifications
- Diminish hazard of misunderstandings with suppliers
- Provide better control of the end product
- Reduce and simplify inspection

INVENTORIES

- Reduce capital requirements and amount of capital tied up in inventory
- Reduce record keeping
- Reduce storage area
- Reduce material handling
- Reduce obsolescence and spoilage hazards
- Reduce stockkeeper's time requirements
- Reduce stockkeeper training required
- Facilitate more accurate and predictable planning and budgeting
- Provide quicker service

PRODUCTION

- Facilitate more routine activity and familiarity with fabrication and assembly
- Reduce re-work
- Facilitate mechanization
- Avoid production delays through stocked standard parts

- Emphasize on producibility in standard design accrues benefits with every application of the standard without the need for further design

MAINTENANCE

- Reduce breakdowns and downtime
- Reduce preventative maintenance time
- Reduce repair time
- Decrease critical expediting
- Reduce the number of unfamiliar jobs encountered
- Decrease the number of service-spares
- Reduce training time

The objective of this chapter is to place shipbuilding standardization in perspective in order to facilitate a more detailed discussion of standardization of naval equipment and components. It is hoped that the reader will gain an appreciation for the complexity of the problems, processes and procedures involved. Achieving the goal of reduced construction cycles and costs will require the use of many different standardization concepts simultaneously, each serving as input for the other. Integrated Logistics Support costs and life cycle costs are directly impacted by standardization and its resultant reduction in the logistics requirements. It is hoped that this study will help to identify criteria which can be used to prioritize and focus valuable attention and dollars in areas that have potential.

Just as standardization has a broad range of objectives, there is a broad range of standardization. There are a wide variety of levels, or tiers, of standardization as well as differing definitions and applications for standards such as:

- Guidance, Requirements and Specifications

- Benchmarks
- Processes
- Baseline Designs/Engineering
- Interim and End-Products

## Standards as Guidelines, Requirements and Specifications[6]

Designers often refer to standard guidelines, requirements, and specifications in order for a particular ship or ship's component to be "blessed" by the Navy or one of the many classification societies or regulatory bodies. These types of standards do not constrain the number or form of the items themselves, but offer a base set of standard requirements that the items must live up to.

In 1933 the United States had 5000 standards in use nationally. Half of these were government documents. At that time, four of 350 standard developing organizations were solely devoted to standardization efforts.

These organizations included:

- American Standards Association (Now ANSI)
- American Society for Testing Materials (ASTM)
- Central Committee on Lumber Standards
- American Marine Standards Committee

Of these, only ANSI and ASTM survived the depression. By 1933 256 standards had been developed for the maritime industry. These numbers have increased over the years.

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6 The reader is referred to:

Toth, Robert; "Marine Industry Standards of the U.S. and the World"; Journal of Ship Production; Vol. 2, No. 3; Aug 1986, pp. 179-184, for a more detailed discussion of the history of U.S. and international standards.

More than 81,000 standards exist nationally in the United States today. Of the 81,000 U.S. standards, 9700 (12%) are related to the marine industry. This represents the largest number of standards internationally (excepting the now defunct Soviet Union), although the growth rate of U.S. standards is low in comparison to that of other nations. On first glance one may believe that these Figures demonstrate that the U.S. is a world leader in standards development and use. In reality, the Figures imply that the U.S. continues to circulate out of date standards which are rarely updated when a better standard is developed and popularly used, thus leading to a confusing variety of "standards". Another point of concern is that countries overseas cooperate on the introduction of standards, while the U.S. continues to use unique standards which are anything but "standard" on a global scale. Of the 9700 U.S. marine related standards, the majority (7100) are promulgated by the government. The vast majority of these are Navy standards and specifications. These types of standards do little to promote the U.S. shipbuilding industrial base.

In studying the decline of the U.S. shipbuilding industrial base and its potential to return to international competitiveness, it is important to keep in perspective the influence which Navy requirements have had on the U.S. industry as a whole. In the absence of commercial contracts, major U.S. shipbuilders have been catering to the Navy for the last twenty years. In an effort to facilitate their interaction with, and ability to satisfy, the Navy and its strict requirements, U.S. shipyards have evolved into organizations modeled in many respects after their Navy customers. The U.S. shipyard is burdened with a high overhead bureaucratic organization which has evolved over time in order to handle the vast quantities of paperwork associated with the construction of a Navy ship. During this time U.S. shipyard personnel have grown used to the stringent Navy requirements, and designers have grown accustomed to meeting Navy requirements. U.S. designers and engineers are no longer intimately familiar with true commercial design practices. Testing and inspection departments have developed over time which are no longer familiar with inspection for sound shipbuilding practices, but are instead familiar with inspecting for Navy requirements which are extremely conservative. These large organizations which are very familiar and comfortable with Navy requirements but have little recent commercial experience are poorly prepared for commercial shipbuilding.

## Standard Processes[7]

It is important to break production down into effectively managed tasks. In order to standardize production processes it is useful to first group related tasks together. This is the first step towards GROUP TECHNOLOGY, a methodology by which interim products are classified according to the processes required to construct them. In order to discuss standard tasks and standard products, the concept of modular/zone construction must first be understood. This concept will be discussed further in relation to standard ship modules in Chapter 8 of this thesis.

After identifying the processes utilized in the shipyard, it is important to group the parts and products that require similar processes and manufacturing such that they are handled more effectively. The evolution of group technology is discussed in more detail later in this thesis. At the moment, consider that in order for this concept to work, adequate resources and instructions must be set up in the planning stages. A natural complement to the group technology approach is standardization within the production planning process.

Standardized production planning lends itself to modular/zone construction. A module may be thought of as any structural assembly that will be directly erected onto the ship or hull block. This module is built up from subassemblies, interim products and piece parts. A simple analogy may be that this type of production is similar to LEGO® toy building blocks.

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7 The reader is referred to:

Wade, Michael; "Use of Standard Task Blocks to Simplify the Ship Production Process"; Journal of Ship Production; Vol. 2, No. 2, May 1986, pp. 101-109, for a detailed discussion of the task block approach.

The size of modules used to construct a ship will depend on the physical capability of a particular yard and the logical divisions present in the ship design. Standard modules with applications across ship types and multiple application within a single ship may also be developed. These should be flexible modules which permit a variety of equipment to be utilized as necessary, i.e. be able to adapt to changing technology. The design and use of the modules should be such that they do not lock-in the function of the final product, the ship, but do facilitate an efficient production plan once the ship's function and gross characteristics are determined. The use of modular construction permits the workforce to perform the production tasks necessary for a particular module earlier than would be possible using traditional construction planning where the steel trades would typically finish their work before other trades could gain access to the ship. These production processes may also be conducted within closer proximity to the required shops and resources, cutting transit times and generally improving the efficiency of the workforce. Using the modular approach, trades have greater access to areas of the module they are working on, reducing the need to remove work already completed to access a covered location. As the modules are completed they are erected onto the ways or the hull. Because the modules are outfitted extensively prior to being erected onto the hull, a greater percentage of the construction will be complete upon launch, which reduces congestion problems during post-launch work and shortens overall time to delivery.

As modules are erected onto the ways, they lose their individual identity. As modules come together, they form ZONES. Typically, a zone is a more obvious segregation of the ship. It may be defined as an enclosed compartment, series of compartments, hull area or deck area which has outfitting requirements that are distinct from those of neighboring zones.

Work packages that include parts lists, production drawings, production sketches and a schedule are the basic ingredients for a standardized task block. Mr. Michael Wade of David Taylor Research Center (DTRC) describes the standard task block as a node in a matrix defined by a production stage axis and a type axis. Two similar matrices may be constructed in this manner. A "standard modular breakdown" matrix may have one axis defined by fabrication, subassembly, construction, pre-outfit and erection while the other axis may be described by deep tank, stern, bow, wing/side shell, deck, inner bottom, superstructure etc. This matrix helps to define the module by location and processes involved in its construction. Similarly, a "standard zone breakdown" matrix may be defined by one axis consisting of zone fabrication, zone subassembly, zone preliminary outfit, zone final outfit and zone/system testing and completion and another axis consisting of engine room machinery space, non-engine room machinery space, storage/cargo space, tank/void space, steering gear space, weather deck area, accommodations space, pilothouse space, and exterior hull area. Figure 2.0 illustrates the modular matrix.

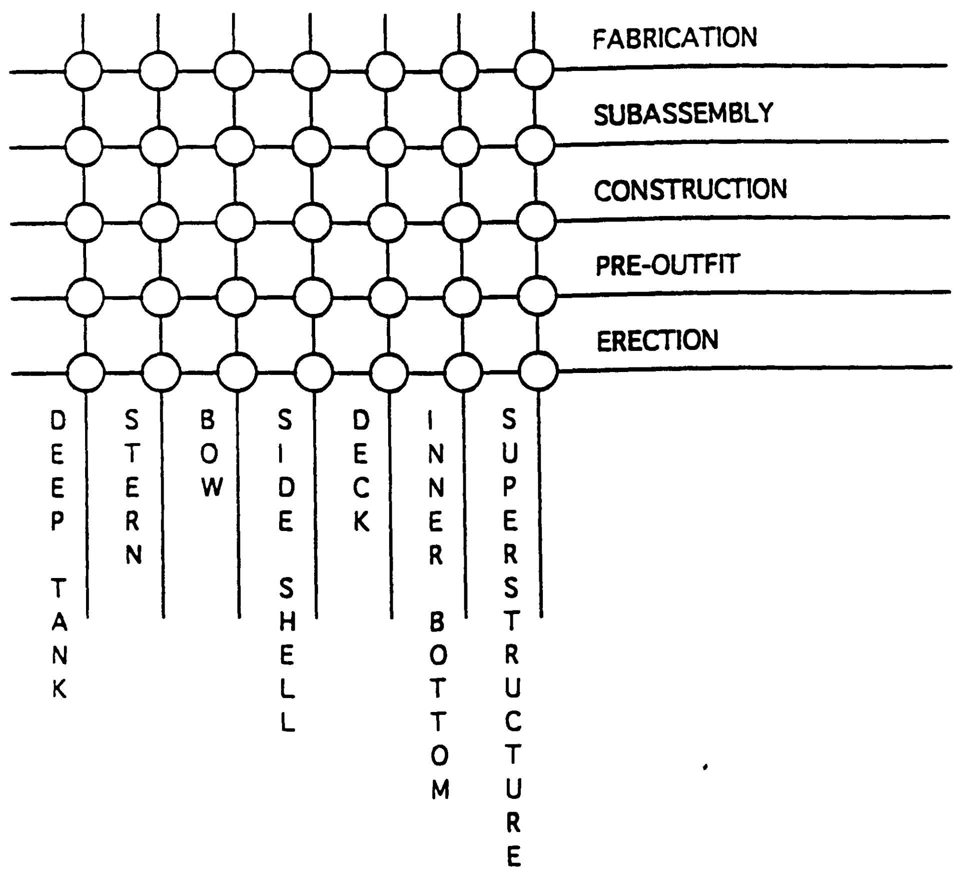


Figure 2.0 - Task Block Matrix

Construction of the modules and zones is broken down into stages. The following definitions for modular and zone construction stages appear in Mr. Wade's paper:

MODULAR STAGES:

| | |
|---|---|
| FABRICATION: | Numerically controlled and optical burning of plate; cutting of structural shapes; cutting and forming of pipe and tube; cutting cable to length; blasting and priming applicable parts |
| SUBASSEMBLY: | Manufacture of 2-D panels with stiffeners such as decks and bulkheads; small structural assemblies such as simple foundations; coamings and stiffeners; piping, ventilation and electrical subassemblies needed for the modular pre-outfit stage; would include hot work items, pipe sleeves, multiple transit frames, doors, hatches, studs, including blasting and painting of these parts |
| CONSTRUCTION: | 3-D units incorporated into the modules; installation of all outfitting hot-work planned to be performed at this time; blasting and painting of the module |
| PRE-OUTFIT: | Final installation of all outfit items planned for installation prior to erection (this is separated from "construction" by the lack of hot-work in this stage to minimize damage to paint and outfit work) |

**ERECTION:** All activities related to actual structural erection of the module upon the vessel or hull block; encompasses all tasks that will occur during structural erection such as fitting and installing stern tubes; pieces needed to tie the module into ship structure would typically be included in the parts list for this task, but not those for the module next in line; also included are parts left off until erection such as fender pipe.

**ZONE STAGES:**

**FABRICATION:** Manufacture of all parts to support the zone assembly, sub-assembly, pre-outfit, outfit and testing/completion

**SUBASSEMBLY:** Manufacture of subassemblies and interim products needed to support onboard outfitting of zones

**PRE-OUTFIT:** Major piping runs, ventilation duct work, and hull insulation installed/connected between modules; installation of major machinery; incidental structural work; tank testing

**FINAL OUTFIT:** Connections from equipment to piping, electrical and ventilation systems; incidental painting and insulation; underlayment and flooring; joiner work and sheathing; stage continues until pipe testing is required

COMPLETION: includes compartment pressure testing; finished insulation; covering; miscellaneous installations, loading of spare parts and outfit items; touch up and final painting; installation of labels and plates; tank closing and inspection; operational tests on systems in the zone (distinguished from system wide testing)

The stages and types are differentiated by unique requirements common to that stage or type. If the matrices are set up as described, then ship construction can be described by 35 modular task blocks and 45 zone task blocks for a total of 80 task blocks. More refined matrices may be used to further describe the construction process in more detail. Once an adequate set of matrices has been developed, work tasks common to the task blocks can be identified. These work tasks can be identified by analyzing the structural systems and components associated with each module and zone. Having defined the stages and basic tasks, it is necessary to relate work tasks to one another. Some work tasks must be performed before others can be started. These tasks can be referred to as being of the predecessor type. Conversely, a successor type is one which requires other tasks to be performed prior to its start. Ideally, one would like to explore manufacturing processes and materials in an effort to maximize the possibility of tasks being performed simultaneously. One would like tasks to be performed in parallel, thereby reducing total time to delivery. Once the production cycle has been studied, and statistics developed and analyzed to characterize notional ship modules and zones, estimates of the work content of typical modules and zones can be made. This information can be utilized in conjunction with other criteria in identifying those areas which could provide savings in acquisition cost, life cycle cost, module weight, or time to delivery.

The notional procedure to follow is to first identify the tasks associated with a construction stage. Next the relationship between these tasks is determined. The work tasks can then be sequenced into a standard task block. This process could be repeated until all such standard task blocks have been identified. Next the relationship between a zone or module should be established. These serve as the basis for a rational and efficient construction plan. A complete task sequence for a module or zone is built up from these standard task blocks. The complete modules or zones can be related to one another by identifying tasks which will interface standard task blocks of different zones or modules. Once the production sequence has been established for the project, estimates of cost and time to delivery can be made. This would be facilitated by accurate estimates of the work content of different types of tasks. By describing modules and zones in terms of their work content as suggested, cost and time estimates should be more accurate and more easily understood. Accurate means of predicting the resources required for production processes is essential for an effective planning and control function. These estimates can be considered benchmarks or production standards.

## Standards as Benchmarks: Production Standards

Zone outfitting and Just in Time (JIT) production are dependent upon conformance to production standards. The concept of a production standard is consistent with the principals of Total Quality Management and Continuous Quality Improvement. An industry must have an understanding of its processes and what the current performance expectations are. Measurements should be taken to continuously improve these processes and insure that the processes are held in control. Production standards are benchmarks useful in measurement, control and improvement process.

SNAME/NSRP Panel SP-8 has published a hierarchy of such standards in the paper "Production Oriented Planning: A Manual on Planning and Production Control for Shipyard Use." In that document, a notional hierarchy of standards is discussed. The lowest level is the most complicated. The next levels are less complicated and utilize information from the first. Two approaches could be used to generate these standards. Aggregation could be used, in which case higher standards are developed from lower ones. Disaggregation is the opposite process. Given one has a high level standard which has proven successful, it can be refined and broken out into greater detail to develop lower level standards. Affinity diagrams can be utilized to determine trends and relationships between tasks. The following hierarchy of standards is suggested by SP-8:

- Process standard
- Production standard
- Scheduling standard
- Planning standard
- Cost Estimating standard

An additional category which will be discussed might be:

- Standards for accuracy (i.e. tolerances)

The standards differ depending upon their end use and the information available in their development.

A typical production standard deals with the work content of a particular production job which may have been defined as a standard process. An example may be the time expressed in man-hours to fabricate a specific pipe spool detail in a fabrication.[8] Such a standard would be based upon a number of process standards. A process standard describes a single work process such as the time required to make a particular cut in a particular sized plate of a specific size material. This type of benchmark can clearly be associated with a standard process as discussed in the preceding section. It should be recalled that while a *standard process* refers to a listing of all the procedures or instructions to perform a task, *process standards* refer to the

8 Graves, Robert; McGinnis, Leon; Robinson, Rodney; "Shipyard Production Standards"; Journal of Ship Production; Vol. 4, No. 1; February 1988; pp. 65-69

time required to perform elements of the work content outlined in the standard process. The sum of all the process standards associated with a particular standard process would define a production standard. A production standard would not include unmeasured work not covered in the process standards. Interprocess and congestion delays are also excluded from these standards. Those details would be included in scheduling standards.

The scheduling standard estimates the elapsed time in man-hours for specific operations. These standards generally refer to the time required for larger assemblies rather than a production standard, and may represent the sum of many production standards related to all the processes and standard processes which are used to develop a small module for example. This standard is used to plan manpower for shops and craft groups. These provide the input for planning standards.

Planning standards are used to determine work package budgets. They are used in developing key event schedules and milestones for the construction of major ship modules and zones. Cost estimating standards are used to estimate ship construction costs based upon the previous standards.

Of concern in shipyard construction is the accuracy to which components can be built. Assuring that there are minimal variations in hull structure from project to project is important for successful standardization. The Japanese Society of Naval Architects publishes a list of indicators which pertain to hull variations. This publication lists, in terms of mean values and standard deviations, the accuracy in structural details that are normally achieved by the Japanese shipbuilding industry. The publication, the "Japanese Shipbuilding Quality Standard (Hull Part)", is updated to reflect improvements and is used in contracts to establish acceptability criteria.

Recent studies of naval ship construction using photogrammetric surveys indicate that there are substantial variations which are illustrated in Table 2.0.[9] This has had an impact on

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9 Chirillo, Louis; "Flexible Standards: An Essential Innovation in Shipyards"; Journal of Ship Production; Vol 7, No 1; Feb 1991, pp. 1-11

repair work. A yard that has endeavored to construct replacement structure before the arrival of the ship at the dock may find it necessary to do considerable rework in order to integrate the structure with the ship properly.

| | Diff. from Design | | | Dev. from Tolerance | | |
|---|---|---|---|---|---|---|
| | YARD X | YARD Y | YARD Z | YARD X | YARD Y | YARD Z |
| LOA | -13.25 | -6.25 | -7.125 | -8.75 | -1.75 | -2.625 |
| LBP | -3.125 | -3.75 | -0.125 | accept. | accept. | accept. |
| BEAM,DK | -1.500 | -2.25 | -0.500 | -0.500 | -1.375 | accept. |
| BEAM,DWL | -2.875 | -4.25 | -1.125 | -1.875 | -3.25 | -0.125 |
| DEPTH | -1.125 | +2.00 | -1.125 | -0.125 | +1.00 | -0.125 |

Table 2.0 - FFG-7 Construction Survey, inches

Techniques to construct these standards have been developed by panel SP-8 of SNAME/NSRP. Unfortunately, many shipyards do not have a firm enough grasp of their processes to take this approach. These standards are the natural evolution of the measurement and estimating systems already in place in most shipyards. An opportunity exists to study these estimates further and to apply the aggregation and dissagregation techniques suggested by the panel in an effort to establish a more streamlined approach to production planning. These estimates must detail construction time and construction costs in terms of the work content rather than empirical relationships to ship weight and volume, for example. Such an approach would be part of a typical continuous quality improvement initiative which utilizes statistical process control (SPC). SPC is a means of measuring performance against norms which facilitates determining when a procedure has gone wrong. SPC also makes it easier to measure the impact of changes to the production system. With a grasp of the processes and a means to predict resource requirements, project management tools and optimization techniques can be utilized more effectively and production streamlining can take place.

## Standard Interim and End-products

Standardization can be implemented at every level of shipbuilding. The piece parts making up ship equipment may be standard. The equipment itself may be standard. Structural components may be standard. Ship modules or zones may be standard. One may also develop families of standard ships.

Equipment standardization may refer to the development of a family of standard designs to be used throughout the fleet; it may refer to limiting the variety of equipment throughout the fleet, within a class or within a ship. It may also refer to standardizing equipment dimensions and interfaces. Each of these varying levels of equipment standardization has advantages and disadvantages. Developing standard families of equipment reduces the logistics costs associated with a fleet which utilizes the standard family. This savings comes at the expense of the equipment development costs, and costs associated with the use of equipment which may not be performance or cost optimal for the application at hand. Furthermore, this strict form of standardization is likely to result in some degree of "lock-in" to a technology which may not be the state of the art. This type of standardization by definition standardizes dimensions and interfaces, which has a dramatic impact upon design and the production schedule. In the course of this research many shipyards were surveyed and they unanimously cited the lack of timely delivery of critical Vendor Furnished Information (VFI) as a source of problems. Standardization of critical characteristics allows the shipbuilder to know what to design for, even if the vendor has not yet been selected. Minimizing the proliferation of new equipment into the supply system for the operator of a large fleet, like the Navy, has the effect of reducing Integrated Logistics Costs, but does not adequately impact the design or production schedule unless the critical VFI is made readily available to the contractors. In the case of the Navy, the author found that a combination of minimizing needless proliferation of new equipment into the supply system plus a concerted effort to standardize dimensions, interfaces, and assemblies is a sensible course of action. Strict standardization on a particular equipment design accross the entire fleet is best suited to those instances when performance, reliability and maintainability are critical areas of historical concern (i.e. existing equipment is not adequate and the Navy deems the only answer to be an in house design or a design contracted to specifications). Standardization and flexibility or adaptability need not be contradictory. This will be discussed further later.

Standardization of equipment provides savings in life cycle costs associated with the equipment and may reduce the acquisition costs through economies of scale. This must be traded off against the use of "over-rated" or "non-optimum" components. Standardizing equipment has many benefits beyond costs directly and traditionally attributed to the equipment. The use of modules and zone construction is greatly facilitated by up front planning and design which requires detailed information regarding equipment dimensions, weights, interfaces and constraints. Standardization of equipment is an important first step in this direction.

The Japanese shipbuilding industry has used this approach to great advantage. Their use of standards has been reported to greatly simplify their material procurement and shipbuilding processes. The Japanese shipyards maintain files of vendor-catalog items that have been pre-approved, which the Japanese yards refer to as their "standard equipment". For a particular application, two or three vendors' equipment are listed in the file. Using special agreements with the vendors, all the information is kept up to date. Savings from bulk orders is achieved as is timely delivery. These "quality partnerships" are discussed later.

In addition to controlling the supply system, thereby insuring timely delivery of vendor furnished information and the equipment itself, the Japanese shipbuilder and designer is not as dependent upon VFI since equipment dimension standards are maintained across vendors. The

Japanese government requires detailed standards to be utilized in Japanese industry. The Japanese Marine Standards Association is responsible for preparation of Japanese marine standards, which then go through a rigorous review by government industrial agencies, and are then promulgated throughout the Japanese Shipbuilding industry. Representatives from major marine industrial interests collaborate in the standard development. In the United States, many groups exist with stated goals of promoting standardization, such as the NSRP panel SP-6 which is devoted to shipbuilding standards. The societies which actually develop standards do not always get input from industry representatives, and rarely is a standard developed by industry consensus as it is in Japan. For a more detailed discussion of commercial dimensional standards, the reader is referred to "Commercial Substitution as a Means to Build the Industrial Shipbuilding Base", by Neil Gallagher (MIT Thesis, May 1993).

To date, the Navy has concentrated its standardization effort at reducing equipment life cycle costs and improving maintenance records by standardizing on a reliable design and increasing the depth of the supply system while decreasing its breadth. This maximizes the likelihood of spares being available at any given time. Although these are important goals, standardization has an impact upon the ship construction cycle which must be considered and used in an advantageous manner by any forward thinking naval equipment standardization policy. It was this positive impact upon the construction cycle which motivated Japan's standardization program. Japan's program was driven by the builders and the vendors who recognized it to be in their mutual interest to speed construction and delivery. Structural design details and components can also be standardized and this standardization can often be linked to equipment standardization efforts. In order for concurrent engineering (the parallel design and determination of how the product is to be produced) to be successful and shrink the ship production cycle, it is imperative that delivery of VFI be timely and that standard dimensions and interfaces be sought.

The U.S. Navy has placed a great emphasis upon weight reduction as a means of controlling costs. Weight reduction reduces fuel costs and allows flexibility with regard to weapons payload and growth potential for the future, but it is not clear that it leads to reduced construction costs. This policy was largely the result of a lack of understanding of the production processes involved. Although it is true that the costs of simple ship structure are proportional to weight in many respects, this is not the case for more complicated structure. Complex structure, such as equipment foundations, are typically only 10% of the ship's weight but represent over 50% of the construction costs due to the intricacies of their production.[10] An emphasis on weight reduction rather than producibility is a misdirected approach since such a large percentage of the construction cost is actually directly attributable to a very small percentage of the ship's displacement.

Construction costs are further increased by delays attributable to misunderstandings or lack of proper information regarding the equipment to be mounted to foundations and the constraints upon ship arrangements and production sequences. In order to weight optimize the construction, engineers would often require structural shapes to be modified in the yard or fabricated as entirely custom structural parts. Often, weight reduction efforts led to very expensive back-up structure being required to meet shock requirements, since the primary structure was not designed for these loads in an effort to reduce primary structure weight. This leads to high costs and delayed delivery. Increased variety in the ship scantlings require the shipyard to manage and store an increased variety of scantlings. The costs associated with managing a complicated supply system can be tremendous. It requires extra storage space and more complicated information systems as well as more personnel. The variety also increases the frequency of construction errors, such as light angles being used where heavy angles were required. These errors are often caught late in the construction cycle during inspection periods and require expensive re-work. Furthermore, the lighter structural shapes are often much more expensive since they do not benefit from economies of scale and are often custom built to weight optimize the design.

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10 Presentation by John Hopkinson of Vibtech, inc. to NSRP Panel SP-6 on standardization of foundations

Once again a trade off exists, in this case between a weight optimized design and a design which minimizes the variety of structural shapes. By providing designers and engineers with lists of available standard structural components along with all the information necessary to do the design work, including the costs of structural components, cost trade-offs could be utilized as one of the design parameters. Just as designers traditionally would be provided with dimensions and weight information to allow them to study weight optimization, costs could be considered easily as well. "Standardization of Ship Structural Design" by George A. Kriezas offers a comparison between cost optimized and weight optimized designs. A study of the design of a Large Crude Carrier indicated that a savings of $8614 could be achieved per meter of midship section while only $2555 would be lost in carrying capacity per meter (at 10 $/ton calculated in present value terms over an estimated ship life). When one considers that this comparison only accounted for the costs of acquiring steel structural shapes and did not incorporate re-work expenses, storage costs, time to delivery and management costs, it is evident that much is to be gained by standardizing ship structure. Even more incentive exists for naval combatants. Commercial ship structure is not as complicated since less equipment is installed and it need not stand up to rigorous shock requirements. The cost savings associated with naval ships which have more structure, equipment and complicated foundations to be standardized would be considerably higher. Vibtech, Inc. of Rhode Island has expertise in this area, and has found that 20% savings in foundation construction costs can be achieved by emphasizing producibility in the design and minimizing the needless introduction of extra structural components. The time required to construct these foundations is also reduced.

By standardizing equipment dimensions and attachments, more detailed foundation design could be conducted up front, with producibility and commonality as the driving considerations which would result in even greater savings. There have been several recent projects involving the re-design of naval foundations to reduce costs in follow-ships after it was discovered that lead ship construction costs were considerable. Had the appropriate care been taken early in the design process, these re-engineering costs could have been avoided.

Vibtech provided the author with information regarding these projects. Among the ship classes studied were a Canadian Patrol Frigate, DDG-51, CG-47, FFG-7 and the AOE-10. Foundations can be classified according to their attachment location, means of attachment and shape. For example, foundations can be mounted to bulkheads either on stiffeners or plate; to decks from above (on the plate) or below (hung from stiffeners); to the side shell or side shell structure; to the inner bottom; or platforms levels and tank-tops. These locations are important as they define the forces which the structure must withstand according to Navy Shock Criteria (DDS-072, MILSTD-907D). The foundation shapes may be broken down into several types. Some of these types include:

- Grillage
- Frame
- Truss
- Rack/Panel
- Cantilever/Shelf

Figure 2.1 illustrates these types of foundations. Given that most foundations may be classified in this way, and that equipment serving the same purpose will generally be definable within a certain range for weight, geometry and size and have the same or similar requirements for foundation stiffness and location in space, it may be possible to utilize standard foundations for many applications. Vibtech has compiled a database of foundation geometry for the ships which it has worked on. Figure 2.2 illustrates the point that for a given foundation type, the encountered geometries are not limitless. The foundation designs are defined within bounds because they are driven by the same requirements and equipment characteristics do not vary wildly for a given application. Equipment characteristics vary just enough to require foundations developed through traditional means to be engineered for each application. Equipment statistics can be utilized to bound the design problem prior to foundation design.

Figure 2.3 illustrates some of the elements of such a study. Using these equipment statistics, parametric studies can be performed to show that foundations of a certain type have particular limits of applicability.

Progress is being made in this area as the Navy and shipyards are forced to study the problems of foundation design as a means to reduce costs by developing more producible designs. The lack of dimensional and interface standards in the United States complicates foundation design and production. By limiting the variety of equipment which can be introduced in a contract, progressive foundation and detail design work should be able to continue if designs are developed which are flexible and can accept the pre-qualified equipment by accounting for the possible envelope dimensions and bolting patterns. Dimensional control is a powerful approach which has aided foreign shipbuilders and limits the success of U.S. shipyards. In practice it was found that the attention paid to foundation design not only saved production costs but also resulted in reduced weight since the producible designs often eliminated welds and back-up structure which was proven unnecessary through detailed structural analysis. This approach can be extended to the development of common modules based upon the same statistics and principals.

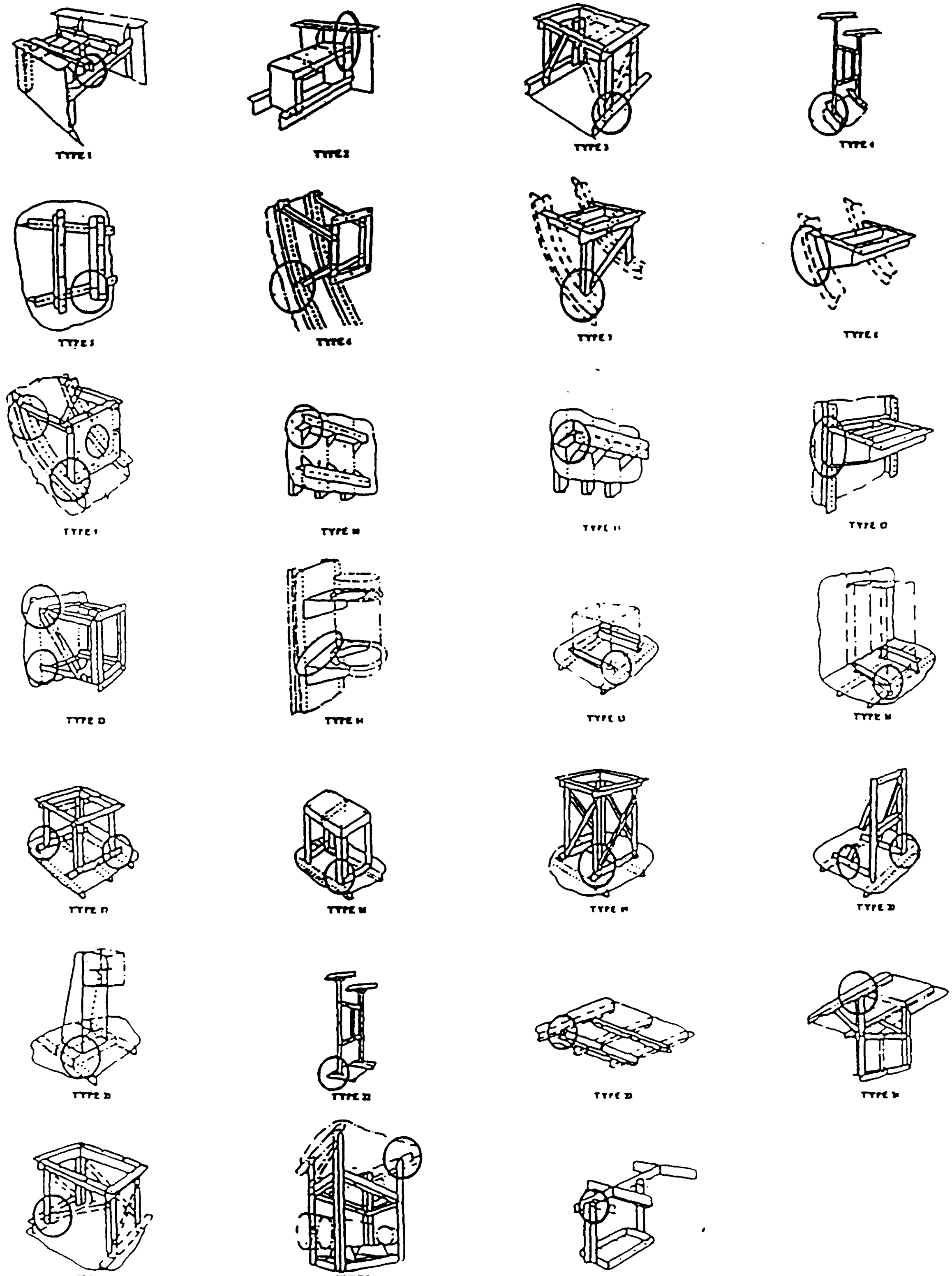

Figure 2.1 - Foundation Characterization[11]

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11 Reprinted by permission of VIBTECH, INC.

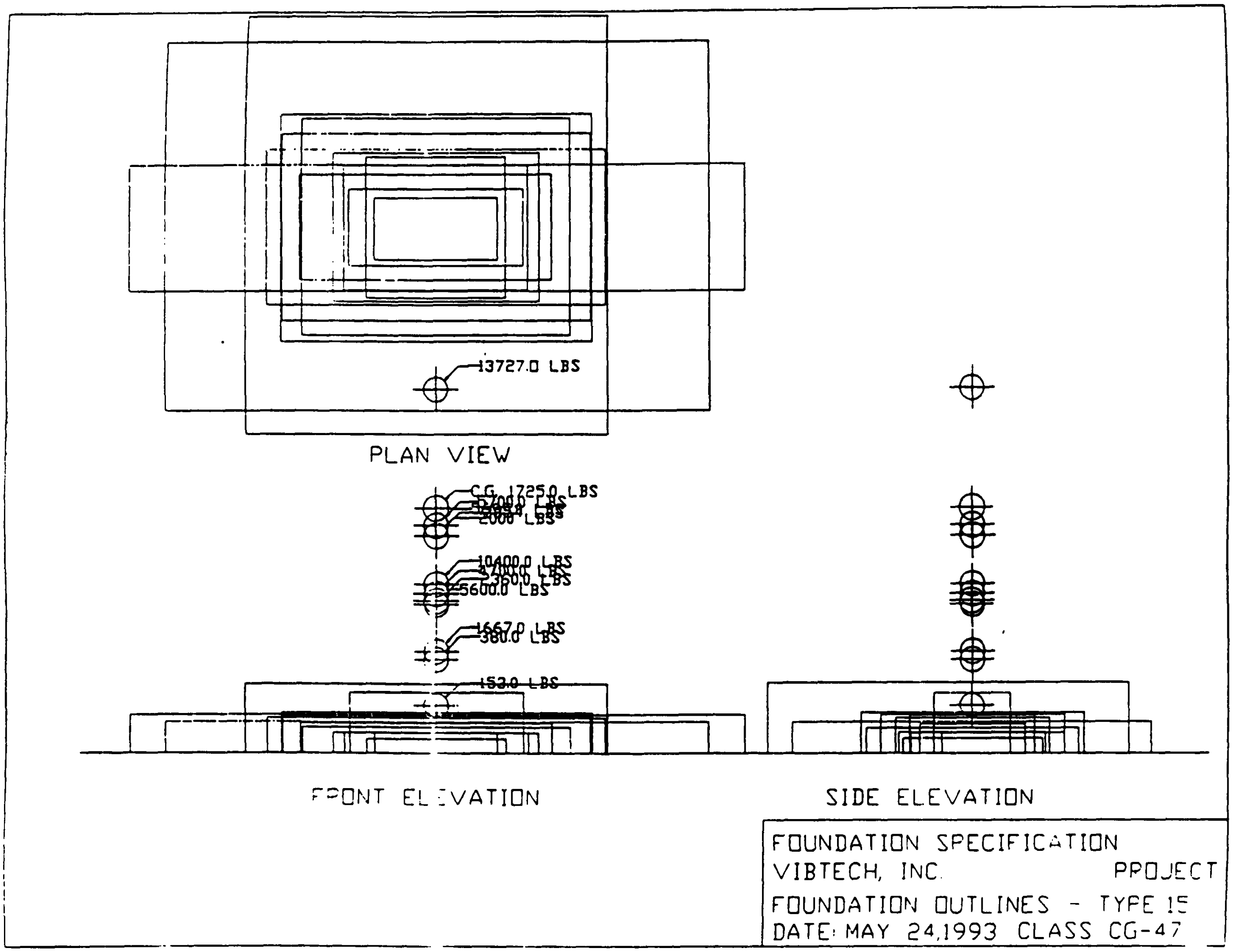


Figure 2.2 - Graphical Illustration of Foundation Statistics[12]

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12 Reprinted by permission of VIBTECH, INC.

## STATISTICS - METHOD MOUNTING EQUIPMENTS

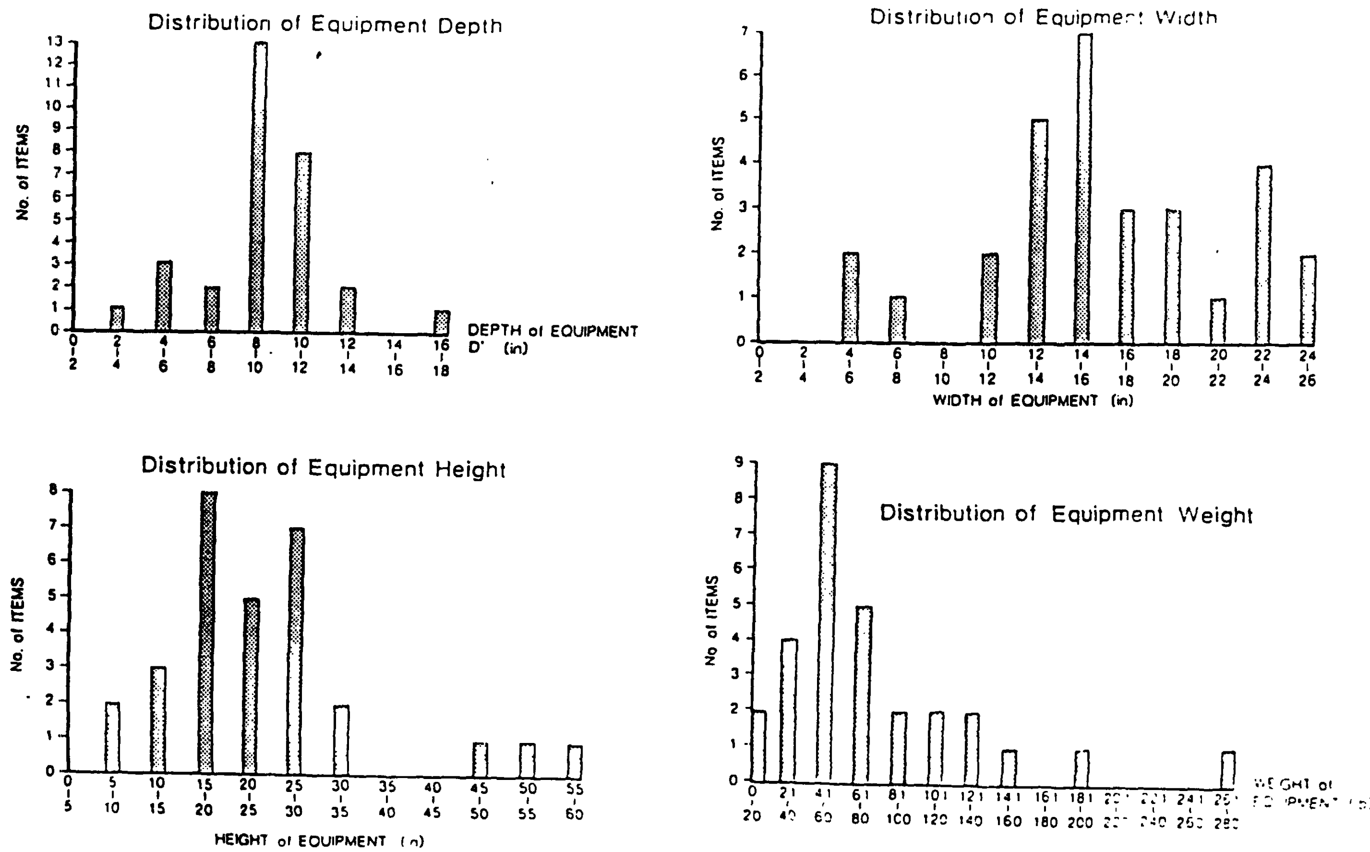


Figure 2.3 - Key Equipment Statistics[13]

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# <u>CHAPTER 3: PROGRESS WITHIN THE NAVY</u>

In this chapter the progress of the Navy towards standardization goals will be discussed. Several important distinctions should be made with regard to standardization of naval equipment. Standardization can take several forms, differentiated by timing and scope. Standardization can be both *Pre-active* and *Reactive*. Pre-active standardization efforts take place prior or parallel to the initial ship design. Often, it is necessary to standardize after significant design activity has taken place, or even after construction has been started as a means of controlling costs. This would be an example of reactive standardization. Standardization scope refers to the degree of standardization. A standard design may be developed, requiring a specific equipment design to be installed. The variety of equipment installed may be required to be reduced, with maximum utilization of equipment already in the Navy supply system. Generally, equipment standardization can take the following forms which are illustrated in Figure 3.0:

- Standardization across the fleet
- Standardization across ships within a class
- Standardization within a ship

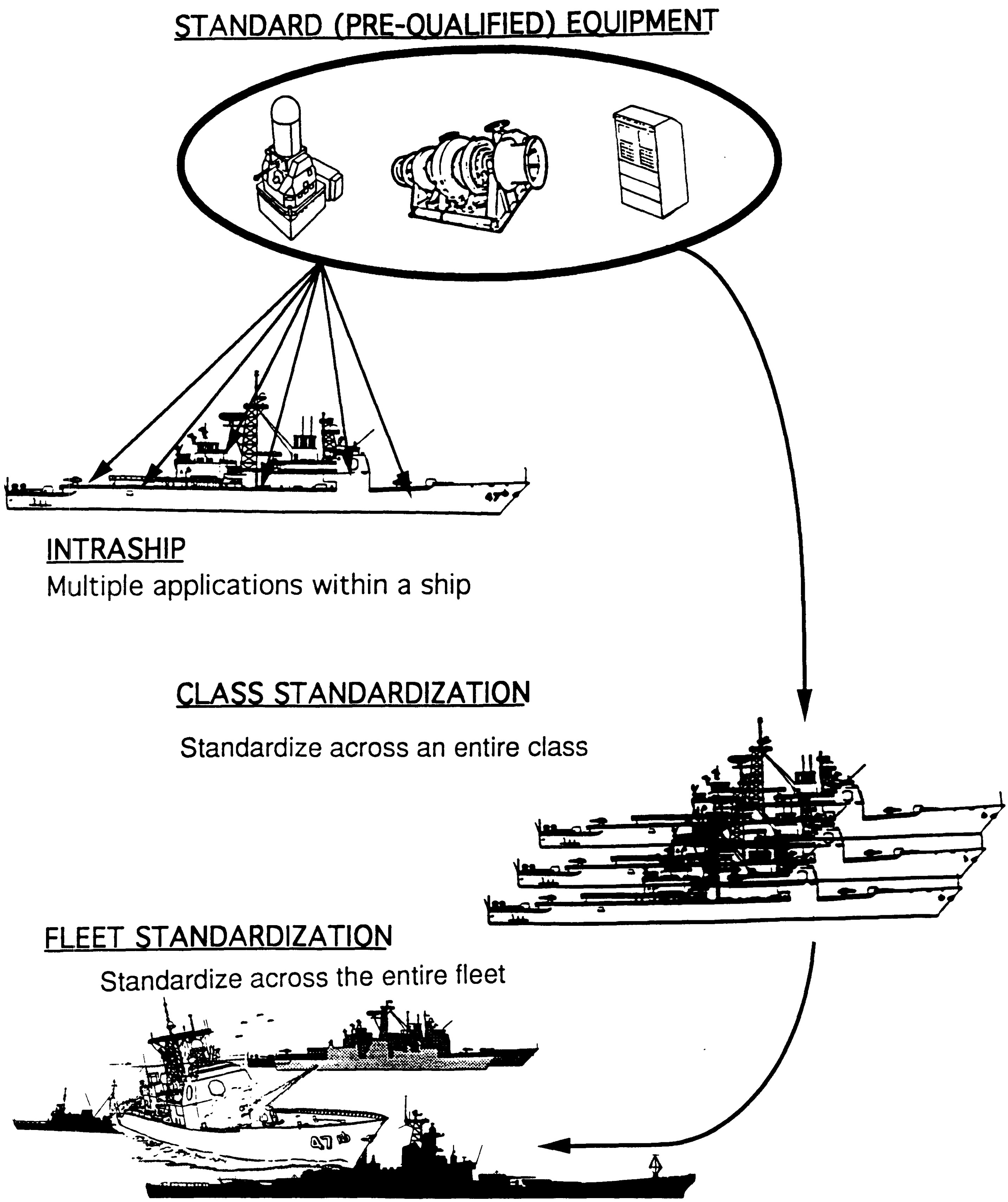


Figure 3.0 - Naval Equipment Standardization

Fleet standardization can have significant advantages with regard to savings in logistics costs. By utilizing the same equipment across the fleet, the demands on the logistics organization are decreased and the availability of spares should increase with the decreased requirement to supply a wider variety of equipment support. Fleet standardization can take two forms. One can actually endeavor to decrease the number of items of supply by developing standard designs, which has the greatest advantages with regard to logistics costs. Another option is to minimize the introduction of new items of supply. Minimizing the number of new items of supply keeps increasing logistics costs in check without the necessity of developing a standard design, or the problems of locking into a design which may prove to be obsolete.

The arguments for fleet standardization are generally a result of a desire for reducing logistics costs or locking into a reliable design. Fleet standardization would have an impact upon construction costs if the standardized item was one which was used frequently across all ship types. Reduced construction costs are dependent upon a standardized mounting method, standardized interfaces and on timely delivery of both the equipment and vendor furnished information. Fleet standardization could provide all these things, but at a high cost which must be weighed against the attributable savings in other areas.

Fleet standardization requires the government to either develop an equipment itself, creating all drawings and engineering itself, or buy all necessary information from a vendor. This would not be the case if the Navy were to simply sign a sole-source contract with a vendor. This is not done for a number of reasons. First of all, it is viewed as an impediment to competition. Secondly, competition is viewed as necessary to keep costs in check since the Navy does not have confidence that vendors would continue to supply equipment at low costs once competition has been eliminated. Eliminating competition could eliminate companies, which has political and legal ramifications. One approach may be to form "quality partnerships" based upon option contracts. These will be discussed in more detail later. Developing equipment "from scratch" as a fleet standard is expensive, as is purchasing the information. Once a standard item has been developed, it is then put up for competitive bid by vendors, who build the item to the developed specifications. Equipment manufactured this way is always considerably more expensive than equipment which has been developed by a vendor and then adapted to use by the Navy. This result is counter to the philosophy that by maximizing the number of applications of an equipment, the price should go down as a function of economies of scale. One such development is the family of standard titanium fire pumps.[14] During the course of this research, the resounding opinion in government and industry was that while economies of scale reduce the cost for items which are adaptations of commercially viable products, this would not be true for military items since Navy volumes alone are not adequate to justify the expense involved. Navy volumes combined with commercial sales of the same or similar product tend to reduce costs.

The consensus among experts interviewed in the Navy, industry and standards associations is that the appropriate steps to take are to minimize the introduction of new items of supply to those times which truly warrant it. The difficulty is in deciding when this is the case. The Navy has taken steps in this direction by requiring contractors to give priority to current items of supply in selecting equipment. Unfortunately, the contractual language regarding this preference for current items of supply is weak. The contractual language does not, in the case of a lead ship, demand preference be given to equipment already in the supply system. Instead it suggests it or states that contractors "are encouraged to...". Contractors are the first to admit that without stronger language, they will utilize equipment which they can get a "good deal" on. This is a result of the shipbuilder's perception that the Navy is more interested in low acquisition costs than a contractor's adherence to a weakly worded portion of an RFP. Many of the people interviewed had stories of contracts in which the Navy spoke highly of standardization goals early on, only to eventually base a decision solely on

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14 For a detailed discussion of the standard titanium fire pumps, the reader is referred to: Marcus, H.S., Zografakis, N., Tedesco, M.P.;Building Upon the Successes of Standardization Within the U.S. Navy; NSRP Ship Production Symposium, 1992

acquisition prices as a result of political pressure. Some industry personel indicated that even when an RFP mentioned a financial incentive was being considered for meeting standardization goals, these incentives sometimes disappeared once the details of the contract were revealed. For these reasons, contractors go after a "good deal" rather than a supported item, unless explicitly required to do otherwise. This good deal may be in reference to better price, preferential treatment for other equipment deals, or better supply arrangements.

Class standardization refers to an effort taken to insure that follow ships utilize equipment which has been installed in the lead ship. The Navy has taken definite steps in this direction with stronger language than that for lead ships regarding the use of class standard equipment. The Navy requires as part of a CDRL (Contract Deliverables Requirements List) that contractors provide a standardization program plan for follow ships. This program plan must demonstrate that the shipyard has some organization in place to handle the standardization and integrated logistics support engineering functions which assigns responsibility for key decisions. Generally, the contractual language requires contractors to procure equipment in the following order of preference:

- Class Standard First
- Supported equipment if possible when class standard is not acquired
- Other equipment

Contractors are required to provide an economic evaluation and justification with a waiver request when an equipment other than a class standard item is used. Class standardization could be very powerful in that it maximizes construction cost savings from lessons learned, and could provide savings from economies of scale if approached correctly. Unfortunately, class standardization is not always utilized to full advantage today.

Class standardization was achieved by Total Package Procurement (TPP), which was the established policy prior to 1971. TPP required that the bidding shipyards be responsible for providing a design which met a *performance specification.* The bid price was to include design and engineering costs, construction costs for all the foreseen ships in the class, ILS costs and outfitting costs. Although this approach generally resulted in savings in construction costs from lessons learned, series ship construction, and established relationships with vendors, the Navy was unhappy with this acquisition practice. This dissatisfaction was a result of performance rather than cost considerations. The economic climate in the Navy was significantly different than it is today, and it was believed that the Navy could get a superior product if it adopted a "fly before you buy" approach to follow ships, acquiring the lead ship or ships first. The lead ships would be tested extensively, and lessons learned or new requirements used in follow ships. The decision could also be made to completely revise or abandon the design. Reacting in 1971, the policy was changed and only current fiscal year ships were to be acquired in a contract. This meant that a lead ship yard was no longer guaranteed follow ship work. A further result was that the Naval Sea Systems Command took control over the design, with the shipyards offering assistance. This tended to result in designs which neglected producibility considerations, since NAVSEA did not have adequate experience and contact with the shipyards. These contracts were competitively negotiated fixed price contracts.

In 1973, the Navy utilized a Cost Plus Incentive Fee structure for the lead ship FFG-7 frigate in an effort to reduce costs of follow ships through careful "design to cost" engineering and purchase plans. The Navy approached class standardization relatively successfully in its acquisition policies and procedures for the FFG-7 class frigates. This ship was the first ship to be "designed to cost" under a cost constraint. Government Furnished Equipment (GFE) for the combat systems in the lead ship was procured and delivered to the lead yard, Bath Iron Works (BIW), according to a contractually established schedule. For follow ships, the GFE inspecting, testing, and delivery was handled by third party "grooming sites" such as Sperry Systems Management Division. In addition to three GFE combat systems/communications systems, 42 other major equipment were identified by the Navy to be CLASS STANDARD.

The Navy only called out the equipment type and specs, the task of selecting vendors was relegated to BIW as the lead yard. Acquisition cost was the driving factor behind BIW's choice of vendors. The price BIW was required to use as its criteria was the total price for the lead ship plus 30 additional shipsets to be delivered according to a possible range of pre-established delivery rates to accommodate likely follow-on schedules. The fixed-price options for the equipment for the 30 follow ships were to be excersisable by the follow yards, by the government or by BIW as the government's agent. Three of the 42 non-combat items were identified to be supplied as GFE to follow yards by BIW as the government's agent. These items included Gas Turbines, diesel-generator sets and main reduction gear. These items were singled out to ensure adequate delivery schedules which could minimize the critical path for construction.

Class standardization of major equipment types naturally leads to standardization of Class Working Drawings. These drawings included component foundations, installations and ship arrangements. A system was created that was intended to motivate but not mandate follow ships be built to lead ship drawings. The FFG-7 class finally included 51 ships, constructed at three shipyards with a high rate of class standardization. This high degree of class standardization came as a result of economic incentives to follow yards in the form of a low negotiated option price on equipment for contractor furnished equipment. Some items were required to be utilized and were delivered as GFE.

The FFG-7 program's class standardization requirements assured savings with regard to delivery times and equipment acquisition costs through the use of option purchase plans with vendors. Such an approach is often referred to today as a "quality partnership" with a vendor.[15] Although it is beyond the scope of this thesis to explore the multitude of contracting options for quality partnerships, it is important to understand this concept which could provide

15 The reader is referred to:

Dickenson, T.E.; Contractual Aspects for Standardization of HM&E Equipment in Naval Ship Acquisitions; MIT Thesis; May 1993 major benefits for the Navy if approached correctly. The first major roadblock to vendor partnering is the perception that regulations forbid it.

Many vendors and contractors cite the Competition in Contracting Act of 1984 (which came into being long after the FFG-7 acquisition) and the Federal Acquisition Regulations as barriers which prevents true quality partnership and class standardization. The 1984 act, and the definition of competition, has been a point of confusion. It is often unclear whether competition requires bids to be received for every discrete acquisition on a fiscal year basis, implying that each time a major delivery is requested that item be competed, or that competition may be assumed to be required at the beginning of a process towards a quality partnership for a particular class of ships. A vendor, dissatisfied with the results of such a contract is likely to sue, claiming a sole source contract in contradiction of the Federal Acquisition Regulations. Vendors and contractors have the impression that long term partnership contracts are not legal. Although this view is often taken, there are a number of places in the FAR which imply that quality partnerships are legal, given competition exists at the outset of the process and a mechanism is in place to adjust the process at some point if it is believed the vendor is not acting fairly. Certainly the interpretation that the 1984 act and the FAR forbid partnerships is contrary to the language and spirit of standardization statutes, such as the Standardization Act of 1952.

As was mentioned, there a variety of contractual mechanisms which can be put in place. Although Congress recognizes a need to improve the acquisition process, they are not eager to adopt a system which limits their ability to kill a project which they believe is wasteful, doesn't perform, or no longer meets the needs of the Navy. The author believes that an acquisition policy could be put in place which would provide this flexibility and still maximize benefits.

Another type of standardization is intra-ship standardization. This refers to an effort to minimize the variety of equipment and components installed within a ship. This effort has three major benefits. First, it provides the greatest construction benefits by maximizing the possibility for common mountings and production processes. This type of standardization minimizes the chances of utilizing the wrong component and subsequent re-work. Secondly, it simplifies the support requirements for the ship and increases availability by increasing the odds that a spare part will be available since less variety needs to be supported. Thirdly, it maximizes crew performance by minimizing the variety of equipment and procedures the crew must be familiar with. The Navy has made a recent effort to standardize the valves aboard the DDG-51 class.

# Information Systems

In order to maximize the benefits attributable to standardization, standardization efforts must be involved as early as possible in the design process. This requires that standardization be a guiding principal in the design phase and all other phases of acquisition and Navy R&D. For this to be a reality, designers and engineers must have access to the widest variety of information regarding the equipment in the Navy supply system. Both performance and physical characteristics must be supplied in order to facilitate decisions. Ideally a comprehensive database would serve this purpose. The Naval Sea Logistics Center maintains data useful for standardization and ship design.

## Hull, Mechanical and Electrical Data Research System

A database has been available since October 1990 for general use and has been distributed by the Naval Sea Logistics Center. This database, the Hull, Mechanical and Electrical Equipment Data Research System (HEDRS) is a significant step in the right direction. In the past the Navy relied upon performance specifications and standards for equipment. These specifications and standards did not identify existing equipment and as a result new and differing equipment was introduced at great logistics expense. The cataloging function which a database such as HEDRS performs serves to define the "universe of supported equipment" while the standardization function works to compress this universe. The HEDRS database is a personal computer Compact Disk Read Only Memory (CD-ROM) based system which is available at no cost to those involved with Navy acquisition, including designers. The system is intended to provide application, identification, physical and performance characteristics, availability of logistics documentation, points of contact with specialists, and reprocurability information on all HM&E equipment currently installed in the Active and Active Reserve fleet. HEDRS consists of four principal segments:

- Component Characteristics File (CCF): Describes equipment installed in the fleet by form, fit, function and some applicable Milspec information. The CCF tracks equipment by its Allowance Parts List number. The APL number is used by NAVSEALOGCEN to identify the parts making up an equipment's ILS package. APL numbers generally (but not always) define unique items of supply. Sometimes two items with different APL numbers may in fact be the same item with only a minor change which was entered into the system as a separate item through error, oversight or loopholes in the procedures. This duplicity generally increases ILS costs and complicates the standardization process. CCF data is obtained from the Navy's Ship Parts Control Center (SPCC).

- Equipment Applications File: Identifies ships on which equipment is installed and tracks the number of installations per ship, class or in the fleet. Information tracked includes installation location by the Service Application Code (SAC), Expanded Ship Work Breakdown Structure (ESWBS) and Ship Work Authorization Boundary (SWAB). The equipment applications file is very useful for generating equipment lists for particular ships or classes. It also allows the user to obtain information about an equipment type which satisfies certain performance characteristics and is, for example, installed in more than a particular number of ships.

- Supportability: Each APL is assigned an Engineering Support Code (ESC) which defines the level of availability of equipment support. The ESC is determined during a survey of manufacturers which is updated every few years.

- Integrated Logistics Support: The ILS database tracks the existence of ILS data for a particular equipment and provides information regarding whether the ILS data is possessed by the Navy.

NAVSEALOGCEN has divided equipment into 99 equipment categories. Table 3.0 lists the different equipment categories. Within each equipment category are subcategories identified by numbers relating the category to a Lead Allowance Parts List number (LAPL). Within each LAPL are a number of APL's.

| EC | DESCRIPTON | EC | DESCRIPTION | EC | DESCRIPTION |
|---|---|---|---|---|---|
| 01 | pumps | 33 | air conditioning | 66 | engines |
| 02 | boilers | 34 | starters | 67 | plumbing |
| 03 | heat exchangers | 35 | wipers | 68 | magnetos |
| 04 | condensers | 36 | audible alarms | 69 | gears |
| 05 | turbines | 37 | bearings | 70 | governors |
| 06 | compressors | 38 | indicators | 71 | ignition eq. |
| 07 | heaters | 39 | clutches | 72 | small boats |
| 08 | distilling plants | 40 | fans | 73 | ejectors |
| 09 | battery chargers | 41 | shop eq. | 74 | eductors |
| 10 | meters | 42 | regulators | 75 | strainers |
| 11 | converters | 43 | galley eq. | 76 | purifiers |
| 12 | maintenance & repair eq. | 44 | dehumidification | 77 | traps |
| 13 | transformers | 45 | gages | 78 | couplings |
| 14 | circuit breakers | 46 | testing and measuring | 79 | silencing eq. |
| 15 | controllers | 47 | chemical warfare | 80 | brakes |
| 16 | generators | 48 | filters | 81 | blowers |
| 17 | motors | 49 | carburetors | 82 | welding |
| 18 | motor generators | 50 | panels | 83 | ship/boat propulsion |
| 19 | relays | 51 | isolaters | 85 | deck machinery |
| 20 | rheostats | 52 | hydraulic eq. | 86 | photographic eq. |
| 21 | switches | 53 | capstans | 87 | underwater log eq. |
| 22 | switchboards | 55 | reels/towing eq. | 88 | valves |
| 23 | visual alarms | 56 | davits | 89 | misc. parts |
| 24 | lighting fixtures | 57 | cranes | 91 | laundry |
| 25 | gyro compass | 58 | hoists | 92 | tanks |
| 26 | projection eq. | 59 | elevators | 93 | pipe, tubing, fittings |
| 27 | interior comm. | 60 | steering gear | 94 | ASW/minesweeping |
| 28 | navigational | 61 | control eq. | 95 | automotive |
| 29 | injectors | 62 | winches | 97 | periscopes/masts |
| 30 | burners | 63 | windlasses | 98 | special power plant |
| 31 | marine hardware | 64 | Fire Fighting | 99 | misc. equipment |
| 32 | refrigeration | 65 | lubricators | | |

Table 3.0 - Equipment Categories

A drawback to the HEDRS system is that critical manufacturer's data often needed to fully describe the equipment in a meaningful way has often been inadvertently omitted or withheld by the manufacturer. This severely limits the utility of the system as a design aid. A further drawback to the HEDRS system is that it is difficult to access the information necessary to perform standardization activities. The reason that the information is difficult to apply to standardization activities is that HEDRS was not intended for this purpose when it was introduced.

The HEDRS system was initially intended to be used as a reference for equipment which satisfies a tight envelope of performance requirements. It was not intended to be used to perform the broad reviews necessary for standardization activities. Functions which must be made available to designers and engineers if standardization efforts are to succeed include:

- <u>Detailed vendor furnished information</u>: The construction cycle is severely hampered by delays in obtaining VFI. Providing this information in a database would speed the process. The ability to obtain statistics regarding weight and envelope dimensions for all equipment types on a large scale should be incorporated into HEDRS. This information could then be used to statistically bound the engineering problem, allowing the designer to develop structural systems and interfaces which may be used for a variety of equipment. At this time HEDRS has a limited amount of this information for some of the equipment which is in the database. Access to the data is not efficient. This should and may be improved in future releases of the database.

Even with these drawbacks, the HEDRS system has proven to be a very useful tool which should be given more attention. It has been used extensively in this study to identify and prioritize equipment which may have standardization potential. With HEDRS, the Navy must take the responsibility of cooperating with designers in equipment selection decisions.

This requires direction and monitoring. This direction and monitoring may come as a result of the requirement for standardization deviation reviews and the use of a database management system like HEDRS. Since its introduction, an improved version of HEDRS has been introduced from time to time. NAVSEALOGCEN will soon introduce a version which should provide significant benefits in that it allows easier access to more detailed VFI. In future development of the system, it is imperative that it be made very easy to use if the Navy is to require it to be utilized as part of a contract. The Navy will need to provide training materials and support for the system. Beyond this, NAVSEALOGCEN must be prepared to conduct equipment surveys in a timely fashion at the contractor's request if the contractor has difficulty with, or is unable to utilize, HEDRS. NAVSEALOGCEN appears receptive to these suggestions.

## Ships' 3-M Reference CD

The Naval Sea Logistics Center has historically maintained a database of maintenance and reference information for the ships in the fleet. NAVSEALOGCEN has recently developed a Compact Disc of Ship's Reference Information. It contains information about Navy equipment and ships such as ship steaming hours and equipment population data (i.e. number of ships installed on and number of total installations). Among the options and cross references available in this database are:

### Ship Information/Steaming Hours:

This option accesses the Activity/Steaming Hours File, or ASF. The ASF contains the steaming hours underway and not underway for the activity. Steaming Hours Underway refers to the number of hours that the engineering department is "ready to answer all bells". Steaming Hours Not Underway is the number of hours the ship is anchored and the main engines are secured. The database also lists commission and delivery dates, overhaul dates and fuel use data.

Service Application Code:

This option is used to group equipment, components and assemblies according to system or service applications aboard a ship. This option has the potential to be useful for common module design. Once equipment which has potential for standardization has been targeted, the SAC search can be used to identify other equipment associated with the targeted equipment.

Equipment ID Code:

The EIC is a four to seven digit alphanumeric code which identifies the system, sub-system and equipment.

Allowance Parts List:

An APL number is an eight digit number which identifies the parts list of an equipment or component.

Expanded Ship Work Breakdown Structure:

ESWBS is a numerical code which defines uniform system boundaries for use throughout the industrial process and the preventive maintenance system (PMS).

The 3-M database and HEDRS are tools which can serve as a basis for standardization decisions. These systems should be expanded to meet their potential as powerful design and acquisition tools.

# Cost Analysis Models

## Integrated Logistics Support Costs

The Naval Sea Logistics Center developed a cost algorithm which is to be used as a trade-off tool for evaluating the merit of introducing a new item into the naval supply system. Evaluation of impact upon life cycle costs is an important part of the standardization puzzle. Many organizations, both in government and industry in many fields, have wrestled with the question of evaluating logistics and life cycle costs. The Naval Sea Logistics Center model, along with others, is reviewed in detail in Chapter 4.

## Data Ownership Analysis Model[16]

The Data Ownership Analysis model attempts to quantify how much the government should be willing to pay for manufacturing data rights and Level III drawings for reprocurement action. Data rights and Level III drawings are the detailed information required in order to allow any manufacturer to build an equipment to specification for the Navy. This information would need to be bought or developed any time the Navy wanted to settle on a fleet-wide standard equipment which it did not want to sole source to a vendor. Since the beginning of the "Breakout" and the "Buy Our Spares Smart" (BOSS) programs in 1983, the

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16 The reader is referred to:

Johnson, CDR. M.S., Klingel, LCDR, M.J.; Management Consulting Report for Commanding Officer NAVSEALOGCEN, October 1989

and

Marcus, H.S., Zografakis, N., Tedesco, M.P.; Building on The Successes of Standardization in The Navy; NSRP Ship Production Symposium, 1992

Navy has steadily concerned itself with getting the data rights from the original equipment manufacturer (OEM). However, securing data rights may not always be worthwhile. Vendors justifiably view data rights as "proprietary". Accordingly, vendors require reimbursement or financial incentive to relinquish this information. This NAVSEALOGCEN model attempts to quantify how much the government should be willing to spend. NAVSEALOGCEN freely admits that the model is in need of considerable work and could never replace a decision maker's sound judgment. The model tries to develop an analytical approach for the economic analysis necessary to objectively evaluate the cost/value to the Navy for the procurement of manufacturing data and rights in data for parts, components and equipment. The model is constructed such that it evaluates the trade-off between the value of Data (DV) and the Potential Savings (PS) associated with acquiring data rights for parts. When evaluating equipment, the model is repeated for each part making up the equipment . The workings of the model will not be discussed in detail here. The reader is referred to one of the referenced documents from footnote 17 for a detailed explanation of this model.

The Data Ownership Analysis Model has not been used extensively. It should be stressed that the decision of whether or not to purchase data rights need not be coupled with the decision of whether or not to standardize. Data rights are not a necessity for efforts to minimize the introduction of new items of supply, or for class standardization efforts which seek to set up purchase options and quality partnerships with vendors.

## Standardization Candidate Selection Criteria Model[17]

The objective of the Standardization Candidate Selection Criteria Model (SCSC) is to enable NAVSEALOGCEN to more effectively perform an economic analysis on a group of equipment (identified by APL numbers) to determine whether or not it would be worthwhile to standardize that equipment. The model is intended to provide a framework for prioritizing functionally similar equipment types that show the greatest potential for standardization savings. The model is divided into three principal phases.

PHASE I : EQUIPMENT NOMINATION

In Phase I, a list of APL's is created which corresponds to a nominated equipment or equipment type. Application and equipment data which is necessary to perform the analysis is collected during this phase. During this phase the base of manufacturers for the equipment is studied. This is important to the Navy because it is an important factor in maintainability and reliability. The population of the equipment is studied to determine if it is a frequently utilized equipment type and if there are many APL's satisfying similar performance requirements with few applications per APL. These concepts are discussed in more detail later in this thesis along with a discussion of other criteria identified in the course of this study which are not utilized in the SCSC model. Phase I is principally concerned with population data. In Phase II, costs will be considered. Figure 3.1 illustrates the steps in Phase I.

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17 For a detailed description of the NAVSEALOGCEN model:

NAVSEALOGCEN; Standardization Candidate Criteria Users Guide

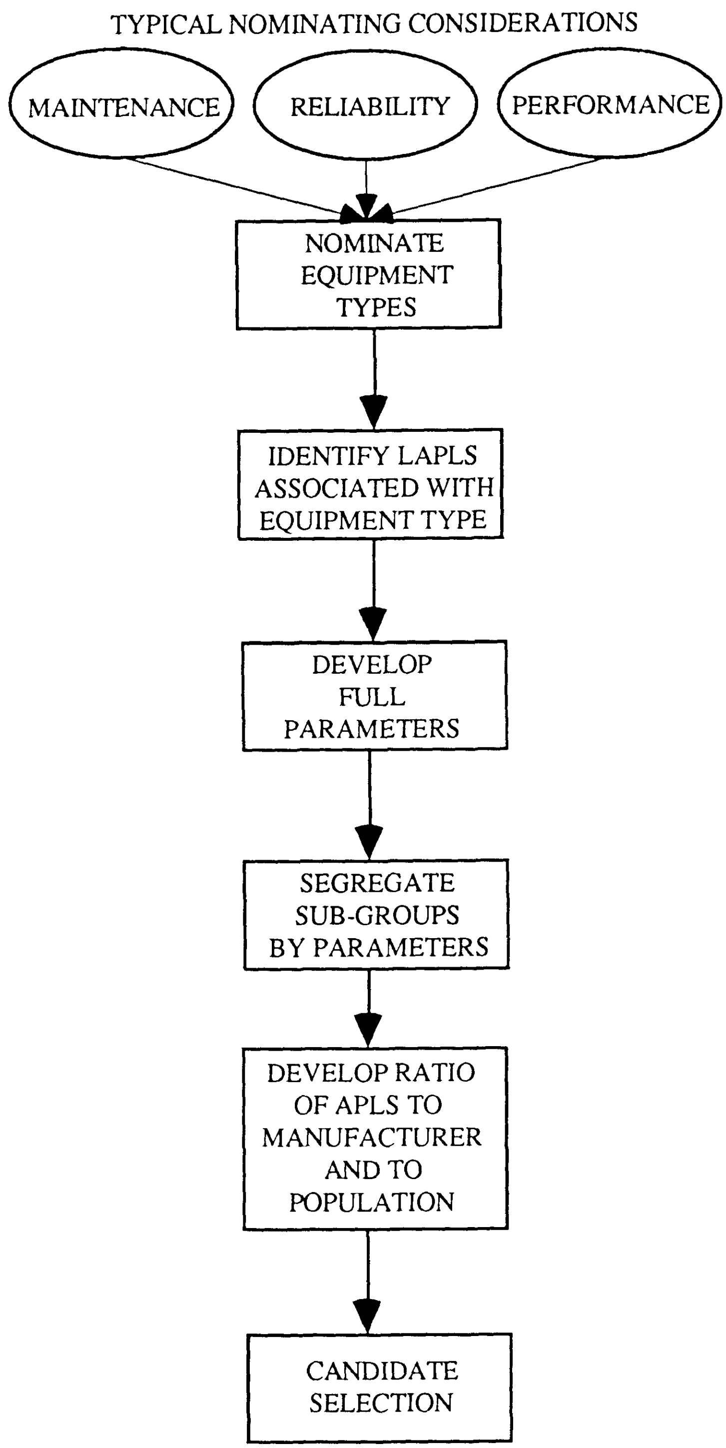


Figure 3.1 - SCSC PHASE 1[18]

18 Adapted from: NAVSEALOGCEN; Standardization Candidate Criteria Users Guide

PHASE II: ECONOMIC ANALYSIS PREPARATION

In Phase II, data regarding Integrated Logistics Costs and maintenance costs are collected. In this phase, an average annual repair cost is determined. An economic analysis is performed to determine the economic potential for standardization. Figure 3.2 illustrates the notional process flow for phase II.

PHASE III: DESIGN SELECTION

In phase III, the availability of engineering data rights is explored for equipment which has been identified as being economically feasible for standardization. Figure 3.3 illustrates this process.

The SCSC model serves as an excellent starting point and as a framework. Before standardization can be successful and fulfill its potential as a means to help bring rising acquisition costs into check, a system such as SCSC must incorporate more considerations than logistics costs and reliability concerns. This thesis explores other considerations which should be incorporated into systems like NAVSEA's SCSC.

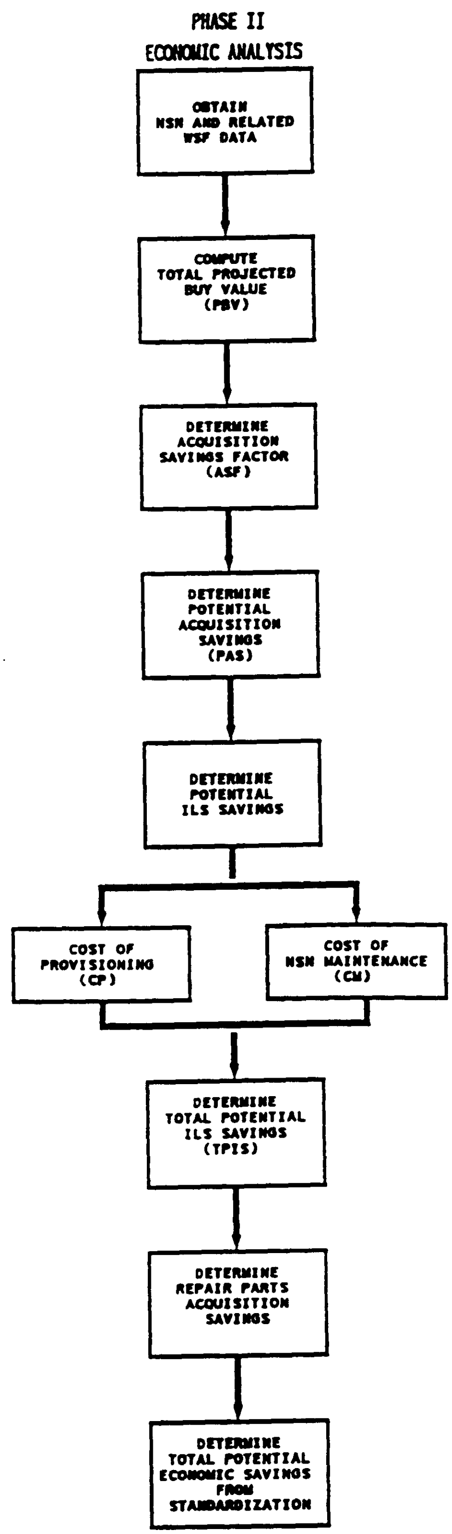


Figure 3.2 - SCSC Phase II[19]

19 Adapted from: NAVSEALOGCEN; Standardization Candidate Criteria Users Guide

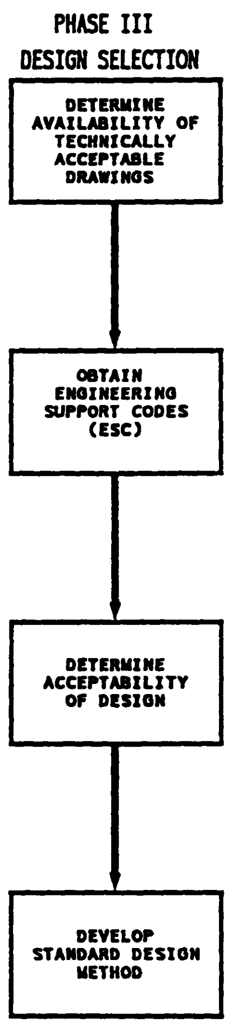


Figure 3.3 - SCSC PHASE III[20]

20 Adapted from: NAVSEALOGCEN; Standardization Candidate Criteria Users Guide

## Quantifying the Navy's Progress

In order to improve any process, it is first necessary to measure the current level of performance. In the case of naval equipment standardization, one quantifiable measure of the Navy's success in controlling the proliferation of new equipment into the supply system is the number of new APL's introduced each year. The Naval Sea Logistics Center tracks APL proliferation each year as a means of measuring the impact of its programs. A reduction in the number of APL's introduced each year for a particular equipment category would have an associated reduction in integrated logistics support costs. Each year NAVSEALOGCEN produces Standard Profiles Reports which provide these statistics.

A review of the statistics indicates that many of the same equipment categories which were the largest contributors to the proliferation problem in 1979 were still contributors in 1989. Table 3.1 illustrates this for seven equipment categories.

| | | APL PROLIFERATION | |
|---|---|---|---|
| CATEGORY | DESCRIPTION | FY79 | FY89 |
| 01 | PUMPS | 211 | 214 |
| 15 | CONTROLLERS | 225 | 260 |
| 17 | MOTORS | 331 | 351 |
| 21 | SWITCHES | 181 | 100 |
| 32 | REFRIGERATION | 176 | 134 |
| 61 | CONTROL EQUIP. | 328 | 293 |
| 88 | VALVES | 1991 | 821 |

Table 3.1 - Proliferation Contributors

In 1979 these seven equipment categories were responsible for 47% of total new APL introductions, while in 1989 they were responsible for 53%. Although total proliferation fell from 7370 new APL's in 1979 to 4114 in 1989, this drop must be taken in the context of the reduced level of ship construction and overhaul. It is this factor, the actual number of equipment installations each year, which must be taken into account to truly represent successful progress towards inhibiting APL proliferation. Furthermore, it makes little sense to concentrate effort on those equipment categories which proliferate due to rapid technological turnover (obsolescence) rather than through mismanagement of the acquisition function.

A review of all of the statistics for 1992 reveals the top twenty proliferation "offenders". These twenty equipment categories have historically been more significant than the others. Table 3.2 lists these twenty categories.

| | | | |
|---|---|---|---|
| 01) | 88 - Valves | 11) | 31 - Hardware and Hull Items |
| 02) | 17 - Motors | 12) | 38 - Indicators |
| 03) | 07 - Heaters | 13) | 32 - Refrigeration Equipment |
| 04) | 50 - Panels | 14) | 27 - Interior Communication Equipment |
| 05) | 61 - Control Equipment | 15) | 72 - Landing Craft/Small Boats |
| 06) | 01 - Pumps | 16) | 48 - Filters |
| 07) | 52 - Hydraulic Equipment | 17) | 64 - Fire Fighting Equipment |
| 08) | 15 - Controllers | 18) | 95 - Automotive & Construction |
| 09) | 21 - Switches | 19) | 41 - Shop Equipment |
| 10) | 43 - Galley Equipment | 20) | 75 - Strainers |

Table 3.2 - High Proliferation Equipment Categories

Figure 3.4 illustrates the total APL proliferation on a yearly basis, 1977 to 1992. The Figure shows that proliferation began to increase dramatically in the early 1980's, along with the naval construction boom. In 1986, proliferation began to decrease as naval construction waned and emphasis turned to less complicated low-mix ships.

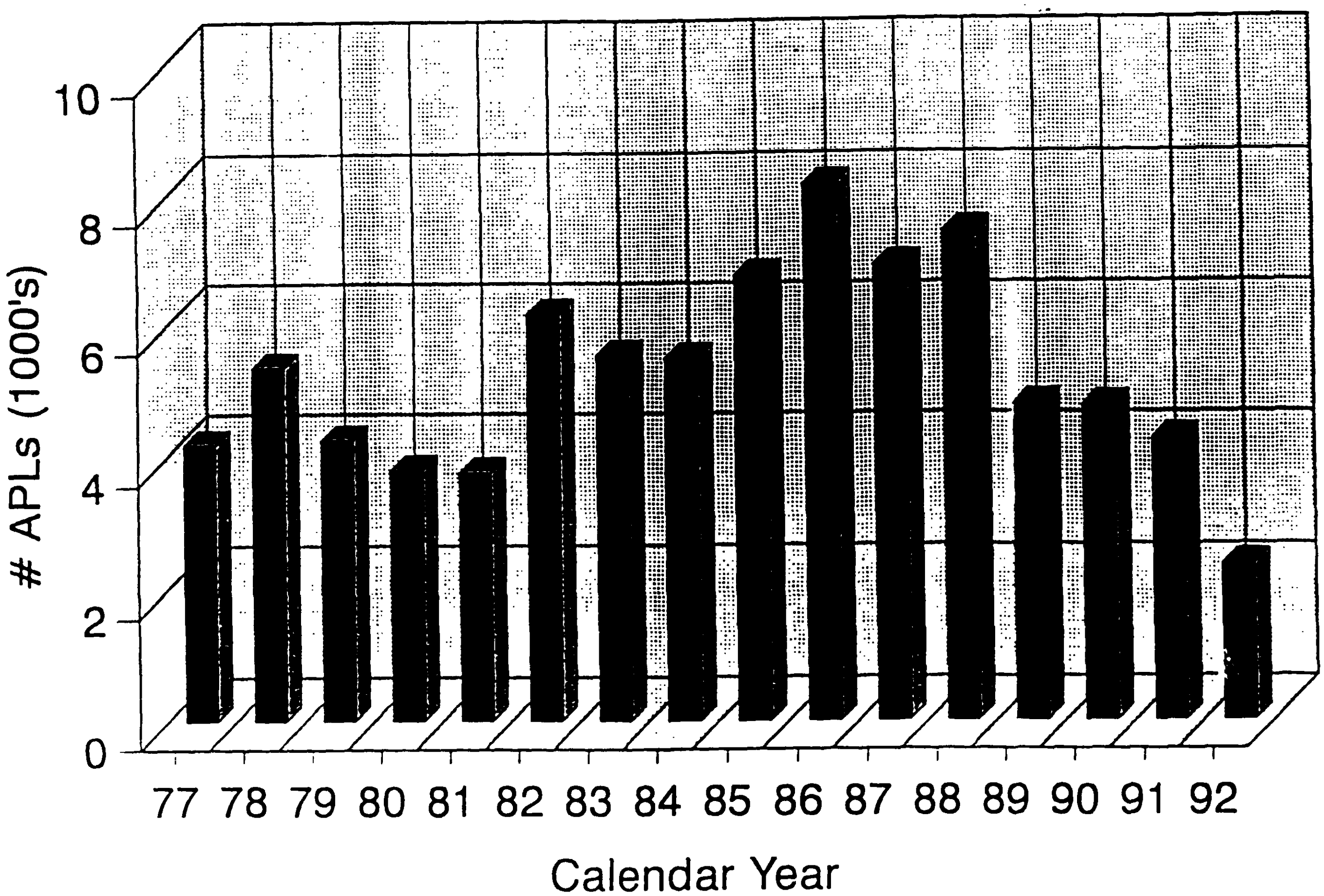


Figure 3.4 - Proliferation Trend[21]

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21 Figure supplied by NAVSEALOGCEN

Figure 3.5 illustrates the naval construction trend data which is supplied by NAVSEA. While proliferation has begun to decrease, so has the level of ship construction and the complexity of the ships being built (low mix verse advanced combatants and submarines).

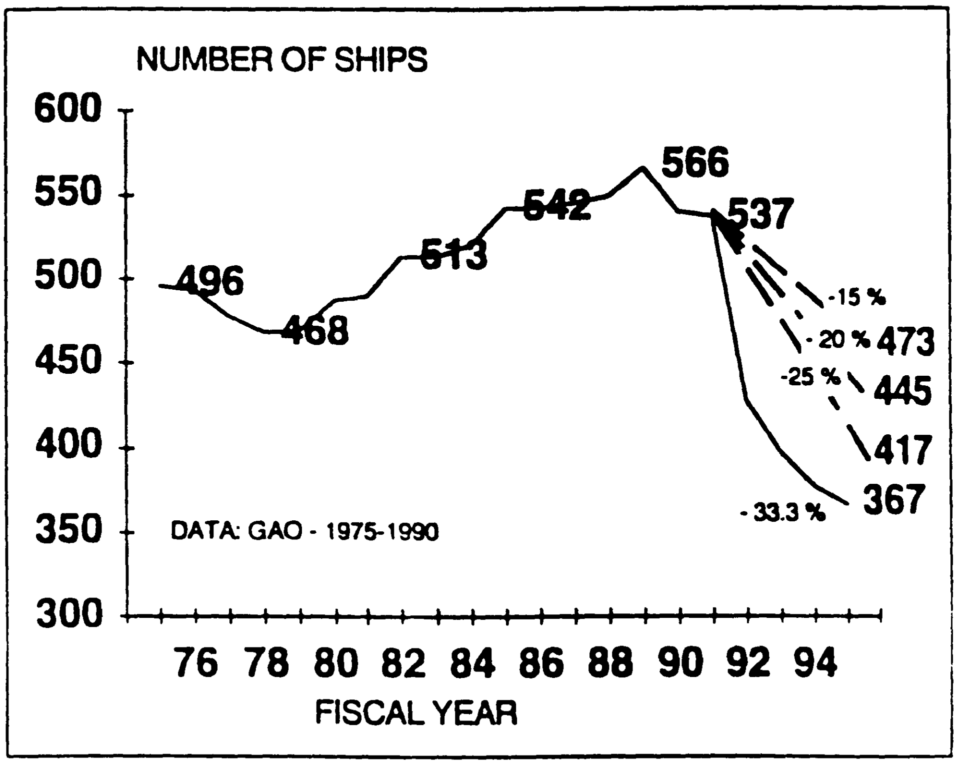


Figure 3.5 - Naval Construction[22]

22 Figure supplied by NAVSEA

The HEDRS database which was discussed earlier has potential as a design tool and a tool for standardization. It is currently intended to be provided to contractors in support of the policy of preference for equipment found to be supported in the fleet. It should be noted that other private companies offer databases which provide equipment information. One such system is the ILS electronic market offered by the Inventory Locator Service, Inc. (a division of the Ryder System Company). This system is best known for providing information regarding the availability of a particular equipment and can pin-point sellers who have the equipment to sell immediately. The system is currently set up to track national stock numbers, but can also track APL numbers. The systems capabilities complements HEDRS since HEDRS gives points of contact for manufacturers but little information regarding immediate availability of a component.

In order for the HEDRS effort to be successful, it is necessary for the information included in the database to be as complete as possible. A review of NAVSEALOGCEN statistics reveals that on average, 45% of the data is entered. Of the possible envelope dimension entries, 5.6% are complete on average. Figures 3.6 and 3.7 illustrate the current level of completeness of the database with regard to total information and envelope dimensions. As can be seen, and is already recognized by NAVSEALOGCEN, considerable work is needed to provide a more complete system. NAVSEALOGCEN is working towards this goal.

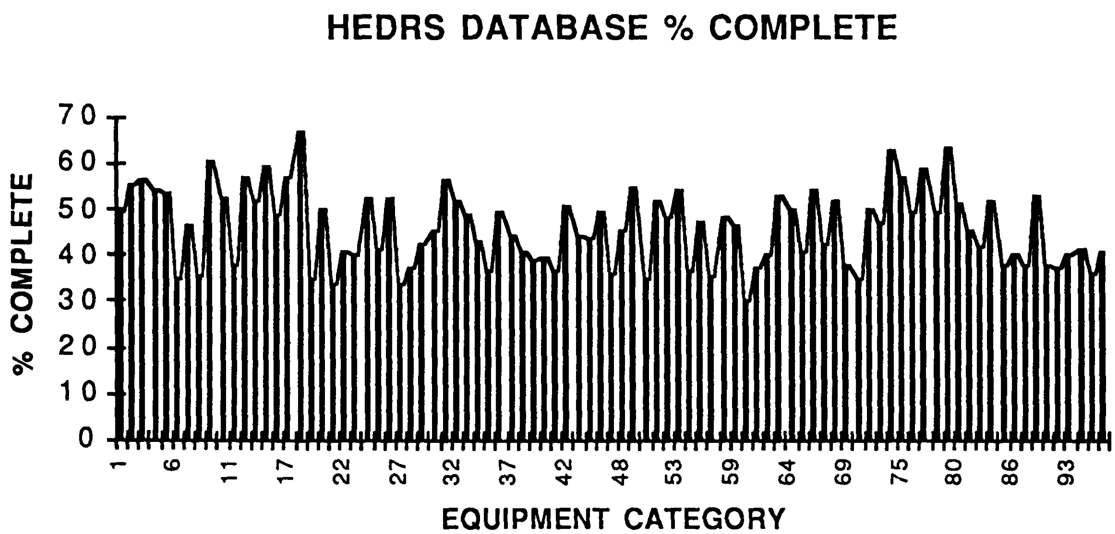


Figure 3.6 - HEDRS Completeness[23]

23 Figure created from statistics provided by NAVSEALOGCEN

HEDRS ENVELOPE DIMENSIONS % COMPLETE

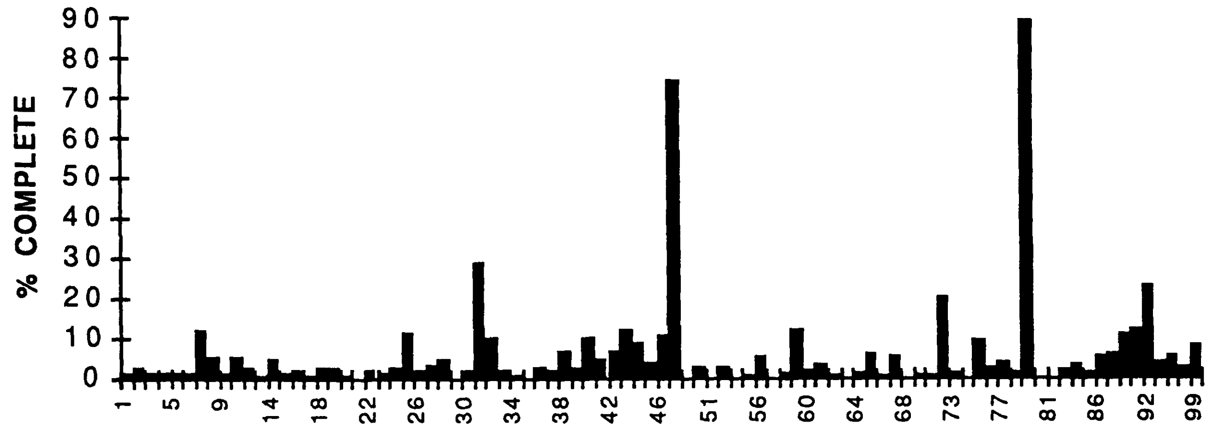


Figure 3.7 - HEDRS Envelope Dimension Completeness[24]

24 Figure created from statistics provided by NAVSEALOGCEN

# Navy Standardization Organization

The responsibility for standardization within the Navy is found in the Navy Departmental Standardization Office (DepSO). The DepSO in turn can delegate authority to Standardization Management Activities. The DepSO answers ultimately to the Under Secretary of Defense for Acquisition. Figure 3.8 illustrates the broad Department of Defense organization for standardization.

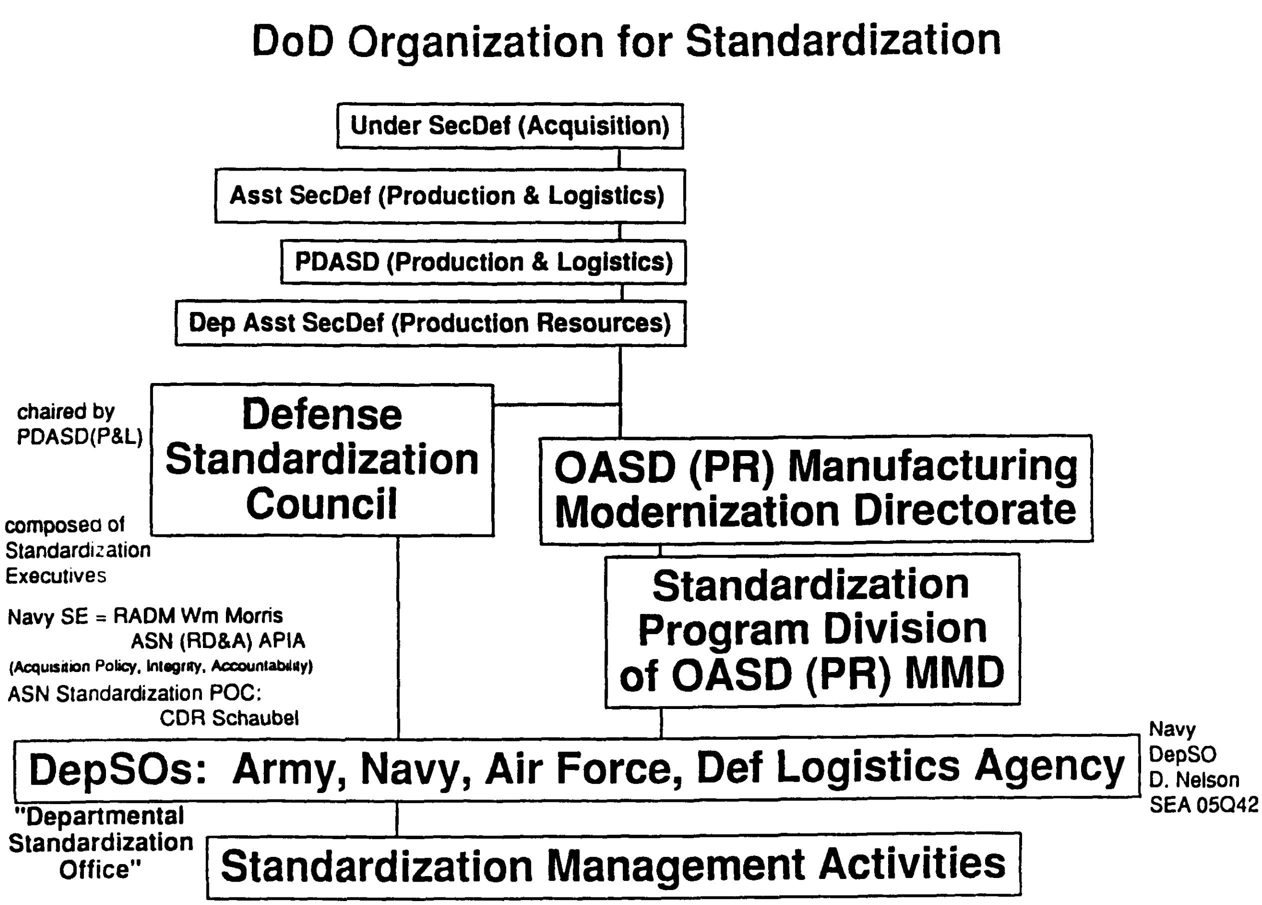


Figure 3.8 - DOD Organization for Standardization[25]

25 Bosworth, CDR M.; Navy Standardization Policy Background and Issues; presentation 11/25/92

The Navy DepSO reports to the Navy Standardization Executive. The DepSO currently assigns responsibility within NAVSEA. Figure 3.9 illustrates this organization. Although on the surface it appears that a broad organization and the mandate is in place to deal with standardization, this organization is geared towards Navy specification preparation, review and promulgation rather than equipment and component standardization. In March of 1992, the Naval Audit Service determined that there was no coordinated approach within the Navy to manage the standardization of HM&E equipment. The DepSO has broad responsibility and has indicated that the resources are not available to do the job right. Furthermore, while other services' DepSO's are at the secretariat/headquarters level, the Navy DepSO is not at such a high level. The Navy Standardization Executive also has broad responsibility and few assets. An Equipment Standardization Program steering committee and working group exists within NAVSEA, but is part time and ad-hoc.

The Affordability Through Commonality (ATC) program has seven full time participants and ten part time participants focusing on standardization and modularity for targeted case studies. Figure 3.10 illustrates the organizational matrix for standardization and commonality within the Navy. This Figure illustrates the point that the standardization organization is weak and lacks the resources to do the job. NAVSEALOGCEN develops tools for standardization because it recognizes that standardization will have a positive impact upon the supply system. Although NAVSEALOGCEN realizes that standardization could simplify its job in the future, it also suffers from a lack of resources in the current budgetary climate.

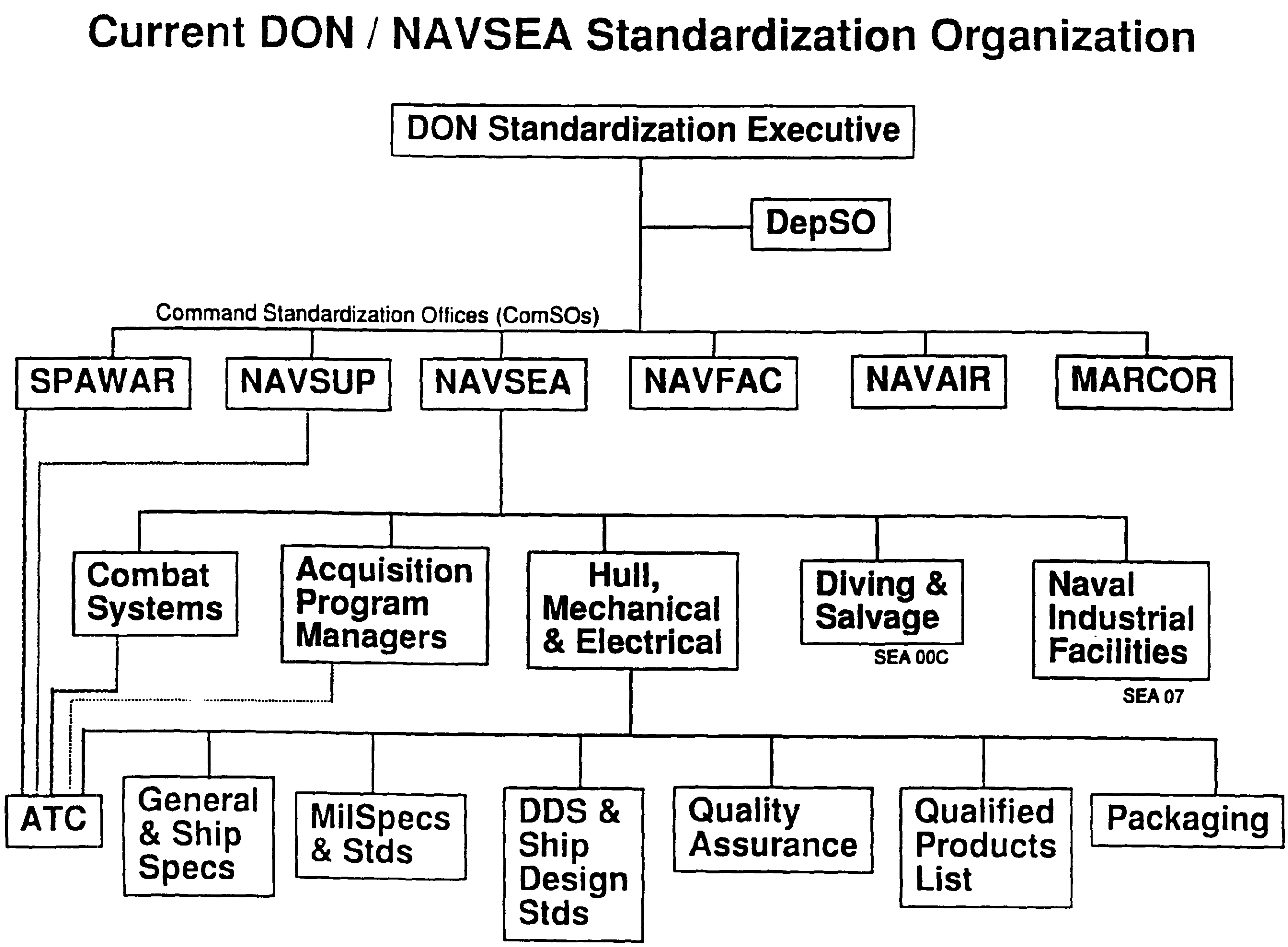


Figure 3.9 - NAVSEA Organization[26]

26 Figure supplied by NAVSEA

# Organization Matrix
## for standardization and commonality

| *level* | AUTHORITY | REQUIREMENT | CONSTRAINTS | EXECUTION |
|---|---|---|---|---|
| FLEET | 1952 Law DoD 5000.2 | **None** | lack of coordination, OPNAV & NAVSEA baronies (newly reorganized) | **None** |
| SHIP | 1952 Law DoD 5000.2 | **None** | SHAPM's single ship class/type focus | SHAPM's for single ship class/type, none across types |
| SYSTEM | 1952 Law DoD 5000.2 | **None** | very limited uncoordinated | Combat Sys = yes HM&E = limited, ad hoc |
| COMPONENT | 1952 Law DoD 5000.2 | Fed. Acq. Regs Mil Standards | weak due to lack of resources, enforcement & incentives | SEA 05Q4 SEA 04MS |
| PARTS | 1952 Law DoD 5000.2 | Fed. Acq. Regs Mil Standards | uncoordinated lack of teeth in contracts | SEA 05Q4 SEA 04MS |

Figure 3.10 - NAVSEA Organizational Matrix[27]

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27 Figure supplied by NAVSEA

Much of the responsibility for HM&E standardization has fallen into the hands of the Naval Sea Logistics Center, which has been concerned with reducing ILS costs. The Naval Surface Warfare Center in Annapolis, Md. (formerly DTRC) is responsible for studying equipment with regard to reliability and performance, and has on occasion promoted the development of standard designs to solve these problems. With standardization receiving more attention these days, NSWC finds itself in a position where it is necessary to demonstrate that a project has standardization or ILS implications in order to maintain its budget.

In his brief (11/25/92) to RADM Firebaugh, CDR M. Bosworth stated that for standardization to move forward the organization will need to change. It was suggested that the DepSO be moved to the Assistant Secretary of the Navy level (RD&A). This would put standardization at the same high level within the Navy that it has in other services (like the Air Force and Army). Such a move would improve lines of communication and give higher level attention to standardization. Unfortunately, it is not clear that the ASN would have any more resources than NAVSEA to devote to standardization, and NAVSEA has a better technical understanding of the problems. The actual work would still need to be accomplished in NAVSEA, NAVSEALOGCEN and other activities.

# CHAPTER 4: INTEGRATED LOGISTICS SUPPORT

Some mention has been made of Integrated Logistics Support and its contribution to life cycle cost. Life Cycle Cost (LCC) refers to the total cost of ownership of a system, in this case a ship. The LCC for a naval ship is typically broken down into non-recurring costs and recurring costs. Non-recurring costs are typically those costs dealing with the design and construction of the ship, as well as the initial fleet introduction package. The recurring costs typically include the operating and support costs as well as the costs of managing the system over its life.

Integrated Logistics Support, or ILS, refers to a systems management approach linking system support to system design adopted in response to the fact that the cost of supporting a system after initial acquisition is a major element of the life cycle cost of the system. ILS encompasses both non-recurring and recurring costs. Non-recurring fleet introduction costs can be considered Integrated Logistic Support, as the Fleet Introduction Plan develops the support plan for the ship. The majority of the recurring life cycle costs are planned for during ILS. Those elements of life cycle cost which are typically considered at this phase are represented by the shaded portions of Figure 4.0.

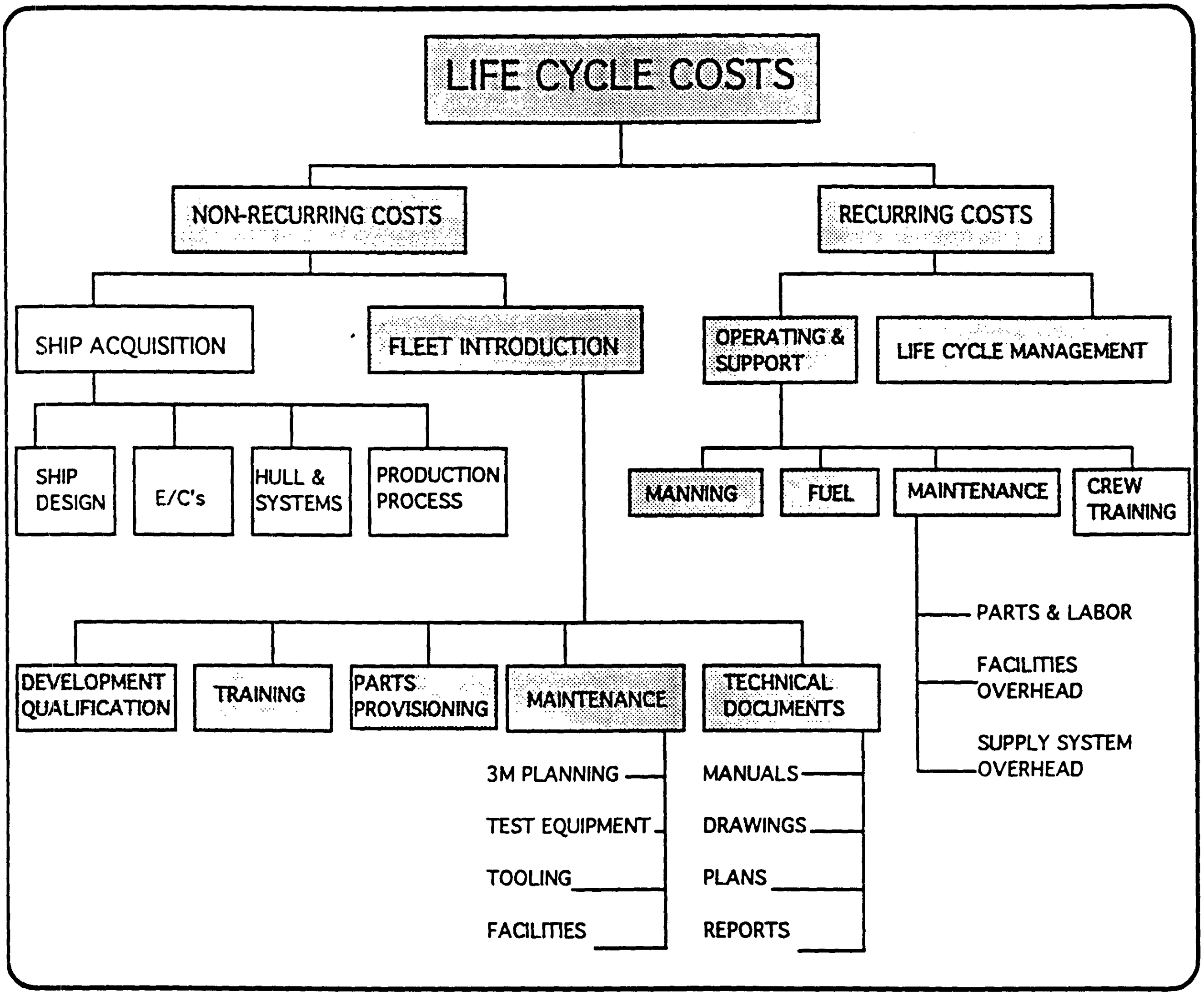


Figure 4.0- Broad Life Cycle Cost Breakdown

The operating and support costs are well over 50% of the life-cycle costs on some systems and equipment.[28] Figure 4.1 illustrates this point for a typical small amphibious ship. The Figure points out major elements responsible for the weight, construction cost and life cycle cost of the ship.

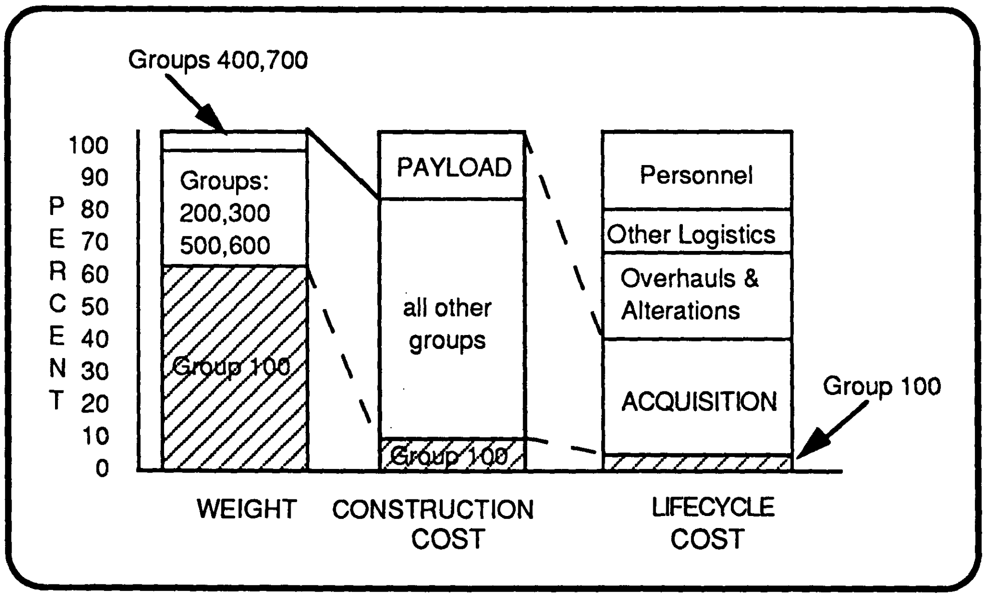


Figure 4.1 - Weight and Cost as a Percentage of light ship weight and total cost[29]

Integrated Logistics Support strives to be "integrated" because many aspects of support are interrelated both before and after a project comes into being. The decisions that will largely determine ILS expenditures are made considerably earlier than the actual expenditure of the funds. Figure 4.2 illustrates this point.

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28 Biedenbender, Dick; Eisaman, John; Vryn, Florence; The ILS Manager's LSA Toolkit: Availability Engineering; p. 326; McGraw-Hill; 1993, New York

29 adapted from a presentation by Tom Rivers of NAVSEA 05D51/05R33 for the Affordability Through Commonality Project, October 1992

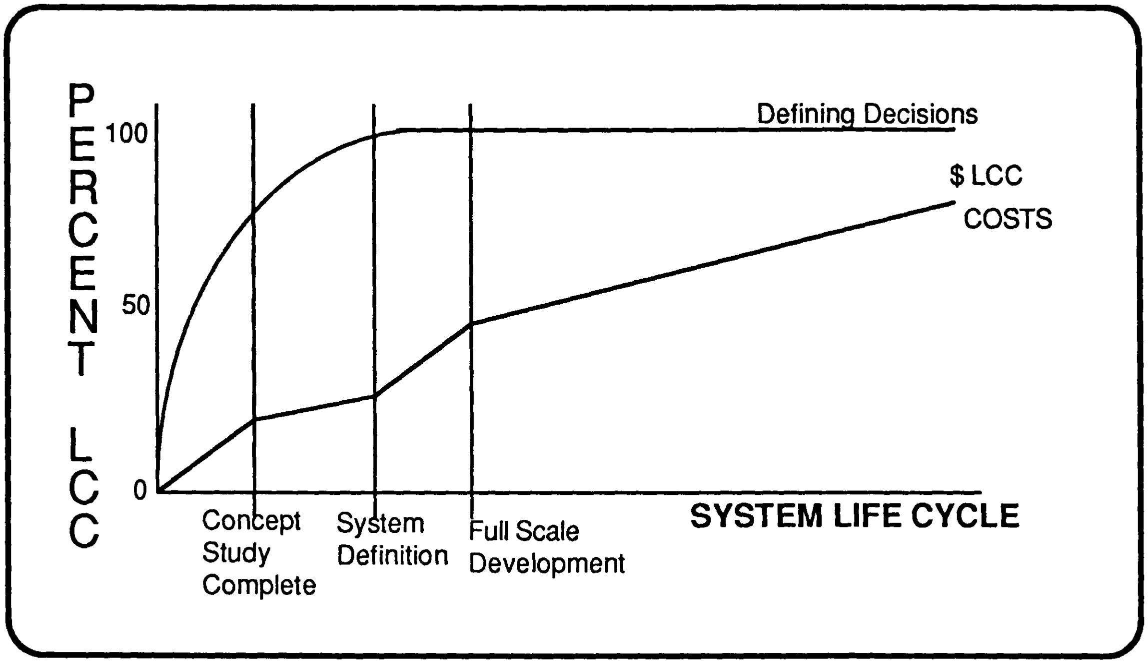


Figure 4.2 - Commitment vs. Expenditure[30]

The Department of Defense defines Integrated Logistics Support as:

*"A disciplined, unified and iterative approach to the management and technical activities necessary to:*

- *Integrate support considerations into system and equipment design*
- *Develop support requirements that are related consistently to readiness objectives, to design and to each other;*

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30 Figure adapted from:
Biedenbender, Dick; Eisaman, John; Vryn, Florence; The ILS Manager's LSA Toolkit: Availability Engineering; p. 326; McGraw-Hill; 1993, New York

- *Acquire the required support, and*
- *Provide the required support during the operational phase at minimum cost."*

There are essentially two ways to reduce ILS costs. One can streamline the ILS process such that the cost per item requiring ILS is reduced. One can also strive to reduce the number of items, or types of items that require ILS. Standardization provides benefits in both these areas. Standardization strives to reduce the number and variety of equipment/components in the supply system. Standardization also provides an opportunity to insure that only reliable and maintainable equipment finds its way onto Navy ships, thereby reducing the ILS cost per item. By standardizing, conceivably more of the same items require the same spares, improving availability. In conjunction with efforts to minimize the introduction of new items of supply, the ILS process must be studied, benchmarked against more efficient operations in other industries, and streamlined to reduce the cost of ILS per item remaining in the supply system.

It has been mentioned that ideally one would be able to quantifiably evaluate all the merits of a particular standardization proposal in monetary terms. An evaluation of all standardization benefits cannot be made in terms of dollars since many of the benefits are intangibles. It can also be very difficult to obtain the data required to evaluate standardization in these terms. The impact upon ILS can be estimated in terms of dollars and cents, and is an important element of the total life cycle cost impact of standardization. A broad defense and industrial study conducted in the 1960's concluded that 40% of the benefits accrued from standardization were in the area of logistics.[31] Interviews with both Navy and Industry personnel indicate logistics is no less important today. The evaluation of these costs is important at several phases of project development and to both the Navy and a contractor.

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31 Biedenbender, Dick; Eisaman, John; Vryn, Florence; The ILS Manager's LSA Toolkit: Availability Engineering; p. 91; McGraw-Hill; 1993, New York

Once a standard component exists, it is important to be able to evaluate when savings in another area, such as reduced acquisition cost or improved performance, makes introducing an equipment other than the standard worthwhile. The same considerations can also be made for "supportable" rather than strictly "standard" equipment. In these cases, the majority of the ILS costs are already being incurred for that piece of equipment and the installation of the same equipment will not increase the total ILS cost to the Navy.

The vast majority of equipment used by the Navy is procured through performance specifications. This procurement philosophy is intended to provide greater flexibility with respect to equipment design and competition, which is intended to produce better quality at the lowest possible price. The traditional method for measuring the economic advantage of competition is to compare the difference in procurement prices. This practice only makes sense for those situations where no follow on logistical support and life cycle costs are anticipated, which is very rare. The practice also does not consider the differing impact two pieces of equipment may have upon the construction cycle. When follow on logistics support is required, which is the case for almost all Navy equipment, additional economic considerations must be evaluated to realistically measure the net savings resulting from competition. These considerations typically were not considered in the past, since the bill of the life cycle cost would be passed on in the next fiscal years.

In accordance with the Federal Acquisition Regulations (part 14), the Government is authorized to incorporate economic evaluation criteria in procurement contracts. Savings resulting from competitive procurement of functionally interchangeable equipment is equal to the actual savings resulting from the least cost equipment procurement minus the costs associated with the increased needs for logistics and infrastructure support of more items.

It has become more common for an ILS life cycle cost evaluation requirement to be part of a contract. The intent is to require the contractor to evaluate the ILS costs associated with the use of a non-standard item in lieu of an item on the standard parts list. This has caused some confusion for shipbuilders whose job is to perform the evaluation when they would prefer to use another item. For example, as part of the requirements for the Sealift Conversion and New Construction Contracts (October 2, 1992), CDRL B084 is invoked. Block 16 of that CDRL requires ILS Life Cycle Costs to be determined:

> *"The contractor shall prepare a request for standardization exception where there is no standard item that meets the specification requirements or no standard item that can be purchased in time to meet schedules or if the available standard is not the best or most effective design choice. Include in the request a tabulation of ILS Life Cycle costs associated with introduction of the non-standard equipment."*

Additionally, the revised General Specifications for Ships of the United States Navy includes standardization requirements in Section 070, design and construction.

A variety of ILS and Life Cycle Cost models have been developed within DOD, the Navy specifically, and industry. There is considerable confusion on the part of both the Navy and contractors as to what is an appropriate solution. A number of models were evaluated as part of this research.

Such a model must look at the incremental additional ILS cost or savings of utilizing or not utilizing a standard equipment or component. A tradeoff exists between the accuracy of a model and the ease with which it can be used. The model should be simple enough to be easily understood and adapted to a need which may be outside the parameters initially considered in the model's development. If the model is complicated enough to require the aid of a computer, the model should be easily transportable from one organization to another, regardless of the type of computers the organization is using.

A total model to evaluate the value of standardizing must also include the incremental costs of standardization projects. These costs of standardization include the fixed costs of a standards development group, investment in R&D or adaptation costs from subsequent use of overrated equipment. Savings attributable to standardization in areas other than logistics must also be considered in an evaluation of the standardization function, but are not critical for the type of evaluation required of contractors.

## Naval Sea Logistics Center ILS Cost Algorithm[32]

The ILS Cost Analysis Model, associated with introduction of new equipment to the Navy, has as an objective the development of a logical, rational methodology to accurately evaluate the Integrated Logistics Support Costs associated with the introduction of a new item to the supply system. The increased pressure to minimize cost has forced the Navy to focus considerable attention on improved efficiency and economics. The analysis is intended to:

- Provide a reproducible, logical, and conservative mathematical model for the assessment of costs associated with objective ILS variables,

- Provide a consistent criteria to objectively evaluate the cost proposals submitted in competitive procurements where the basis for competition is a performance specification, and

- Provide a rational basis to develop budget and fiscal requirements associated with ILS.

The model identifies a number of cost drivers and attempts to estimate the incremental costs associated with the introduction of a currently unsupported equipment or component to the supply system. The model was first introduced in 1986, and many of these cost drivers are currently out of date. For this reason, current cost data was sought for this study. Unfortunately, efforts to update the cost coefficients used in the model were not successful. This was largely due to the fact that many of the costs were not accounted for in

32 The NAVSEALOGCEN model was developed by Richard Jones, Director of the Hull, Electrical and Auxiliary division of the Naval Sea Logistics Center. The model algorithm description and original cost factors are attributable to him.

typical transactions. It may be possible to update the cost coefficients through the application of an extensive interview process. Discussions with key players which should have access to this information indicated that it would take quite some time to update the Figures. Time constraints did not permit this. The model in its original form has been successfully used by contractors in their ILS cost evaluation of non-standard equipment. The model has been generalized to allow for introduction of up to date cost data at any time. The following description presents the model, along with the original cost drivers and the updated cost drivers.

Cost of Provisional Technical Documentation (PTD)

PTD is necessary to develop adequate support. Normally this cost is buried in the initial contract price for HM&E equipment. Accordingly, very little data is available on which to base an objective estimate of the value of PTD. This variable, however, is considered virtually meaningless in the context of this analysis, if during the competitive procurement the requirement for PTD is exercised and included as part of the contract price. In this situation, all competitive quotes must include the cost of PTD. Therefore:

$$C_{PTD}=0$$

in this analysis in order to avoid double-counting of this cost.

Cost of Provisioning (Cp)

Support must be developed for each new piece of equipment introduced to the Navy. The process which accomplishes the development of support is known as provisioning. In this process PTD is analyzed, maintenance philosophies are developed, management data is developed, parts are cataloged, initial supply support quantities are projected and procured, and all relevant support data are loaded to data files. The result of the data files loading is an Allowance Parts List (APL) which fully describes intended maintenance philosophies and requisite parts support. This cost is based upon the number of parts making up the equipment or component which are new items of supply versus current items of supply. This evolution requires substantial resources which can be estimated by the following equation:

$$Cp = Cp1 + Cp2\,(NPN) + Cp3\,(PN)$$

where:

NPN = Number of Parts Representing New Items of Supply

PN = Number of Parts Currently in the Supply System

Cp1 = fixed provisioning cost

Cp2 = cost per new item of supply

Cp3 = cost per part currently in supply system

| FACTOR | $ 1986 |
| --- | --- |
| Cp1 | 450 |
| Cp2 | 300 |
| Cp3 | 75 |

Initially, a practical means for estimating the value of this variable, as well as all others, is to assume that the number of parts contained in the piece of equipment will be the same as that in the competed alternative. A further credible assumption is that 25% of the parts identified in any HM&E equipment PTD will represent new items of supply and that 75% will represent current items of supply. For Electronics, only 15% represent new items of supply and 85% represent current items of supply so:

$$Cp = Cp1 + 0.25\ Cp2\ (P) + 0.75\ Cp3\ (P) \text{ for HM\&E}$$

$$Cp = Cp1 + 0.15\ Cp2\ (P) + 0.85\ Cp3\ (P) \text{ for Electronics}$$

where:

P = Number of different Parts in the equipment to be competed

Cost of NSN/APL Maintenance (CM)

Part of the cost of new equipment to the Navy resulting from competition is an increase in the universe of parts which must be supported by the Supply System. Costs associated with the management of these additional (new) parts can be quantified and, in fact, represent a negative benefit to the desirability of competition. The initial costs associated with NSN maintenance are those related to the provisioning evolution which is covered by the section on Cost of Provisioning. This section deals exclusively with costs associated with the annual maintenance of new items of supply. Two variables must be considered to effectively estimate the costs associated with the maintenance of new items of supply resulting from competition. These variables are:

1. the number of new items of supply to be managed, and
2. the projected life cycle for the new items.

$$C_M = Cm1\ (NP)\ (L)$$

where:

| | | |
|---|---|---|
| NP | = | Number of New Items of Supply |
| L | = | Projected Life Cycle of Equipment |
| Cm1 | = | Annual cost to maintain an item of supply |

Based on a 1981 Department of the Army report, the annual cost to maintain an item in the supply system is $ 448.

Taking into account estimates for the percentages of new items of supply...

$C_M$ = Cm1 (0.25) (P) (L) for HM&E

$C_M$ = Cm1 (0.15) (P) (L) for Electronic

Cost of Training ($C_T$)

Increased training costs resulting from the introduction of new equipment is a function of numerous variables. Depending on the complexity of the equipment, these costs are a function of:

a. length of training required,

b. training aids, tools and support equipment,

c. development of course material and text books,

d. maintenance parts support,

e. training site costs, and

f. travel and labor costs for both students and instructors.

For this model a more conservative and considerably simplified estimate is used based on the following assumptions:

1. The new equipment is being introduced as a competitive alternative, rather than as a new application. All training requirements for the original equipment have been established. Therefore, there is no cost impact related to items a, c, e, and f above. In other words, it is being assumed that training programs exist for the standard item and the incremental additional cost of utilizing a non-standard item involves an extension or equipment modification of current training courses and equipment.

2. With respect to item b, it is assumed that two pieces of equipment will be required to augment current training facilities.

3. With respect to item d, maintenance, repair and occasional replacements will cost an average of 50% of training hardware capital costs per year for the expected life cycle training requirements.

4. Need for training will be eliminated 4 years prior to the projected life of the equipment application.

Based on the above assumptions:

$$C_T = 2\ (PR) + 0.5\ (2)\ (PR)\ (L-4)$$

where:

PR = Unit Price of the Equipment

L = Life of the Equipment Application

so...

$$C_T = PR\ (L-2)$$

The Management Consulting Directorate of the Office of the Auditor General of the Navy has made several recommendations regarding the ILS cost algorithm. One of these recommendations was a change to the cost of training. The cost of training associated with the introduction of any new piece of equipment will automatically require a minimum of one senior technician to review course material, to liaison with manufacturing representatives, to ensure training is pertinent, and to visit manufacturer's plants.

Therefore:

$$CT = Ct1 + 2(PR) + .5(2)(PR)(L-4).$$

Where:

Ct1 = Fixed cost training

This cost was assessed as at least $2000 in 1989. It should be noted that shipyard ILS managers believe that the cost of training as defined by this model is exaggerated. They believe that the model assumes the equipment in question requires lengthy training, which may not always be the case.

Cost of Technical Manuals($C_{TM}$)

The estimate of the cost to develop and print technical manuals for HM&E equipment covers a wide range of values. The cost is approximated by the following equation:

$$C_{TM} = Ctm1\ (P) + Ctm2\ (POP)$$

Where:

| | | |
|---|---|---|
| P | = | number of parts |
| POP | = | number of equipment procured |
| Ctm1 | = | cost per Part Number |
| Ctm2 | = | cost per copy of the technical manual |

However, since our interest is in the incremental additional cost of using a new item of supply, the cost per copy of the manual is effectively zero since we can assume the same number of manuals are required regardless of which equipment is procured.

$$C_{TM} = Ctm1\ (P)$$

The Management Consulting Report recommended a change to the cost of technical manuals. The cost of technical manuals for standard hull and mechanical systems which are basically commercial items and have commercial technical manuals may be zero. However, the ordinance and electronic systems are generally government specific and their manuals must conform closely to specifications. In such cases, reproduction and changes cost $200-$300 per page, with 20-30 pages average. A one time added cost is recommended for electronic systems.

$$CTM = Ctm3 + Ctm1 (P).$$

| Factor | 1986 |
| --- | --- |
| Ctm1 | $62.50 |
| Ctm2 | $20.00 |

Ctm3 was evaluated to be $5000 by the Management Consulting Directorate in 1989.

Cost of Installation Drawing Changes ($C_D$)

Assuming that equipment introduced as a result of performance specification competitive procurements meet only those functional requirements of the application, it is reasonable to assume variations in form and fit will exist between the original equipment and the competed equipment. Differences in these variables will result in the need for installation drawings revisions. There is a cost associated with these changes:

$$C_D = Cd1(CL)$$

where:

CL = Number of Classes of Ships Receiving Equipment

Cd1 = Cost per ship class affected

In 1986 Cd1 was estimated to be $1000.

Cost of Configuration Control ($C_{CC}$)

Identification of equipment is the single most important factor in the development of consolidated shipboard allowance lists (COSAL's). The principal mechanism for reporting configuration changes is the OPNAV 4790/CK form which is necessary to adjust the WSF configuration records. Assuming that the introduction of competitively procured equipment will result in the need for OPNAV 4790/CK forms for all applications, this cost can be Figured as follows:

$$C_{CC} = CCC1(POP)$$

where:

| | | |
|---|---|---|
| POP | = | Number of Pieces of Equipment Competitively Procured |
| CCC1 | = | Cost to process an OPNAV 4790/CK |

SECAS representatives indicated that processing cost $20 in 1986.

Cost of Testing ($C_{OT}$) (in dollars)

One of the basic premises of this model is that procurement specification is a performance specification. The implication is that performance testing is necessary to assure product conformance. Costs associated with testing are integrated into the competition quotations. The option to waive testing requirements can be made by the Government. In view of the above, no performance testing costs need to be developed in the cost competition analysis, since these costs are included as part of the bid and the purpose of this ILS model is to provide a trade-off analysis. Therefore:

$$C_{OT}=0$$

Cost of Planned Maintenance ($C_{PM}$) (in dollars)

Although Planned Maintenance (PMS) is an integral part of ILS, consideration in the economic analysis related to competitive procurement is negligible. If PMS is required to support the original equipment, the assumption is made that similar maintenance will be required by the competed equipment. There is a cost to identify repair parts on the individual maintenance requirement cards (MRC's), a review of the original MRC's to assure compatibility with the competed equipment and promulgation of new MRC's. Therefore:

$$C_{PM}= CPM1$$

When the model was initially developed, this value was estimated at $500.

Summing all the elements, the ILS cost is as follows:

$$C = Cptd + Cp + Cm + Ct + Ctm + Cd + Ccc + Cot + Cpm$$

Where:

C = ILS Costs

Cptd = Cost of Provisioning Technical Documentation

| | | |
|---|---|---|
| Cp | = | Cost of Provisioning |
| Cm | = | Cost of Maintenance |
| Ct | = | Cost of Training |
| Ctm | = | Cost of Technical Manuals |
| Cd | = | Cost of Installation Drawing Changes |
| Ccc | = | Cost of Configuration Control |
| Cot | = | Cost of Testing |
| Cpm | = | Cost of Planned Maintenance |

Substituting the original cost data, the model for mechanical components is summarized below:

$$C=950+ 193.75(P) + 112(P)(L) + (PR)(L) + 1000(CL) + 20(POP) - 2(PR)$$

and for electronic equipment:

$$C=950+ 171.25(P) + 67.2(P)(L) + (PR)(L) + 1000(CL) + 20(POP) - 2(PR)$$

where:

| | | |
|---|---|---|
| C | = | ILS Costs |
| P | = | Number of parts in the original equipment |
| L | = | Life cycle of the equipment in years |
| PR | = | Price of the original material (in dollars) |
| CL | = | Number of classes of ships receiving the equipment |
| POP | = | Number of equipment competitive procured |

## Defense Electronic Supply Center (DESC) Model[33]

Mr. Charles E. Gastineau of the Defense Electronics Supply Center found that four factors account for 80% of the total life cycle costs of a part with regard to standardization efforts:

- The cost of preparing a document that describes the nonstandard part, taking into account the labor charges, overhead, burden, and other charges related to document preparation.

- The cost to test nonstandard parts

- The cost of managing a part in the inventory

- The cost incurred in maintenance owing to the reliability or unreliability of a nonstandard part.

A simple algorithm for determining these four costs was developed based in part upon the National Aerospace Standard 1524 and another model developed by the Air Force Institute of Technology. The intent of the model was to serve as a tool to measure the cost difference between using a standard part or not using a standard part in conjunction with the Military

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33 Gastineau, Charles; Kerr, Donald; "Don't Cry: Justify"; The Economics of Standardization; Toth, Robert ed.

a secondary source of a description of the model was

Corbett, John; Standardization of Hull, Mecahnical and Electrical Equipment Inventory; MS thesis; Naval Postgraduate School 1987

Parts Control Program. The NAVSEALOGCEN model is based, in part, upon the DESC model. The basic philosophy chosen was:

$$Vso = Lcc - Is$$

Where:

| | | |
|---|---|---|
| Vso | = | the value of the standard |
| Lcc | = | the life cycle cost avoidance from using the standard part(s) which is the sum of the four costs avoided as above |
| Is | = | Investment in the standard |

Although this model was developed in the early 1970's, the philosophy is still sound. As with the NAVSEALOGCEN model, a generalized presentation is given, with comments on the cost data.

Non-Standard Part Documentation

This cost represents the additional costs incurred to prepare documentation to assure that a manufacturer has complete definition of the requirements, and that the activity can purchase the same part in later logistic support and production. Detailed drawings will be required for configuration control. The National Aerospace Standards Committee studied the effort required to prepare such drawings in 1973. They found that these statistics varied considerably. It took an engineer between two and 145 hours to develop a drawing for a new part and 67% of the necessary drawings were for new parts.

$$DOC = (MH)(\$/MH)(\%ND)$$

Where:

| | | |
|---|---|---|
| DOC | = | Documentation Cost Avoidance |
| $/MH | = | Cost per Man-hour |
| MH | = | Number of man-hours required |
| %ND | = | % New drawings |

In 1973 the industry average was $25 per man-hour. The % new drawings has generally been taken as 50%.

<u>Non-Standard Part Testing</u>

A requirement to test and evaluate a non-standard part can represent a very significant cost as compared to a standard part which requires no such testing and evaluation.

$$TEST = (\%PT)(\$/T)$$

Where:

| | | |
|---|---|---|
| TEST | = | Testing costs avoided |
| %PT | = | Percentage of parts tested |
| $/T | = | Average cost per test |

Surveys made by DOD Military Parts Control Advisory Groups (MPCAGS) in the 70's established the average costs for testing to range from $5000 to $75000 for electronic parts and \$4800 on average for mechanical parts. The National Aerospace Standards Committee study indicated that 70% of all parts are tested. When utilizing a model such as this, it is important to be confident in the cost data. There are always exceptions to average Figures. One should try to validate the cost data and err on the side of conservatism.

Item Management Cost

According to the same National Aerospace Standards Committee (NASC) survey, parts drawings list an average of 7.3 parts per drawing. The study concluded that of these 7.3 parts, only three were usually provisioned and assigned stock numbers. The item management cost is the additional cost accrued from entering a stock number into the logistic system and maintaining it for a period of time. This cost is made up of both a one time fixed cost as well as the annual maintenance cost.

$$IM = [(\$/C)+(y)(M\$/y)](\%ND)(NPN)$$

Where:

| | | |
|---|---|---|
| IM | = | Inventory Management Cost over y years |
| \$/C | = | Cataloging Cost (one-time cost) |
| y | = | Number of years of the study |
| M\$/y | = | Annual Management Cost |
| NPN | = | Number of New Parts Per Drawing |

The NASC survey suggested that a ten year life expectancy before a part needed to be upgraded was reasonable. DESC estimated that it cost \$207 a year to enter a part into the supply system and \$165 to manage the part.

Maintenance Cost Impact

Using standard parts of known, proven reliability has been shown to significantly reduce field failures, thereby lowering the life cycle costs. This cost is modeled as follows:

$$MC = (y)(\$R/y)$$

Where:

| | | |
|---|---|---|
| MC | = | Maintenance Costs Avoided |
| $R/y | = | Annual repair costs |

The DESC model used $300 per year for electronics, but set the value to zero for other types of parts.

TOTAL SAVINGS

Summing the four elements yields the total ILS savings per part as follows:

$$CA = (MH)(\$/MH)(\%ND) + (\%PT)(\$/T)+[(\$/C)+(y)(M\$/y)](\%ND)(NPN) + (y)(\$R/y)$$

Where:

| | | |
|---|---|---|
| CA | = | Cost Avoidance |
| $/MH | = | Cost per Man-hour |
| MH | = | Number of man-hours required |

| | | |
|---|---|---|
| %ND | = | % New drawings |
| %PT | = | Percentage of parts tested |
| $/T | = | Average cost per test |
| $/C | = | Cataloging Cost (one-time cost) |
| y | = | Number of years of the study |
| M$/y | = | Annual Management Cost |
| NPN | = | Number of New Parts Per Drawing |
| $R/y | = | Annual repair costs |

## Corbett Standardization Costing Model[34]

John Corbett developed a model incorporating what he felt were the best elements of the NAVSEALOGCEN and the DESC models and presented this model in the referenced thesis. As was the case with the NAVSEALOGCEN model, the assumption was made that maintenance associated with the new non-supported equipment would be similar to those of the supported equipment and therefore could be ignored. This models also assumes that the training costs associated with the non-supported equipment are similar to the supported equipment and can be ignored. The model separates one time costs from annual costs in order to make the short term and long term impacts more obvious. The model was developed with a ten year equipment life in mind, but can be applied to other life spans. The model also introduces a factor to account for multiple equipment.

### NON-RECURRING COSTS

The model utilizes the following non-recurring costs:

- Non-Standard Technical Data
- Provisioning
- Testing
- Technical Manuals
- Installation Drawings
- Training Equipment
- Planned Maintenance

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34 Corbett, John Charles; "Standardization of Hull, Mechanical and Electrical Equipment Inventory"; MS Thesis, Sept. 1987, Naval Postgraduate School

Non-Standard Technical Data is data necessary to insure proper support of an item introduced into the supply system. This cost is modeled by both the NAVSEALOGCEN model and the DESC model. Mr. Corbett felt that the NAVSEALOGCEN model overestimated this cost contribution. For this reason, he chose to utilize the DESC estimate which was based upon the NAS model.

$$DOC = (MH)(\$/MH)[(NSP)/4](E)$$

Where:

| | | |
|---|---|---|
| DOC | = | Technical Documentation Cost |
| MH | = | Number of man-hours required |
| $/MH | = | Cost per Man-hour |
| NSP | = | Number of non-standard parts |
| E | = | Number of new equipment |

In 1982, DESC cited a Figure of $52/hour and 27 man-hours per drawing on average.

The Provisioning cost estimate was left consistent with the NAVSEALOGCEN model.

$$Cp = Cp1 + (Cp2\ (NPN) + Cp3\ (PN))E$$

where:

NPN = Number of Parts Representing New Items of Supply

PN = Number of Parts Currently in the Supply System

Cp1 = fixed provisioning cost

Cp2 = cost per new item of supply

Cp3 = cost per part currently in supply system

E = Number of new equipment

The model adopts the DESC TESTING cost. Corbett suggests raising the DESC estimate of 25% tested to 50% tested. In 1982 DESC increased the cost per test to $7,872.

$$TEST = (\%PT)(\$/T)$$

Where:

| | | |
|---|---|---|
| TEST | = | Testing costs avoided |
| %PT | = | percentage of parts tested |
| $/T | = | Average cost per test |

The cost of Technical Manuals was estimated as in the NAVSEALOGCEN model. Mr. Corbett did not have an opportunity to include the recommendations of the Management Consulting Report, which were made after his study.

$$C_{TM} = Ctm1\ (P) + Ctm2\ (POP)$$

Where:

| | |
|---|---|
| P | = number of parts |
| POP | = number of equipment procured |
| Ctm1 | = cost per Part Number |
| Ctm2 | = cost per copy of the technical manual |

With Ctm = $62.50 and Ctm2 = $20.00 in the original model.

The cost of Installation Drawing Changes was calculated as in the NAVSEALOGCEN model.

$$C_D = Cd1(CL)$$

where:

CL = Number of Classes of Ships Receiving Equipment

Cd1 = Cost per ship class affected

In 1986 Cd1 was estimated to be $1000.

The non-recurring costs for Training Equipment are calculated similarly to the NAVSEALOGCEN model.

$$CT = 2(PR)$$

Where:

CT = The cost of Training Equipment

PR = The equipment unit price

The model utilizes the NAVSEALOGCEN approach to the non-recurring Planned Maintenance cost, labeling it CPM. In 1986 CPM was estimated to be $500.

## ANNUAL OPERATING COSTS

The model considers the following annual operating costs:

- NSN Management Costs
- Training

- Configuration Control

The NSN Management Costs were calculated as in the NAVSEALOGCEN model.

$$C_M = Cm1 \,(NP)\,(L)$$

where:

NP = Number of New Items of Supply

L = Projected Life Cycle of Equipment

Cm1 = Annual cost to maintain an item of supply

Based on a 1981 Department of the Army report, the annual cost to maintain an item in the supply system is $ 448.

The annual cost of Training is calculated differently than in either the NAVSEALOGCEN or DESC models. The approach is similar to that of the NAVSEALOGCEN model, except that it is assumed that training costs accrue until the equipment is replaced.

$$CT = PR$$

Where:

CT = The annual training cost

PR = Unit price of the equipment

Configuration Control costs are calculated somewhat differently than in the NAVSEALOGCEN model. The failure rate of the equipment in question is considered in this model.

$$CC = CC1(BRF)(NSP)(E)$$

Where:

| | | |
|---|---|---|
| CC | = | Cost of Configuration Control |
| CC1 | = | Notional cost per equipment |
| BRF | = | Failure rate of the parts |
| NSP | = | Number of non-standard parts |
| E | = | Number of equipment |

## National Aerospace Standard 1524: Standardization Savings, Identification and Calculation[35]

The National Aerospace Standard is very popular due to its ease of use and level of detail. NAS 1524 identifies 52 benefits (tangible and intangible) associated with the use of a standard or standard component. Not all the benefits may be attributed to a single standard, that is to say that some benefits are mutually exclusive.

The practices detailed in NAS 1524 provide methodologies for calculating savings and cost avoidance as a result of utilization of a standard. Although the standard was developed with the aerospace industry in mind, and the Figures and examples cited in NAS 1524 are for aerospace projects, it is not difficult to apply the approach to the marine industry. The following are considered.

- *Savings from increased quantity purchases*

  An example of savings attributable to quantity purchases may be the discount received by obtaining options on equipment for an entire class of ships through a quality partnership with the vendors of equipment on a class standard equipment list.

- *Savings in paperwork and handling*

  An example may be the savings attributable to the reduced number of purchase orders that may be associated with utilization of standard versus non-standard equipment.

- *Savings from reduced storage requirements*

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35 Aerospace Industries Association of America, "National Aerospace Standard 1524 - Standardization Savings, Identification and Calculation", The Economics of Standardization, Toth, Robert ed.

This savings is significant for both the Navy and the shipbuilder. A standardization project reducing the variety of valves used in a particular ship or class of ships would reduce the storage space required both at the shipyard and at the Navy's supply center.

- *Savings from reduced engineering search time*

  This savings is attributable to the reduced effort required to find required engineering data which may be more readily available as a result of conglomerating data pertaining to a standard family of equipment into a standard reference guide. For example, utilization of a class standard list of equipment or pre-qualified vendors would reduce the time spent by engineers searching through VFI to find an applicable component. Creation of a database (such as an extension of HEDRS) which contains important VFI for supported equipment would also reduce engineering time. Use of standard patterns/panels and modules is another example of an activity which would reduce engineering search time.

- *Savings from using a stocked standard part in lieu of establishing a new standard*

  This is a useful trade-off between updated performance a new standard may deliver and the savings from utilizing an existing standard. The assumption here is that the new item would be considered a standard as well and that there is a cost associated with establishing it as a standard as well as a cost associated with adding it to the supply system.

- *Savings from control and reduction of the number of items in inventory through simplification or use of a supersedure procedure*

  This savings is associated with the cost of maintaining an item in the supply system and is annual. This savings is similar to that modeled in the NAVSEALOGCEN model. NAS 1524 points out correctly that these savings may be derived by NOT introducing a new item into the supply system or *by introducing the item and eliminating another.* In essence, the new item would be considered interchangeable with the old equipment and would take its place in the supply system. The SUPERSEDURE approach may prove to be a useful process in developing a flexible standardization policy. A problem with supersedure is that, in the case of equipment, it would often require replacement of the entire equipment with the new item rather than utilization of a replacement part once all remaining maintenance spares have been used up. This is one more trade-off which must be considered.

- *Savings from using a stocked standard part in lieu of using a non-stocked part*

  This savings differs from that discussed earlier in that the assumption here is that the new item is of existing design and would not be considered a standard part even though it would be supported in the supply system. This savings more closely resembles the NAVSEALOGCEN model, since the NAVSEALOGCEN model does not consider costs associated with creating standard equipment lists etc.

- *Savings from using a design standard in lieu of detailing the data completely on the drawing*

  Standard foundations, arrangements, attachments, patterns/panels and modules are all examples of savings opportunities in this area. By utilizing standard baseline designs which have a high frequency of application throughout a ship or class, significant savings could be achieved in this area.

NAS identified five costs typically associated with inventory. These include:

- Interest on invested capital
- Insurance charges
- Cost of warehouse space
- Labor cost to maintain stock

- Cost of obsolescence, surplus, breakage etc.

NAS also identified six costs typically associated with introducing a new item into the supply system.

- Engineering time
- Drafting time
- Checking and release time
- Evaluation or qualification tests
- Preparation of initial procurement and stocking documents
- Preparation of initial inspection plans

The NAS document is very complete and easily understood. The NAS standard differs significantly from the NAVSEALOGCEN, CORBETT and DESC approaches in that it covers a broader range of standardization savings. The other models consider costs directly related to traditional Integrated Logistics Support operations and costs, while NAS more realistically considers a broader range of Life Cycle costs. The NAVSEALOGCEN model would be appropriate for calculating the savings attributable to NOT introducing a new item of supply as outlined above, but does not consider the broader range of benefits and costs associated with standard equipment. For this reason, those models can only be a piece in the puzzle of evaluating standardization. Furthermore, the models reviewed are more appropriate for decisions regarding introduction of non-standard equipment, rather than as a criteria for standardizing equipment. NAS 1524 is a more detailed approach which may be better suited to identifying candidates for standardization projects.

## Cost Analysis Strategy Assessment (CASA) model

The CASA model was developed by the Defense Systems Management College and is available as a software package for IBM compatible machines. It was derived from Honeywell's Total Resource and Cost Evaluation (TRACE) family of logistics and life cycle cost models which were available for mainframe computers. CASA is based upon ILS estimating routines developed in the 1970's but provides a user friendly atmosphere with which to use them. It, like most of the ILS cost models available, is not validated. The Defense Systems Management College warns users of the model that they should use another model to cross-check the results as further evidence to any official review group. A detailed description of the model and the software is available from DSMC in the software manual, from which much of the following discussion is referenced. The following describes the model's philosophy and places it in a standardization perspective.

The CASA model is intended to be a life cycle model which covers the entire life of a system, including initial research costs, yearly maintenance costs, spares, training and other expenses. The program has a multitude of functions for projecting costs and determining probabilities of meeting and exceeding life cycle cost targets. Among the tasks CASA is intended to perform are:

- Life Cycle Cost (LCC) estimates
- Trade-off analysis
- Repair level analysis
- Production rate and quantity analysis
- Warranty analysis
- Spares provisioning
- Resource Projections (for manpower and support

equipment)

- Risk and uncertainty analysis
- Cost driver sensitivity analysis
- Reliability growth analysis
- Operational availability analysis
- Spares optimization
- Operation and support cost contribution

The CASA LCC model is intended to make cost projections for three phases of system life. These phases include the RDT&E phase, the acquisition phase, and the operation and support phase. This is a Life Cycle Cost model rather than a model of only logistics support costs. Some of the other models studied modeled only the integrated logistics support costs. This will be discussed later.

CASA utilizes RDT&E subcategories to determine the feasibility of a system. RDT&E subcategories include:

- System/Project management cost
- System test and evaluation cost
- Training cost
- Data cost
- Demonstration and validation cost
- Research and development cost
- Software cost
- Other cost

The total acquisition cost represents the initial investment cost once the system is approved to be procured. These costs are those associated with the design, development and procurement of systems and support items necessary to make the system operational. CASA includes costs from the following categories when summing totals for each year of the study to determine the total acquisition cost:

- Production tooling and test equipment cost
- Production start up cost
- System acquisition cost
- System shipping and storage containers cost
- Pre-production engineering cost
- Pre-production units refurbished cost
- Installation cost
- Support equipment cost
- Hardware spares cost
- Spares reusable containers cost
- Technical data cost
- Initial training cost
- Training devices cost
- New or modified facilities cost
- Initial item management cost
- Initial software development cost
- Miscellaneous acquisition cost
- Warranty price

CASA considers the following elements of operation and support costs:

- Operation labor cost
- Repair labor cost

- Support equipment maintenance cost
- Recurring training cost
- Repair parts and material cost
- Repair consumables cost
- Condemnation spares replenishment cost
- Technical data revisions cost
- Transportation cost
- Recurring facilities cost
- Recurring item management cost
- Software maintenance cost
- Contractor services cost
- Engineering changes cost
- Miscellaneous operation and support cost
- Recurring warranty cost

If a system has a warranty, the CASA model allows some of the cost categories mentioned to be set to zero while under warranty.

A detailed description of the CASA model algorithms is given in the CASA manual. As can be seen from a review of the other models presented so far and the listing of CASA considerations, CASA is a considerably more complex model. The CASA model also differs in another very important regard. CASA is a generalized model intended to be applied to a variety of situations. For example, CASA requires the user to enter the cost factors to be used in the analysis. No baseline cost factors are available to users as a starting point. By comparison, the NAVSEALOGCEN model is intended strictly for Navy ILS cost considerations.

Additionally, the costs are grouped differently in the CASA model than in the others. CASA is intended to serve as a cost estimating model for an entire project, rather than as a tool for cost-benefit analysis of a single component separate from the project as a whole. CASA is intended for detailed Logistics Support Analysis of a project. Given that the model has been created for a project, the impact of a change in costs associated with a particular component can be studied in great detail. It is not easy to look at the costs associated with a particular component without having modeled the entire project.

Such a tool may not be appropriate in the case of cost-benefit analysis of standardization. In particular, the needs of contractors to evaluate ILS costs to fulfill contract requirements must be met. In order to facilitate these calculations, it is important that the tool be easy to use and understand. For this purpose, a model dedicated to Navy ILS costs associated with non-standard and non-supported equipment may be better suited. The algorithmic approach used by CASA to calculate components of the Life Cycle Cost is very detailed and may be applied to a dedicated model. For example, CASA breaks costs down further than the other models presented so far. Unfortunately, it is not always possible to get the cost Figures needed for such a detailed evaluation, although it may be possible to get cost Figures in less detail.

## The FLEX System[36]

FLEX is a computer system designed to project, track and analyze program life cycle costs. The intent was to provide a flexible system (thus the name FLEX). The flexibility of FLEX is what sets it apart from other models. Like CASA, FLEX is intended to serve as an all purpose system. It is less a model and more a model development system.

FLEX development began with the Naval Material Command (NAVMAT) LCC Implementation Team which was formed from Navy commands and field activities. The techniques developed were published in 1974. At this point the algorithms were simple in nature and fixed by cost data and a cost estimating approach similar to those discussed so far. The system was refined over time through feedback with algorithm users who typically sought tailored systems for their needs. In the mid 1970's, the algorithm was made available in computer form as FLEX. FLEX was modified by various users for their purposes. Changes to the system included the additional capability to account for inflation and discount rates. In 1982 Management Systems Designers incorporated new capabilities such as project tracking (actual vs. estimated expenditures etc.). At this time the program was "cleaned up" and developed an integrated data dictionary for use in the model. The model was also tailored to allow a work breakdown structuring of the costs in addition to the traditional cost elements used in other models. The FLEX system incorporates life cycle costs in several phases of a system life such as research and development, investment, operation and support, and disposal.

In summary, FLEX provides the following four key features:

- The model's cost breakdown structure can be tailored to classical and Work Breakdown Structure formats

36 Information regarding the FLEX system is from the FLEX LCC System Manual, Management Systems Designers, Inc.

- The model can use a different cost estimating procedure for each element of the cost breakdown structure.

- The model uses a common data base to integrate the data generated by the various participating functional organizations.

- A multiple run tradeoff analysis feature is available for cost tradeoff analyses. Any element cost estimating procedure or parameter value can be changed from one run to another.

## The FECA Cost Analysis Model[37]

The Material Readiness Support Agency (MRSA) developed and published a model known as Front-End Analysis (FEA). The joint project Office for Unmanned Aerial Vehicles has adopted this approach and developed a model known as FECA (Front-End Cost Analysis). These models are intended to overcome the data burden present in other models. Other models, such as CASA require many inputs. CASA requires over 400 inputs for a detailed LCC analysis. FECA utilizes a little over 200 inputs. Another feature of FECA is that it was developed with computer spreadsheet programs in mind. Rather than developing a computer program, the association chose to develop a model which was to be used with popular spreadsheets. This approach is advantageous since there is much more compatibility from spreadsheet program to spreadsheet program and data from one computer (IBM or IBM clone for example) can be easily ported to another (Apple Macintosh for example). If a unique application program had been written, this would have seriously limited the ability to use the model on any machine. Additionally, use of the spreadsheet is likely to require less training time than a specialized application since most engineers are already familiar with the use of popular spreadsheet programs like LOTUS, EXCEL and QUATRO-PRO. The approach also makes it considerably easier for the user to make modifications to fit his own needs. Unfortunately, the approach also makes it easier for the user to make an unnoticed error.

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37 Information regarding FECA was found in:

Biedenbender, Dick; Eisaman, John; Vryn, Florence; The ILS Manager's LSA Toolkit: Availability Engineering; McGraw-Hill; 1993, New York

## Evaluating The Available Models and Suggestions for Life Cycle/ILS considerations

Clearly there are a wide variety of models available. The majority of these models use similar approaches in that each tries to evaluate different elements of logistics and life cycle support costs. Some of these models, such as CASA, are intended to be used in evaluating large projects. These models are overly complicated and do not seem to be appropriate for evaluating individual equipment selection decisions. All of the models are intended to evaluate systems in terms of whether or not they should be utilized in a particular project. None of the models are intended to be used to evaluate entire equipment categories for standardization need or potential. Cost data is difficult to obtain and is usually not in the level of detail necessary for many of the models presented. Useful analysis could still be done by utilizing cost factors which represent averages for equipment categories.

In order for standardization to be successful, it is important that a cost evaluating scheme is available which is both quick and easy to use. Only then will this type of evaluation be made on a regular basis as required in current acquisition contracts. The author believes that the NAVSEALOGCEN, DESC, NAS and CORBETT models are most appropriate for this type of evaluation for naval equipment. The NAVSEALOGCEN model is already being sent to contractors for their use. The NAVSEALOGCEN model is simple to use and is based on cost factors derived from Navy acquisition. These cost factors must be updated. An attempt was made to update these cost factors in the course of this study, but with no success. Many people were contacted regarding the different aspects of the ILS costs, but it was not possible to obtain any information which might be used to update the cost factors. This is largely because costs are not accounted for at a detailed level. The timing and costs associated with different phases of an acquisition project are not tracked. In order for savings and costs regarding standardization to be measured in a meaningful way, the timing and costs associated with the different phases of an acquisition project, from concept development through crew training and maintenance and logistics support will need to be studied further.

Another important point is that in evaluating costs which are recurring over a number of years, costs should be discounted to represent the time value of money. The NAVSEALOGCEN model does not explicitly require the user to incorporate net present value into the calculations. The present value of an investment accounts for the fact that a dollar earned or saved today has earning potential in the form of interest. This will tend to reduce the impact of the costs. NPV also has the effect of reducing the impact of future savings or expenditures which is appropriate from a risk point of view. The future is unclear, and by utilizing NPV, costs and savings which occur recently are favored over future costs and savings which may not be completely trusted.

In summary, the Naval Sea Logistics Center model is an excellent start with regard to evaluation of specific equipment options for a project, given that savings and costs are discounted to reflect NPV and cost data is updated and checked for realism. The NAVSEALOGCEN model could be applied to the broader task of evaluating equipment categories if aggregate data exists for this purpose. NAVSEALOGCEN supplied some of this data which is used later to evaluate the ILS costs of the different equipment categories. The NAVSEALOGCEN model does not incorporate all the costs and savings associated with standardization projects, since it was intended to evaluate ILS costs only, and must be used in conjunction with other factors when evaluating standardization projects. The NAS model incorporates many of the elements of the NAVSEALOGCEN model and goes further, including other costs and savings. This model serves as a useful guide for broader evaluation.

# CHAPTER 5: CRITERIA AND CONSIDERATIONS FOR EVALUATING STANDARDIZATION CANDIDATES

In Chapter 3, current work in this area undertaken by NAVSEALOGCEN was described. The Naval Sea Logistics Center has developed the Standardization Candidate Selection Criteria Model. This model was developed in response to a need for evaluating the feasibility of standardizing an equipment based upon nomination by some group within the Navy. Typically, equipment was nominated as a reaction to poor maintenance records. It was hoped that by standardizing on a design of known reliability, and providing a depth of spares in the supply system with reduced breadth, availability and maintainability would improve. The Standardization Candidate Selection Criteria Model developed by NAVSEALOGCEN provides a framework for economic analysis based upon the NAVSEALOGCEN ILS model as well as an analysis of the improved reliability that can be expected. It provides a basis for equipment candidate selection based upon the availability of sources, drawings, and data rights. The model outlines the process of checking for a high frequency of unique equipment performing the same function which may point to standardization opportunity. The NAVSEALOGCEN model is a good start, but assumes that an item has already been nominated for standardization. It then checks the feasibility of standardizing the item, generally assuming it to be a new design to be named the standard. What is needed now is a rational approach to nominating equipment and ranking this nomination. This nominating process should pinpoint equipment types which deserve attention in the form of standardized interfaces, class standardization, module design or standard design development. Figure 5.0 illustrates some of the considerations currently associated with equipment standardization decisions, and other considerations which are important in this process.

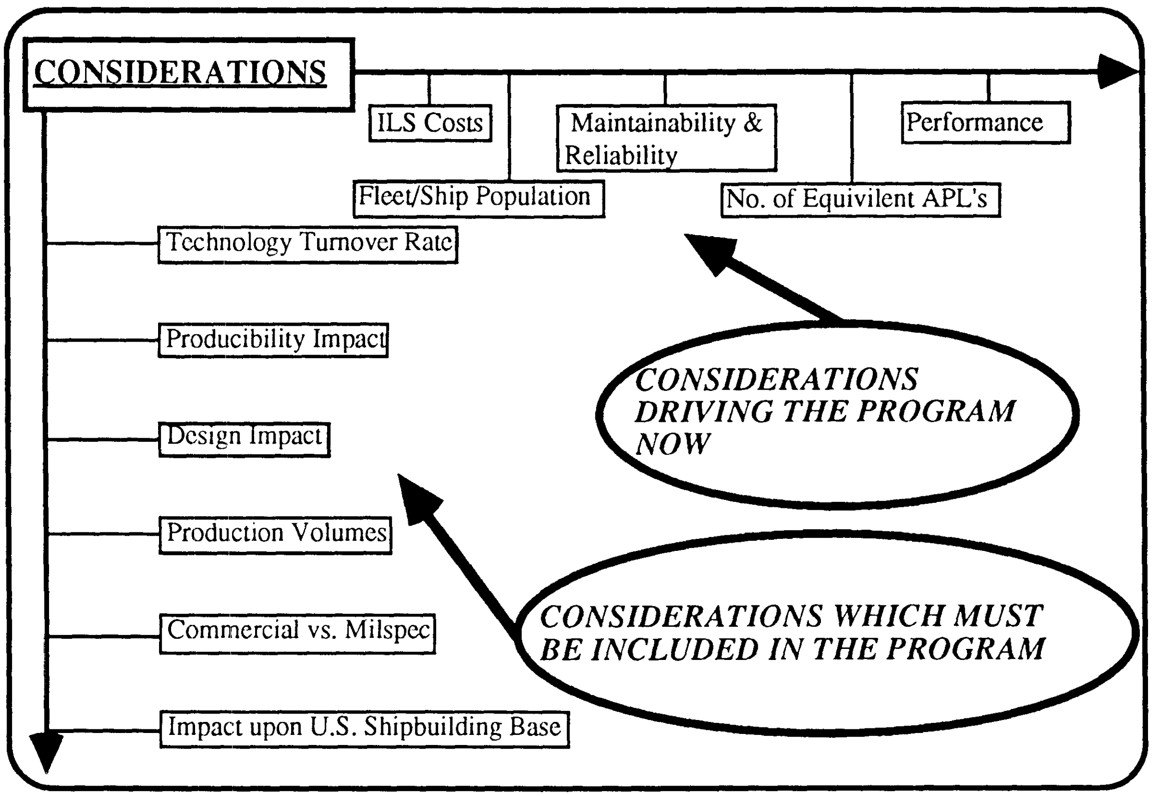


Figure 5.0 - Criteria for Selecting Navy HM&E Standardization Candidates

These criteria guide the gathering of pertinent statistics regarding the equipment types. Such questions as which equipment to mandate as GFE, or as class standard, or to develop a module for, or allow the contractor to select, can be answered more readily if these statistics are available.

In Chapter 3, the 99 equipment categories established by the Navy were discussed. Within each of these categories are subcategories identified by Lead Allowance Parts List numbers. Within these subcategories are equipment identified by Allowance Parts List numbers. The APL usually identifies an item of supply which is unique. Unfortunately, it is sometimes a variant of another APL which in reality should not warrant a unique classification. The APL remains the best identifier for equipment in that it is currently the only measure which is associated with all equipment. Furthermore, the HEDRS database mentioned earlier tracks APL's and can be utilized to generate statistics regarding equipment tracked as APL's. In this chapter, the 99 broad equipment categories are evaluated with regard to identifiable criteria. In reality, these 99 equipment categories are too broad to serve as the basis for standardization decisions. They do serve as a useful first estimate of standardization opportunities which may then be refined at the LAPL and APL levels. It is considerably more time consuming to search at the LAPL level, since each equipment category contains many LAPL categories. This broad review serves as an exploration of the feasibility of the approach.

A number of criteria were identified. Each of these were selected for its impact on either the logistics costs, or the production costs, or time to delivery. In some cases the same criteria impact all three. The criteria explored in this thesis include:

- Redundancy and Commonality
- Uniqueness
- APL Proliferation
- Maintenance Data

- Population
- VFI and Manufacturing Lead Time
- Potential ILS Cost Avoidance
- Technology Turnover - Obsolescence
- Adaptive Costs
- Producibility - Critical Path Impact

Each of these is described in the following pages.

## REDUNDANCY AND COMMONALITY

Redundancy refers to the existence of many unique items of supply which perform the same or very similar functions (i.e. many APL's with the same or similar characteristics). At the LAPL level, redundancy is most effectively studied through the use of scatter diagrams which plot points representing APL's having particular characteristics. The approach is best suited to equipment which can be distinctly defined in terms of a few key characteristics. The Navy has utilized this approach in the past in determining the feasibility of developing standard designs in response to reliability concerns. These scatter diagrams are also very useful for developing envelopes of characteristics which are to be satisfied by the standard or standard family. The statistics provide empirical evidence of standardization potential with regard to performance characteristics. Redundancy appears on these illustrations as clusters of APL's within identifiable envelopes of characteristics which are tight enough to be satisfied by a single item. There are several questions to ask when evidence of a cluster is visible.

- Could all, many, or any, of the items identified as part of the cluster have satisfied the majority of the performance envelope?

- Could an item be developed to satisfy the performance envelope identified or desired?

The answers to these questions will help to guide any subsequent standardization project should one be undertaken.

It is also important to check for exact matches which would overlap on scatter diagrams (in other words a point would represent more than one APL). Figures 5.1, 5.2 and 5.3 are illustrative of this criteria. The Figures illustrate the population of APL'S for centrifugal pumps, compressors and dehydrators. These items have been examined by the Navy (DTRC, NSWC and NAVSEALOGCEN) in an effort to improve reliability.

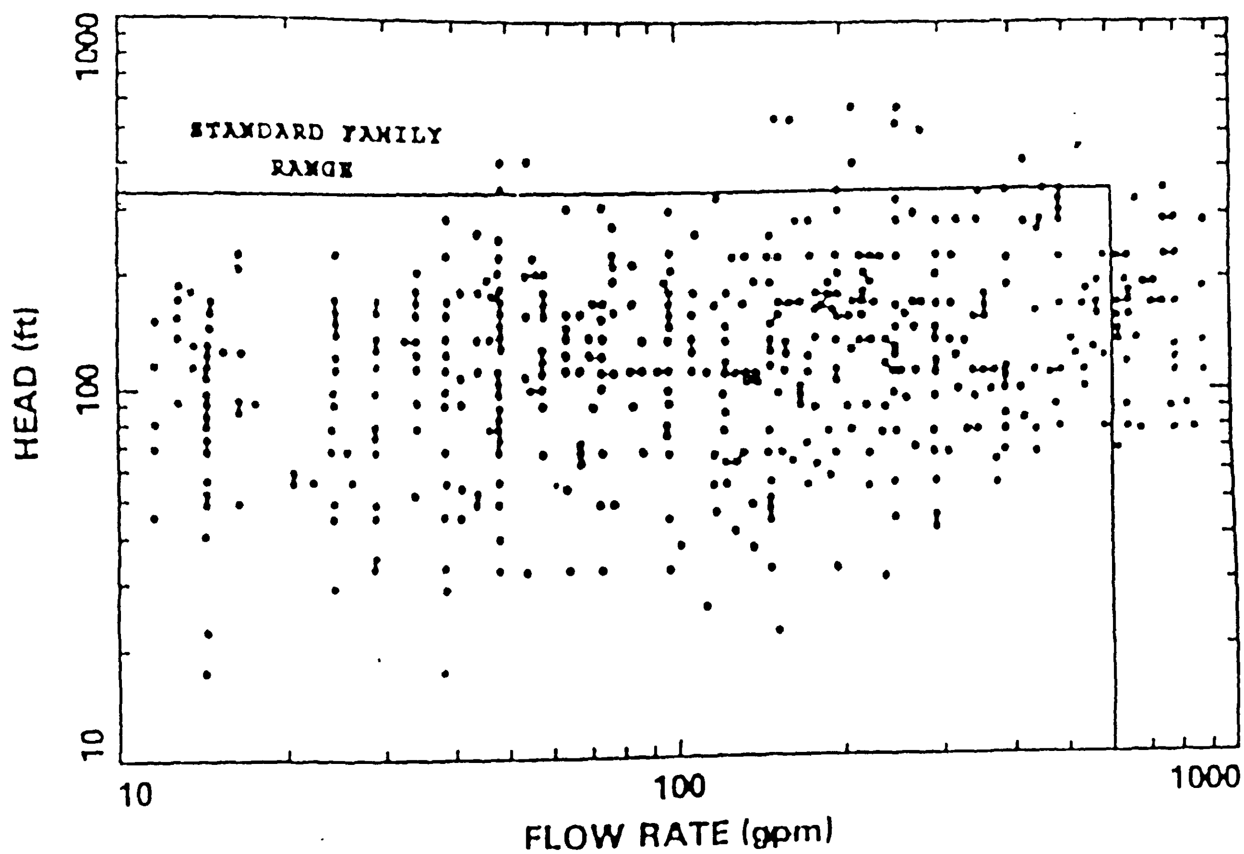


Figure 5.1 - Surface Combatant Pump Distribution[38]

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38 Figure supplied by NAVSEA

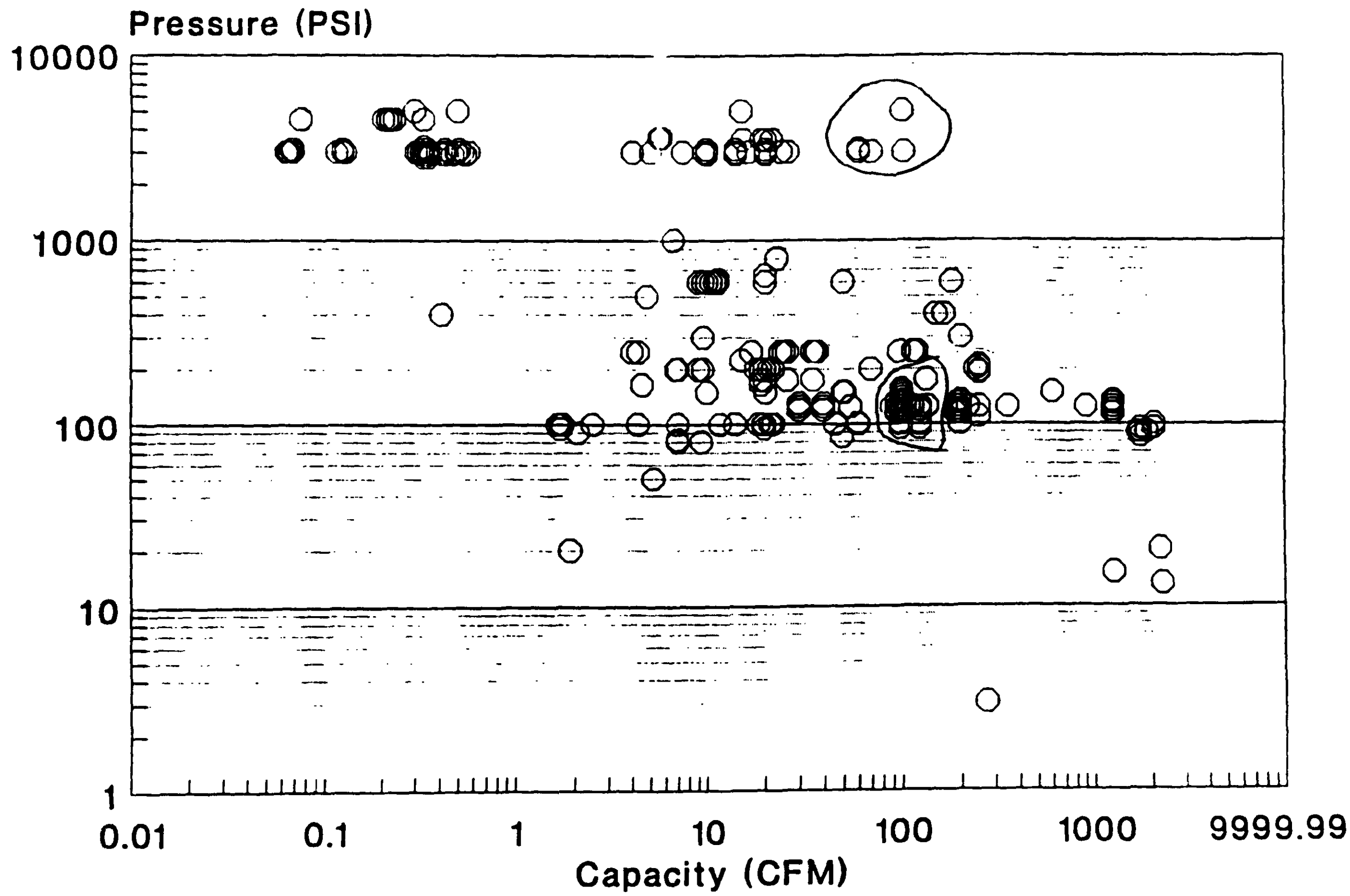


Figure 5.2 - Fleet Compressor Scatter Plot[39]

39 Figure supplied by NAVSEA

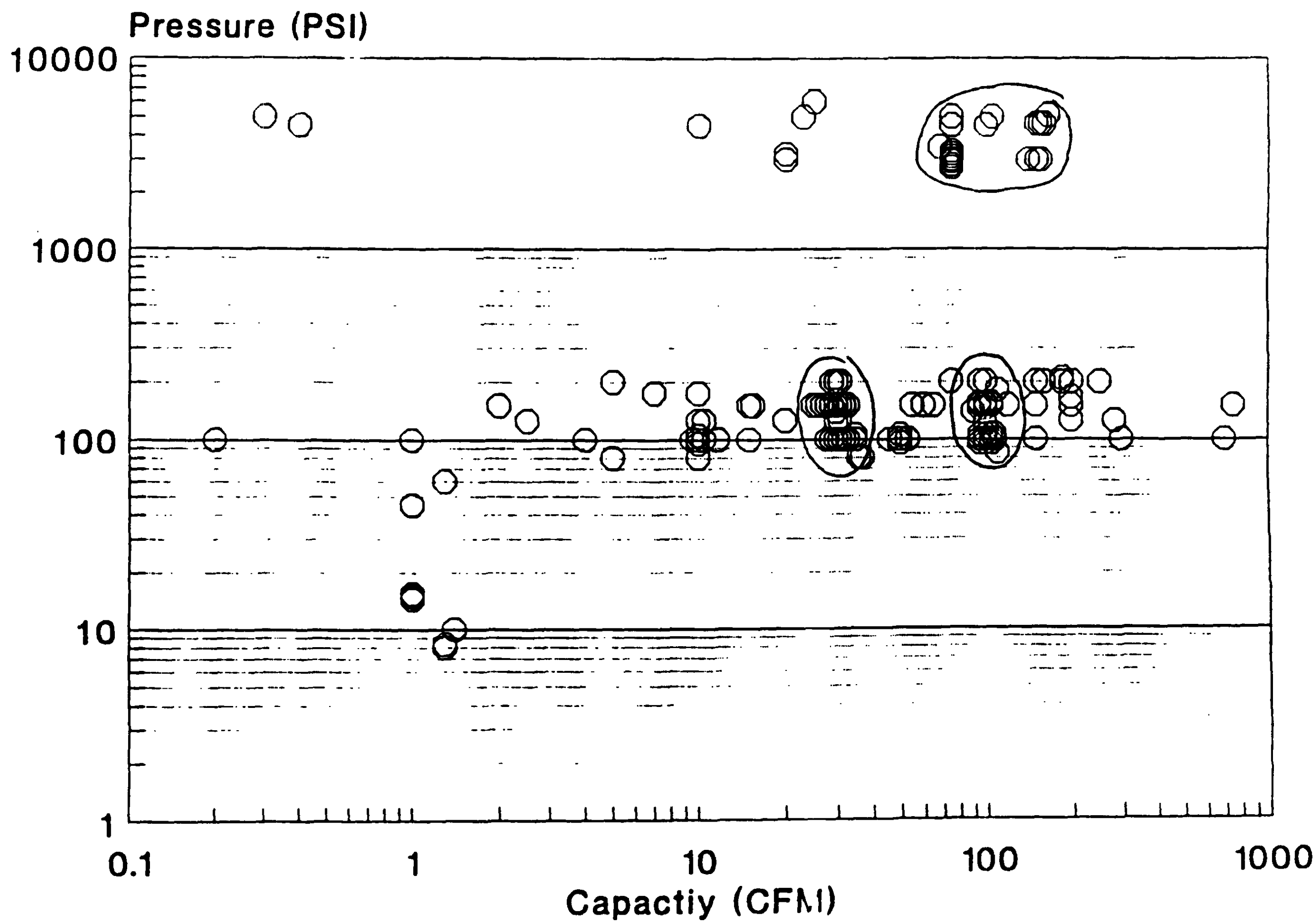


Figure 5.3 - Fleet Dehydrator Scatter Plot[40]

40 Figure supplied by NAVSEA

In performing the broad study, the total number of APL's in each category was considered. Each equipment category is broken down into a number of sub-groups, or LAPL's. Dividing the total number of APL's by the number of LAPL's for the equipment category give the average number of APL's per LAPL. Translated into English, this roughly indicates the average number of equipment which warrant an identification number which can be found in each sub-category. This Figure is only a rough indicator, and is intended only as a starting point. First, it assumes that the average number of APL's per LAPL at least distinguishes order of magnitude differences between equipment categories. This is not always true since some equipment categories have a number of lowly populated LAPL's which would drive down the average Figure. It further assumes that there is a greater likelihood of finding redundancy within highly populated LAPL's than within LAPL's which do not contain as many APL's. In general, this should be true. It should be noted that this measure gives no indication of the population of the APL's themselves. For example, an LAPL may have 47 APL's within it, and the fleet may have 300 of each APL installed. On the other hand, another LAPL may only have 100 APL's within it, but each of those may only have a fleet population of 50 items. In this case, there may be greater savings if some of the 100 APL's can be eliminated than if some of the 300 APL's are eliminated. The frequency of application in a single ship, class or the fleet is also important. All these, and other considerations must be accounted for. These will be discussed as separate criteria.

Figure 5.4 illustrates the APL population per equipment category, as determined utilizing information from NAVSEALOGCEN. Dividing through by the number of LAPL's per equipment category and visualizing the results in a pareto diagram results in Figure 5.4.

# APL'S per EQUIPMENT CATEGORY

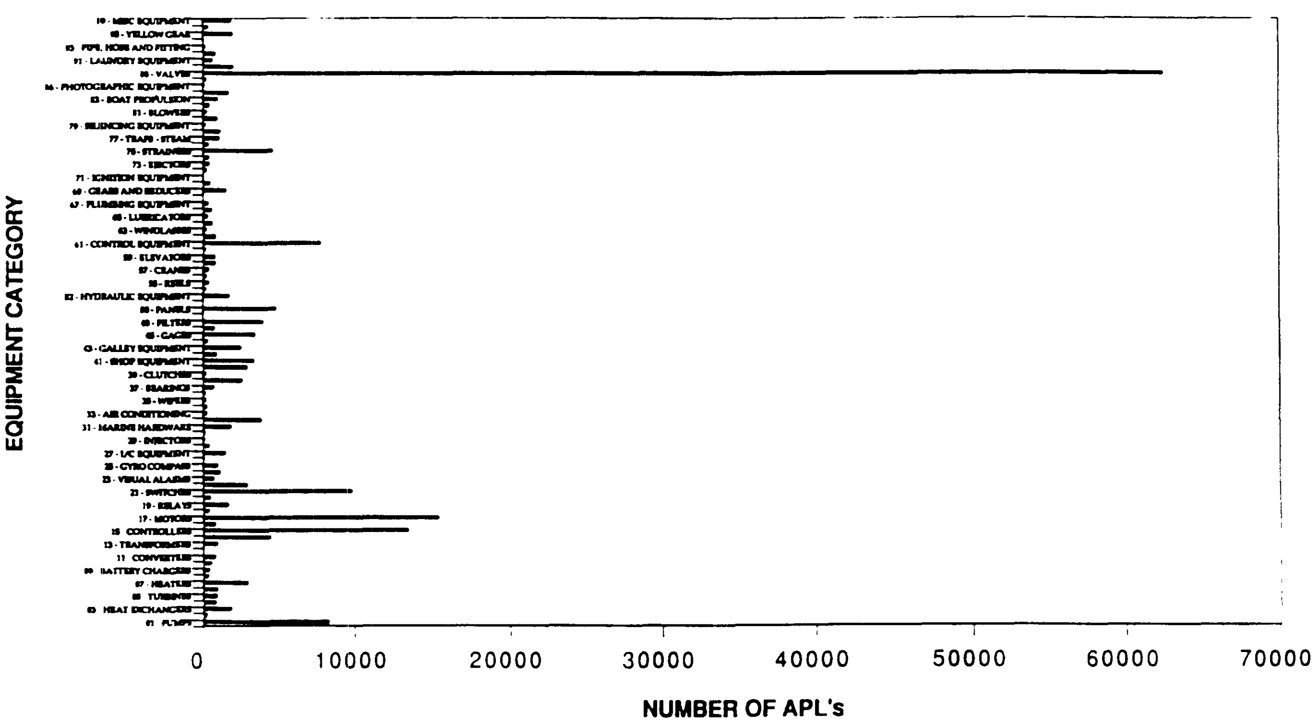


Figure 5.4 - APL's Per Equipment Category Histogram

# APL/LAPL RATIO PARETO

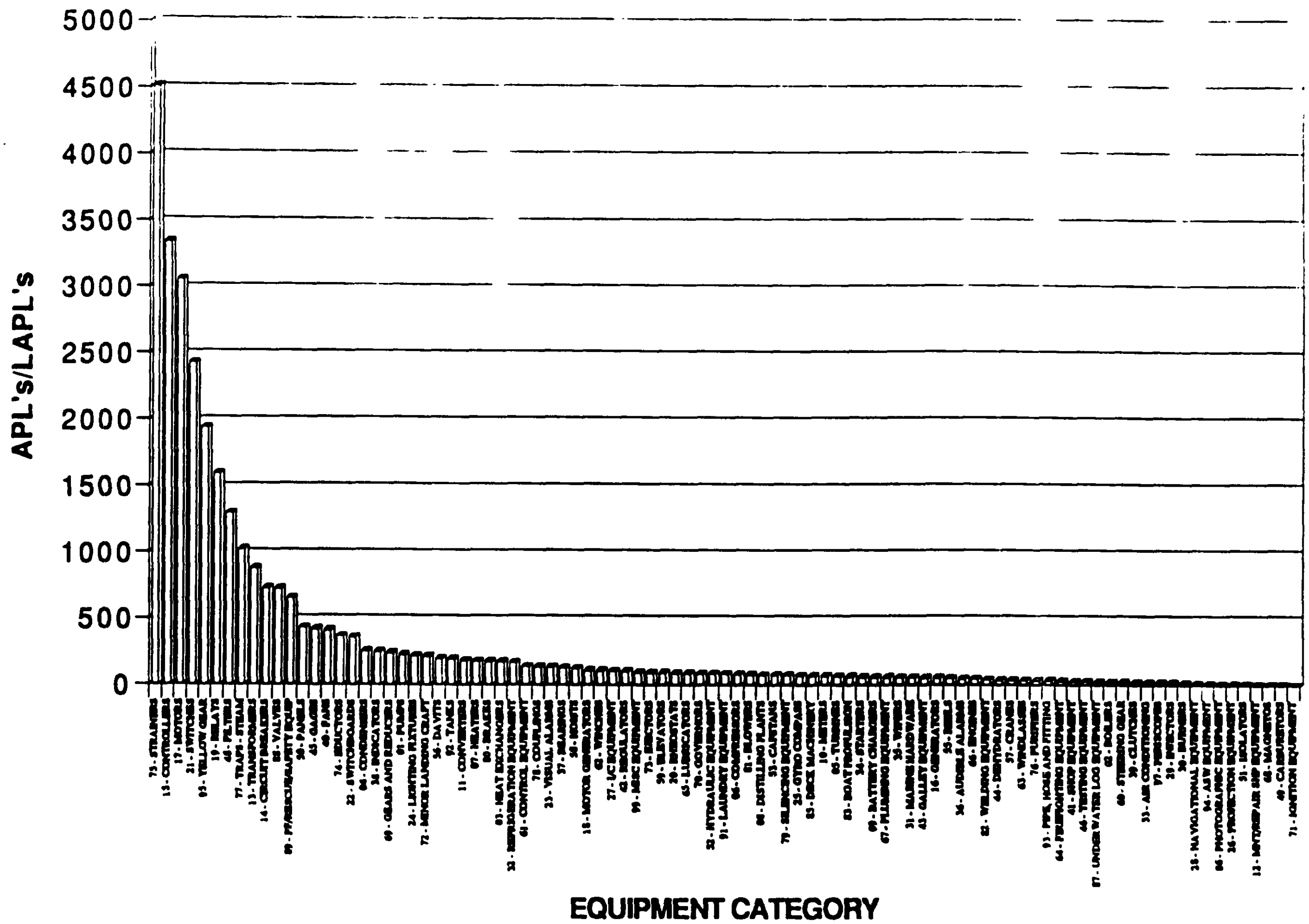


Figure 5.5 - APL/LAPL RATIO PARETO

The results allow the following list of the top twenty equipment categories with regard to APL's per LAPL's to be made:

| | | | |
|---|---|---|---|
| 1) | Strainers | 11) | Valves |
| 2) | Controllers | 12) | Firefighting/Rescue/Safety |
| 3) | Motors | 13) | Panels |
| 4) | Switches | 14) | Gages |
| 5) | Yellow Gear (NUKES) | 15) | Fans |
| 6) | Relays | 16) | Eductors |
| 7) | Filters | 17) | Switchboards |
| 8) | Steam Traps | 18) | Condensers |
| 9) | Transformers | 19) | Indicators |
| 10) | Circuit Breakers | 20) | Gears and Reducers |

TABLE 5.0 - APL/LAPL RANKING

## UNIQUENESS

One argument for standardization which is often put forward is that it allows economies of scale. That is to say, if larger quantities of each APL could be utilized, it should result in more efficient use of Integrated Logistic Support dollars, more timely delivery and possibly lower acquisition costs. In this regard, there is an incentive to consolidate APL's in those cases where there are few installations of APL's serving the same or similar purpose. The information contained in the HEDRS database can be used to shed light on this subject. The average population per APL for each equipment category was calculated and used to prioritize the list of equipment categories. Figure 5.6 illustrates the total fleet population of each equipment category.

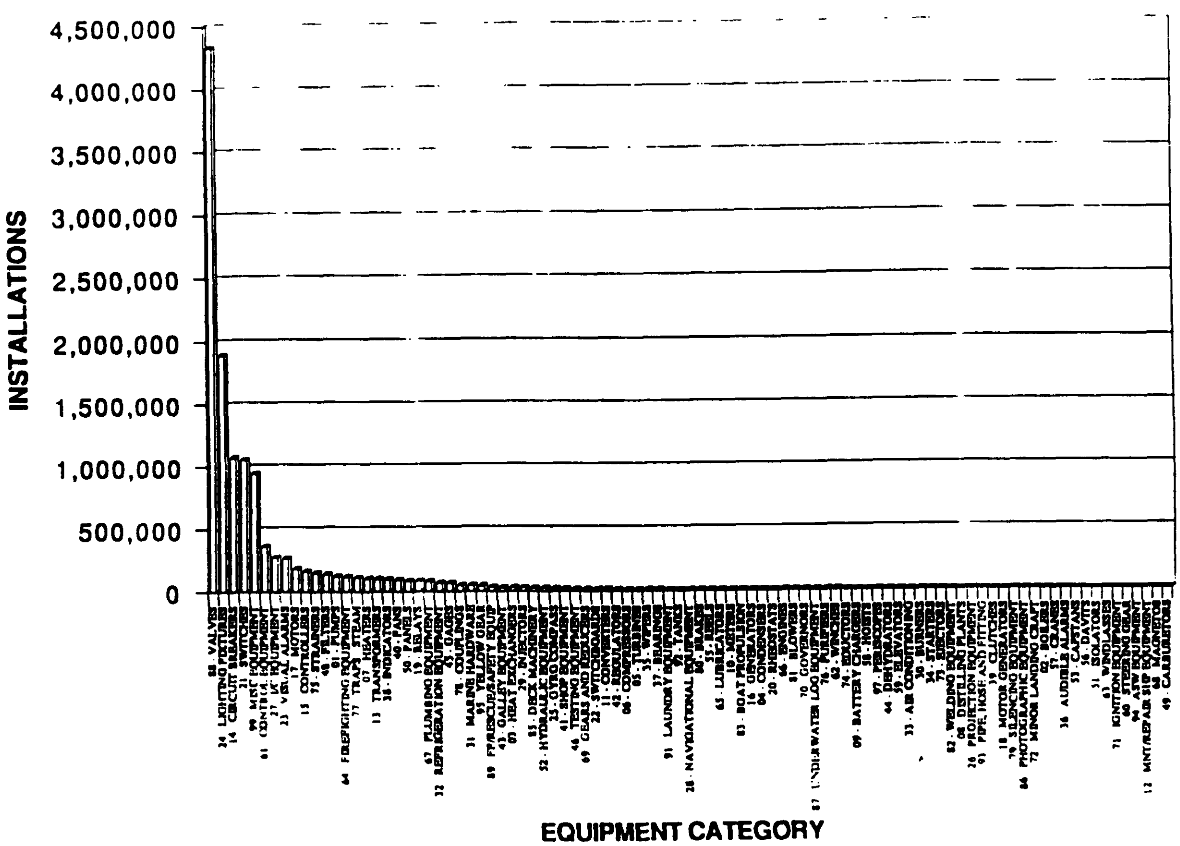


Figure 5.6 - Total Fleet Population

After evaluating the total number of installations in the fleet, the average number of installations per APL was calculated by dividing the total fleet population by the total number of APL's in each equipment category. Once again, this is a rough indicator and is intended as an illustrative beginning. In order to fully describe the uniqueness of an APL, the actual fleet population of each APL must be examined. This is a time consuming task which was beyond the scope of this exercise. Figure 5.7 illustrates the average population per APL.

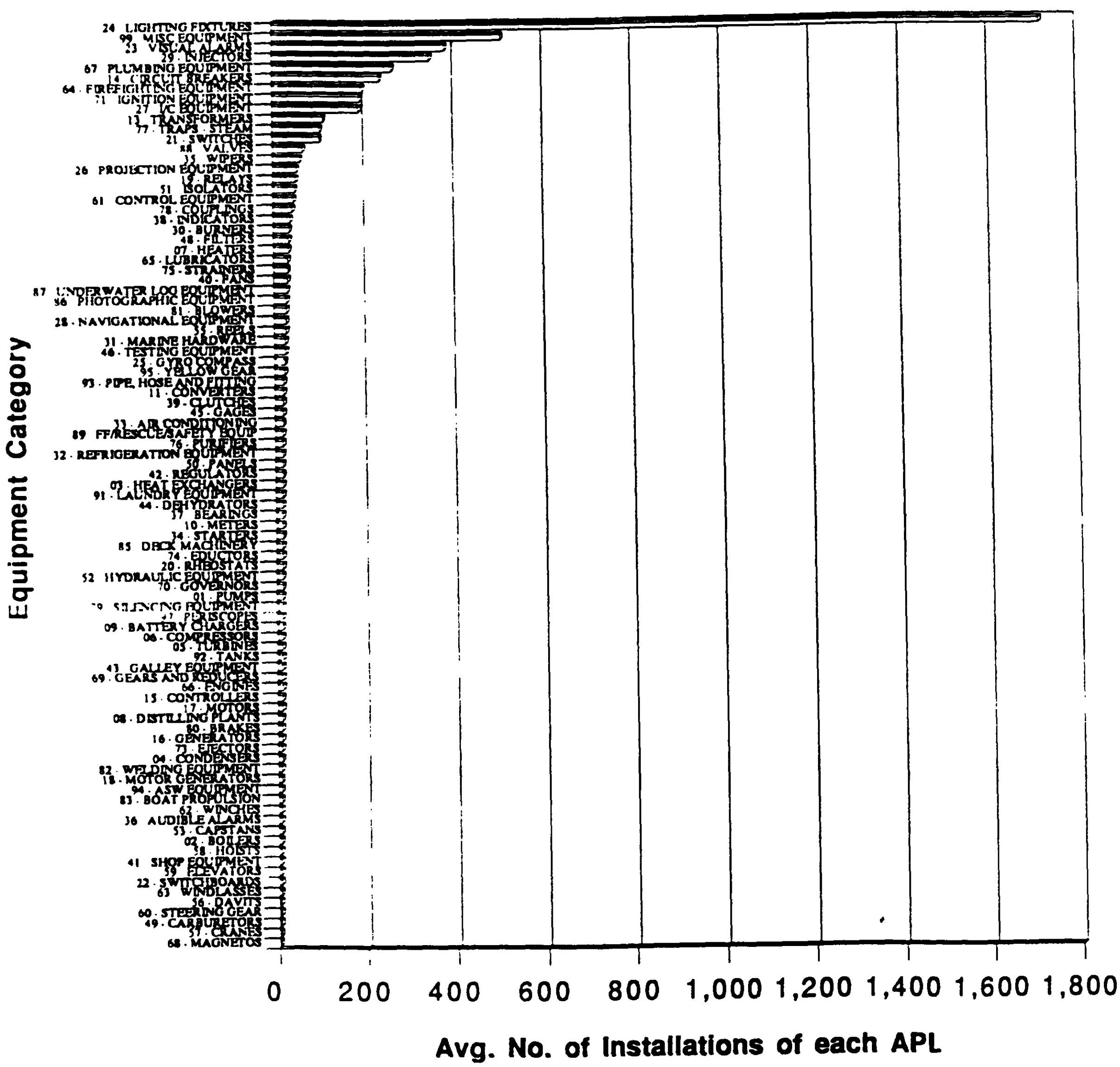


Figure 5.7 - Average Population Per APL

The resulting top twenty-one candidates are listed below:

| | | | |
|---|---|---|---|
| 1) | Magnetos | 11) | Boilers |
| 2) | Cranes | 12) | Capstans |
| 3) | Carburetors | 13) | Audible Alarms |
| 4) | Steering Gears | 14) | Winches |
| 5) | Davits | 15) | Small Boat Propulsion |
| 6) | Windlasses | 16) | ASW Equipment |
| 7) | Switchboards | 17) | Motor Generators |
| 8) | Elevators | 18) | Welding Equipment |
| 9) | Shop Equipment | 19) | Condensers |
| 10) | Hoists | 20) | Ejectors |
| | | 21) | Generators |

Table 5.1 - Uniqueness Criteria

## APL PROLIFERATION

As was mentioned earlier, the proliferation of new APL numbers into the supply system is one indicator of the degree of standardization which is being achieved. High APL proliferation is to be avoided if at all possible, since it may represent needless introduction of unique items into the supply system resulting in higher ILS costs. High APL proliferation is also undesirable since it leads to inconsistency across the fleet which may complicate construction efforts and undermine other standardization efforts. It should be noted that a high proliferation rate may also be an indicator that a particular equipment category may have a high technology turnover rate (obsolescence), and this must be considered when reviewing the results of this survey. The Naval Sea Logistics Center provided data regarding the current average number of new APL's which are introduced per year per equipment category. A question exists as to what is an appropriate measure of APL proliferation. One may measure the actual number of APL's introduced as a raw Figure, or one may measure the APL proliferation as a percentage of the total number of APL's in each category. Proliferation as a percentage may be more useful, as it "normalizes" the data for the existing variety of equipment, indicating when an unusually large number of new APL's is being introduced. Figure 5.8 illustrates the proliferation of new APL's per equipment category per year. Figure 5.9 illustrates the proliferation as a percentage.

## PROLIFERATION OF NEW APL'S PER YEAR

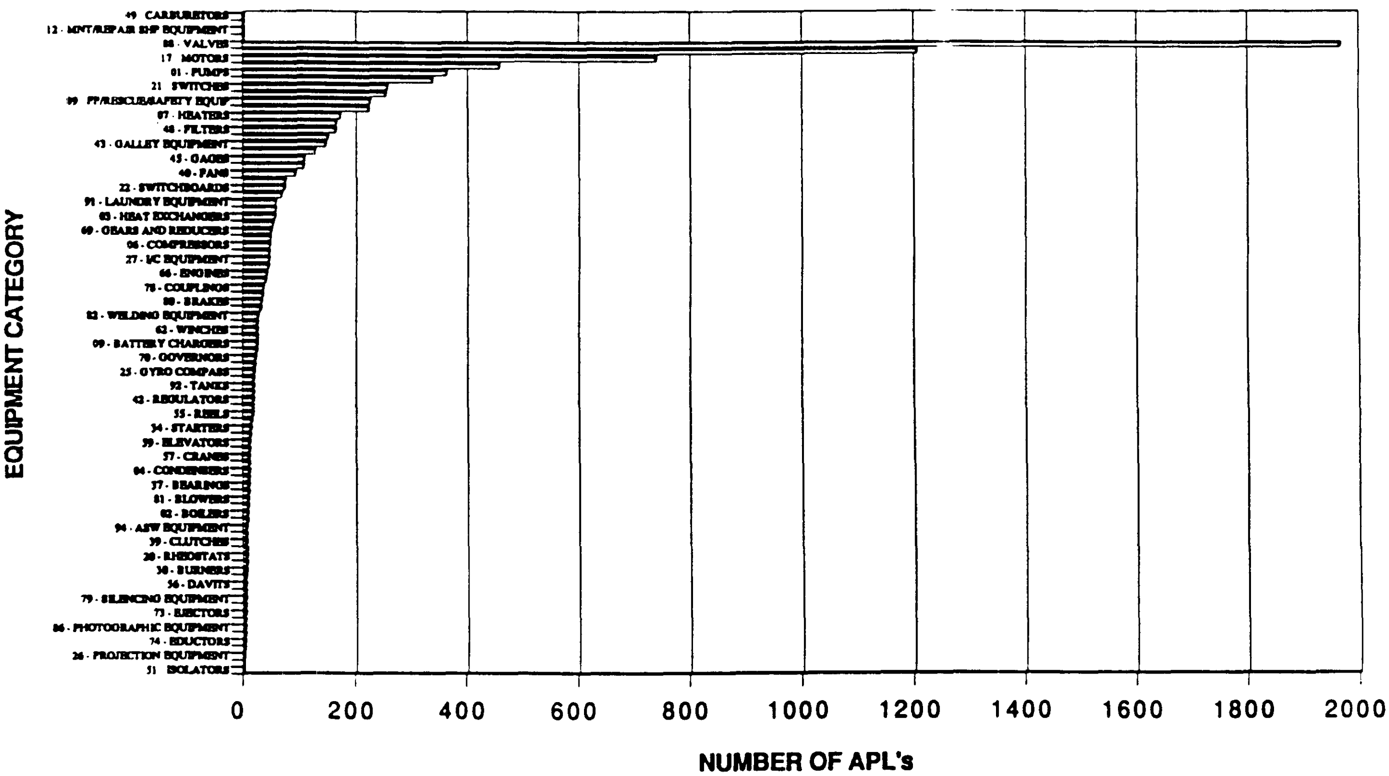


Figure 5.8 - Proliferation of New APL's per Year

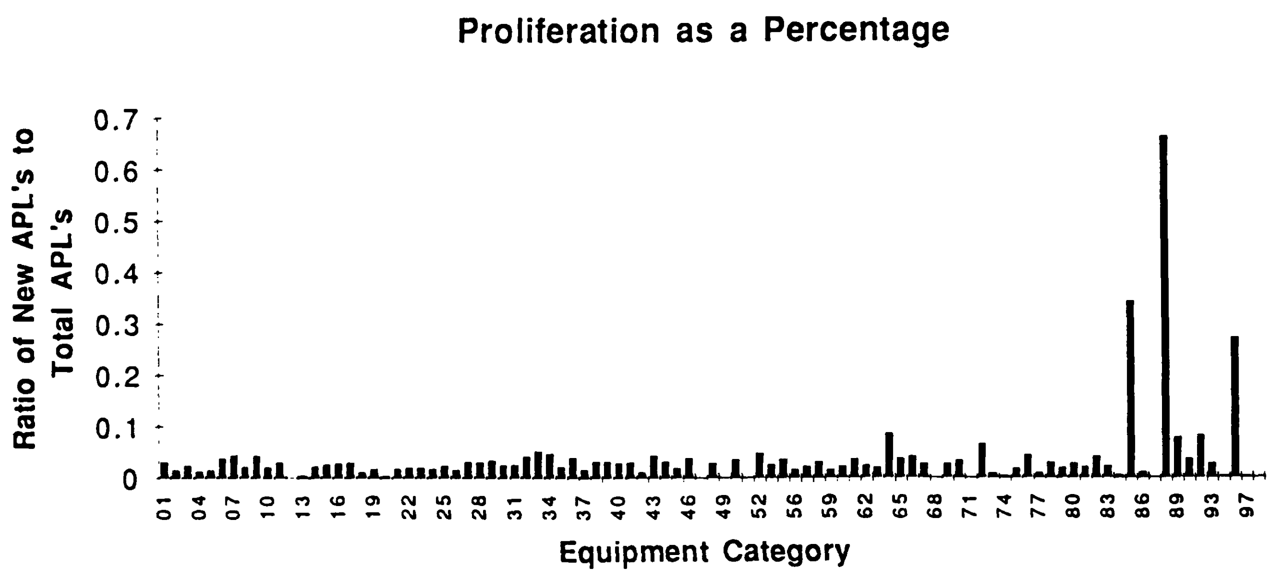


Figure 5.9 - Proliferation as a Percentage

There is an incentive to try to minimize this proliferation, and a high proliferation indicates that the reasons behind it should be studied. If these reasons are not found to adequately justify the proliferation, extra effort could be taken to mandate that currently supported equipment be utilized. As was discussed during the review of Navy progress, proliferation does not provide the whole story. APL proliferation should also be studied in the context of the actual number of units which were acquired in a given year. For example, proliferation of 3 APL's per year may be more indicative of a problem when only 3 items are actually acquired in a year than when 100 items are acquired in a year.

## MAINTENANCE DATA

Data from the 3M database was studied by the Naval Sea Logistics Center and a list of 25 "problem" equipment was created. Standardizing upon a more reliable design improves the reliability of the system and also increases the availability of spares by allowing NAVSEALOGCEN to cut back on the variety of spares and increase the number of stocked spares for the standard item. Table 5.2 lists the 25 equipment along with maintenance action statistics.

### 3M TOP 25 PROBLEM EQUIPMENTS

| RANK | EIC | NOMENCLATURE | MAINT ACTNS | SHIPS REPTING | DEFERALS FOR PARTS/ASST | RATIO OF MAINT ACTIONS TO SHIPS | PARTS COSTS | MAN HOURS | TOTAL FAIL STATS 2 OR 3* | FAIL DT HOURS (THOUS) |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | T801 | Fire mains | 15005 | 439 | 2554/4955 | 34.2 | 14890897 | 211460 | 6599 | 5360.4 |
| 2 | TF01 | High Pressure Air Systems | 11643 | 460 | 1801/3860 | 25.3 | 4299666 | 174774 | 4668 | 2551.0 |
| 3 | TF03 | Intermediate & Low Pressure Air Systems | 11111 | 501 | 1893/3124 | 22.2 | 3305809 | 144372 | 4171 | 2519.8 |
| 4 | F101 | Main Steam Boiler | 16156 | 226 | 1127/7922 | 71.5 | 2249664 | 389131 | 6427 | 4741.8 |
| 5 | GV00 | MK 15 (Phalanx) Close-In Weapon System | 10725 | 249 | 3320/947 | 43.1 | 17623448 | 110064 | 4118 | 1112.6 |
| 6 | T401 | Chilled Water Air Conditioning System | 6879 | 367 | 1255/1868 | 18.7 | 1714608 | 122928 | 3329 | 2356.1 |
| 7 | TK03 | Low Pressure Distilling Plant | 6777 | 330 | 999/2361 | 20.5 | 1421427 | 139454 | 2911 | 1997.0 |
| 8 | 4505 | Lighting Fixtures, Permanent Mount | 9629 | 408 | 1675/924 | 23.6 | 762750 | 94203 | 3308 | 2529.4 |
| 9 | AD01 | Doors | 9063 | 425 | 1312/3837 | 21.3 | 661498 | 91044 | 5379 | 5709.1 |
| 10 | T806 | Sea Water Service System | 5559 | 445 | 783/2287 | 12.5 | 1875107 | 81746 | 2455 | 2052.5 |
| 11 | 310C | 60 Hz Steam Turbine Generator Set | 6514 | 312 | 642/2677 | 20.9 | 1145790 | 134754 | 2193 | 1644.1 |
| 12 | T605 | Fueling Service, Transfer & Blending | 5337 | 291 | 844/1233 | 18.3 | 3595495 | 67936 | 2601 | 2326.8 |
| 13 | F303 | Centrifugal Pump Unit (Multistage) | 4727 | 207 | 450/1914 | 22.8 | 2839558 | 103592 | 1977 | 1042.5 |
| 14 | T706 | Piping & Valve Group | 5069 | 412 | 696/2058 | 12.3 | 683508 | 66718 | 2861 | 2502.4 |
| 15 | B101 | Diesel Engine | 5601 | 151 | 693/2883 | 37.1 | 1796569 | 77271 | 2200 | 1276.0 |
| 16 | TB04 | Fresh Water Cooling Systems | 4894 | 381 | 954/1618 | 12.8 | 858869 | 55088 | 1881 | 1252.7 |
| 17 | TB03 | Pure Water System | 4795 | 392 | 1005/1096 | 12.2 | 835177 | 58933 | 1931 | 1466.4 |
| 18 | F401 | Air Supply System Blower Group | 3475 | 194 | 278/1653 | 17.9 | 898113 | 61717 | 1621 | 1157.8 |
| 19 | TA01 | Trim & Drain System | 4062 | 391 | 148/1664 | 10.4 | 1311219 | 51261 | 1757 | 1277.6 |
| 20 | TH03 | Supply System, Shore Steam | 4206 | 350 | 176/1905 | 12.0 | 669558 | 55398 | 1995 | 1368.3 |
| 21 | T503 | Refrigeration Plant (R-12 Dir Exp) | 4165 | 437 | 845/1054 | 9.5 | 888994 | 64618 | 1747 | 1231.2 |
| 22 | 3301 | 60 Hz Diesel Engine DVN Generator Set | 4152 | 298 | 442/1863 | 13.9 | 851622 | 84249 | 1208 | 716.0 |
| 23 | 3101 | 60 Hz Diesel Engine Generator Set | 4239 | 197 | 543/1994 | 21.5 | 990545 | 60416 | 1544 | 754.6 |
| 24 | T40S | Air Conditioning System (R-114 CWP) | 4097 | 210 | 716/1094 | 19.5 | 793352 | 59368 | 1478 | 1028.1 |
| 25 | TA03 | Bilge & Ballast Systems | 3325 | 392 | 503/1464 | 8.5 | 800172 | 47474 | 1759 | 1673.3 |

*This column contains total failures which had maintenance actions with status codes 2 or 3, indicating the equipment was non-operational or operating with reduced capability

Table 5.2 - Maintenance Data

## POPULATION

An extremely important consideration with regard to impact upon producibility and the construction cycle is the frequency with which the equipment in question is to be installed. This criteria can be broken down to ship population, class population and fleet population. Each takes on a different importance depending on the level of standardization sought. Each also has a different impact upon the construction cycle.

In the earlier discussion of uniqueness, fleet population was discussed and presented. Fleet population is particularly important with regard to logistics support costs. Fleet population is also important with regard to standardizing equipment installation systems across the fleet.

An equipment type which is utilized frequently throughout the ship is an excellent candidate for standardization consideration since there is incentive to maximize the use of common interfaces and installations, work instructions, drawings, engineering and so on. It is important to plan the acquisition such that the variety of equipment installed on the ship is minimized as much as feasibly possible.

Class standardization is of importance with regard to both logistics and construction costs. Clearly there is an advantage in utilizing the same equipment as the lead ship in order to maximize the savings attributable to lessons learned on the lead ship. Follow ships can also utilize the same design and structural systems, thereby reducing design, engineering and construction costs. Logistically, class standardization can result in significantly reduced ILS costs as well as savings attributable to option pricing and quality partnerships with vendors.

The HEDRS database contains information regarding the frequency of application of a particular APL within the fleet, a class or a ship. Unfortunately, it is difficult to have HEDRS simply provide a list of all APL's in the LAPL or equipment category and their associated populations since HEDRS requires characteristic ranges to be input. If a characteristic field happens to be blank for a particular equipment, it is not added to the output list. Given that there are 99 equipment categories and many LAPL's associated with each, about 1000 HEDRS runs would be required to generate the lists needed to study population in great detail. Each run can take 30 minutes to several hours to complete. After the run is finished, the output must be segregated into data fields readable by a spreadsheet program like Lotus, Quatro Pro or Excel since HEDRS does not provide output in an easily used format. After that is finished, the data must be sorted as desired and statistics arrived at for the average ship population per LAPL. This is an enormous task and given the time constraints on this study, it was not possible to acquire the data necessary to rank all the equipment categories according to intra-ship and intra-class standardization. Experience and expert opinions can be used to help guide decisions, but these statistics must be compiled in order for detailed development to be possible.

## VFI AND MANUFACTURING LEAD TIME

The time it takes for an equipment to reach the construction site once an order is made is referred to as the manufacturing lead time. Knowledge of the manufacturing lead time for a particular item of supply is essential to efficient production planning. In general, reducing manufacturing lead time is beneficial for those items which are on the critical path and must be installed in a particular sequence. Reducing the manufacturing lead time for non-critical items does not necessarily save production time or costs. It is beyond the scope of this research to pin-point which equipment are on the critical path, but data regarding manufacturing lead times for equipment was made available from the NAVSEA Shipbuilding Support Office.

The NAVSEA Shipbuilding Support Office's (NAVSHIPSO) annual Publication of Manufacturing Lead Times (MLTPUB) for Hull, Mechanical and Electrical (HM&E) Ship Components, Basic Material, and Combat Systems reflects a twelve month projection of Manufacturing Lead Times (MLTs) of materials normally utilized by shipbuilders performing Navy related work.[41] Each year the report outlines progress in different areas, as well as listing lead times for the equipment.

The January 1993 report suggested that 12% of HM&E equipment lead times are expected to decrease in the future, while 11% are expected to increase. Low capacity utilization and decline in Navy orders will result in a considerable lead time decrease for some centrifugal castings (brass, steel, and CRES) and a modest decrease for boilers and low pressure compressors. Work force reductions and order backlog increases will increase lead times for electric motors, reduction gears and machine tools.

The report lists lead times for both repeat orders and initial orders. It differentiates between lead times for items ordered to government specs and items ordered to commercial specs, offering a basis for comparison. The statistics indicate that issue of utilization of

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41 NAVSHIPSO; Publication of Manufacturing Lead Times January 1993

commercial specifications is worthy of further study from the standpoint of shorter delivery times as well as the other considerations which have been previously mentioned such as acquisition cost.

Another issue related to manufacturing lead times is the stability of the lead time Figures over the years. Have lead times tended to drop or increase? NAVSHIPSO provided some historical trends for selected equipment types and components. It is not possible to generalize the lead time trends for all equipment, since for some equipment lead times have tended to decrease, while for others they have tended to increase. Without data regarding the critical path of a particular shipbuilding project it is difficult to judge the impact of these trends.

Highly fluctuating lead times represent a managerial problem. As was mentioned earlier in this discussion, long lead times (which are within reason and the scope of the project) are not necessarily a problem provided that they can be planned for. Highly fluctuating lead times make the production planning process considerably more difficult. Furthermore, shortening the lead time on an item which must be scheduled for late installation for other reasons is not valuable. This is especially true if the vendor delivers the equipment to the yard earlier than it is needed. Such an arrangement would add storage costs to the shipbuilding project and increase the likelihood of loss or breakage. Ideally, one hopes for a short lead time regarding the necessity to notify the vendor, but with a scheme for Just In Time (JIT) delivery to the shipyard. Insuring that equipment arrives at the yard AS SCHEDULED is important for the production planning process. While data regarding average lead time was available, data regarding lead time uncertainty was not. Lead time uncertainty should be a driving consideration.

The relationship between standardization and manufacturing lead time is unclear. Of even greater importance is that while manufacturing lead time can be planned for, little design or planning is possible without the Vendor Furnished Information (VFI) which details critical dimensions, weights, bolting arrangements and interfaces. Every shipyard surveyed in the course of this research pointed to the inefficient system associated with vendor furnished or other critical information as one of the leading causes of delays and designs which later prove to be very difficult and costly to produce. VFI delays are the result of a variety of factors. One of these factors is that some of the equipment procured is engineered for the application. That is to say, the equipment is not an "off the shelf" commodity, but is built specifically for the contract at hand.

While the relationship between standardization and manufacturing lead time is unclear, standardization's impact upon the flow of VFI is more intuitive and understandable. Standardization of critical characteristics without actually citing a standard source or physical product would be enough to alleviate many of the problems associated with VFI. The shipyard would know up front the critical dimensions, bolting arrangements and interfaces necessary for the design process to take place and incorporate producibility considerations. Until such industry standards exist, other solutions involving standardization of one form or another can be considered. Developing a standard design has already been discussed as an option which would alleviate the VFI problem, but at an often unacceptable cost. As has been mentioned previously, requiring currently supported equipment to be given preference would limit ILS cost increases. If this approach were combined with a successful effort to include the critical information associated with these equipment in a database and made readily available to those who need the information, designers could develop baselines which had the ability to accept the majority of the currently supported equipment. Embracing quality partnerships and option purchase strategies which begin where the FFG-7 strategy left off and take advantage of FFG-7 lessons learned would also quicken the pace of VFI flow. [42]

While MLT data exists, data regarding its importance or impact with respect to the critical path for ship production does not. For the reasons outlined above, it would be

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42 The reader is referred to :

Dickenson, Thomas; "Contractual Aspects for Standardization of HM&E Equipment in Naval Ship Acquisitions"; MIT SM THESIS; OE DEPT.; May 1993

for a more detailed discussion of partnering as a means to improve the VFI situation misleading to rank equipment based on lead time alone. At the time of this writing, statistics regarding the delivery of VFI and its impact on specific projects was not available.

## POTENTIAL ILS SAVINGS

The Naval Sea Logistics Center has established average statistics for equipment categories regarding population per APL, average number of parts per APL, average number of new parts per new APL, and average APL proliferation. These average Figures can be used to calculate procurement acquisition savings potential per year, the cost of provisioning per year, and the cost of National Stock Number Maintenance per year. Based on these calculations, the savings potential over a particular time frame can be calculated. It has already been mentioned that the Navy considers ILS costs to be a substantial problem. Standardization is one means of reducing this cost.

In the chapter on ILS costs, the NAVSEALOGCEN model was introduced. In this study, the potential for the equipment categories was calculated using the NPV concept with a discount rate of 10% and a five year time period. These Figures are somewhat arbitrary but are adequate for prioritizing the categories.

Figure 5.10 illustrates the results of these calculations. We find that over a five year period, if all APL proliferation were stopped, 712 Million dollars could be saved. It should be noted that if NPV was not introduced into the calculation, this savings Figure would appear to be 940 Million dollars. Appendix A includes these calculations. While the accuracy of the cost accounting is a matter of debate, the relative ranking of equipment should be adequate as a means of determining where potential exists. These calculations offer the following list of twenty equipment categories which represent higher ILS costs. Table 5.3 lists these candidates. It should be noted that the data is from 1992, and all values are in 1992 dollars.

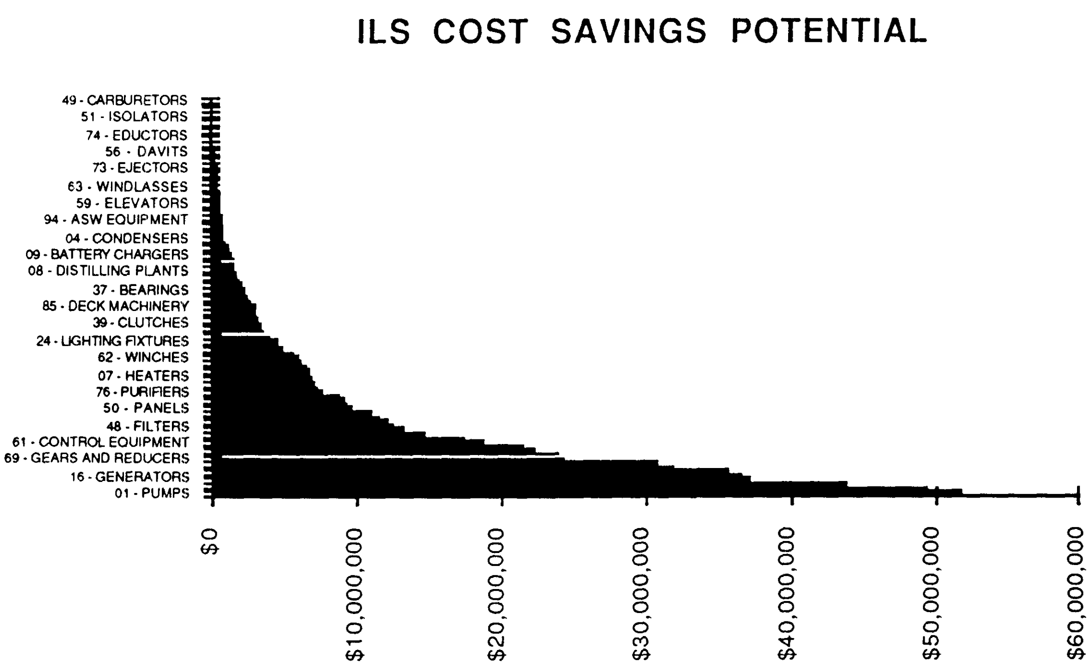


Figure 5.10 - ILS Cost Savings Potential

| | | | |
|---|---|---|---|
| 1) | 01-Pumps | 11) | 78-Couplings |
| 2) | 66-Engines | 12) | 27-I/C Equipment |
| 3) | 32-Refrigeration Equipment | 13) | 61-Control Equipment |
| 4) | 52-Hydraulic Equipment | 14) | 89-FF/Safety/Rescue Equipment |
| 5) | 16-Generators | 15) | 06-Compressors |
| 6) | 88-Valves | 16) | 43-Galley Equipment |
| 7) | 17-Motors | 17) | 48-Filters |
| 8) | 05-Turbines | 18) | 95-Yellow Gear |
| 9) | 69-Gears and Reducers | 19) | 21-Switches |
| 10) | 64-Firefighting Equipment | 20) | 14-Circuit Breakers |

Table 5.3 - Top Twenty ILS Candidates

## TECHNOLOGY TURNOVER - OBSOLESCENCE

Certain types of equipment, such as electronics, become obsolete more quickly than other types of equipment from a performance standpoint. Other types of equipment become obsolete from a cost standpoint. Technological advances may lead to new materials which can reduce the cost of production for components, or may lead to increased reliability/maintainability. Other technological advances may lead to items with reduced weight.

The acquisition process must have a procedure in place for contractors/designers to utilize unsupported equipment if the technology warrants it. A trade-off study must be facilitated which is as undisruptive and as quick as possible. Even if this trade-off study was as facilitated as possible, it would still require time. There is an incentive to minimize this disruption. One option may be for certain types of equipment, which have been shown to be highly likely to be obsolete or undesirable some time in the near future, not be concentrated upon for standardization efforts. For these equipment types, contractors should not be required to follow strict standardization guidelines, since utilizing a supported equipment could result in the use of an undesirable item or require extensive effort on the part of the contractor to limit the introduction of APL's for these equipment categories even though after extensive trade-off studies are performed it is highly likely that the conclusion will be to go ahead and introduce the new item anyway.

Data regarding obsolescence was not available for this study. This is an important aspect of the problem and should be pursued in more detail in future work in this area. The equipment categories targeted by this study should be looked at in this regard if contractors are to be required to pay close attention to the standardization effort.

## ADAPTIVE COSTS

Adaptive costs refer to costs incurred as a result of the use of a standard or supported equipment rather than an equipment selected precisely for the particular application. These costs are more likely to be high in the case of a strict standardization effort in which a standard is developed or the supply base is actually shrunk rather than merely limited by restricting the introduction of new APL's. These costs break down into two basic types:

- Costs incurred as a result of non-optimum performance
- Costs incurred as a result of the use of a "over designed" equipment.

The first of these, non-optimum performance costs, will be a result of extra costs for running off the optimum point for the equipment and possible extra maintenance or reliability considerations. Ideally, these considerations would be included in equipment selection decisions as part of the trade-off process. Furthermore, use of flexible standard mounting systems or modules would allow production cost and schedule savings to be achieved without strictly limiting the introduction of new equipment when adaptive costs may be high.

Costs incurred as a result of the use of "over designed" equipment may result more from an effort to develop standard designs than an effort to limit the introduction of new items of supply. These costs are a result of higher acquisition costs which may be associated with equipment designed to higher military specifications than may actually be required by the application. Such equipment may also be heavier or require more volume.

Adaptive cost data is difficult to acquire. A detailed study of each equipment for each application on a case by case basis is required for each project. This thesis did not attempt to quantify the adaptive costs associated with standardization efforts. Qualitatively, the less restrictive the standardization effort is, the lower the risk of high adaptive costs. This is an argument in favor of limiting the introduction of new items of supply and requiring intraship and class standardization trade-off studies for new ships up front, while limiting focused fleet-wide standard equipment development (i.e. eliminating items from the supply system and mandating the use of a standard family of equipment designed or contracted by the Navy) to extreme cases when maintainability, reliability and performance are deemed to be at high risk.

## PRODUCIBILITY-CRITICAL PATH IMPACT

While many of the aspects discussed so far impact the production costs associated with ship structural assemblies and installations for the equipment, there are other considerations which also play a role. In the discussion of manufacturing lead time, the importance of acquiring information regarding which equipment is on the critical path was mentioned. Equipment installations may be on the critical path due to location within the ship or other considerations. Speeding the installation of these equipment is more important than other equipment because it is the critical path which dictates the schedule. While slack time exists in other areas, those items on the critical path must be installed at a certain time or the entire schedule will be impacted. For these reasons, it is important that statistics regarding the scheduling of equipment installations be developed in order to pinpoint equipment types for which installation and structural assembly producibility design studies would provide the greatest benefits. As was already mentioned, knowledge regarding the equipment up front is the best weapon against needless schedule delays if the knowledge is used to develop a producible design.

Just as speeding equipment installation is more important for some equipment than others due to the make-up of the critical path, certain equipment installations are traditionally more costly than others regardless of the equipment installation being located on the critical path. It is therefore important to collect statistics regarding the cost of installation for equipment types. This cost would include design and engineering costs, construction costs, part travel time throughout the shop and so on. Armed with information regarding which equipment types are traditionally very costly with regard to their installations, decisions regarding the development of standard and less costly method mountings, foundations or modules can be made.

Unfortunately, data regarding timing and costs are not available at this time. Shipyards are understandably hesitant in releasing this information because they regard it as proprietary.

Unfortunately, even if they were willing to release all the data they had, it would not be adequate. The shipyards themselves understand the shortcomings of their cost estimating capabilities and their knowledge regarding the movement of material throughout the yard and the timing and costs associated with their processes. The Navy and industry should work together in gathering this data, as it is beneficial to all involved.

# CHAPTER 6: AN APPROACH TO PRIORITIZING THE CANDIDATES

Once all the candidates have been individually studied with regard to each of the criteria, the next task is to prioritize these candidates. A number of criteria have been presented, each with a prioritized list of equipment associated with it. The task ahead is to conduct a broad trade-off analysis for all the criteria and candidates. One way of visualizing the situation is to consider each criteria as having a set of equipment which are highly ranked according to the criteria. The intersection of these sets represent standardization opportunities which may save money in more than one way. Equipment which is highly ranked according to all or most of the criteria may represent better opportunities than others, assuming that no single criteria is orders of magnitude more important than another.

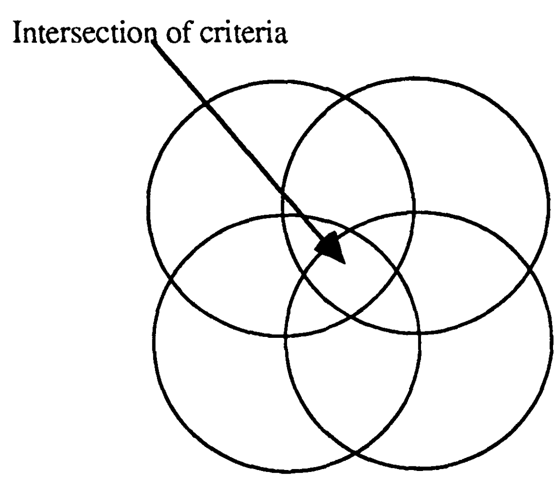


Figure 6.0 - Criteria Intersections

This approach is adequate when there are few criteria, each having equal importance in ranking the candidates overall and when one is interested in equipment which are highly ranked (top 10 for example) on as many criteria as possible. Due to the lack of statistics regarding some of the more important criteria presented in the preceding chapter, this is the method which was used to select a case study to be presented in this thesis. A more rigorous approach is to use the Analytical Hierarchical Process (AHP).

AHP allows all the candidates to be ranked and prioritized according to weighted criteria. The approach organizes complex problems into a multi-dimensional decision matrix, or framework, as illustrated in Figure 6.1.

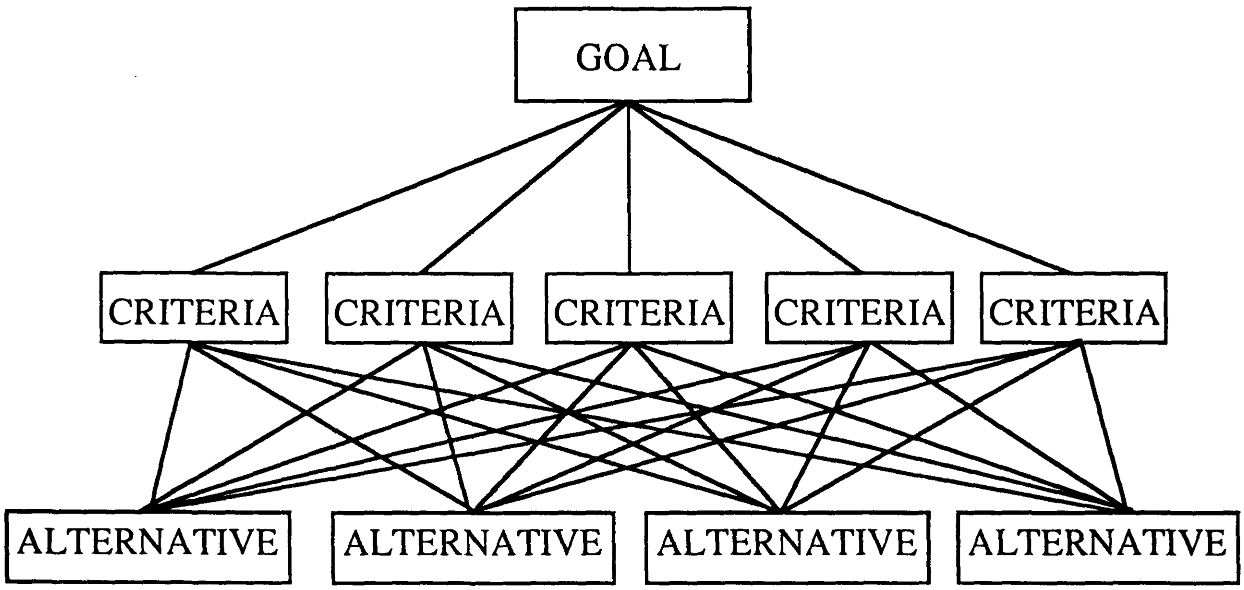


Figure 6.1 - Decision Matrix

In our case, the goal is a prioritized list of equipment categories. The criteria are those outlined in the preceding chapter, and the alternatives are the equipment categories themselves. AHP allows both objective and subjective judgments to be modeled. AHP also has the advantage of allowing the criteria to be weighted, skewing the prioritization in accordance with these associated weights. If multiple decision makers are involved, each with its own set of priorities with regard to each of the criteria, AHP allows the synthesis of all the decision makers' judgments. A further advantage to many computer AHP systems is that they allow some uncertainty with regard to qualitative judgments. Rarely are qualitative judgments certain or perfectly rational, and a little uncertainty does not hinder the application of AHP. Computer programs, such as Expert Choice by Expert Choice, Inc., allow some uncertainty and provide the user with an inconsistency ratio (IR). If the IR is low (below 0.1) then the results of the analysis are generally acceptable.

Once the goal has been identified, as have the alternatives and the criteria by which to judge them, these criteria must be weighted according to their relative impact on the prioritization. Ideally all the criteria could be judged in terms of dollars or time savings, but this is not possible. Some personal judgment is necessary to rank the importance of these criteria relative to each other. Differences in opinion regarding these relative weights would result in different prioritization. While the opinions of a large number of experts have not been incorporated at this time, it is important to point out that such an incorporation is not difficult once the information has been collected. The AHP model framework discussed here could be used in the future once these opinions have been catalogued.

As has been pointed out previously, statistics for equipment categories regarding many of the criteria were not available at this time. Before a more meaningful and broad analysis can take place, more information regarding these statistics must be acquired. Furthermore, while statistics regarding equipment categories were used and presented here, it would be considerably more accurate and meaningful to do this type of analysis at the LAPL level, although this would take significantly more time. Rather than present a prioritized list of equipment categories which may not be accurate and does not reflect many of the more important considerations, the decision was made to create a case study for a more detailed analysis based upon an equipment category which showed promise in many areas for which statistics were available.

# CHAPTER 7: GENERATOR SETS - A CASE STUDY

A review of the of equipment category statistics presented in Chapter 5.0 will reveal that the generator equipment category is one of the categories which is worthy of study in greater detail. Other categories which also show promise include small fittings, Valves, and lighter electrical items which are used frequently throughout the ship and are also important by several other criteria. It was decided to present the generator category since it is more easily associated with other equipment as a system and is therefore a potential candidate for a module design. Discussions with shipyard personnel also indicated that generator set installation is one of the more costly and time consuming machinery installations.

The Generator equipment category was ranked highly with regard to potential ILS savings, uniqueness, APL proliferation and maintenance and reliability concerns. Discussions with contractors indicated that VFI and Lead Time were concerns with generator sets and that the installation of these systems was often on the critical path and therefore standardization would have a potential impact upon producibility. Generator sets may be a candidate for the ATC program as well. HEDRS was used to study this equipment category in more detail.

The Generator equipment category contains 13 LAPL's. One of these corresponds to GENERATOR SETS, which were believed to have the greatest potential. Generator sets were catalogued as having 450 APL's which loosely translates into 450 different items in the supply system. These 450 APL's were found to have a total of 4373 applications. Each APL can be further categorized by AC/DC, fuel, turbine and so on. Of these, 290 APL's were associated with AC Generator Sets.

Using HEDRS it was found that 90% of AC GENSET APL's are installed in significantly less than 10 ships. Furthermore, 74% of AC GENSET APL's have fewer than ten total installations in the fleet. We also find that Generator Sets are manufactured in the United States. The existence of U.S. manufacturers indicates that there is hope for maintaining a U.S. industrial base for this technology. Figure 7.0 illustrates the number of ships each AC GENSET APL is installed in. Figure 7.1 illustrates the total fleet population of each APL.

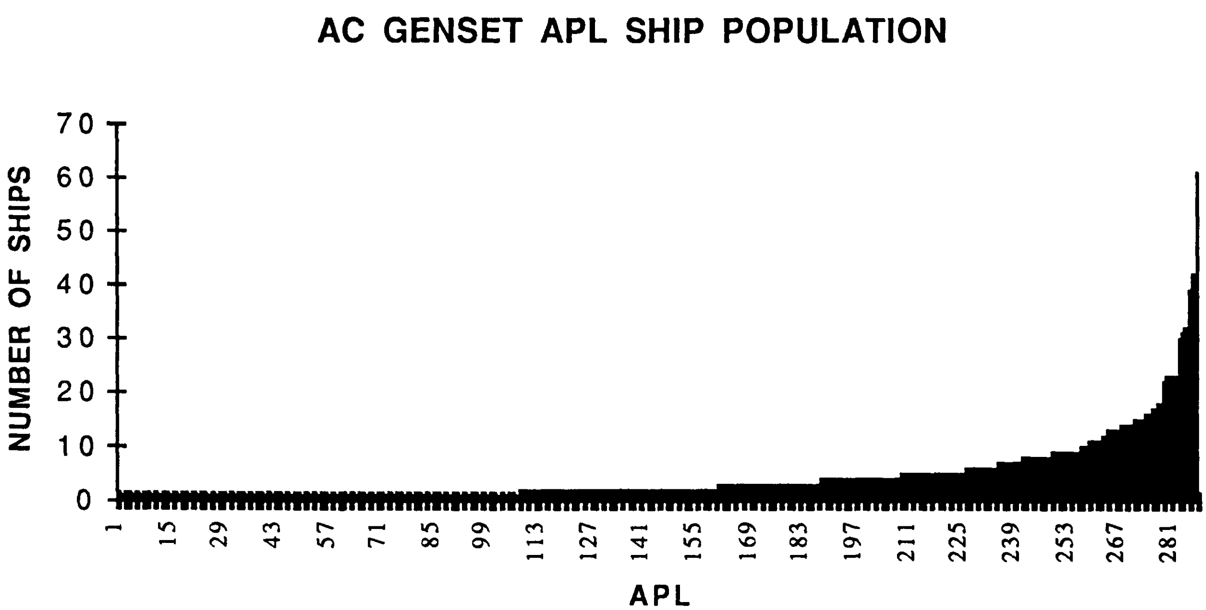


Figure 7.0 - Ship Population

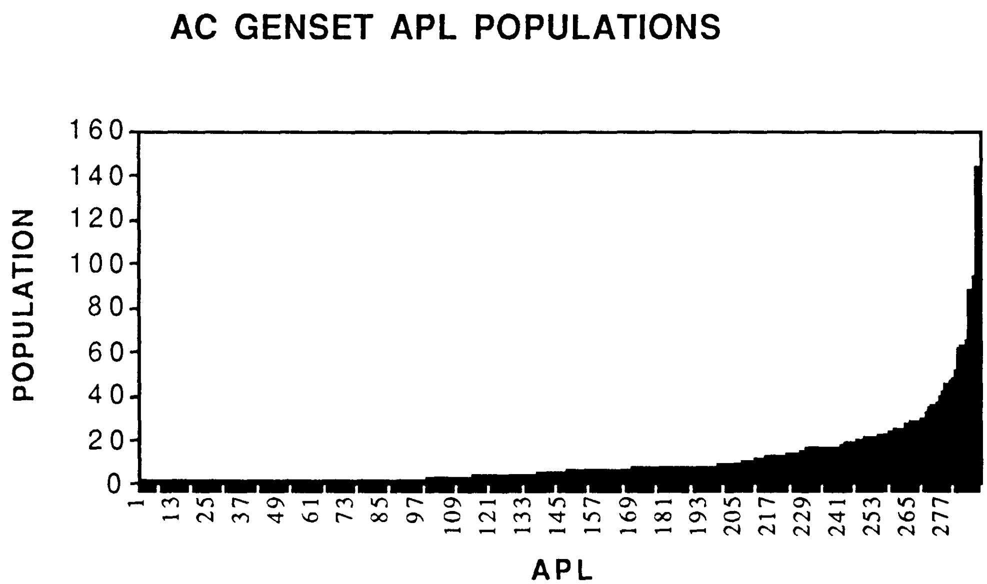


Figure 7.1 - Fleet Population

After looking closely at the population statistics for Generator Sets, HEDRS also makes it possible to study the function these APL's perform in order to look for potential commonality. A scatter plot was created which illustrates RPM vs. KW OUTPUT for each APL. By studying Figure 7.2, one can look for envelopes of combinations of RPM and KW for which many APL's are serving the same purpose. These situations should be studied in greater detail. If several APL's are serving the same purpose, one should ask several questions:

- Is there a good reason for this? Do these APL's represent the same equipment with only minor modifications? Are different equipment needed to satisfy different requirements which are not captured in such a simple scatter diagram? In many cases the answer to these questions will be yes.

- Are each of the APL's in the cluster low application APL's or do each have many applications in the fleet? If there are many applications, it may be less problematic than if many APL's serving the same function each have few applications.

Observing Figure 7.2, we see that there are areas where a number of APL's appear to be performing similar functions.

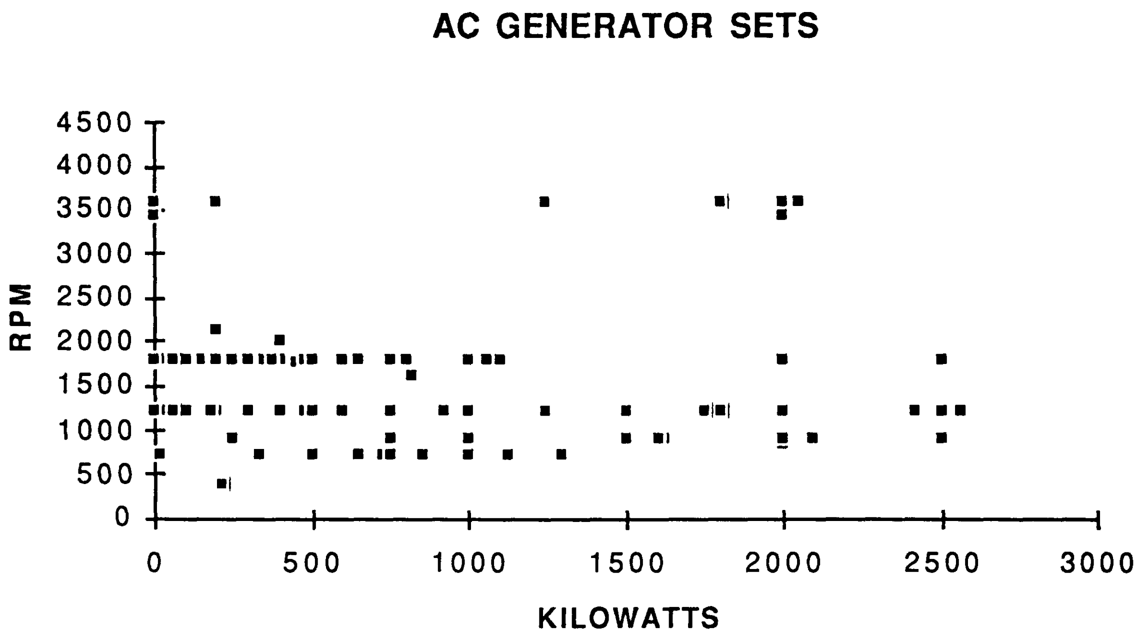


Figure 7.2 - AC Generator Sets Scatter Diagram

One must examine the potential for eliminating APL's from the future supply system by studying the areas of overlap more closely. While the decision may be made to try to eliminate this redundancy and commonality, in conjunction with those efforts, data regarding critical dimensions and VFI should be studied to develop guidelines for standard foundations or modules which can accept a variety of supportable equipment. It has already been mentioned that this data is not adequately represented in HEDRS at this time. Data regarding some generator sets available from two manufacturers was gathered and plotted to demonstrate the concept of envelopes. Information regarding Wartsila and MAN B&W generator sets running at 720 RPM and 60 Hz was studied. The data regarding generator set width vs. power is presented in Figure 7.3 to illustrate that over a specified power range, an envelope of anticipated dimensions for the manufacturers studied exists. If the majority of anticipated manufacturers and models for a particular class of equipment was studied in a similar manner for all critical characteristics, flexible installations could be developed.

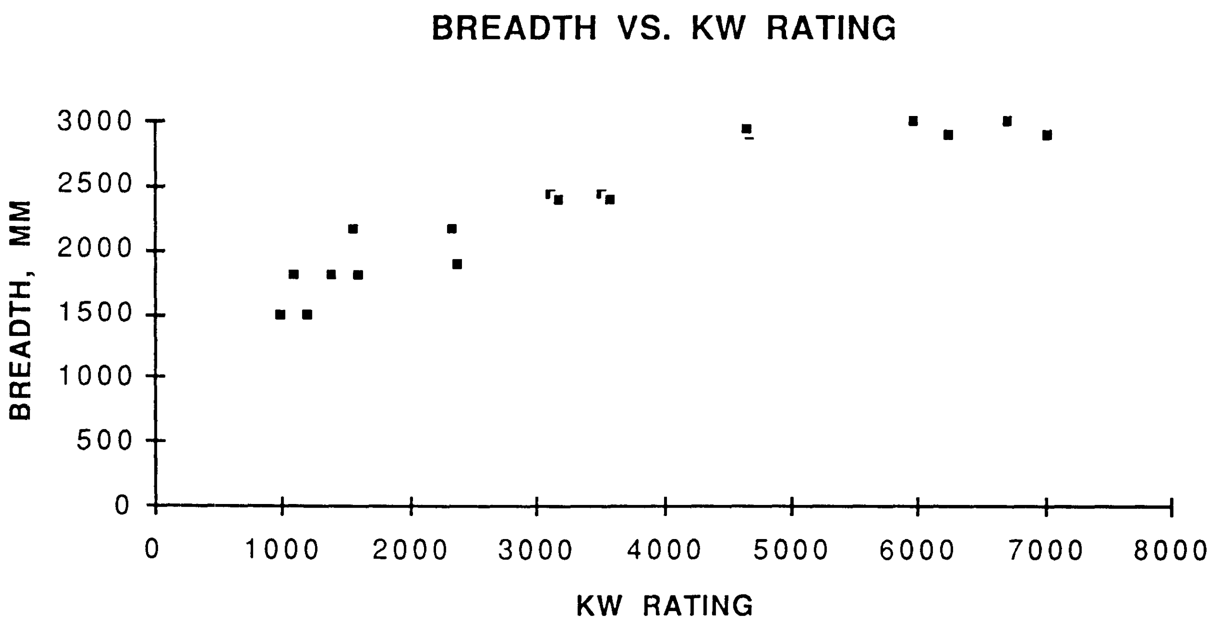


Figure 7.3 - Genset Dimensional Envelope

# CHAPTER 8: THE MOVE TOWARDS MODULARITY

Having discussed standardization of equipment piece-parts, equipment and ship structural details and foundations, the next logical step would be to look at groupings of related equipment and structure. Opponents of standard products voice the argument that performance will be degraded through off-optimum design points. While each component has not been optimized for a particular application, as a system the final product can meet customer requirements at lower costs. Furthermore, flexible design and production approaches can provide a great deal of customization of these baseline modules. This concept, the production of custom products from common building blocks and processes, is often referred to as "mass customization".[43] There are many examples of successful mass customization in a variety of industries.

Mass customization is a response to the realization that consumers no longer want mass produced products. As communication has become easier and faster, and changing customer requirements come streaming into the office, product life cycles have decreased with consumers expecting their requirements to be embodied in the design of the products they buy. Another important point is that many industries have matured to the point where the machinery involved in its production could be purchased by many other companies in many other countries. Completely standard end-products are easily reproduced by completely standard and common machinery. This led to countries with low wage rates having the upper hand. Furthermore, because manufacturing was new to these up and coming companies, they did not

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43 The term "mass customization" was coined by Stan Davis in his book, Future Perfect. The concept was studied in greater detail by B. Joseph Pine II in his MIT Leaders for Manufacturing thesis (1991) and his subsequent book:

Pine, B.P.; Mass Customization: The New Frontier in Business Competition; Harvard Business School Press; Boston; 1993 suffer from the same paradigms and bureaucracy of U.S. firms. They saw an opportunity not only to compete on wage rates, but also to refine the manufacturing process to reduce cycle times and construction costs. U.S. firms are faced with no choice but to compete by streamlining manufacturing processes and to provide what the customer wants, when the customer wants it. Shipbuilders have always been faced with customers who demand a highly specialized product. For the U.S shipbuilders to compete, they must achieve the goal of producing ships which meet the customer's requirements and can be built quickly and efficiently. This can be accomplished by employing flexible manufacturing systems, standard processes, baseline designs and standard interim products (modules) utilizing equipment and supplies acquired through effective agreements with vendors which can be adapted to a particular requirement or mixed and matched to produce a product which the customer sees as meeting their needs.

"The best method for achieving mass customization - minimizing costs while maximizing individual customization - is by creating modular components that can be conFigured into a wide variety of end products and services. Economies of scale are gained through the components rather than the products; economies of scope are gained by using the modular components over and over in different products; and customization is gained by the myriad of products that can be conFigured."[44]

Karl Ulrich of MIT's Sloan School has done significant research into discrete product modularity. Karl Ulrich has developed a typology which classifies six types of modularity.[45] This classification system is described in Mr. Pine's book, and those types which are relevant to this discussion follow:

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44 Pine, B.P.; Mass Customization: The New Frontier in Business Competition; Harvard Business School Press; Boston; 1993

45 Mr. Pine's descriptions are based upon:

Ulrich, Karl; Tung, Karen; Fundamentals of Product Modularity; working Paper #3335-91-MSA, Sloan School of Management, MIT, September 1991

Component-Sharing Modularity refers to the same component being used across multiple products to provide economies of scope. This form of modularity is useful in controlling a proliferating product line whose costs are rising even faster than the number of products. This type of modularity reduces costs while permitting variety and faster end-product development. One example of this type of modularity is found in General Electric's program to reduce the costs associated with its circuit breaker production by replacing 28,000 unique parts with 1,275 components shared across 40,000 different circuit breaker box designs.[46] Another example of this type of modularity can be found at Komatsu, a heavy equipment manufacturer which found its costs increasing dramatically throughout the 1970's as its product variety increased to meet the challenges of different markets throughout the world.[47] Komatsu chose to standardize several key modules which could be shared across its product lines. They found that this successfully allowed them to provide a variety of products which met their market needs. The Navy's Affordability Through Commonality initiative is an example of a plan which will utilize component sharing modularity in Navy ship design and production, as evidenced in the ATC Policy Statement:

> *"Naval ships will be designed and built using common modules comprised of standard components and/or standard interfaces. These modules will be used across ship types and will be integral with standardization, zonal systems architecture and generic build strategies.*
>
> *This policy of increased commonality is intended to reduce the total cost of ownership and is the cornerstone of the affordable fleet."* [48]

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46 Mr. Pine's cited example is based upon:

Dumaine, Brian; "How Managers Can Succeed Through Speed," Fortune, February 13, 1989

47 Mr. Pine cited this example from:

"Komatsu: Ryoichi Kawai's Leadership," Case #390-037 Harvard Business School

48 Bosworth, CMDR; cover letter accompanying the report:

The ATC program is the Navy's latest standardization and modularity effort. It is discussed in greater detail later in this chapter.

Cut-to Fit (fabricate to fit) Modularity refers to a system in which one or more of the "standard" components is variable within pre-set limits. One example of this type of modularity can be found within a subsidiary of Matushita of Japan, the National Bicycle Industrial Co.[49] Matsushita provides its customers a bicycle tailored to their individual needs through the use of flexible modules. They are capable of producing 11,231,862 variations on 18 basic models in 199 color patterns. The customer provides the shopkeeper with preferences and key dimensions, which are then entered into a computerized database which searches for the appropriate components, generates the construction drawings and work instructions and numerical control which is then sent on to a highly automated production system. Skilled workers then assemble the finished components, perform any necessary custom detailing and send the final product on to the customer. In ship production, where customers have historically demanded customization, the ideal of fabricate to fit modularity should serve as a model and basis for continued research and development.

Bus Modularity refers to a standard interface system which allows different components to be quickly assembled. The automobile industry has taken some advantage of bus modularity. GM has utilized a modularized body and variety of components which quickly attach to a basic chassis and wiring harness. Both Chrysler and Ford are making headway in this area. Nissan is looking at taking the concept even further utilizing a variety of modularity concepts to produce custom cars. In ship production, bus modularity is a more

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A Strategic Plan for the Affordability Through Commonality Project; December 1992; Decisions and Designs, Inc.

49 Moffat, Susan; "Japan's New Personalized Production," Fortune; October 22, 1990

complex issue which is not easily recognized as a possibility within the traditional structural paradigm. Research into the Generic Build Strategy (GBS) concept represents a step in this direction. GBS represents an attempt to define a production approach for a particular ship type which serves as a baseline production plan which can be used to facilitate efficient production of a ship in a variety of shipyards. The Navy has looked into the GBS as a means to reduce construction times for its ships within the same class which are produced in a variety of shipyards. In the future, the technology may be available to utilize structural systems which emphasize quick assembly and allow equipment to be method mounted[50] directly to these novel structural systems for primary ship structure.

Sectional Modularity refers to the configuration of a number of standard components in arbitrary ways through standard interfaces. Lego toy building blocks and the many similar systems are an ideal example of this approach. While bus modularity stresses the quick attachment of standard components to a standard structural system, sectional modularity removes the need for the primary structural system by incorporating it into the components themselves, which then can be assembled together. The engineered panels produced by Balley Engineered Systems are an example of a system which incorporates sectional modularity.[51] Balley utilizes a pre-engineered panel to create a dramatically wide variety of end products such as refrigerated warehouses, environmental rooms, and walk-in coolers. Balley has developed a single process which is capable of forming a variety of panel types and geometries. Vibtech, Inc. has researched a ship structural system concept which incorporates a similar panel construction approach which would facilitate method mounting attachments directly to the panels themselves through the use of standard method mountings. While it may be difficult to envision an entire ship taking advantage of sectional modularity at this time, one can envision

50 Method mounting refers to the use of a standard interface which emphasizes quick assembly, such as double flux studs

51 Pine, B.P.; Mass Customization: The New Frontier in Business Competition; Harvard Business School Press; Boston; 1993

zones made from standard components which fully define a three dimensional space and provide standard structural interfaces and input and output interfaces for electrical and fluid distributive systems for many parts of the ship.

Many of the companies which have taken advantage of these concepts have discovered the added advantage of reconfigurable products. Products can be easily recycled or reconfigured at the customer's request. Computer manufacturers provide upgradability through bus modularity. Nissan is exploring the "evolving car" concept which would permit owners to bring their car in to be quickly upgraded or customized. Similarly, these approaches could provide shipowners with a ship which could be more efficiently reconFigured to meet changing requirements. A tanker owner, for example, could have a ship built at a yard and know ahead of time that it could be expanded or shortened and still provide adequate performance, stability and essentially be pre-approved by a classification society. With all of these concepts, it is important to know what the customers or market want. The Navy's Variable Payload Ship (VPS) concept is another example. VPS is discussed in more detail later.

Different ship types may be broken down into obvious zones. For example, a tanker may be broken down into its machinery space, accommodations space, the stem and steering gear, propeller shafting and housing, bow/forecastle, tank compartments and the deck and its associated machinery. This approach is not new. It has been used successfully in this country towards the development of standard designs and design families in the past and is currently used in other countries like Japan and Germany.

The Bethlehem Steel Corporation produced a standard family of tankers in the 1960's and 1970's.[52] In the late 1950's a series of 12 identical 35,700 DWT tankers were built for a variety of owners. They offered few options with these ships, but for all practical purposes

52 Gallagher, Neil; "Commercial Substitution as a Means to Build the Industrial Shipbuilding Base"; MS Thesis, MIT Ocean Engineering, 1993

the products were identical. In the 1960's the market changed and larger tankers were demanded. A 62,000 DWT tanker was developed based upon the earlier ship. The major difference was a new and more powerful propulsion plant and a lengthened and deepened hull. The same machinery was used when possible, and when that was not practical, the same prior vendors were used. The overall layout of the ships was kept identical. Three of the 62,000 DWT tankers were built, and then the size was increased further to 70,000 DWT by adding tanks at the parallel midbody. Six of these ships were built. The trend towards larger tankers continued and Bethship saw a demand for 120,000 DWT vessels, of which four were built. In this case more powerful propulsion plants were installed in an identical engine room. Again, the ship was a lengthened version of the previous ship, but with a new bow design. In the early 1970's the largest ships of the "series" were built at 265,000 dwt. Bethship successfully employed the modularity concept, although in the beginning of the process it is not clear that the outcome had been envisioned. They were able to keep their engineering cost low through the repetitive use of baseline designs. Production costs were kept low through the repetitive use of standard components and processes. Relationships with the vendors provided lower acquisition costs and timely delivery. Use of the same or similar equipment and sole source vendors further simplified the engineering and design and assured customers of significantly reduced logistics and life cycle costs, especially for those customers who purchased a number of ships. While this success story illustrates the feasibility of the concept, planning for the variety of ships up front would provide even greater benefits and allow the shipyard to develop an optimum strategy for building the ships. Detailed planning, the application of new technology and a move closer to the ideal of "mass customization" would provide true flexibility and a final product tailored specifically to the customers needs.

While the general approach to looking at natural ship divisions is not new, advances in manufacturing processes and procedures and a better understanding of production have sparked renewed interest in the approach. Recognizing that a shipyard is generally not in control of wage rates and material costs, but does have some control over labor hours, component transport times and throughput rate, there is an incentive to adopt a design and production approach which emphasizes production improvements.

Conventional outfitting, or the planning and implementation of production plans which were functionally based (i.e. a system would be installed at a particular time, even if it was distributive and located in a variety of places throughout the ship), inevitably leads to delays and interferences between trades as discussed earlier in this thesis. Conventional outfitting stresses on-board installation of each piece-part which is the reason it is so inefficient. Even so, conventional outfitting does have an advantage with regard to accuracy control requirements. Since final assembly of parts did not occur until they had been brought to their installation location, final adjustments could easily be made to insure that they fit. By contrast, pre-outfitting stresses the outfitting of large structural sections or pallets within a shop prior to erection onto the hull block. While this is a more efficient system, it places more stress on the planning function. Furthermore, it places stricter requirements on tolerances. Since the outfit package is being built in the shop according to the ship's drawings rather than at the installation site, it is important that the final product (the package and the structure to which it is to be attached) actually match the drawings. While smaller work packages can be built which have some extra material at the interfaces to be trimmed at the site to suit, this trimming process requires time and effort. Clearly, accuracy control is worthwhile if it can be achieved at a cost below the expenses associated with the additional re-work necessary to make an inaccurate piece fit. Accuracy control becomes an even more important issue as the size of the modules increase, becoming more influential to the overall ship structure. In the earlier section on standards as benchmarks in Chapter 2, the necessity of compiling statistics regarding variations in an effort to develop tolerance standards was discussed. In Chapter 2, variations discovered in the FFG-7 class of ships were presented. These statistics indicate that modules must be designed not only to allow flexibility with regard to equipment, but with regard to integration with the ship as well.

Zone outfitting refers to an approach in which everything within a pre-defined three dimensional space is planned and outfit based upon its location rather than its system. Zone outfitting was discussed in more detail in the overview of standardization in shipbuilding. Clearly, the planning required for this approach is significantly more involved than that associated with a systems based approach. This is due to many factors, one obvious issue being that at some point during the design, all the systems are defined as systems by the very nature of their individual design processes. Inevitably they will be tested and operated as systems. Zone outfitting requires another set of drawings and instructions to be developed based upon location, rather than system. As the system design progresses or changes, these zone drawings and production plans must change with them. This is an important point most of all for distributive systems, which as the name implies are spread throughout the ship. It has been shown in many other studies that the potential savings of such an approach generally merits the up front planning costs.

Modularity is more easily and obviously applied to commercial ships, and these will be discussed to introduce the concept. Traditionally, the first major milestone in this approach is to determine the ship types and sizes for which major patterns/panels could be developed for each of the obvious zones as outlined above. This is essentially a market trend issue. One wants to concentrate effort on ship types and sizes which will be marketable. It is important to incorporate as much flexibility into the designs as is feasibly and economically possible to allow them to easily be applied to unforeseen applications. Ideally one would like to develop a set of common building blocks from which custom and highly specialized products could be developed. This is especially true in the shipping industry, in which shipowners often demand specialization if they can get it at a reasonable price.

After a market survey has been completed, the results are then used to define an envelope of anticipated customer requirements for the targeted ship types. This envelope would define such things as speed ranges, size (cargo) ranges, and other major gross characteristics and constraints. Figure 8.0 illustrates a notional example of how basic ship variations can be used to cover such an envelope of requirements.

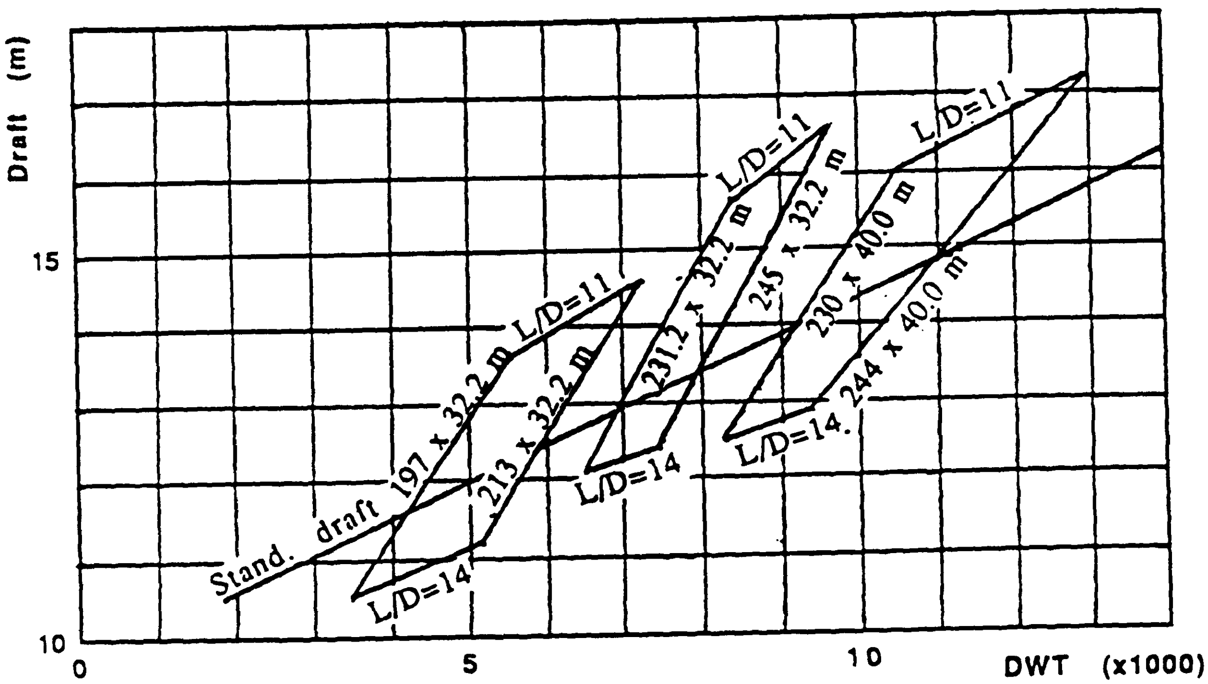


Figure 8.0 - Base Ship Variations[53]

53 Figure from the short course on Advanced Ship Production, Professional Summer at MIT 1992

After defining the envelope of requirements which are to be satisfied by the "standard" series, the next task is to define major design elements which can be adjusted and "mixed and matched" to fill the requirement envelope. For example, a flexible standard series of stern propulsion units could be developed which cover the range of power required to propel the anticipated ship types and configurations. The concept of a standard propulsion plant is not new, and is currently being looked at closely by Wartsila Diesel. Wartsila is marketing its expertise and capability to develop and produce propulsion modules ranging from palletized systems to entire stern modules. The company has recently signed an agreement with the Babcock and Wilcox company in an effort to bring together the expertise and manufacturing capability necessary to develop, produce and service propulsion and generator set machinery and modules which they hope to see utilized in U.S. Sealift construction as well as future commercial construction. Wartsilla developed the PROPAC fully integrated propulsion system module. Now they hope that, together with Babcock and Wilcox, they will develop and build complete ship propulsion modules with all machinery and controls in place ready to be delivered to shipyards anywhere in the world. They are also willing to manage the building of these modules at the shipyard itself if this proves to be advantageous for the yard.

Associated with each of these propulsion modules could be accommodation space modules which correspond to the crew sizes anticipated for the propulsion modules and their associated ship types. Tank compartment and/or container hold modules could be developed. A set of bow/focsle modules could be developed which ideally would be applicable to all the anticipated ship types. It is likely that these modules would need to be not only "stackable" lengthwise at the parallel midbody, but would need to be expandable to adjust the ship's beam. One option for accomplishing this is through the use of a variety of wing tank modules. This could be necessary for a variety of reasons, stability and straight/canal requirements being some of them. This would also allow cargo capacity to be a function of both length and beam rather than length alone. This would facilitate satisfying the envelope of anticipated customer requirements.

An effective shipbuilder may have several standard arrangements, or patterns and panels, in a computerized library from which new ship designs could be developed. All the production planning and estimating would be developed for these baseline designs as described in the earlier overview of standardization. For example, several "standard" machinery arrangements may be on call for different propulsion requirements. This would be tied together with a database of preferred equipment. As equipment was selected, the standard arrangement would become more detailed to adjust for any differences in equipment dimensions or interfaces. Using the previously described standard task blocks, such an ideal system would automatically begin the process of describing the work necessary and developing work packages for completion of the space defined by the arrangement as well as be capable of detailed cost estimating based on cost data available in the database. Such a system, when used in conjunction with automated manufacturing processes such as Computerized Numerical Control (CNC) machines, could have associated with each pattern a set of programs necessary to run the automated equipment to manufacture the associated parts. Recent advances in manufacturing and the trend towards Flexible Manufacturing Systems (FMS) could provide benefits with regard to production time and costs when used in conjunction with such a database, and still provide the flexibility necessary to produce custom products (modules) from a standard starting point. While true FMS has been adopted to varying degrees in a variety of industries, it is still not an entirely mature process. FMS has evolved from the "production cell" concept, which was itself a move away from the traditional process oriented shop.

In the traditional method of manufacture, shops were arranged according to process. This paradigm was very similar to the conventional outfitting outlook which emphasized function over location. The traditional method of manufacture had the advantage of providing trained personnel on familiar machines collocated in one space, just as functionally based outfitting had the advantage of highly specialized experts working on installing a system very familiar to them. This generally meant that the specific process being accomplished, drilling or boring for example, was generally accomplished efficiently. Unfortunately, rarely does a part or component require a single process. This meant that in a traditional process oriented workplace, a part or component had to travel throughout the workplace in order to have all the processes it required accomplished. This transportation time represents a tremendous cost. Furthermore, it promotes part loss/misplacement. This is entirely analogous to the problems associated with conventional outfitting. Rarely is a ship system located in one space, and the time lost in sending multiple trades tracing the system throughout the ship outweighed the advantages the approach had. The author has seen these problems firsthand in a number of shipyards. A step away from this traditional and costly approach is the assembly line or transfer line approach, in which the machinery necessary to accomplish all the tasks associated with a particular part are arranged sequentially with the part moving from one machine to the next. While this minimizes travel time, it typically requires the parts being constructed to be standard in nature and for the machinery to be utilizing many tools specialized for the part in question. The dedicated machinery can no longer be used for anything else. This is clearly poorly suited for shipbuilding.

Another approach is the organization of a shop into production cells. Each production cell would have a number of machines capable of performing the processes associated with a particular type of component, but the machinery is not dedicated for a specific design. This approach also minimizes transport time since all the necessary machinery is collocated, but provides more flexibility. The planning for what type of machinery should be included in a production (manufacturing) cell should incorporate the "Group Technology" concept. Group Technology (GT) is defined as a means for improving productivity by classifying parts according to their common characteristics and production processes. GT began to evolve in several industries in Europe around the turn of the century. It was not until 1959 that the term Group Technology was actually used to describe the manual recording and classifying of parts by production process in card files and catalogues.[54] With the introduction of computers in the 1970's, GT has become widespread in many industries and has, not quite as quickly, been utilized to some extent by U.S. shipbuilders. By performing this classification function, statistics regarding the number of parts requiring similar processes are developed. These statistics should guide the planning of production cells. By performing this function, the shipyard is able to more effectively distribute the work among its machines and labor. Figure 8.1 illustrates the production cell concept and demonstrates that transport time would be reduced as compared to the process oriented shop.

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54 Kalpakjian, Scrope; Manuacturing Engineering and Technology; Addison-Wesley Publishing Company, MA; 1992; page 1186

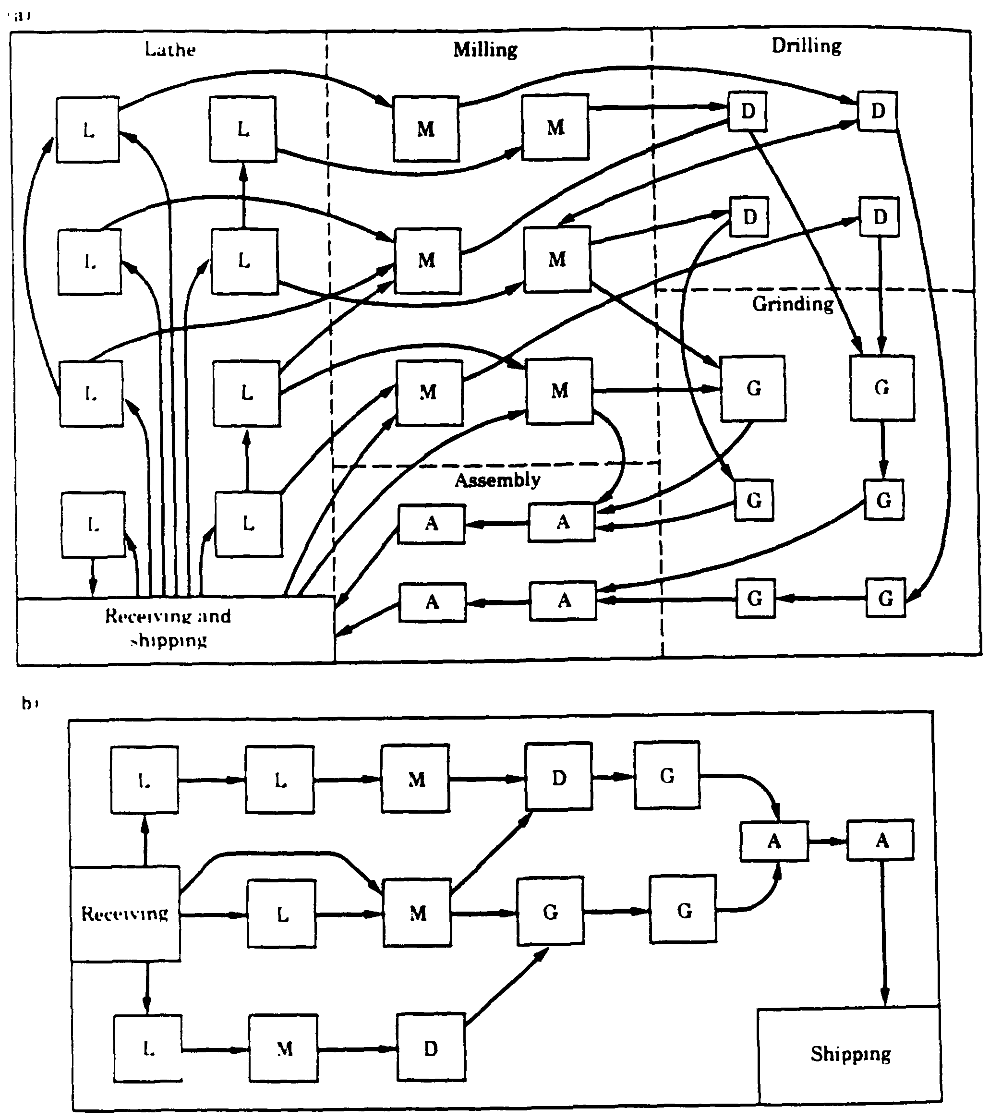


Figure 8.1 - Process Oriented Shop vs. Production Cell Shop[55]

55 Figure from:

Kalpakjian, Serope; Manuacturing Engineering and Technology; Addison-Wesley Publishing Company, MA; 1992; page 1188

Flexible Manufacturing Systems (FMS) are essentially a move toward an ideal automated production cell. FMS refers to a highly automated system, in which similar products are anticipated to be built on a scale which can justify the set-up costs. With FMS, the component is automatically carried throughout the production cell or series of production cells and the machinery in these production cells is numerically controlled. An FMS system would incorporate Adaptive Control (AC), or the ability for the machine or controller to automatically adjust to changing operating conditions or mishaps. While the FMS approach is not entirely mature, the production cell approach with varying degrees of automation has been used successfully throughout many industries, including shipbuilding.

IHI of Japan has a system in place which takes advantage of some of these modularity concepts, and has been using it in ship designs since 1987. IHI's Future-Oriented Refined Engineering System for Shipbuilding Aided by Computer, or FRESCO, integrates standard modules and arrangements with information regarding availability of equipment.[56] It also produces drawings and production planning information as described in the discussion of production planning standards. For example, collections of fittings to be assembled separate from the hull structure as outfit units are represented by machinery and piping dimensions which are frequently encountered, but these dimensions are automatically updated once the actual equipment has been selected from the database. The output includes material definitions and work instructions for pipe-piece and outfit unit assembly work, and this information is linked to the benchmarks which estimate man-hour requirements. As of February 1991, seventy modules were implemented in FRESCO. Even more (150) are expected to be available in the near future and will include classifications such as equipment modules and piping modules. Human engineering aspects could be integrated into the program such that appropriate clearances are generated for walkways, handrails, controls and displays.

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56 Chirillo, Louis; "Flexible Standards: An Essential Innovation in Shipyards"; Journal of Ship Production; Vol. 7, No. 1; Feb 1991, pp. 1-11

These standard arrangements represent modules and zones. There is an opportunity to identify modules and zones which may be applicable to a range of ship types. Figure 8.2 Illustrates this modular approach. By studying equipment characteristics, and moving progressively from a single item to an item and its associated equipment, modularity begins to take shape. The criteria developed for evaluating equipment standardization would also be applicable at the module level.

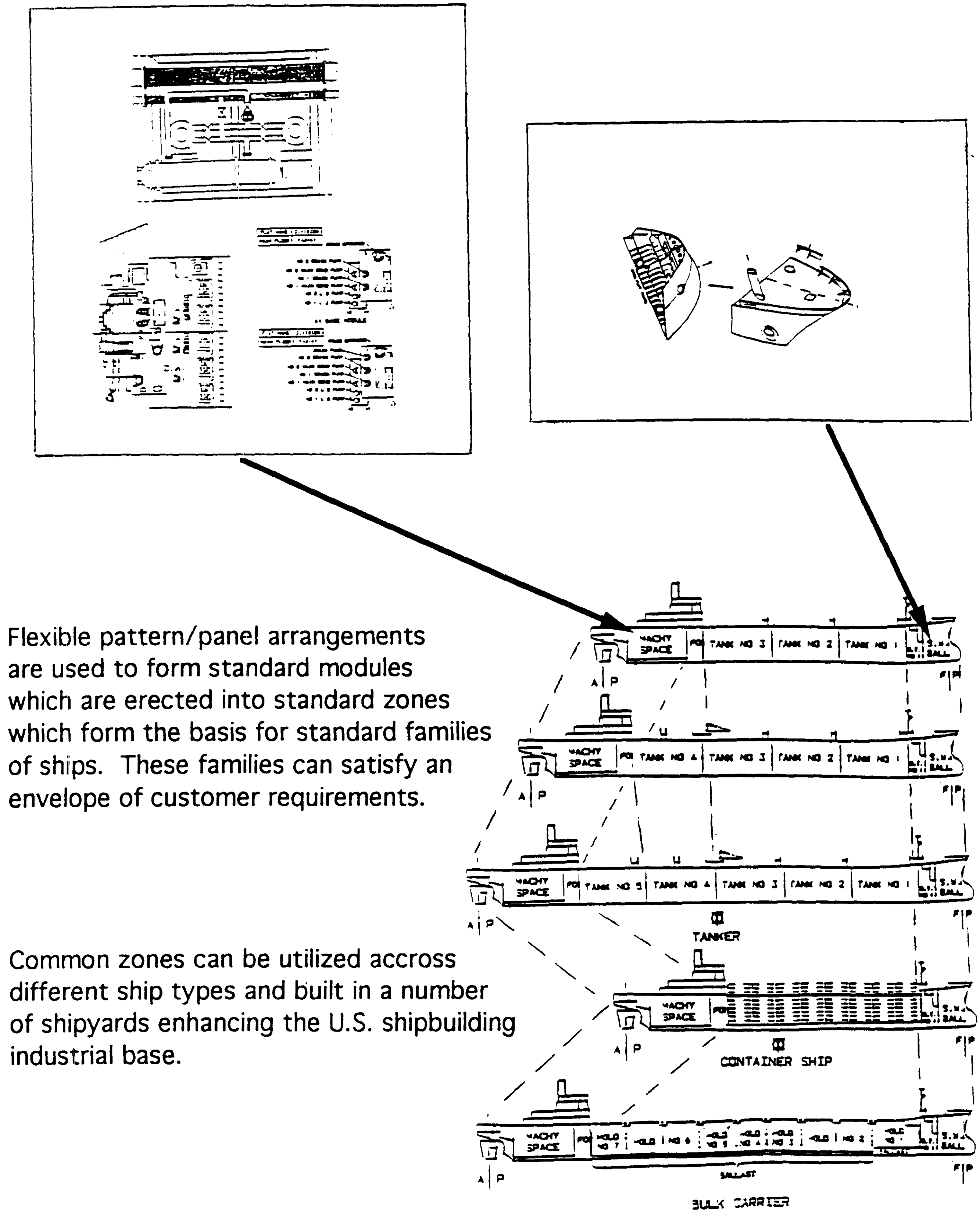



Figure 8.2 - Modular Standardization

Data is available regarding the difference in costs associated with two fleet oilers built at Avondale. The AO-177 class was built using conventional outfitting methods. The T-AO 187 class was built using the modular approach. Table 8.0 compares the two.

| | AO-177 | T-AO 187 |
|---|---|---|
| **ENGINEERING** | | |
| Number of Drawings | 1417 | 1844 |
| Man-hours/DWG | 1.0 | 0.90 |
| Man-hours | 1.0 | 1.17 |
| **PRODUCTION** | | |
| Hull Steel | 1.0 | 0.72 |
| Piping | 1.0 | 0.78 |
| Machinery Installation | 1.0 | 0.80 |
| Coating | 1.0 | 0.85 |
| Sheetmetal Installation | 1.0 | 0.82 |
| Electrical Installation | 1.0 | 0.85 |
| Relative Construction | 1.0 | 0.85 |

Table 8.0 - Comparison of Modular and Traditional Construction[57]

As the table shows, there is an increase in pre-planning time which leads to significant reductions in production costs (38% to 15%).

The fine hull forms of naval combatants and the lack of commonality of compartments within the ship (and little parallel midbody) pose challenges to the development of large zone modules for naval combatants. However, large modules could be developed if the Navy were willing to move in this direction and accept the associated loss of hullform flexibility. The use

57 The table is from a set of illustrations used in a NAVSEA presentation on commonality.

of smaller modules may be more feasible and provides a greater degree of flexibility with regard to hullform. This concept is not new and was used extensively during World War II. It should be noted that the Navy has had considerable success with modularity for submarine production. This is largely due to the historical emphasis of tight tolerances for submarine work and the existence of parallel midbody. It should also be noted that the Navy has already modularized weapon systems to a large extent. Many weapons systems are contained within defined envelopes with standard interfaces to facilitate quick removal and upgrade. This advance was in response to quickly changing technology and ships taking full advantage of the system are referred to as Variable Payload Ships (VPS). The first application of this concept is on the DDG-51. Figure 8.3 illustrates the VPS concept. The VPS concept separates the weapons systems from the rest of the ship, referred to as the platform. The ship is designed such that the weapons systems can be installed/replaced after the construction of the rest of the ship has been completed. This concept ties into the Generic Build Strategy concept. VPS has several benefits. Construction time should be reduced, since installation of the weapons systems which usually have high lead times and problems associated with them has been removed from the critical path for the platform. The weapons systems should be easier to test at a standard facility, which should reduce testing time and complications. Finally, the weapons system mix of the ship can be more quickly revised or varied to more accurately match foreseen mission requirements. Clearly this is a move towards the Mass Customization concept for naval combatants.

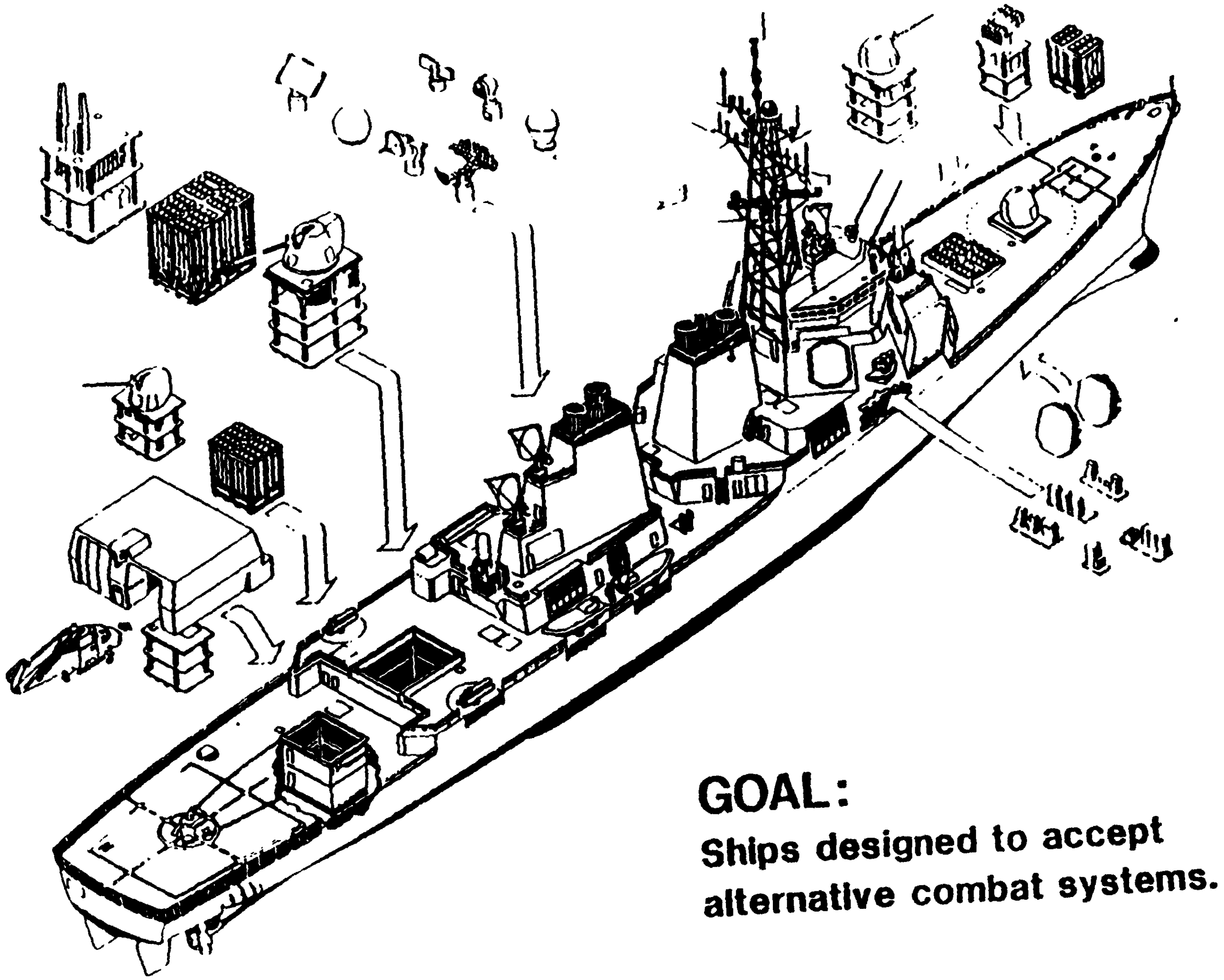



Figure 8.3 - Variable Payload Ship[58]

58 Tibbitts, Prof. B.F.; presentation entitled "MODULARITY"

Just as standard foundations and modules for HM&E equipment require statistics regarding dimensions, VPS utilizes statistics regarding combat systems. The zones designed into the platform to accept the combat modules are designed with service capacities intended to be capable of powering the most demanding module foreseen. The zones and modules take advantage of standard mountings, attachments and interfaces. Several standard module sizes were developed based on combat system statistics. This is illustrated in Figure 8.4.

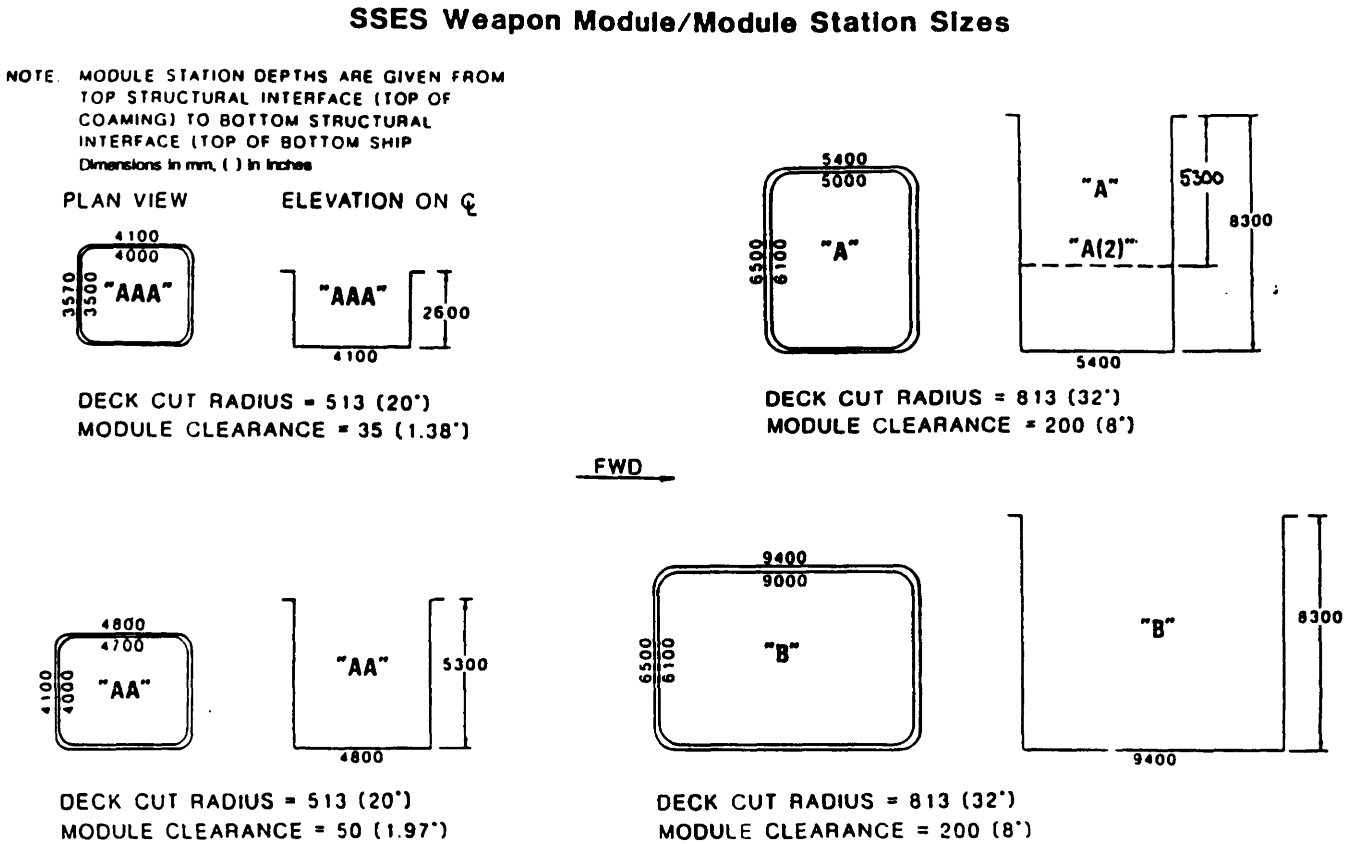



Figure 8.4 - Module Station Sizes[59]

59 Tibbitts, Prof. B.F.; presentation entitled "MODULARITY"

It should be noted that Navy module design is further complicated and constrained by the need for the modules to be easily produced and erected in a variety of shipyards. While an individual shipyard designing and building a commercial ship can size and design its modules to take full advantage of the shipyard's facilities, Navy modules must be developed based upon typical or lowest anticipated shipyard capacities. Table 8.1 illustrates this problem with Figures regarding lift capacity for a number of major U.S. shipyards. As can be seen, capacities vary significantly. This variation is another reason for concentrating upon smaller modules for Navy construction. Larger module designs would need to be easily subdivided and assembled by yards with lower capacities if the Navy would like to be able to build its ships in most U.S. shipyards. This problem has important political and legal implications. If the Navy designs large modules, they will be accused of favoring larger shipyards like Newport News. Yards like Newport News, on the other hand, would like to utilize larger modules since they have a competitive advantage in this area and may be resistant to efforts emphasizing smaller subassemblies. It should be noted that if the modules are designed such that they may be assembled into larger sub-assemblies and then erected onto the ship, yards with larger crane capacities can still take advantage of them effectively.

| | | | METRIC TONS | | | |
|---|---|---|---|---|---|---|
| SHIPYARD | BRIDGE CRANE | LUFFING DERRICK | REVOLVER CRANE | TOWER CRANES | MOBILE CRANES | GANTRY CRANE |
| ALABAMA SHIPYARD | 275 | 1400 | | | | |
| BATH IRON WORKS | | 220 | 220 | | | |
| BETHLEHEM STEEL | | | | 91 & 45 | | |
| INGALLS SHIPBUILDING | 182 | | | 54 | | |
| MARINETTE MARINE | 45 | 220 | | | | |
| MOSS POINT | | | | | 159 | |
| NASSCO | | | | | 159 | |
| NEWPORT NEWS | | | | 45 | | 900 & 315 |
| TAMPA SHIPYARDS | 800 | | | | | |

Table 8.1 -Representative Shipyard Lifting Capacities

The VPS concept, while new to the U.S., has been used successfully for many years by the German shipyard, Blohm & Voss. They have designed ships, ranging from patrol craft to frigates, which accept a variety of standard weapons payload "containers" (modules). This MEKO concept has resulted in ten deployed ship platform designs which Blohm & Voss markets. The 76 mm OTO Melara Compact Gun weapon container has been used successfully since sea trials of the module integrated with the Federal German Navy destroyer Z4 were conducted in 1975.

## AFFORDABILITY THROUGH COMMONALITY PROGRAM

The Navy is currently studying the opportunities discussed so far as part of its Affordability Through Commonality Program. The stated goals of the ATC program are to improve the process by which the Navy designs, acquires and provides lifetime support for its ships. ATC builds on the current success within the Navy and learns from the experience of other industries and other Navies. ATC recognized early on that while design costs are only 2% of total ship life cycle costs, it is this 2% which locks in the other 98%. ATC decided to study how the design process and resultant proposed designs impact upon producibility, supportability and upgradability and use this insight to develop means to positively impact these costly aspects of the ship life cycle. The ATC effort began in 1992 with a survey of other industries and how commonality was utilized as a means of reducing their costs. The survey included representatives of the aerospace, communications and electronics, utilities, industrial products and shipbuilding industries. This survey served to provide suggestions about how the Navy might reduce cost and improve schedules. Table 8.2 provides a summary of industry techniques revealed during the industry survey. The results of this survey are consistent with the information gathered during the course of this research.

| INDUSTRY | COMPANY | TECHNIQUES | | | BENEFITS | | |
|---|---|---|---|---|---|---|---|
| | | STANDARDIZATION | SIMPLIFICATION | CONCURRENT ENGINEERING | COST | SCHEDULE | QUALITY |
| Aerospace | McDonnell-Douglas | | | • Multifunction | • 60% savings on bid costs for selected projects | • 18 month reduction of design time for one aircraft design project | • Scrap reduced 58%<br>• Rework reduced 29%<br>• Non conformance reduced 38%<br>• Weld defect reduced 70%<br>• Engineering changes reduced 68% |
| | Boeing Ballistic Systems Division | | • Eliminate marginal value-added features | • Product development team | • 30% below bid price | • Material lead time reduced 30% | • Material shortages reduced to 0%<br>• 99% defect free operations |
| | Boeing Aircraft Division | • 1,096 common parts between 757 and 767 | | | • 18% equivalent fuel burn savings<br>• Common crew and supply support | | |
| Communications and Electronics | AT&T | | | • Multifunction team<br>• Early stage producibility design | • Circuit breaker repair cost reduced 40% | • Process time reduced 40% | • Defects reduced by 30 to 87% |
| | IBM | | | • Multifunction team | • Assembly hours reduced 45% | • 40% reduction in electronics design cycle | • Fewer engineering changes<br>• Better producibility |
| Utilities | Westinghouse Nuclear Power Division | • Fewer parts | • Simpler systems | • Modular construction | • 15 to 20% savings in equipment costs | • Construction time reduced by 2 years | • Improved safety |
| | Commonwealth Edison | | | • Modular construction | • 5 to 10% for most projects | • 4 months savings on a 36-month project | • Improved over stick-built method |
| Industrial Products | John Deere | • Number of different parts reduced 60% | | • Group technology<br>• Benchmarking<br>• Continuous process improvement | • 30% savings in development cost<br>• Manufacturing cost reduced 42% | • 60% savings in development time<br>• Reduced development time 35% | • Inspectors reduced by 67%<br>• Product failure rate reduced 60%<br>• Scrap/rework reduced 75% |
| | Whirpool European Division | • Standard packaging | Consolidated number of different models | | • 10% production cost savings<br>• Lower support cost | | |
| Shipbuilding | Blohm & Voss (MEKO Frigates) | • Standardized weapons and MME modules | • Zonal auxiliaries distribution | • Modular construction | • 5% reduction in ship cost | • 1 year reduction in construction time | |
| | Kvaerner-Masa | • Common process lanes | | • Modular construction<br>• PODAC | • 50% reduction in outfitting cost | • Reduction in building time | • Reduced damage<br>• Reduced rework |

Table 8.2 - Summary Industry Survey[60]

60 Cable, C.W; Rivers, T.M.; "Affordability Through Commonality," ASNE DDG-51 Technical Symposium; Sept. 1992

The results of the ATC survey were further reduced to lists of suggestions, which then guided the ATC effort. Table 8.3 lists these broad suggestions.

| COST | SCHEDULE |
|---|---|
| ◊ Use commercial specifications and practices | ◊ Use commercial specifications and practices |
| ◊ Steady production /volumes | ◊ Larger volume orders |
| ◊ Firm designs or use standard designs | ◊ More standardization |
| ◊ Improved procurements practices | ◊ Improved procurement practices |
| ◊ Reduce testing | ◊ Reduce test and inspection requirements |
| ◊ Less stringent specifications | ◊ Simplify designs |

Table 8.3 - Suggestions to reduce shipbuilding cost and schedule[61]

With these suggestions in mind, ATC is intended to employ a three-pronged approach:

- MODULARITY
- EQUIPMENT STANDARDIZATION
- PROCESS SIMPLIFICATION

61 Cable, C.W; Rivers, T.M.; "Affordability Through Commonality," ASNE DDG-51 Technical Symposium; Sept. 1992

In addition to these stated elements, this study has found that certain other elements exist which must be emphasized in the formulation of a policy or plan in this area:

- LEGAL/CONTRACTUAL ELEMENTS
- MILSPEC REVIEW/REVISION

While each of these may be argued to be included within the third prong of the ATC approach, process simplification, they are each important and complex issues which deserve individual, rather than broad, emphasis.

The author agrees with the members of the ATC team that finding solutions to the affordability problem will require an understanding of all these elements and their interactions. No single element can provide benefits without skewing problems towards another direction or set of directions. The elements must be studied together in order to arrive at a balanced approach which does not merely replace problems, or create more problems than it solves. For example, equipment standardization is a means of achieving reduced integrated logistics support costs and more rapid ILS response because it allows the Naval Sea Logistics Center to reduce inventory breadth and increase inventory depth; i.e. they no longer need to track as wide a variety of parts and would then have the capacity and resources freed to assure a greater probability of the availability of a part for those that are still being tracked. It has also been shown that equipment standardization has certain drawbacks or costs which may make it undesirable for certain types of equipment. It has also been shown that standard interfaces and readily available VFI are necessary for speeding the construction cycle; standard equipment designs are one way of achieving this, but are the least flexible way of doing so. For these reasons, the goal of reduced ILS costs must also be studied outside the context of equipment standardization. The ILS processes must be streamlined in an effort to reduce the costs associated with the ILS function per tracked part, independent of an effort to reduce the number of tracked parts. Significant gains are likely to be found in this area, and that insight may change the view or requirements for equipment standardization. We can define *flexible modularity* as the design of a module which can accept some variation within it but provide standard interfaces and envelope dimensions. Flexible modularity provides the up front information and interfaces necessary for reducing construction cost and construction cycles, but does not impact the ILS function in a significant way unless the use of standard or supported equipment within the module is also addressed. Even after all the issues discussed above have been considered, the legal and contractual aspects of the plan could limit its success. Several key questions require answers for a Navy designed and driven modularity program to be embraced by the U.S. shipbuilding community. Some of these include:

- Are these modules to be built in a separate facility and delivered to the shipyard? What are the contractual and legal ramifications?
- Does the Navy take full responsibility for the performance of these modules, or are the module designs merely strong suggestions, with the contractor having final responsibility for their use and performance?
- How will the vendors be involved? Are quality partnerships to be employed? What are the legal roadblocks to such an approach?

It is also important to remember that one of the greatest contributors to high naval combatant costs are the Milspecs. Stringent requirements and testing procedures add additional costs to the engineering and development phases, the construction cycle, and the entire life cycle of the ship. Serious attention must be given to studying these Milspecs and every effort made to reduce the requirements where possible in an effort to reduce costs. This reduction in requirements is not intended to be at the cost of performance. Many of the Milspecs may disallow certain sound engineering practices which at the time of the Milspecs writing were not fully mature. Such practices which may provide the required performance at a reduced construction cost should be studied and utilized in the development of ATC modules. The multi-pronged approach is correct and necessary to insure that an optimum policy, one which takes the best advantage of all elements at the least cost with the greatest performance, is developed.

ATC is currently in its planning and preliminary stages. ATC leaders recognized the necessity to take a multi-disciplinary concurrent engineering approach. Both specialists and generalists from many segments of the Navy were collocated for the ATC program. ATC's initial effort was aimed at developing a list of candidate modules to study further. Initially, ATC focused on the LSD-49 as a baseline ship for studying the impact of ATC initiatives. The reasoning behind this included the fact that it is representative of near term acquisitions, and it is sufficiently recent that data is readily available. ATC developed an initial list of module candidates based upon the following guidelines:[62]

- The module must have multi-class applicability.
- The modules must limit APL growth by utilizing supported or standard equipment.
- The modules should address fleet maintenance problems.
- The systems selected should traditionally have high installation or outfit costs which modularity might reduce.
- Prototype modules should be representative of broad classes of equipment types in order to maximize gains from lessons learned.

These considerations were used to prioritize a list of candidates for the early case study. The candidates were initially nominated through group consensus and by looking at some statistics regarding the associated equipment. From this initial list of 22 candidates, 8 were selected for further study at that time. Case studies were developed around the selected candidates in an effort to begin to study the module development process, and the impact these modules may have upon ship weight, volume and performance. While the LSD-49 was the baseline for the

62 NAVSEA; ATC Modularity Case Study; Feb 1993; NAVSEA Technical Note No. 051-05R-TN-099

study, future fleet needs were studied and considered in developing the case studies. Along with future fleet projections, projections of manning levels were utilized in studying the development of certain modules, such as habitability modules. The results of these studies provided input for a second, more detailed round of development.

The effort is currently aimed in two simultaneous directions. The first of these is top-down systems engineering. Top-down systems engineering includes research into generic build strategies for production process impact, whole ship and whole fleet systems engineering, and cost analysis tool development and use. It was mentioned in the earlier discussion of equipment standardization criteria that detailed production cost information is not currently available. ATC is collecting cost data through contracts with shipyards engaged in Navy ship production. This data will serve as input to the module selection process and help to estimate the impact of adjustments to the engineering and production processes. While NAVSEA is not at the liberty of releasing this data at this time , they do foreseen a time after all the data has been collected when it will be aggregated to develop cost statistics for general use.

The second aspect of the current effort is detailed engineering and acquisition of prototype modules. These prototype modules are currently in various levels of development and include:

- Reverse osmosis desalination plant module
- HVAC module
- Sanitary space module utilizing commercial standards
- 5"/54 Mark 4 gun module

Just as equipment statistics can be gathered to help guide standardization decisions, the same type of statistics can be developed to guide the choice of module candidates. The data required to make decisions regarding modules will include that already collected at the equipment level. ATC selected candidates for prototype modules based on its study into modules which could provide benefits and have application in the near future. The prototype modules are intended to be a learning experience, since not all the data has been collected to make more detailed selections. Future modules will be developed based upon lessons learned and analysis of the data collected simultaneously in the systems engineering research. Figure 8.6 illustrates the proposed ATC module selection process.

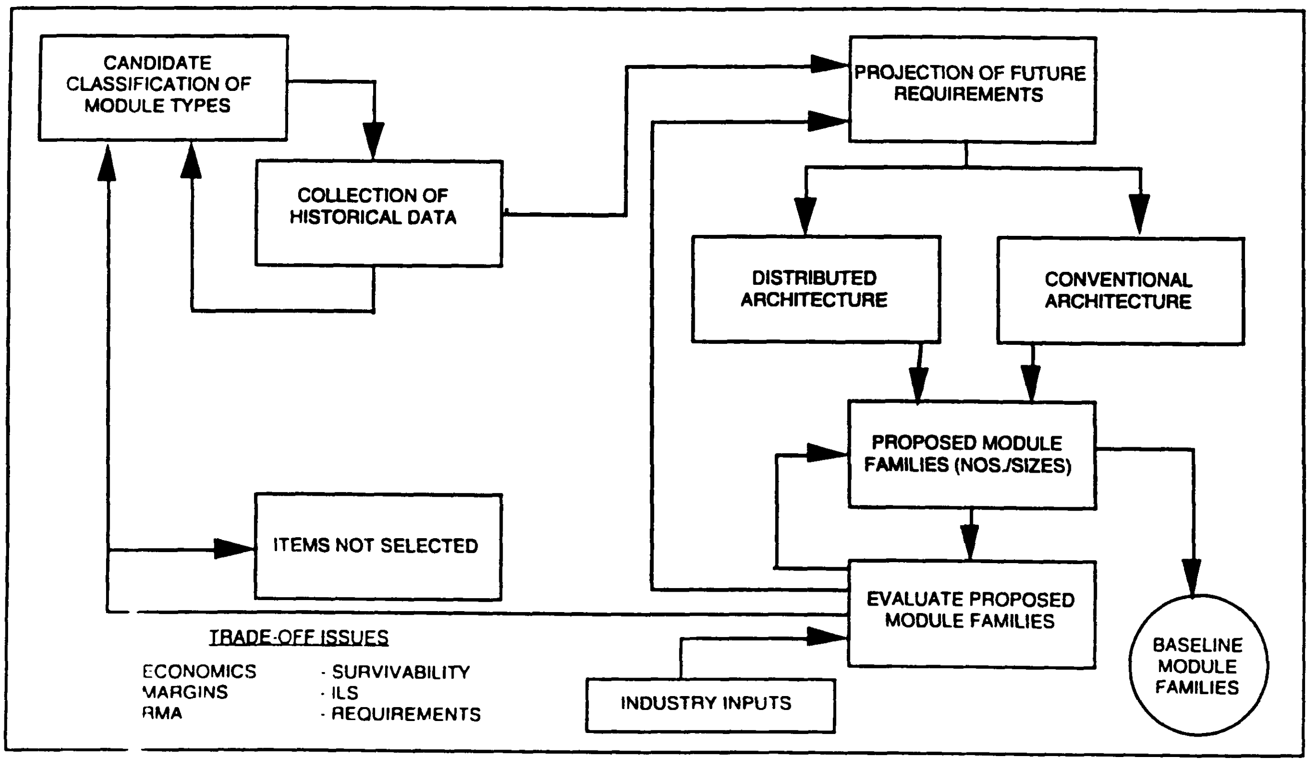



Figure 8.6 - ATC Module Selection Process[63]

63 Bosworth, M.; Hough, J.; "Improvements in Ship Affordability"; SNAME annual meeting transactions; Sept 1993

ATC recognizes that modularity can take place on many scales. ATC determined that it should focus its development effort upon palletized equipment modules, which consist of a main equipment and its auxiliary equipment, or upon small enclosed and densely outfitted three dimensional compartments like a habitability module. Figure 8.7 illustrates the two types.

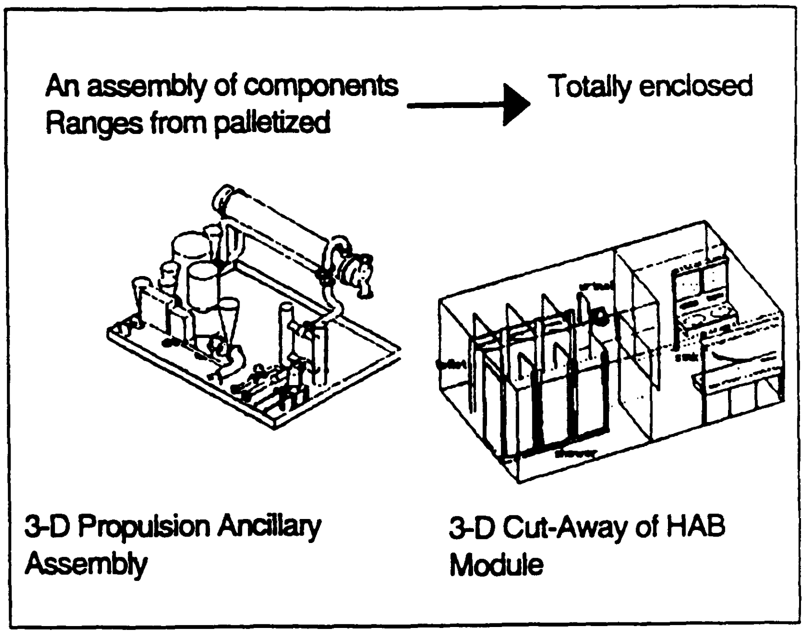



Figure 8.7 - ATC module size ranges[64]

As was discussed earlier, this is a sensible choice of sizes for naval combatants in order to maintain flexibility with regard to the fine hull forms of naval combatants. With regard to process streamlining, ATC identified the traditional system oriented sequential design approach as a key problem. The conventional design approach as discussed earlier does not incorporate zone production early enough, if at all, in the design process. By the time production feedback is available, it is too late to incorporate it into the design. Figure 8.8 illustrates the proposed

64 Bosworth, M.; Hough, J.; "Improvements in Ship Affordability"; SNAME annual meeting transactions; Sept 1993

ATC integrated design engineering and production approach as compared to the conventional approach.

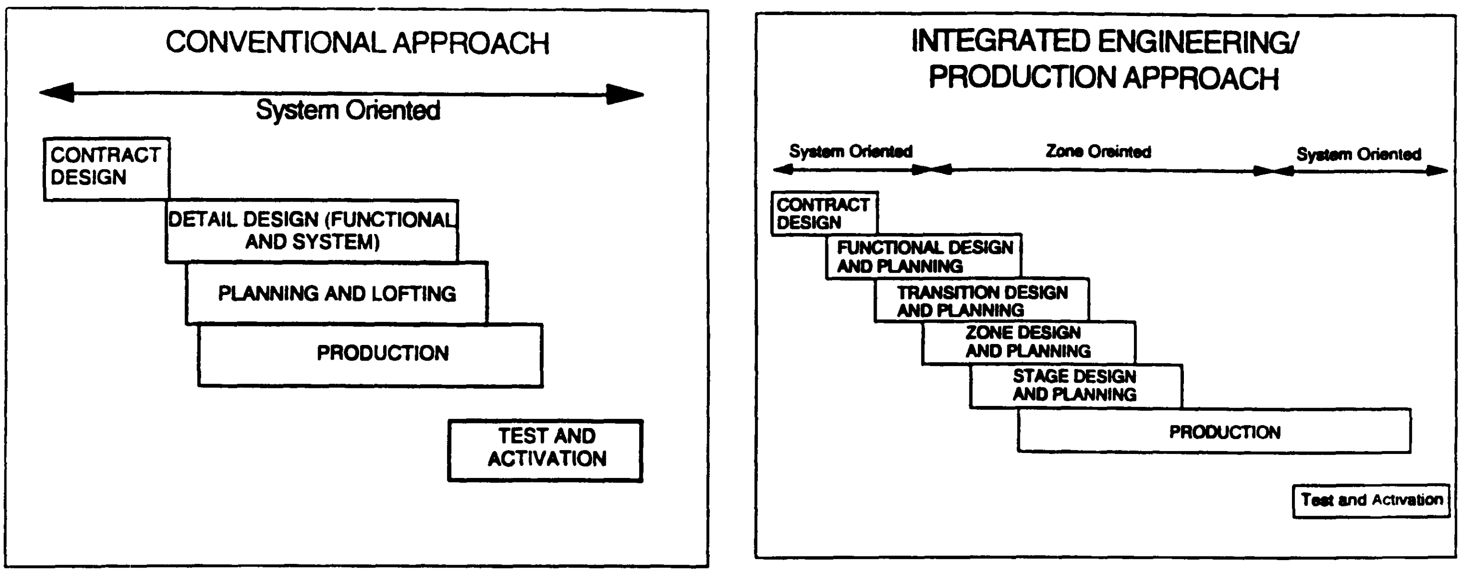


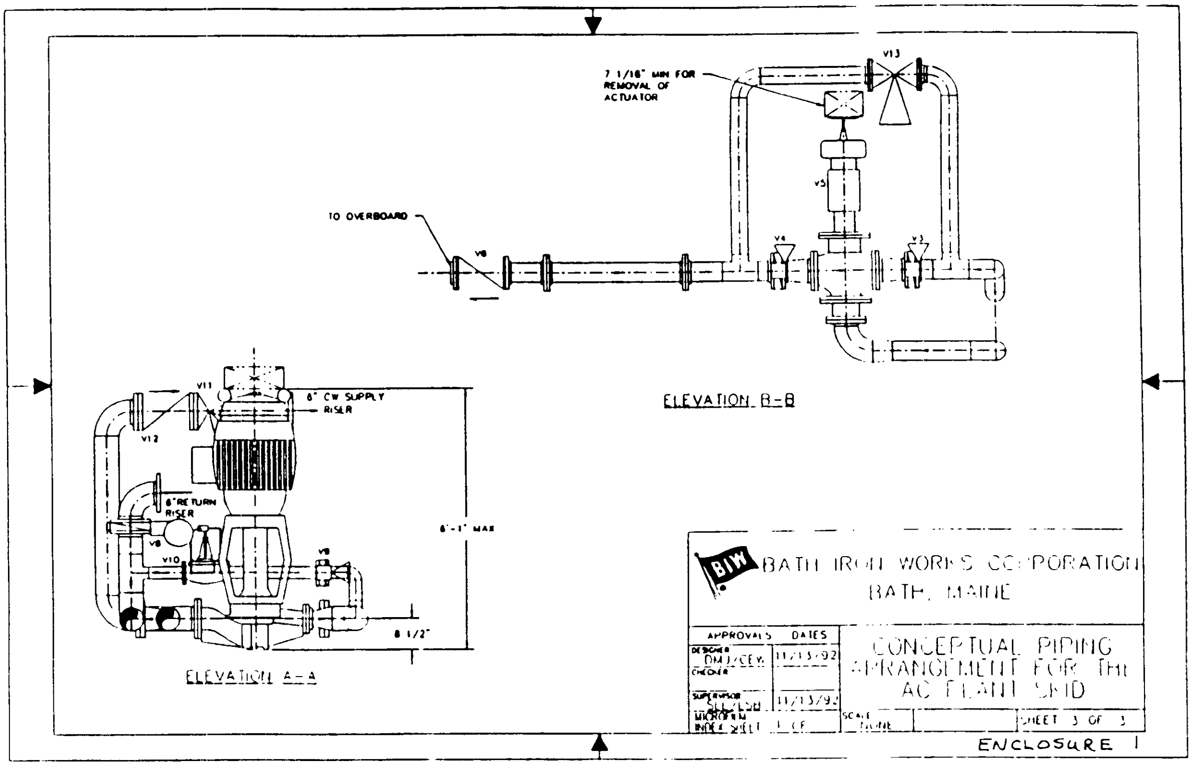

Figure 8.8 - Design Process Revision

While the illustrated approach demonstrates the introduction of the zone architecture into the contract design phase, it is also important to revise the traditional conceptual and preliminary design phases. A concurrent engineering approach should be utilized at these early phases as well, in order to better utilize baseline module designs and producibility considerations. In conjunction with the proposed inclusion of zone oriented engineering, ATC proposes to take advantage of the Generic Build Strategy concept. In conjunction with the GBS research, ATC will look at a reordering of equipment installations and a relocation of equipment as is practically possible to more efficiently facilitate production.

ATC anticipates that although only basic research is currently available to be used in the development of the prototypes, at the end of FY 93 more detailed information will be available and the lessons learned from the prototypes can be used to further refine the process simplifications. ATC foresees more funding in FY 94 - FY 99 during which time more modules will be developed.

In conjunction with the ATC effort and the Navy's effort to convert to HFC rather than CFC Air Conditioning Plants, Bath Iron Works has progressed in the development of an HFC Air Conditioning Plant package. The scope of the project was to develop an outfit package which supplied a standard interface for supply and return piping and power cables. This type of module is representative of the smaller range of ATC modules. It would be a standard pre-outfit package. BIW's package incorporates associated piping, valves, pumps, strainers and chillers on a common subbase. The package is intended to be resiliently mounted to ship structure. Since the package is viewed as a system, the necessity to resiliently mount each of its individual components to pass shock requirements has been reduced. This will result in the elimination of 15 resilient mounts per plant. Allowing the equipment to be hard mounted to the subbase also eliminates many unnecessary flexible couplings. The incorporation of the associated piping into the plant package reduces labor hours during the expensive outfit stages. The system also reduces the number of attachments to tank top structure by approximately 50/plant. BIW estimates that the labor savings per plant is on the order of 500 man-hours/plant.

In developing the package, BIW identified a number of important constraints which guided their design. The first of these was compartment configuration. Small deck to deck heights, fine lines for naval combatants which result in sloping and rising tank tops, and highly dense confined spaces filled with piping and components all posed challenges to the design team. The lack of detailed interface planning during the conceptual, preliminary and contract design phases introduce problems during outfit of ship components. This planning should include efforts to maximize flange to flange connection of components which eliminates piping runs and conserves space and weight. This is facilitated by the ability to view the module as a system which can be shock qualified as such. BIW cited the lack of a proactive effort to develop standard auxiliary packages for current and future propulsion plants as a constraint. The use of Milspecs when commercial specs might be suitable was also cited as an expensive constraint on the design of common modules. BIW also cites the use of expensive materials vs. low cost carbon steel as a related problem. The necessity to design to "infinite life" flow rates vs. 15 to 20 year lives drives the costs higher. BIW developed the module incorporating many of these considerations. Figure 8.9 illustrates the piping arrangements for the proposed module.



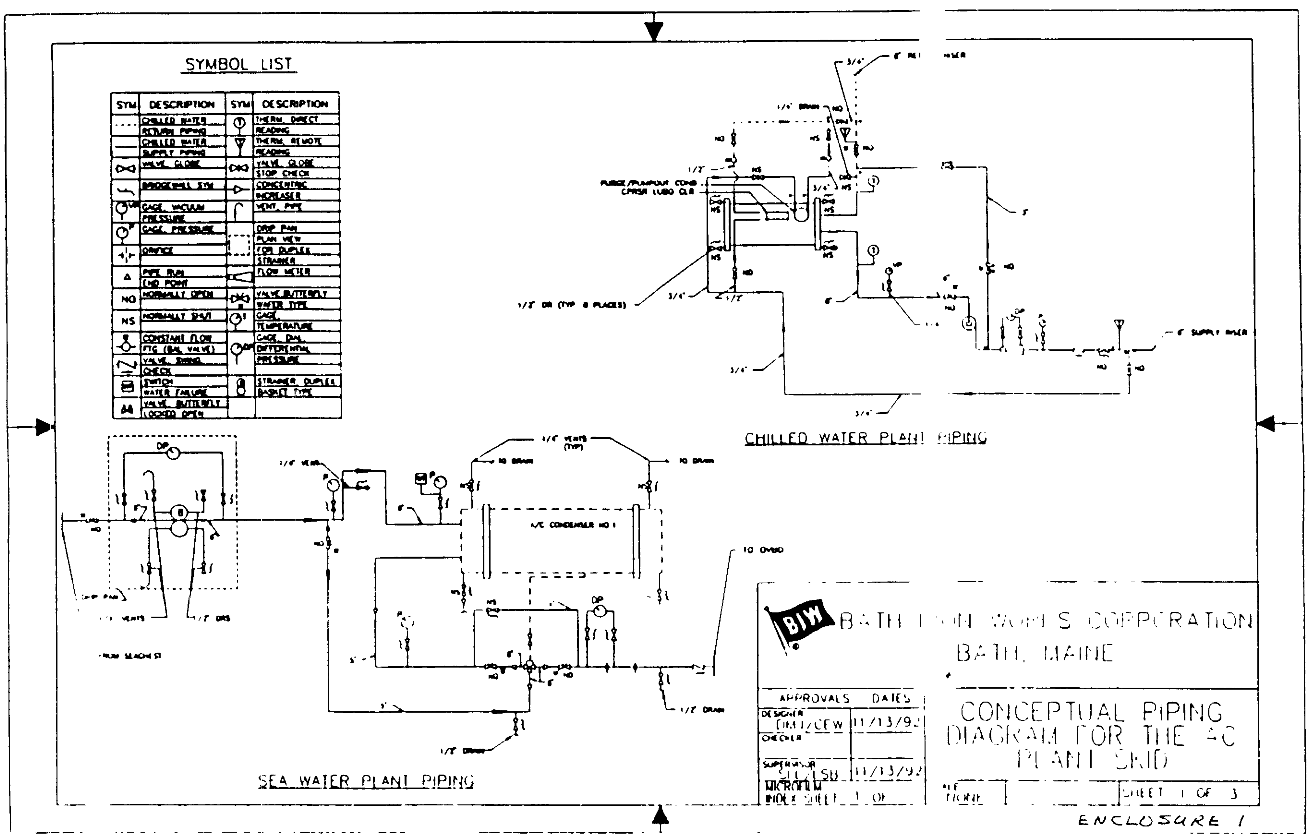




Figure 8.9 Conceptual Piping Diagrams

In summary, modularity efforts face many technical, logistical, legal and contractual challenges. The standardized modular philosophy impacts design in a variety of ways, both positive and negative. It is hoped that the reader now has an appreciation for the trade-offs involved. In general, the savings in production costs should outweigh negative design impacts. Due to the variety of equipment dimensions, flexible modules would generally need to be designed to accept the largest reasonably likely equipment dimensions. This requirement would tend to increase the volume of a ship which utilizes these standard modules as compared to a fully custom ship. Secondly, arrangement flexibility is more constrained than that for a custom ship, which also drives volume higher. The extent of the volume increase is not clear. First of all, while there are a variety of dimensions, it is not a limitless variety. The largest dimension is not typically orders of magnitude above the mean dimension for the equipment type. Secondly, the detailed attention and spatial analysis afforded to the module design may actually result in a more efficiently proportioned system than may have been possible during the traditional contract design phase. In the contract design of the DDG-51, BIW utilized envelope dimensions which represented the largest anticipated equipment dimensions in order to more easily competitively bid equipment. In the detail design phase, arrangements were modified to incorporate the actual equipment dimensions. It was found that the machinery room volume decreased by 31% for major machinery from contract to detail design.[65] This increase in volume is significant. Had options for equipment been available and dimensions known up front, redesign and excess volume could have been avoided. While standard modules would need to incorporate excess volume in order to accept a variety of equipment, the design of the modules may be more efficient.

Standard module design is also constrained by weight distribution for an equipment type. A flexible module must support the heaviest likely equipment of the class of equipment,

65 Grigg, L.R; "Standardization of Naval Ship Equipments"; MIT Thesis, MS in Ocean Systems Management; May 1990

which in turn would require the use of heavier scantlings than a weight optimized design. This would lead to a heavier standard module as compared to a custom, weight optimized, design. Modules which fully define a three-dimensional space, rather than a palletized unit, also tend to increase weight relative to a custom design further. The three dimensional space is typically defined by a top, a bottom and four sides. Stacking these three-dimensional units in any direction results in interfaces which may be twice the required structure as illustrated in Figure 8.10. This poses a technical challenge on the design of such modules. A creative interface must be developed which provides structural integrity without increasing weight needlessly.

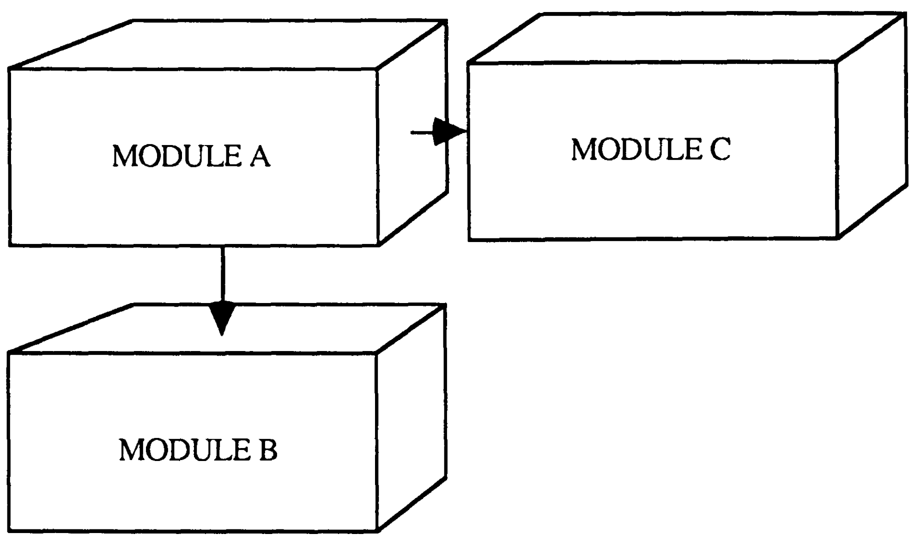



Figure 8.10 - 3-D Space Interface Challenge

It is not clear that these weight increases would be significant. First, shipyards tend to utilize standard scantlings and shapes in order to minimize inventory costs and the costs associated with rework. This standardization of scantlings tends to keep the selected scantlings standard over a range of weights for a given geometry. Secondly, the design process for the standard module incorporates producibility concepts which are not traditionally taken advantage of. This would tend to reduce the weight and cost associated with the standard module.

Another important point with regard to Navy modules is that the standard module may in fact weigh less, since the module can be shock tested as a unit. ATC proposes developing prototype modules which they intend to performance test. This performance testing includes shock testing. ATC recognizes that the module may behave in such a way that the system passes shock requirements during testing even though MILSTD-901D might place more stringent requirements on its design if testing were not implemented. Specifications for shock tend to increase the selected scantlings associated with foundations beyond the range actually necessary to support the equipment in a shock environment. Shock stresses are inversely proportional to the square root of the stiffness (flexibility) of the structural system. Testing the module as a unit would reduce the required scantlings since the system flexibility would be fully accounted for. ATC should view this shock testing as an opportunity to prove producibility concepts and incorporate the lessons learned into streamlined specifications. Given all these factors, negative design impacts can be offset in many cases and minimized in most cases.

# CHAPTER 9: CONCLUSIONS AND RECOMMENDATIONS

The objective of this research was to study standardization as a means for reducing the costs associated with Navy acquisition and construction. The downward trends associated with shipbuilding work and Navy budgets require action to be taken to reduce the costs associated with ship acquisition. While the emphasis of this research was on Navy acquisition, many of the attributable research benefits, especially those in the construction cycle, are also applicable to commercial design and construction. It is hoped that the author has successfully provided the reader with an appreciation for the costs and benefits associated with standardization of equipment, components and modules. Standardization requires many challenges to be met which were discussed at length throughout this thesis. These can be summarized as follows:

- Decision Systems Challenge: Standardization requires the development of a set of criteria by which to judge the merits of a particular standardization project

- Information Systems Challenge: Standardization requires the development of a detailed database of VFI and application statistics. This database serves the individual concerned with logistics, the individual concerned with design and the individual concerned with evaluating standardization alternatives which have an impact upon logistics, design and construction.

- Technical Challenge: Standardization and modularity imposes a challenge to engineers and designers to develop flexible designs which incorporate advanced manufacturing practices and meet foreseeable customer requirements and can adapt to unforeseen scenarios. The designs and manufacturing systems must continuously improve while maintaining critical elements of commonality.

- Planning and Procedural Challenge: Standardization and concurrent engineering require detailed up front production planning which is fully integrated with the design process. Other elements of the acquisition process must be studied and streamlined in conjunction with a standardization effort if savings are to be maximized.

- Legal and Contractual Challenge: For standardization to be effective, quality partnerships with vendors must be established and legal/political hurdles (both real and imagined) must be overcome. This will require a detailed review of the Federal Acquisition Regulations, the DOD Acquisition Regulations (DOD 5000) and other pertinent acts, laws and rules. Case transcripts, trial briefs and decisions regarding representative cases involving these regulations and acquisition policy should be gathered and studied further to shed light on the situation. In the course of this research, the following were often referenced as either roadblocks or beneficial:

| ROADBLOCKS | BENEFICIAL |
|---|---|
| Competition in Contracting Act of 1984 | Defense Cat. and Stndzn. Act of 1952 |
| FAR in general | FAR Sect. 14 (authorizes econ. eval.) |
| DOD 5000 regulations | |
| FAR Sect. 16 | |

Table 9.0 - Legal Issues

The list in Table 9.0 is merely a starting point. A great deal of work is needed in this area.

- Specifications Challenge: Effort must be taken to review military specifications and options to make them less stringent and producibility "friendly". Effort to substitute commercial specifications must be studied further.[66]

It has been mentioned that many of the immediate production benefits could be achieved if common interfaces and mounting methods were available regardless of the equipment or equipment manufacturer. This is not foreseen any time in the near future in the United States. The author believes that it is imperative to invest in concurrent engineering and design up front to incorporate producibility considerations into the design. This should include an effort to standardize the mountings and foundations of the equipment as a separate but related effort to the equipment standardization process. Even though equipment may have differing bolting arrangements and dimensions, it is still technically feasible to create flexible mounting systems which can accept a variety of equipment as described in this thesis.[67] Without detailed production data regarding the costs and time associated with shipyard processes, it is difficult to determine the economic benefits in a quantitative sense.

It is the current Navy acquisition policy to allow lead ships to be acquired with minimal effort to standardize across the fleet, save in those cases when performance issues or reliability concerns are viewed to be critical. Follow ships are required to utilize class standard equipment when possible, and fleet supported equipment as the next level of preference. Some effort is being made to standardize within the ship. The Naval Sea Logistics Center has made progress towards the development of cost trade-off models. These models must be streamlined, the cost data updated and Net Present Value incorporated. The Navy currently

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66 The reader is referred to:

Gallagher, Neil; "Commercial Substitution as a Means to Bolster the U.S. Shipbuilding Industrial Base"; MIT Thesis, OE Dept. 1992

67 It was mentioned earlier that Vibtech, Inc. has been studying this problem and offered insights during the course of this research.

has an in-house effort to develop common ship modules, but at this time this effort is in its infancy. The author believes that the policy towards lead ship standardization should be strengthened to require contractors to utilize fleet supported equipment when possible as is the case for follow ships. An effort would need to be made to assure that obsolescence or high costs were avoided, therefore some effort would be required to suggest deviation for these reasons or to pinpoint equipment or equipment categories for which serious standardization attention should be given or specifically excused from standardization attention. Quality partnerships, i.e. option plans, with vendors should be established based on an initial competition scheme. This competitive process should incorporate service considerations as well as acquisition costs. Since these would only be options, purchased from a vendor, in the event that the Navy is unhappy with a particular equipment, a new partnership could be established at the expense of forfeiting the money spent on the option. Intraship standardization should be encouraged and required for particular equipment categories which have been targeted by the Navy for special attention. The Navy already requires a Standardization Program Plan as part of a CDRL. This plan should be required to be more detailed, incorporating the suggestions above. The Navy also requires a foundation control plan from contractors which is to outline the organization and responsibility for meeting shock, vibration and fatigue requirements. The requirements for foundations should include requirements for contractors to demonstrate a construction cost control plan which might outline a process for maximizing producibility and commonality of foundations in the foundation control plan. Other requirements which lead to higher costs should be reviewed. Standardization of attachments, mountings and foundations would provide construction cost benefits and allow for flexibility of equipment. It is clearly an important aspect of an effective approach to the standardization and module design problem.

There are many types of approaches and incentives which the Navy could offer to motivate contractors towards these goals. The first "incentive" is to simply make it a requirement. Many contractors indicated that they actually would prefer in many cases to be absolutely required to meet certain standardization goals rather than have incentive clauses. This would assure them of an even playing field during the bidding process. Many contractors do not believe the Navy is serious about many objectives which are approached through "incentives", and do not expect other contractors to consider these goals in their bids. If the contractor considers the objective and has an associated increase in bid price, it runs the risk of being labeled a higher bid and eliminated.

The Navy may also choose to offer an Award Fee incentive in the form of a Cost Plus Award Fee contract. Such a contract would incorporate an amount fixed at the inception of the contract and an award amount based upon performance of a particular goal. Such an award may be received in whole or in part depending on the degree of performance. This award structure is suited best to situations in which the goal or objective cannot feasibly be expressed as a predetermined requirement and quantitative measurement of performance is difficult, but improvements in the area are desired. Such a contract imposes an additional administrative requirement which has a corresponding cost which should be accounted for in considering this contracting alternative. The FAR also places various restrictions upon the use of such a mechanism (see FAR 16.3013-3 and FAR 1604.2).[68] This approach may be used in conjunction with a design to cost contract which requires bidders to meet a particular cost constraint and be compared by the grading of the proposals. While it was outside the scope of this research to study legal and contractual aspects in great detail, research in this area must be undertaken if standardization and modularity are to succeed. Research in this area must include the views and problems faced by shipbuilders, vendors and the Navy.

This thesis presented several classes of statistics which could be used in guiding standardization decisions. The broad Navy equipment categories were reviewed with respect to each of these criteria, and potential was demonstrated to exist. For many of these criteria,

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68 Biedenbender, Dick;The ILS Manager's LSA Toolkit; McGraw-Hill, INC.; 1993, U.S.

the data is not available at this time to make adequate decisions. Among the criteria discussed were:

- Redundancy and Commonality
- Uniqueness
- APL Proliferation
- Maintenance Data
- Population
- VFI and Manufacturing Lead Time
- Potential ILS Cost Avoidance
- Technology Turnover - Obsolescence
- Adaptive Costs
- Producibility - Critical Path Impact

Of these, the data which could help to quantify the impact of decisions upon the construction cycle are either of questionable accuracy, or lacking altogether. This data must be compiled if decisions are to be based on quantitative rather than qualitative criteria. In the interim, while hard data is not available, a structured questionnaire could be developed which uses the expert opinion of shipyard personnel, Navy personnel and vendors to arrive at a prioritization of equipment with regard to the criteria. These criteria can also be used to help guide common module design decisions. Once these statistics have been gathered, and equipment has been studied at a more detailed level than that undertaken in this research, the expert opinion and quantitative information available from industry and Navy sources should be synthesized. The Analytical Hierarchical Process discussed in Chapter 6.0 is a tool which could be successfully applied.

In conclusion, there is substantial evidence that standardization is one means towards reducing the costs associated with ship design, construction and operation. Standardization is an exercise in compromise. In order for standardization to succeed, a great deal of information is required to adequately make decisions. While standardization is one means towards progress, it is not the only means. Effort must be made to streamline all of the related requirements, processes and procedures. A balanced policy for Navy acquisition, and a balanced general maritime policy for the United States must be established quickly if the U.S. Shipbuilding Industrial base is to be expected to survive and provide Navy and commercial ships at competitive rates. Such a balanced policy will require the cooperation of all involved.

# LIST OF REFERENCES


Aerospace Industries Association of America, "National Aerospace Standard 1524 - Standardization Savings, Identification and Calculation", The Economics of Standardization, Toth, Robert ed.

ARPA, National Shipbuilding Initiative Proposal

Biedenbender, Dick; Eisaman, John; Vryn, Florence; The ILS Manager's LSA Toolkit: Availability Engineering;p. 326; McGraw-Hill; 1993, New York

Bosworth, CDR M.; Navy Standardization Policy Background and Issues; presentation 11/25/92

Bosworth, M.; Hough, J.; "Improvements in Ship Affordability"; SNAME annual meeting transactions; Sept 1993

Byrnes, Richard; Marcus, Henry; "A Systematic Approach to Producibility and Lessons Learned for Naval Shipbuilding"; Journal of Ship Production, November 1990

Cable, C.W; Rivers, T.M.; "Affordability Through Commonality," ASNE DDG-51 Technical Symposium; Sept. 1992

Chirillo, Louis; "Flexible Standards: An Essential Innovation in Shipyards"; Journal of Ship Production; Vol 7, No 1; Feb 1991, pp. 1-11

Corbett, John; Standardization of Hull, Mecahnical and Electrical Equipment Inventory; MS thesis; Naval Postgraduate School 1987

Defense Systems Management College; Cost Analysis Strategy Assessment (CASA) Software User's Manual; Ver 2.10; Fort Belvoir, VA; 1991

Defense Systems Management College; Integrated Logistics Support Guide; May 1986

Dickenson, T.E.; Contractual Aspects for Standardization of HM&E Equipment in Naval Ship Acquisitions; MIT Thesis; May 1993

Dumaine, Brian; "How Managers Can Suceed Through Speed," Fortune, February 13, 1989

FLEX LCC System Manual, Management Systems Designers, Inc.

Gallagher, Neil; "Commercial Substitution as a Means to Build the Industrial Shipbuilding Base"; MS Thesis, MIT Ocean Engineering, 1993

Gastineau, Charles; Kerr, Donald; "Don't Cry: Justify"; The Economics of Standardization; Toth, Robert ed.

Graves, Robert; McGinnis, Leon; Robinson, Rodney; "Shipyard Production Standards"; Journal of Ship Production; Vol. 4, No. 1; February 1988; pp. 65-69

Grigg, L.R; "Standardization of Naval Ship Equipments"; MIT Thesis, MS in Ocean Systems Management; May 1990

Hope, Jan; Stortz, Vernon; "Warships and Cost Constraints", Naval Engineers Journal; March 1986

Johnson, CDR. M.S., Klingel, LCDR, M.J.; Management Consulting Report for Commanding Officer NAVSEALOGCEN, October 1989

Kalpakjian, Serope; Manuacturing Engineering and Technology; Addison-Wesley Publishing Company, MA; 1992; page 1186

"Komatsu: Ryoichi Kawai's Leadership," Case #390-037 Harvard Business School

Marcus, H.S., Zografakis, N., Tedesco, M.P.; Building on The Successes of Standardization in The Navy; NSRP Ship Production Symposium, 1992

Moffat, Susan; "Japan's New Personalized Production," Fortune; October 22, 1990

NAVSEA 070-05R-TN-004, May 1993

NAVSEA; ATC Modularity Case Study; Feb 1993; NAVSEA Technical Note No. 051-05R-TN-099

NAVSEA; "Standardization Requirements for Strategic Sealift Ships"; CSP/S-24; 4 Spet. 1992

NAVSEALOGCEN; HEDRS User's Manual, Release 4.0; Mechanicsburg; October 1992

NAVSEALOGCEN; Standardization Candidate Criteria Users Guide

NAVSHIPSO; Publication of Manufacturing Lead Times January 1993

Pine, B.P.; Mass Customization: The New Frontier in Business Competition; Harvard Business School Press; Boston; 1993

Tibbits, B.F.; Gale, P.A.; "The Naval Ship Design/Production Interface"; Journal of Ship Production; August 1986

Toth, Robert; "Marine Industry Standards of the U.S. and the World"; Journal of Ship Production; Vol. 2, No. 3; Aug 1986, pp. 179-184, for a more detailed discussion of the history of U.S. and international standards.

Ulrich, Karl; Tung, Karen; Fundamentals of Product Modularity; working Paper #3335-91-MSA, Sloan School of Management, MIT, September 1991

Wade, Michael; "Use of Standard Task Blocks to Simplify the Ship Production Process"; Journal of Ship Production; Vol. 2, No. 2, May 1986

# APPENDIX A

HM&E STANDARDIZATION PROGRAM

DISCOUNT RATE 8.1

| COMMODITY CLASS | NUMBER OF APLs | FLEET POPULATION | AVG COST PER APL | TOTAL INVESTMENT | AVG POP PER APL | AVG PN PER APL | AVG NPN PER APL | NEW APL PROLIF | PROCUREMENT ACQ SAVINGS/YR | COST OF PROVISIONING/YR | COST OF NSN MAINTENANCE/YR | NUM YRS IN CALC | PROCUREMENT ACQ SAVINGS 'N' YRS | PROVISIONING SAV FOR 'N' YRS | NSN MAINT SAV FOR 'N' YRS | TOT SAV FOR 'N' YRS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 01 - PUMPS | 8,180 | 123,786 | $8,867 | $1,108,588,878 | 15 | 17 | 4 | 384 | [illegible] | [illegible] | [illegible] | 5 | [illegible] | [illegible] | [illegible] | [illegible] |
| 08 - ENGINES | 550 | 7,230 | $82,871 | $455,784,888 | 13 | 430 | 108 | 42 | [illegible] | [illegible] | [illegible] | 5 | [illegible] | [illegible] | [illegible] | [illegible] |
| 32 REFRIGERATION EQUIPMENT | 3,700 | 88,871 | $8,527 | $868,134,817 | 18 | 18 | 3 | 255 | [illegible] | [illegible] | [illegible] | 5 | [illegible] | [illegible] | [illegible] | [illegible] |
| 52 - HYDRAULIC EQUIPMENT | 1,885 | 28,321 | $31,718 | $838,848,478 | 18 | 23 | 8 | 74 | [illegible] | [illegible] | [illegible] | 5 | [illegible] | [illegible] | [illegible] | [illegible] |
| 10 GENERATORS | 763 | 7,884 | $78,881 | $881,878,264 | 11 | 17 | 4 | 48 | [illegible] | [illegible] | [illegible] | 5 | [illegible] | [illegible] | [illegible] | [illegible] |
| 08 - VALVES | 82,412 | 4,331,417 | $180 | $778,855,888 | 88 | 6 | 2 | 1888 | [illegible] | [illegible] | [illegible] | 5 | [illegible] | [illegible] | [illegible] | [illegible] |
| 17 - MOTORS | 16,285 | 184,444 | $3,433 | $633,188,252 | 18 | 5 | 1 | 748 | [illegible] | [illegible] | [illegible] | 5 | [illegible] | [illegible] | [illegible] | [illegible] |
| 05 - TURBINES | 888 | 11,838 | $184,887 | $1,488,883,712 | 13 | 113 | 28 | 18 | [illegible] | [illegible] | [illegible] | 5 | [illegible] | [illegible] | [illegible] | [illegible] |
| 06 - GEARS AND REDUCERS | 1,458 | 18,815 | $37,715 | $788,887,725 | 13 | 28 | 7 | 58 | [illegible] | [illegible] | [illegible] | 5 | [illegible] | [illegible] | [illegible] | [illegible] |
| 54 FIREFIGHTING EQUIPMENT | 588 | 121,838 | $2,881 | $322,888,838 | 288 | 18 | 5 | 45 | [illegible] | [illegible] | [illegible] | 5 | [illegible] | [illegible] | [illegible] | [illegible] |
| 78 COUPLINGS | 1,118 | 48,888 | $14,574 | $727,887,718 | 45 | 4 | 1 | 38 | [illegible] | [illegible] | [illegible] | 5 | [illegible] | [illegible] | [illegible] | [illegible] |
| 27 - IC EQUIPMENT | 1,413 | 278,318 | $2,428 | $878,483,472 | 188 | 18 | 4 | 48 | [illegible] | [illegible] | [illegible] | 5 | [illegible] | [illegible] | [illegible] | [illegible] |
| 61 - CONTROL EQUIPMENT | 7,858 | 384,548 | $872 | $364,332,888 | 48 | 13 | 3 | 338 | [illegible] | [illegible] | [illegible] | 5 | [illegible] | [illegible] | [illegible] | [illegible] |
| 88 - FF/RESCUE/SAFETY EQUIP | 1,888 | 37,568 | $1,818 | $37,831,588 | 18 | 84 | 18 | 227 | [illegible] | [illegible] | [illegible] | 5 | [illegible] | [illegible] | [illegible] | [illegible] |
| 98 COMPRESSORS | 828 | 12,782 | $18,288 | $233,886,836 | 14 | 77 | 18 | 47 | [illegible] | [illegible] | [illegible] | 5 | [illegible] | [illegible] | [illegible] | [illegible] |
| 43 GALLEY EQUIPMENT | 2,488 | 38,412 | $8,441 | $288,772,133 | 13 | 13 | 3 | 148 | [illegible] | [illegible] | [illegible] | 5 | [illegible] | [illegible] | [illegible] | [illegible] |
| 48 FILTERS | 3,885 | 142,783 | $1,883 | $271,718,848 | 37 | 18 | 3 | 184 | [illegible] | [illegible] | [illegible] | 5 | [illegible] | [illegible] | [illegible] | [illegible] |
| 85 YELLOW GEAR | 1,842 | 47,882 | $8 | $8 | 86 | 18 | 3 | 1787 | [illegible] | [illegible] | [illegible] | 5 | [illegible] | [illegible] | [illegible] | [illegible] |
| 71 SWITCHES | 8,784 | 1,855,113 | $488 | $428,218,538 | 188 | 4 | 1 | 268 | [illegible] | [illegible] | [illegible] | 5 | [illegible] | [illegible] | [illegible] | [illegible] |
| 14 CIRCUIT BREAKERS | 4,388 | 1,878,488 | $278 | $285,458,888 | 844 | 18 | 3 | 158 | [illegible] | [illegible] | [illegible] | 5 | [illegible] | [illegible] | [illegible] | [illegible] |
| 58 PANELS | 4,781 | 88,578 | $1,888 | $185,187,888 | 18 | 12 | 3 | 224 | [illegible] | [illegible] | [illegible] | 5 | [illegible] | [illegible] | [illegible] | [illegible] |
| 15 CONTROLLERS | 13,383 | 184,534 | $488 | $81,278,788 | 12 | 15 | 4 | 468 | [illegible] | [illegible] | [illegible] | 5 | [illegible] | [illegible] | [illegible] | [illegible] |
| 83 BOAT PROPULSION | 838 | 7,884 | $48,384 | $323,788,878 | 8 | 7 | 2 | 28 | [illegible] | [illegible] | [illegible] | 5 | [illegible] | [illegible] | [illegible] | [illegible] |
| 88 TANKS | 788 | 18,888 | $37,538 | $388,178,888 | 13 | 5 | 1 | 18 | [illegible] | [illegible] | [illegible] | 5 | [illegible] | [illegible] | [illegible] | [illegible] |
| 78 PURIFIERS | 344 | 8,384 | $18,878 | $115,848,388 | 18 | 84 | 24 | 18 | [illegible] | [illegible] | [illegible] | 5 | [illegible] | [illegible] | [illegible] | [illegible] |
| 38 INDICATORS | 2,827 | 88,484 | $1,318 | $131,118,812 | 38 | 18 | 3 | 127 | [illegible] | [illegible] | [illegible] | 5 | [illegible] | [illegible] | [illegible] | [illegible] |
| 48 - FANS | 2,884 | 84,888 | $2,388 | $228,818,512 | 33 | 2 | 1 | 88 | [illegible] | [illegible] | [illegible] | 5 | [illegible] | [illegible] | [illegible] | [illegible] |
| 83 HEAT EXCHANGERS | 1,778 | 31,378 | $8,848 | $214,888,888 | 18 | 8 | 2 | 57 | [illegible] | [illegible] | [illegible] | 5 | [illegible] | [illegible] | [illegible] | [illegible] |
| 87 - HEATERS | 2,815 | 184,815 | $1,842 | $188,217,238 | 38 | 5 | 1 | 172 | [illegible] | [illegible] | [illegible] | 5 | [illegible] | [illegible] | [illegible] | [illegible] |
| 88 - MISC EQUIPMENT | 1,837 | 845,387 | $848 | $234,438,138 | 815 | 7 | 2 | 53 | [illegible] | [illegible] | [illegible] | 5 | [illegible] | [illegible] | [illegible] | [illegible] |
| 81 - LAUNDRY EQUIPMENT | 815 | 18,744 | $5,587 | $58,187,288 | 17 | 28 | 7 | 58 | [illegible] | [illegible] | [illegible] | 5 | [illegible] | [illegible] | [illegible] | [illegible] |
| 11 - CONVERTERS | 743 | 18,213 | $8,254 | $133,822,188 | 22 | 23 | 8 | 32 | [illegible] | [illegible] | [illegible] | 5 | [illegible] | [illegible] | [illegible] | [illegible] |
| 88 - WINCHES | 788 | 8,887 | $27,838 | $187,775,518 | 8 | 28 | 7 | 28 | [illegible] | [illegible] | [illegible] | 5 | [illegible] | [illegible] | [illegible] | [illegible] |
| 88 - STEERING GEAR | 138 | 887 | $381,788 | $288,185,228 | 5 | 57 | 14 | 3 | [illegible] | [illegible] | [illegible] | 5 | [illegible] | [illegible] | [illegible] | [illegible] |
| 48 TESTING EQUIPMENT | 788 | 18,883 | $2,282 | $43,185,748 | 27 | 18 | 4 | 88 | [illegible] | [illegible] | [illegible] | 5 | [illegible] | [illegible] | [illegible] | [illegible] |
| 78 GOVERNORS | 448 | 8,878 | $18,515 | $72,381,148 | 15 | 88 | 17 | 22 | [illegible] | [illegible] | [illegible] | 5 | [illegible] | [illegible] | [illegible] | [illegible] |
| 34 - LIGHTING FIXTURES | 1,888 | 1,882,474 | $115 | $217,834,518 | 1,727 | 5 | 1 | 24 | [illegible] | [illegible] | [illegible] | 5 | [illegible] | [illegible] | [illegible] | [illegible] |
| 22 - SWITCHBOARDS | 2,883 | 17,881 | $7,218 | $128,788,858 | 8 | 15 | 4 | 73 | [illegible] | [illegible] | [illegible] | 5 | [illegible] | [illegible] | [illegible] | [illegible] |
| 57 - CRANES | 328 | 1,885 | $81,528 | $185,588,488 | 4 | 38 | 8 | 11 | [illegible] | [illegible] | [illegible] | 5 | [illegible] | [illegible] | [illegible] | [illegible] |
| 25 - GYRO COMPASS | 888 | 22,888 | $5,883 | $132,558,587 | 86 | 38 | 18 | 28 | [illegible] | [illegible] | [illegible] | 5 | [illegible] | [illegible] | [illegible] | [illegible] |
| 38 - CLUTCHES | 157 | 3,184 | $28,547 | $83,181,238 | 28 | 18 | 5 | 8 | [illegible] | [illegible] | [illegible] | 5 | [illegible] | [illegible] | [illegible] | [illegible] |
| 23 - VISUAL ALARMS | 888 | 288,813 | $488 | $131,351,757 | 388 | 8 | 2 | 18 | [illegible] | [illegible] | [illegible] | 5 | [illegible] | [illegible] | [illegible] | [illegible] |
| 44 - DEHYDRATORS | 288 | 4,887 | $18,455 | $88,888,485 | 17 | 22 | 8 | 11 | [illegible] | [illegible] | [illegible] | 5 | [illegible] | [illegible] | [illegible] | [illegible] |
| 45 - GAGES | 3,373 | 87,378 | $1,383 | $87,784,837 | 28 | 5 | 1 | 188 | [illegible] | [illegible] | [illegible] | 5 | [illegible] | [illegible] | [illegible] | [illegible] |
| 85 - DECK MACHINERY | 1,888 | 27,321 | $3,528 | $88,188,888 | 18 | 11 | 3 | 48 | [illegible] | [illegible] | [illegible] | 5 | [illegible] | [illegible] | [illegible] | [illegible] |
| 38 - BURNERS | 118 | 4,388 | $14,382 | $82,843,848 | 37 | 38 | 8 | 5 | [illegible] | [illegible] | [illegible] | 5 | [illegible] | [illegible] | [illegible] | [illegible] |
| 41 - SHOP EQUIPMENT | 3,328 | 21,818 | $1,345 | $27,277,858 | 7 | 8 | 2 | 185 | [illegible] | [illegible] | [illegible] | 5 | [illegible] | [illegible] | [illegible] | [illegible] |
| 81 - BLOWERS | 843 | 7,178 | $8,881 | $57,845,738 | 38 | 48 | 12 | 8 | [illegible] | [illegible] | [illegible] | 5 | [illegible] | [illegible] | [illegible] | [illegible] |
| 37 - BEARINGS | 888 | 11,145 | $14,888 | $182,783,878 | 17 | 5 | 1 | 18 | [illegible] | [illegible] | [illegible] | 5 | [illegible] | [illegible] | [illegible] | [illegible] |
| 34 - STARTERS | 853 | 4,387 | $7,884 | $33,818,858 | 17 | 38 | 8 | 14 | [illegible] | [illegible] | [illegible] | 5 | [illegible] | [illegible] | [illegible] | [illegible] |
| 33 - AIR CONDITIONING | 232 | 4,837 | $3,442 | $15,818,384 | 28 | 13 | 3 | 28 | [illegible] | [illegible] | [illegible] | 5 | [illegible] | [illegible] | [illegible] | [illegible] |
| 18 - MOTOR GENERATORS | 331 | 2,887 | $25,388 | $74,848,282 | 8 | 12 | 3 | 8 | [illegible] | [illegible] | [illegible] | 5 | [illegible] | [illegible] | [illegible] | [illegible] |
| 88 - DISTILLING PLANTS | 321 | 3,888 | $15,428 | $84,184,832 | 11 | 18 | 4 | 18 | [illegible] | [illegible] | [illegible] | 5 | [illegible] | [illegible] | [illegible] | [illegible] |
| 31 - MARINE HARDWARE | 1,784 | 48,332 | $1,375 | $88,458,588 | 27 | 8 | 2 | 48 | [illegible] | [illegible] | [illegible] | 5 | [illegible] | [illegible] | [illegible] | [illegible] |
| 82 - BOILERS | 284 | 1,448 | $17,888 | $25,888,588 | 7 | 84 | 24 | 8 | [illegible] | [illegible] | [illegible] | 5 | [illegible] | [illegible] | [illegible] | [illegible] |
| 28 - INJECTORS | 88 | 31,287 | $1,552 | $48,557,484 | 358 | 28 | 7 | 3 | [illegible] | [illegible] | [illegible] | 5 | [illegible] | [illegible] | [illegible] | [illegible] |
| 88 - BATTERY CHARGERS | 372 | 5,387 | $3,338 | $17,728,873 | 14 | 15 | 4 | 25 | [illegible] | [illegible] | [illegible] | 5 | [illegible] | [illegible] | [illegible] | [illegible] |
| 38 - HOISTS | 788 | 5,883 | $2,818 | $13,323,288 | 7 | 18 | 5 | 35 | [illegible] | [illegible] | [illegible] | 5 | [illegible] | [illegible] | [illegible] | [illegible] |
| 55 - REELS | 335 | 8,488 | $2,278 | $21,537,788 | 28 | 13 | 3 | 17 | [illegible] | [illegible] | [illegible] | 5 | [illegible] | [illegible] | [illegible] | [illegible] |
| 82 - WELDING EQUIPMENT | 388 | 3,541 | $2,788 | $8,811,358 | 8 | 18 | 5 | 27 | [illegible] | [illegible] | [illegible] | 5 | [illegible] | [illegible] | [illegible] | [illegible] |
| 84 - CONDENSERS | 778 | 7,448 | $8,482 | $83,188,488 | 18 | 8 | 2 | 11 | [illegible] | [illegible] | [illegible] | 5 | [illegible] | [illegible] | [illegible] | [illegible] |
| 18 - METERS | 488 | 8,378 | $2,884 | $22,287,888 | 17 | 3 | 1 | 21 | [illegible] | [illegible] | [illegible] | 5 | [illegible] | [illegible] | [illegible] | [illegible] |
| 18 - RELAYS | 1,887 | 84,882 | $213 | $18,833,888 | 53 | 5 | 1 | 58 | [illegible] | [illegible] | [illegible] | 5 | [illegible] | [illegible] | [illegible] | [illegible] |
| 87 - PERISCOPES | 338 | 4,887 | $7,782 | $37,777,884 | 15 | 33 | 8 | 5 | [illegible] | [illegible] | [illegible] | 5 | [illegible] | [illegible] | [illegible] | [illegible] |
| 84 - ASW EQUIPMENT | 78 | 871 | $18,735 | $7,283,185 | 8 | 52 | 13 | 8 | [illegible] | [illegible] | [illegible] | 5 | [illegible] | [illegible] | [illegible] | [illegible] |
| 88 - BRAKES | 888 | 8,884 | $1,728 | $18,538,158 | 11 | 8 | 2 | 33 | [illegible] | [illegible] | [illegible] | 5 | [illegible] | [illegible] | [illegible] | [illegible] |
| 28 - NAVIGATIONAL EQUIPMENT | 388 | 18,588 | $482 | $4,488,118 | 28 | 45 | 11 | 15 | [illegible] | [illegible] | [illegible] | 5 | [illegible] | [illegible] | [illegible] | [illegible] |
| 53 - CAPSTANS | 188 | 1,188 | $27,238 | $31,838,884 | 7 | 15 | 4 | 4 | [illegible] | [illegible] | [illegible] | 5 | [illegible] | [illegible] | [illegible] | [illegible] |
| 58 - ELEVATORS | 758 | 4,788 | $8,318 | $38,281,888 | 8 | 28 | 7 | 12 | [illegible] | [illegible] | [illegible] | 5 | [illegible] | [illegible] | [illegible] | [illegible] |
| 42 - REGULATORS | 858 | 15,134 | $1,188 | $17,878,858 | 18 | 18 | 5 | 18 | [illegible] | [illegible] | [illegible] | 5 | [illegible] | [illegible] | [illegible] | [illegible] |
| 75 - STRAINERS | 4,518 | 151,884 | $82 | $13,888,728 | 33 | 3 | 1 | 187 | [illegible] | [illegible] | [illegible] | 5 | [illegible] | [illegible] | [illegible] | [illegible] |
| 88 - PHOTOGRAPHIC EQUIPMENT | 78 | 2,255 | $7,138 | $18,882,888 | 38 | 12 | 3 | 3 | [illegible] | [illegible] | [illegible] | 5 | [illegible] | [illegible] | [illegible] | [illegible] |
| 83 - WINDLASSES | 182 | 887 | $28,585 | $18,473,715 | 5 | 35 | 8 | 4 | [illegible] | [illegible] | [illegible] | 5 | [illegible] | [illegible] | [illegible] | [illegible] |
| 85 - LUBRICATORS | 272 | 8,138 | $1,118 | $18,134,388 | 34 | 18 | 3 | 12 | [illegible] | [illegible] | [illegible] | 5 | [illegible] | [illegible] | [illegible] | [illegible] |
| 83 - PIPE, HOSE AND FITTING | 148 | 3,238 | $5,878 | $18,838,842 | 22 | 4 | 1 | 4 | [illegible] | [illegible] | [illegible] | 5 | [illegible] | [illegible] | [illegible] | [illegible] |
| 77 - TRAPS - STEAM | 1,887 | 113,381 | $314 | $35,884,774 | 118 | 4 | 1 | 13 | [illegible] | [illegible] | [illegible] | 5 | [illegible] | [illegible] | [illegible] | [illegible] |
| 73 - EJECTORS | 381 | 4,883 | $8,853 | $38,834,818 | 11 | 15 | 4 | 4 | [illegible] | [illegible] | [illegible] | 5 | [illegible] | [illegible] | [illegible] | [illegible] |
| 87 - UNDERWATER LOG EQUIPMENT | 288 | 8,518 | $8,188 | $48,187,284 | 32 | 38 | 8 | 2 | [illegible] | [illegible] | [illegible] | 5 | [illegible] | [illegible] | [illegible] | [illegible] |
| 13 - TRANSFORMERS | 881 | 183,843 | $388 | $38,888,884 | 117 | 1 | 8 | 8 | [illegible] | [illegible] | [illegible] | 5 | [illegible] | [illegible] | [illegible] | [illegible] |
| 38 - AUDIBLE ALARMS | 153 | 1,184 | $5,857 | $8,834,888 | 8 | 18 | 3 | 8 | [illegible] | [illegible] | [illegible] | 5 | [illegible] | [illegible] | [illegible] | [illegible] |
| 58 - DAVITS | 188 | 1,858 | $14,885 | $14,852,848 | 5 | 7 | 2 | 4 | [illegible] | [illegible] | [illegible] | 5 | [illegible] | [illegible] | [illegible] | [illegible] |
| 87 - PLUMBING EQUIPMENT | 388 | 83,488 | $81 | $5,881,888 | 271 | 8 | 2 | 18 | [illegible] | [illegible] | [illegible] | 5 | [illegible] | [illegible] | [illegible] | [illegible] |
| 35 - WIPERS | 181 | 11,487 | $81 | $781,317 | 84 | 14 | 4 | 8 | [illegible] | [illegible] | [illegible] | 5 | [illegible] | [illegible] | [illegible] | [illegible] |
| 28 - PROJECTION EQUIPMENT | 81 | 3,373 | $588 | $1,888,588 | 55 | 77 | 18 | 1 | [illegible] | [illegible] | [illegible] | 5 | [illegible] | [illegible] | [illegible] | [illegible] |
| 74 - EDUCTORS | 388 | 5,811 | $2,884 | $15,885,134 | 18 | 2 | 1 | 2 | [illegible] | [illegible] | [illegible] | 5 | [illegible] | [illegible] | [illegible] | [illegible] |
| 28 - RHEOSTATS | 458 | 7,274 | $857 | $4,778,818 | 18 | 5 | 1 | 8 | [illegible] | [illegible] | [illegible] | 5 | [illegible] | [illegible] | [illegible] | [illegible] |
| 78 - SILENCING EQUIPMENT | 188 | 2,484 | $882 | $1,838,528 | 15 | 3 | 1 | 4 | [illegible] | [illegible] | [illegible] | 5 | [illegible] | [illegible] | [illegible] | [illegible] |
| 72 - MINOR LANDING CRAFT | 817 | 1,887 | 8 | | | | | | [illegible] | [illegible] | [illegible] | 5 | [illegible] | [illegible] | [illegible] | [illegible] |
| 51 - ISOLATORS | 18 | 887 | $4,838 | $4,483,872 | 52 | 7 | 2 | 8 | [illegible] | [illegible] | [illegible] | 5 | [illegible] | [illegible] | [illegible] | [illegible] |
| 71 - IGNITION EQUIPMENT | 4 | 788 | $2,888 | $2,288,848 | 288 | 23 | 8 | 8 | [illegible] | [illegible] | [illegible] | 5 | [illegible] | [illegible] | [illegible] | [illegible] |
| 12 - MNT/REPAIR SHP EQUIPMENT | 5 | 52 | 8 | | | | | | [illegible] | [illegible] | [illegible] | 5 | [illegible] | [illegible] | [illegible] | [illegible] |
| 88 - MAGNETOS | 5 | 14 | $188 | $1,442 | 3 | | 8 | | [illegible] | [illegible] | [illegible] | 5 | [illegible] | [illegible] | [illegible] | [illegible] |
| 48 - CARBURETORS | 3 | 14 | $48 | $672 | 5 | | 8 | | [illegible] | [illegible] | [illegible] | 5 | [illegible] | [illegible] | [illegible] | [illegible] |
| TOTALS | 283,882 | 12,738,188 | $1,248 | $15,884,487,878 | 83 | | | 8783 | $188,464,982 | $16,530,593 | $14,884,320 | | [illegible] | [illegible] | $64,165,836 | $711,886,186 |