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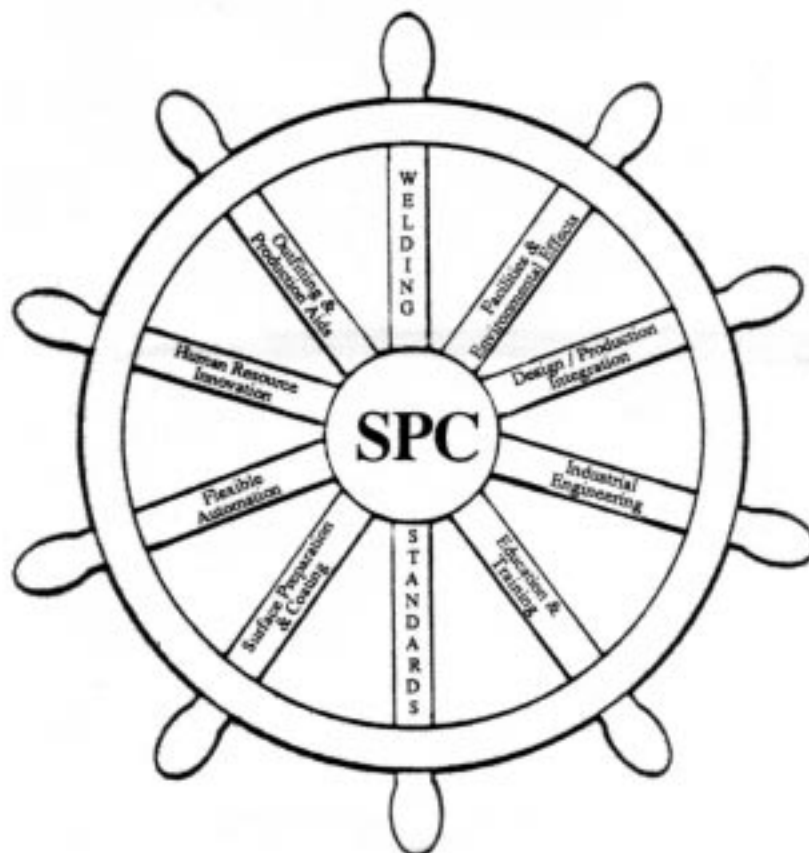
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Importance of Considering Life Cycle Maintenance and Modernization Costs in the Design of Navy Ships

6B-1

F.W. Banks, Visitor, Naval Sea Systems Command, Washington, D.C., M.H. Spicknall, Member,
University of Michigan Transportation Research Institute, Ann Arbor, MI

ABSTRACT

Experience with maintenance and modernization (M/M) of Navy ships has shown that life cycle maintenance and modernization costs significantly exceed initial acquisition costs, particularly for submarines and complex surface combatants. The purpose of this paper is to draw increased attention to the influence that initial ship design has on the cost of maintenance and modernization of Navy ships, and to emphasize the need for greater consideration of these costs in Navy ship design.

This paper presents several examples of actual design-related maintenance and modernization problems, along with possible design solutions, identified through a survey of U.S. Naval shipyards. The paper also provides recommendations for increasing consideration of maintenance and modernization costs in Navy ship design through education, through the development of specific communication interfaces between design and maintenance and modernization production functions, and through research.

NOMENCLATURE

Maintenance- The term "maintenance" is inclusive of all work performed in a shipyard environment to repair and overhaul ships and their existing infrastructures of components and systems.

Cost- The term "cost" is inclusive of all direct and indirect costs associated with the performance of maintenance and modernization work, including the cost of labor related time.

Shipbuilding/Production- The terms "shipbuilding" and "production" are inclusive of all maintenance and modernization work done in a shipyard environment.

INTRODUCTION

Today's climate of reduced tension between the United States and the Soviet Union is resulting in significant reductions in defense spending. This in turn is resulting in reduced budgets for operation and maintenance of Navy ships. As these budgets decrease, the cost of ship maintenance and modernization is coming under

increased scrutiny. Without improvements in the costs of maintenance and modernization, the Navy may be forced to operate with a reduced number of ships, with ships having reduced capability, or with reductions in both numbers and capability.

Most of the attention given to reducing maintenance and modernization costs thus far has been focused on improving productivity of actual work processes within shipyards. Shipyards performing this work have made significant progress in improving the productivity of related work processes. However, focusing attention on shipyard process improvement alone is not enough, as the actual physical execution of the work is only the last step in the whole maintenance and modernization process.

Initial ship design must be recognized as an integral and crucial part of the maintenance and modernization process; the influence that design has on the performance and cost of maintenance and modernization work must be appreciated. The premise of this paper is that the influence of initial Navy ship design on maintenance and modernization costs is not adequately recognized and appreciated, resulting in insufficient attention being given to minimizing these costs during initial design. In these times of ever tightening budgets, increased consideration must be given to maintenance and modernization requirements and costs during initial design of Navy ships in order to assure maximum future Navy capability.

NAVAL SHIPYARD SURVEY

In March 1990 a letter was sent from NAVSEA 072, Naval Shipyard Management Group, to all Naval shipyard Production Officers and Planning Officers requesting examples of design related problems encountered during the course of maintenance and modernization work, along with possible design alternatives that might minimize or eliminate the associated problems. This request was presented solely as a means by which the authors could either support or reject the premise of this paper. In the course of day to day activities at the Naval shipyards, it is not unusual to set aside such requests in way of higher priority production work. Therefore, it was not at all certain what, if any, response would be forthcoming.

During the next six weeks 129 example problems, with suggested design alternatives, were received from six Naval shipyards. Removal of redundant examples, and examples which were not specifically related to design and maintenance and modernization, reduced the data set to 117 usable examples. These remaining examples were then categorized based on commonalities. The percentage of survey responses in each of these categories is shown in Figure 1.

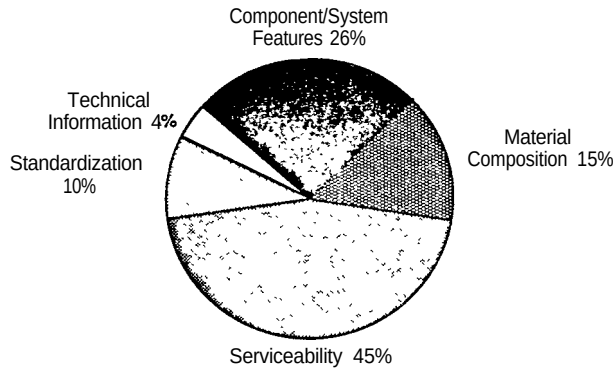


Figure 1. Survey Response By Category

Some examples are very specific while others are quite general. All examples highlighted that to reduce the cost of maintenance and modernization, ship systems should be designed to:

- reduce required maintenance and modernization work through the inclusion of system features which either extend the maintenance cycle or extend the service life of system components, and/or
- simplify required maintenance and modernization work through the inclusion of system features which make this work easier to perform, requiring fewer, manhours and less time.

A short discussion of each problem category, and some of their associated examples follow. Example problem statements and recommendations are reproduced as they were received from the Naval shipyards. There is no intent to suggest that the recommendations received and presented here would be either technically viable, cost effective, or contractually feasible; the intent is to demonstrate that there is a source of information that is not being utilized,

and to give examples of the types of things which could be considered in design to reduce life cycle maintenance and modernization costs.

Component/System Features. 30 examples; 26 percent of total. This category includes examples which call for the addition, elimination, or substitution of components and system features.

- 1) Problem Description: Within the Fleet Modernization Program, the necessity to recable, i.e. rip out entire runs of old cable systems and install new cables for new systems, whenever a new electronics or weapon system is installed during a modernization availability is the single largest component of electrical cost for this type of modernization work.

Recommendation: Install signal area networks, similar to computer local area networks, in areas of high congestion in the ship control, communications, and tactical spaces. Redundant capabilities could also be factored into the area networks to enhance survivability. Also, design in ship space for wireways through compartments and passages in areas of continuous modernization (especially electronics/weapons spaces) that accommodate the removal/installation of cable.

- 2) Problem Description: Bearing temperatures for major submarine rotating machinery units are remotely detected through use of remote temperature detectors (RTDs) imbedded into bearing babbits with epoxy. Bearing oil temperatures are also locally monitored with thermometers at the drain side of the oil from the bearing. Overhaul history has shown that significantly more bearing caps are lifted and bearings removed and worked due to defective RTDs than for actual bearing failures. The relative merit of obtaining actual bearing babbitt temperatures is suspect. Loss of oil flow or misalignment, and associated temperature increases would be detected by increases in oil temperature. A casualty of this type would most likely be immediate and would result in bearing damage before any corrective action could be taken.

Recommendation: Where monitoring of actual temperatures is required, an improved design would be to use tip-sensitive RTDs that make direct contact with the bearing and are inserted through a well in the machinery housing, allowing removal for repair and calibration without having to lift bearing caps or rework bearings. Also, other sensing

devices, such as remote reading thermometers that sense oil temperature as it leaves the bearing, could be used to determine bearing temperature in place of RTDs where practical.

- 3) Problem Description: Maintenance activities frequently require sound tapes of rotating machinery to make repair determinations. This requires special equipment and frequent trips from the yard to the ship while it is in operation.

Recommendation: Incorporate sound monitoring equipment into the design of key rotating machinery. This would allow both the ship operation and maintenance activities to have readily accessible information on equipment condition.

- 4) Problem Description: Ships are not designed to allow adequate access to bilge and tank areas. This makes cleaning of bilge and tank surfaces difficult and leads to inadequate surface preparation and preservation.

Recommendation: Make bilges and tanks more accessible during initial design. Use corrosion resistant materials in areas that are not readily accessible.

Material Composition. 17 examples; 15 percent of total. This category includes examples which call for material changes to increase the longevity of components. The primary thrust of these examples is to substitute materials which are more resistant to corrosion from sea water and other mediums internal to systems.

- 1) Problem Description: Extensive weld repair, cleaning, painting, and represervation is done to bilge areas during overhaul. Extensive corrosion occurs to the inside of shell plating, stiffeners, foundations and support structure, piping, valve bodies, and machinery.

Recommendation: Thermal spray a protective layer of aluminum on structure, piping, foundations, etc. during initial building phase to significantly reduce maintenance costs.

- 2) Problem Description: Corrosion is the Navy's worst maintenance problem. Most sea water components need repair not because of wear, but because of corrosion. The use of ceramic material has greatly reduced corrosion processes in certain applications on surface ships. The use of ceramic materials could greatly increase the life of sea water components and possibly help extend the length of time between overhauls of components and ships, including submarines.

Recommendation: Allow ceramic material to be used in new and repaired components, such as valve bodies, impellers, and pump casings. A great increase in component life could be realized.

- 3) Problem Description: Frequent plant shutdowns promote the formation of rust products in the steel shell of main condensers. These rust products are difficult and costly to remove.

Recommendation: Change the material of main condenser shell and tube supports to a non-ferrous material compatible with the tubes and water treatment being used. The material chosen must be resistant to stress.

- 4) Problem Description: Deterioration of sea water cooling systems has resulted in routine replacement of 90/10 copper/nickel (CUNI) piping and/or heat exchanger tubes in all classes of surface ships.

Recommendation: Install 70/30 CUNI piping and heat exchanger tubes exclusively in all sea water systems during initial construction. The thicker cuprous oxide film eliminates or significantly reduces repair costs and more than offsets original acquisition costs.

Serviceability. 53 examples; 45 percent of total. This category includes examples which call for the inclusion of system features which improve the serviceability of the systems.

Several suggestions were received relating to on board shipping routes/accesses for major components. The overhaul and repair process is perturbed by a general inability to rapidly remove major components from the ship. Frequently component removal is delayed until piping and electrical systems are deactivated, secured, and removed. Following is a related example.

- 1) Problem Description: Standardized plans do not exist for interference removal, internal routing, and specific hull cut locations to support removal of major components. The process of removal/replacement of major components, including making hull access cuts, often require removal of interferences including structure, piping, or other major components, and results in additional work and testing not directly associated with repair/replacement of the primary component. As no standards exist, each activity develops and utilizes its own plans, including location of hull cuts. This results in unnecessary differences between individual ships of a class.

Recommendation: Planned routing for major components (pumps, motors, compressors, etc.) including specific locations and sizes of hull accesses, and associated interference information should be incorporated into original design arrangements and documented on standardized class plans for use by all repair activities. Interference removal should be minimized and, if necessary, provided with mechanical takedown capability to eliminate cutting and rewelding operations. When necessary, hull access cut interferences, particularly piping systems, should be designed with mechanical joints to facilitate ease of removal/reinstallation, maintenance of system cleanliness, and restoration of system operation while the access is open.

Several suggestions were received relating to access for temporary services in support of repair and testing operations. A tour of any ship in the midst of a major overhaul is all that is necessary to explain these concerns. Passageways and accesses are usually congested with temporary services encumbering the free flow of workers and material. Following is a related example.

- 2) Problem Description: Excessive labor is expended providing temporary service access cuts for temporary power, ventilation, water services, welding cables, etc. These hull cuts must be welded back in later and must be carefully placed to avoid obstruction of shipping routes and accesses for ship machinery, and to avoid obstruction of ship work.

Recommendation: Provide "Service Access Trunks" to major ship machinery spaces adjacent to emergency personnel access trunks. This is most practical in surface ships and less practical in submarines. This will allow quicker installation of temporary services and avoid obstruction of emergency escape trunks and shipping accesses. Fewer hull cuts will be needed.

Ships' piping and electrical systems generally do not provide connection points for the installation of temporary support systems, for repair process support, and for testing. Several suggestions were received relating to these problems. Two examples follow.

- 3) Problem Description: During maintenance periods, installation of temporary electrical power is often required (in addition to the ship's normal shore power) while repairs are made to electric plant equipment such as ship service motor generator (SSMG) sets and major electric plant circuit breakers. This

type of temporary power is installed directly to the ship's bus and usually requires partial disassembly and reassembly of permanent cabling and/or bus work to facilitate the installation. For example, temporary power is installed to the vital bus while repairs are made to the motor generator-alternating current (MG-AC) breakers, motor generator-turbine generator (MG-TG) breakers, and SSMG set. Also, after major repairs to SSMG sets, ship service turbine generator (SSTG) sets, and diesel generators, the testing mandated by the Deep Diving General Overhaul Specification (DDGOS) predicates the use of load boxes which must be connected directly to the ship's bus. This type of installation requires extensive electrical tagout, is time consuming, and creates additional work within the electric plant.

Recommendation: Design of electric plant switchboards should incorporate permanent connections (cam-lok style) exterior to the switchboards to support installation of temporary power and test equipment. The connectors provided for each vital switchboard should be capable of carrying the rated load of a SSMG set, and the connectors provided for each non-vital switchboard should be capable of carrying the rated load of a SSTG set. These installations could be used for SSMG testing, SSTG testing, diesel generator testing, super shore power, and any other special shore power requirement.

- 4) Problem Description: Considerable piping system disassembly is often required to support testing and purging.

Recommendation: Provide test/purge connection points/fittings to support all commonly performed evolutions. Standardize connection points/fittings for ease of hookup.

Standardization. 12 examples; 10 percent

of total. This category includes examples which call for reducing the range of variation in components with similar functions, and reducing the number of applicable specifications.

Problem Description: Electronic systems on board Navy ships use hundreds of different types, styles, and configurations of connectors. Special equipment assemblies, differences in pin sizes, backshells, and adaptors require a wide range of parts support making this method of doing business costly for production, procurement, and engineering (researching substitute components when designed connectors are not available).

Recommendation: Minimize the different types of connectors used (provide incentives if possible) through new system/ship contract specifications. If competition is required, develop the appropriate military standard so that there is a specific connector for each type of Navy cable.

- 2) Problem Description: Foundations and mounting structure frequently must be rebuilt because replacement mechanical and electrical components do not fit properly.

Recommendation: Use standard design mechanical and electrical components.

- 3) Problem Description: Present fastener specifications are an accumulation of requirements determined through the years. With the materials available now, there is no apparent need for all the specifications presently in use. Material ordering is extremely complex and cumbersome due to the wide variety of specifications.

Recommendation: Standardize the specifications for fasteners to reduce the quantity of specifications to a more economical number. Many specifications could be combined or eliminated.

Technical Information. 5 examples; 4 percent of total. This category includes examples which call for improving the content and format of technical information (drawings, technical manuals, etc.) provided by design engineering for maintenance and modernization work.

- 1) Problem Description: Vendor developed detail drawings and assembly drawings are not available for use by maintenance activities. In many cases, NAVSEA (detail dimensional) drawings do not exist, and the vendor considers this information as proprietary and, therefore, does not have a contractual obligation to provide the necessary detailed information. In these instances, and particularly for emergent work, the user activity must utilize a "make as per sample" approach for replacement parts which are not available in the supply system and/or require long lead time for purchase from the vendor.

Recommendation: As part of the initial design process, include all detailed technical information, including vendor detailed drawings, within the ship's drawing index, and make all information available for anticipated and emergent maintenance and replacement work on vendor supplied components.

DESIGN FOR MAINTENANCE AND MODERNIZATION

During initial design of a Navy ship, considerable effort should be given to identifying, reducing, and simplifying ship system and component life cycle maintenance requirements, with special attention being given to maintenance that will be required frequently and/or will be complex and labor intensive. Features should also be provided to simplify anticipated future ship modernization.

However, for maintenance and modernization requirements and costs to be considered in initial Navy ship design:

- minimization of maintenance and modernization costs must be made a design priority, and
- designers, design engineers, and design managers must have experience with maintenance and modernization work and/or have direct and effective communication with production personnel experienced with this type of work.

The results of the Naval shipyard survey show that more could have been done during initial design of existing Navy ships to reduce maintenance and modernization costs. The more recent Trident, DDG-51 and SSN-21 design efforts placed some priority on incorporating design features which will reduce future maintenance and modernization costs; the effectiveness of these design efforts will be seen in the years to come.

In these more recent Navy ship design efforts, priority has been given to "design for production" or "producibility," emphasizing reduction of initial ship construction costs. This emphasis on producibility is primarily a result of U.S. shipyards losing commercial shipbuilding market share because of significantly lower initial construction costs of foreign built commercial ships. Producibility should have priority over maintainability in the design of commercial ships because maintenance and modernization is much less costly for commercial ships than for Navy ships when compared to initial construction costs. However, because of the relatively high costs associated with maintenance and modernization of Navy ships when compared to initial construction costs, maintainability and producibility should have equally high priority in all Navy ship design phases and decisions. Maintainability and producibility can both be incorporated into ship

system design, but only if the importance of maintainability is recognized and accepted by Navy design functions.

“It is arguable that the conventional design process does not necessarily take into account the operating requirements of maintenance, overhaul, and repair. The design which has been developed to enhance producibility can also enhance operating characteristics.” [1]

Also, as noted above, for maintenance and modernization requirements and costs to be considered in initial Navy ship design, designers, design engineers, and design managers must have experience with maintenance and modernization work and/or have direct and effective communication with experienced production personnel.

Research has shown that many engineers and scientists entering ship design and shipbuilding functions today have little or no background in shipbuilding.

“Of the (shipbuilding and ship design) engineers and scientists surveyed, only 20 percent are naval architects or marine engineers. Those are the only degree programs that have significant content directed specifically towards ship production. This means that the other 80 percent of the entry-level technologists most likely have not been exposed to the shipbuilding industry (and its products, processes, terminology, etc.) prior to graduation.” [2]

Shipbuilding research, and the authors' experience suggest that many ship design organizations, particularly in the U.S., have not done an adequate job of training ship designers and design engineers in shipbuilding.

“In Japan and Scandinavia in particular, shipbuilders have had a clear policy for many years for the training and development of shipbuilding engineers. Elsewhere too many designers are in the position of having to make major decisions having barely seen, let alone worked in a shipyard.” [3]

“The positioning of engineers in the production departments at all levels has been shown by the Japanese to lead to significant benefits, (such as) maintaining a high technology level in production, and promoting superior communication. In U.S. shipyards the

duties and responsibilities of such engineers could be equivalent to those in Japanese shipyards, where they are involved in planning, scheduling, material flow, accuracy control, and manning requirements for their areas of responsibility, or **they may be restricted to the usual U.S. role of engineering liaison** (emphasis added).” [4]

There are a relatively small number of engineers in U.S. shipyards who work in ship production areas as trades supervisors, process analysts, production controllers, planners, accuracy control engineers, etc. In Naval shipyards, the majority of these engineers work within the industrial engineering organizations. These engineers have gained valuable shipbuilding experience.

“There are still many untapped opportunities for our industrial engineering efforts. . . . Our ship designs have rarely given adequate consideration to maintainability - our industrial engineers have the necessary skills to identify changes which can be made in ship design to improve access and reparability, without compromising the system technical requirements.” [5]

There are also managers, supervisors, and mechanics on the waterfront without engineering backgrounds who, nevertheless, are extremely knowledgeable in their specific areas of production, and, in the Total Quality Management sense, are probably the most knowledgeable of specific maintenance and modernization problems related to design.

Given the present level of shipbuilding experience in design organizations, another way of identifying maintenance and modernization cost saving ideas for new Navy ship designs is to have a direct and effective means of communication between design and the experienced production personnel mentioned above.

Following are descriptions of the existing communication interfaces between government design functions and Naval shipyard production related functions.

- In 1984, the Naval Sea Systems Command (NAVSEA) established a working interface between Naval shipyards and design engineering to review proposed design changes for cost and schedule impact.

- In 1986, NAVSEA initiated a study for maintainability that focused on the aircraft carrier hull expansion program.
- In 1987, NAVSEA initiated reviews of specifications, drawings, standards, and handbooks through participation as a member of the NAVSEA Specifications Control Board.
- In 1987, NAVSEA began reviewing Integrated Logistic **Support** Plans.
- In 1987, Navy design engineering began reviewing Uniform Industrial Process Instructions (UIPIs), developed by Industrial Engineering in Naval shipyards, for their ability to produce products that meet technical requirements.
- The recent Hazardous Waste Minimization Program requires production to communicate to design engineering when it is known that a specific job can be done alternatively excluding or minimizing hazardous material. Design engineering is required to respond. [6]

Some of these activities represent after-the-fact reviews by NAVSEA of design generated material for existing ships. The maintainability study of the aircraft carrier hull expansion program was a one-time-only activity. The Navy design engineering reviews of UIPIs only address the technical applicability of production processes. None of these activities provide a means of communicating specific design ideas for reducing maintenance and modernization costs between production and design functions. It has been the authors' experience that little or no communication interface exists today for this specific purpose.

CONCLUSIONS

- The survey response supports the premise of this paper that the influence of initial Navy ship design on maintenance and modernization costs is not adequately recognized and appreciated.
- Changes in Navy ship design can contribute to significant reduction of life cycle maintenance and modernization costs.
- Maintainability must be given the same priority as producibility in initial design of Navy ships.

- Navy ship designers, design engineers, and design managers require additional education, training, and experience in shipbuilding.

- There are many ideas available from shipyard personnel relating to design improvements which could help reduce maintenance and modernization costs.

- There is presently no formal and effective means of communicating ideas related to reducing maintenance and modernization costs between design and experienced shipyard personnel.

- There are presently no recognized and published generic design methods and attributes which are known to contribute to reducing maintenance and modernization costs.

RECOMMENDATIONS

- Provide shipbuilding education and training to undergraduate designers and engineers who will be entering the ship design field. Include programs through which these students can obtain hands-on shipbuilding experience; successful co-op and internship programs already exist through several colleges and shipyards. Most naval architecture programs today have minimum requirements for studies in ship production. These education and training programs should emphasize equally the need for maintainability and producibility in Navy ship design.

- Provide shipbuilding education and training to existing Navy ship designers and design engineers. Include a means for designers and design engineers to obtain hands-on shipbuilding experience, particularly with maintenance and modernization work. These education and training programs should emphasize equally the need for maintainability and producibility in Navy ship design.

- Establish formal and effective communication interfaces between production and the Navy design functions for discussing design ideas related to maintenance and modernization cost saving.

- Establish methods of cost-benefit analysis that would be applicable to judging the economical merit of design related maintenance and modernization cost saving ideas, such as the ones presented in this paper.

Conduct research to identify generic design methods and attributes which would contribute to reduction of maintenance and modernization costs, and to study how these methods and attributes might coincide or conflict with the already established methods and attributes which contribute to producibility.

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