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Life Cycle Design for Marine Vehicles

IXA-2

M.M.A. Pourzanjani, Member, and J. Knezevic, Visitor, School of Engineering,
University of Exeter, UK

ABSTRACT

The design process for a marine vehicle is essentially an iterative process where different characteristics and parameters are modified until the optimum compromise is achieved. However, in day to day running of these vehicles we notice that they don't perform as well as we expect. This is an indication that some of the parameters have been ignored during the design process. In this paper it is suggested that when designing a ship, a life cycle analysis should be carried out. Many concepts should be included in the conceptual design, which include: maintainability, maintenance, supportability, reliability, logistics support, safety, and testing. In essence, it has been found that Reliability, Maintainability and Supportability (R/M/S), as design characteristics could have a tremendous impact on the ultimate effectiveness and economic support of a system in the user environment. Further, it has become increasingly evident that R/M/S considerations are not adequately addressed in the design process. If considered at all, these factors are introduced "after-the-fact," which can be a costly experience should changes be required at this stage.

This paper proposes a new approach to design, a life cycle engineering approach, which presents an integrated approach for bringing competitive products and systems into being in such a way as to minimize their deficiencies and life cycle cost. This involves the integration of performance, producibility, reliability, maintainability, manability (human factor), supportability and other "ilities"

into the overall design process. It would bring R/M/S to the front-end of design of a new system or piece of equipment. This paper deals primarily with application of the above to ships, the concepts, however, are general and can be equally applied to other types of complex technical systems.

INTRODUCTION

Ship design is amongst the professions which were dominated by tradition more than other factors. This is not surprising considering the fact that history of ship design goes back many thousands of years and may be one of the reasons for this industry to have been reluctant to accept new concepts. This picture, however, has been changing very rapidly. Changes are taking place as a result of technological advances, especially in computing areas, and furthermore, there is an increasing demand by the ship owners and operators for more availability of ships (associated with higher reliability and lower maintenance) and the governments and other governing bodies for design of safer vehicles.

Changes in the ship design process can be summarized in more usage of digital computers to conduct various tasks involved in the design process. Computer Aided Design and Manufacture are being used very widely in marine vehicle design. Other concepts such as reliability analysis are also being imported from other industries, specially the military sector, where high reliability of systems is paramount. These new techniques are welcomed by all concerned, as they help the de-

signers and manufacturers to perform their tasks more efficiently, and in this respect the industry seems to have responded well and be on the natural way to progress. However, compared to other industries, with similarities to ship design (e.g automobile design, aircraft design) it would appear that we are lagging behind. This may partly due to the risks involved in a total or partial failure of a ship and partly due to the initial capital investment required to introduce an extra amount of work in the ship design process.

To highlight some shortcomings of the classical approach to ship design let us consider some questions to which this approach cannot provide satisfactory answers.

- * At the beginning of operation a marine vehicle meets its performance and other legal requirements; but will it continue to perform in a reliable and safe manner for the period required?
- * If it should fail, is it maintainable and can it be supported?
- * Can the vehicle be operated and maintained in a cost effective manner?

When dealing with a ship's operational requirements, there are many questions that must be considered. In most cases the answers to the above questions provided by ship designers or manufacturers are very basic and limited. The reason for this is the dearth of information which is the result of inadequate front-end planning and lack of an integrated approach to ship design. Often the problems associated with poor effectiveness and the high costs of operation and maintenance support are the consequences of decisions made in the early stage of design.

In essence, it has been found (specially in the aerospace industry) that engineering disciplines like reliability, maintainability and supportability, as design disciplines, have a tremendous impact on the ultimate effectiveness and economic support of a system in the user environment. Further, it has be-

come increasingly evident that R/M/S considerations are not adequately addressed in the design process. If considered at all, they are introduced at such a late stage ("after-the-fact"), which can be a costly experience should changes be required.

Thus, this paper proposes application of a Life Cycle Analysis Approach to ship design, the main objective of which is to bring a competitive marine vehicle into being in a way which minimizes their operational deficiencies and life cycle cost. This involves the integration of: performance, producibility, reliability, maintainability, manability, supportability and other related disciplines into the overall design process. This approach brings R/M/S to the front-end of design process of a new marine vehicle.

The approach proposed here alters the traditional view of design and supplements it with additional tasks, as a result of which the available information for decision making process during the design considerably increases. The gained knowledge will also reduce the shortcomings of classical approach to ship design already highlighted.

LIFE CYCLE OF A SYSTEM

Fundamental to any engineering design practice is an understanding of the cycle which end product goes through during its life. The life cycle of a system or product begins with the initial identification of the needs and requirements and extends through planning, research, design, production, evaluation, operation, support, maintenance and its ultimate phaseout (see Fig. 1). The above phases are common to all engineering systems but certainly the scope and activities performed in each of them would depend on each individual system considered.

The classical approach to engineering looks at each of these phases as separate entities. Designers design the system, production team produce it, operators use it, maintenance engineers perform all repairs and so forth, without adequate interaction and feed-

back between these groups and activities. Indeed some of the operational problems associated with ships are believed to stem from the lack of coordination, contact and feedback between the above mentioned groups.

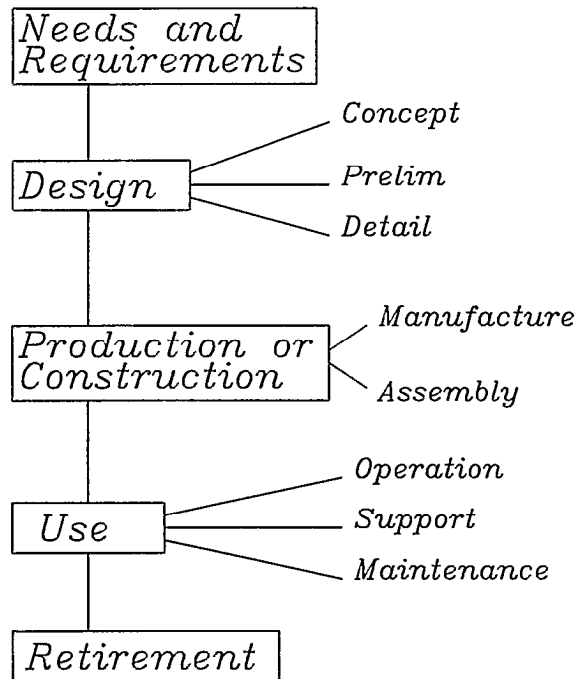


Fig. 1 Life Cycle

Following list contains some of the tasks and activities performed at various phases of Life Cycle:

Design:

- * Management
- * Planning
- * Research
- * Engineering design
- * Documentation
- * Software
- * Scale modelling
- * Test & evaluation

Production:

- * Management
- * Operational analysis
- * Manufacturing

- * Assembling & construction
- * Quality assurance
- * Initial logistic support
- * Testing
- * Delivery

Use:

- * Management
- * Operation
- * Distribution
- * Maintenance
- * Inventory (spares etc.)
- * Training
- * Technical data
- * Modification

Retirement:

- * Disposal of non-repairable elements
- * Phase-out
- * Documentation

It is suggested here that a classical design team which consists of experts for various aspects of the design stage, should be transformed into an Integrated Design Team (ITD) which will incorporate other technical disciplines related to the vehicle's life cycle (e.g. production team, operators etc.).

The concept of life cycle design proposes that in designing a complex multi-element system (such as a ship or an aircraft) a better design, from the point of view of minimum Life Cycle Cost (LCC), can only be achieved by considering all cost categories related to the complete life cycle at the conceptual stage of design. The emphasis in more detailed analysis at an early stage is primarily due to the fact that at this stage commitments are minimal and changes can be incorporated at ease and low cost [1] (see Fig. 2). This technique has already proved to be very successful in automobile industry [2].

One of the current requirements of the Department of Defence (USA) is that LCC should be used as one of the main acceptance criteria for all military equipment. It is expected that the U.K. and other European countries will follow the U.S. example in the

near future.

In order to apply the life cycle cost analysis to ship design the new concepts should be introduced into the existing design spiral.

CURRENT PRACTICE: DESIGN FOR FUNCTION ABILITY

The main objective of design for function ability is to create a product which will perform a set of desired functions according to specified requirements. In order to relatively achieve this, designers select all the necessary components and put them into the proper relationship that size, weight, volume, shape, accuracy, capacity, speed of performance, power output and all other technical and physical characteristics that the product must possess during its operational life are relatively satisfied. The ability of the system to perform required functions under specified conditions is defined as function ability [2].

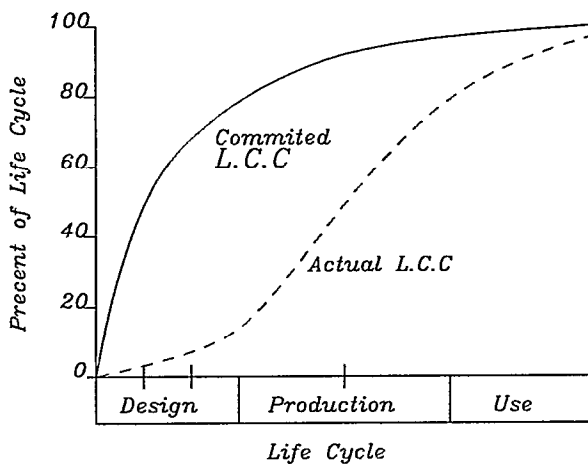


Fig. 2 Actions Affecting Life Cycle Cost

In essence design for function ability implies that at commissioning time a product should satisfy the needs and requirements mentioned above including safety and other legal aspects. Looking at ship design as is practiced today, most of the computing facilities are used only to speed things up and satisfy function ability. Some computer packages are now available in the market which do perform tasks which can be considered as Com-

puter Aided Design (CAD) in the true sense (e.g. designing more refined hull forms using numerical solutions to the hydrodynamic equations). One major problem with most of these packages is that they have been developed very much in isolation and data transfer and integration of these within a larger CAD system is virtually impossible rendering these packages, although very useful in a theoretical sense, somewhat useless. Thus when developing such computer based packages, one should take into account the existing CAD systems and the problem of data transfer in and out of the new tools being developed. Due to economic constraints in most cases the conceptual design stage is a short and speedy process. Therefore a large number of questions remain unanswered and decisions made are based on incomplete information, with the designers confidence mainly based on the previous designs which bear similarities to the design in hand.

A difficult part in any engineering design is the fact that as it proceeds, various options are eliminated. One way of dealing with this problem is to run several different options in parallel (D_i , $i = 1, n$, in figure 3). This approach would have been ambitious and probably impractical a decade ago, however, it is now possible to conduct this exercise using powerful computing facilities with vast storage area at a reasonably acceptable cost. Hence the idea of a design spiral still holds, but instead of one spiral we would have a number of them running in parallel and based on various options. This would allow decisions to be made based on comparison between different design options, at a much later stage of design where more information is available. But this is still classical design, i.e. design for function ability which does not provide sufficient information regarding the operational efficiency and overall life cycle cost effectiveness of the vehicle under consideration.

DESIGN FOR LIFE

The design process described above is a succession of events and iterations through the design spiral or optimization in parallel,

both of which are not satisfactory because they ignore the important life cycle concepts. Some of them are described below. Detailed quantitative descriptions of these are given in references [2] and [3].

Reliability

The characteristic of design and construction concerned with the successful operation of the ship throughout its operational life are known as the reliability characteristics. Reliability is often expressed as the probability of success and is measured in terms of MTBF (mean time between failures), failure rate, percentage life etc. The main objective of reliability based design is to maximize operational success. As a result, failures are minimized.

Maintainability

The characteristic of the design and construction that is concerned with the ease, economy, safety and accuracy in the performance of maintenance actions is known as maintainability. The objective of maintainability is to minimize maintenance times, by providing proper accessibility, diagnostic facilities, and standardization.

Supportability

This characteristic of the design is related to requirements needed for the performance of the maintenance tasks, like: equipment, tools, facilities, personnel, software and supply. The main objective of the supportability analysis is to identify and minimize the support resources required during the life cycle.

Manability (human factor)

The characteristics of the design that is directed toward the optimum human-machine interface (i.e. ensuring the compatibility between the physical system and functional design features and the "human element" in the operation, maintenance and support of the system or equipment) is "manability". Human factor considerations try to ease the use

of equipment and results in reducing personnel skill levels, minimizing training requirements, and minimizing potential personnel error rates.

Producibility

The characteristic of the design that allows for the effective and efficient production of one or a multiple quantity of items of a given configuration is producibility. The objective is to minimize resource requirements (i.e. human resources, materials, facilities, energy) during the production process.

Logistics Support

The characteristic of the design directed towards ensuring that the ship can ultimately be supported effectively and efficiently throughout its planned life cycle is logistic support. An objective is to consider both the internal characteristics of equipment design (reliability, maintainability, human factors) and the design of logistic support capability of the organizations concerned.

Economic Acceptability

The characteristic of the design and production which is directed toward maximizing the benefits and cost effectiveness of the overall vessel configuration is economic acceptability. An objective is to base design decisions on life cycle cost in addition to acquisition cost (or purchase price).

Social Acceptability

The characteristic of design which is directed towards ensuring that the vessel can become an acceptable part of the social system. Here the objective is to seek minimum pollution, ease of disposal, minimum safety risk, high transportability etc.

INTEGRATED FRONT-END DESIGN

In order to encompass all aspects of the life cycle of a ship at the design stage, it is nec-

essary to perform a series of analyses regarding all concepts of design mentioned in the previous sections and integrate them within the design process as shown in figure 3.

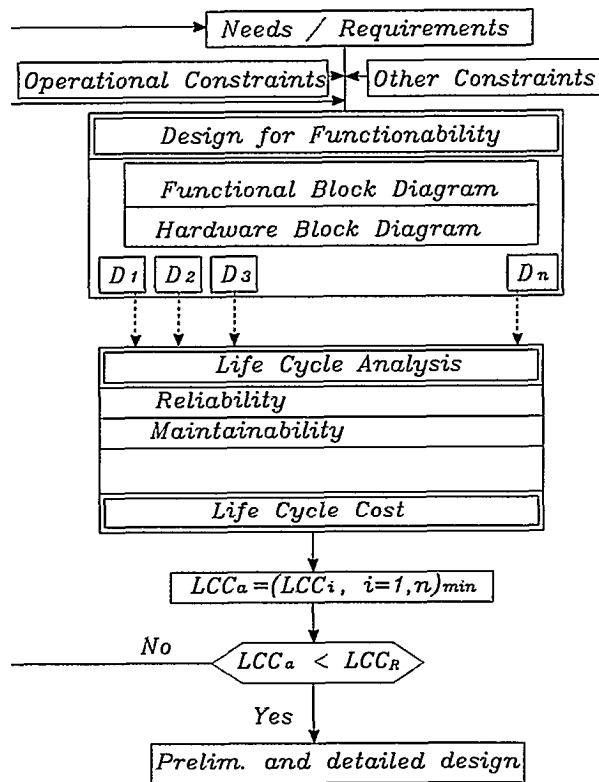


Fig. 3 Life Cycle Design

LCC_a and LCC_r in figure 3, refer to the achieved and required life cycle costs.

Operational concept

The operational concept is a description, qualitative and quantitative, which gives the designers the boundaries for the system. The vessel is defined and constrained by these criteria, which are usually determined through the requirements of the customer or market demand. In many cases such a design description is performance or function orientated, whereas information related to the operating conditions to which the vessel will be subjected are not included. This information is important for the assessment of the design. Environmental conditions which the machine is subjected to, operating profile and stresses

(humidity, shock, vibration, temperature cycles) and transportation profiles for the ship exposed to frequent movement during its operational life are, criteria which influence the decisions of the designers.

Functional Block Diagram

The main aim of producing a functional block diagram is to establish a breakdown structure related to the function which the vessel is expected to perform, applying the top-down approach. Thus at this stage the vessel exists as a collection of elementary functions which have to be performed for the satisfactory operation of the vessel.

Hardware Block Diagram

The basis for the hardware block diagram activity is the establishment of a hardware breakdown structure of a ship to be designed. This is based on top-down approach related to the hardware. Therefore, defining the structure in this way the ship exists as a collection of assembled units grouped in logically, separated entities. For each further breakdown, the vessel is partitioned into its basic building blocks that provide the lowest level of the breakdown structure. The depth for the structure is based on the need that is required for subsequent analysis steps. The hardware block diagram is closest representation of the ship at that moment.

Life Cycle Analysis

At this point of conceptual design the ship under consideration should be analyzed from the points of view of the new topics described in the section "Design For Life" above. Only a few of them will be discussed here.

Reliability Analysis. Part of the integration of the design concept is that reliability should be built into the system and not used for measuring performance after the system has been built.

In making reliability block diagrams of a ship, the individual components, their appli-

cations, stresses and tolerances are evaluated against the operating modes and functions of the vessel as a whole. Thus, the design goal in attaining high reliability rests on the ability to select and apply those components and materials that meet the requirements.

The predictive analysis called the Failure Modes and Effects Analysis (FMEA) [3] involves an inductive approach which starts from failure and goes to effects on the system. It identifies potential system failures, causes of failures, and special maintenance characteristics that have to be observed. The main aim of FMEA is to identify the weaknesses of design, in terms of high failure rate items [4].

Maintainability Analysis. Failure characteristics defined by FMEA require maintenance actions to restore the system to its satisfactory condition and these are defined only to the extent that a task has to be carried out. There is no definition or procedure as to how to carry out that task. The activity which accounts for maintenance actions which have to be performed and the necessary resources identified is called the maintainability analysis [5].

Maintainability characteristics are direct results of reliability and design of the vessel. The main aim is to design a ship in such way that it can be maintained without excessive investments of time, personnel, materials, facilities and support and test equipment. Maintainability can only seek to minimize the resource involved in the performing maintenance actions, whereas their elimination can only be done through design.

Thus maintenance actions are identified through maintainability analysis and they are assigned as a value to the design in a similar way as reliability does with reliability values.

Safety Analysis. When discussing design for functionability it was mentioned that apart from functional requirements and needs, a new design must also satisfy the legal aspects and meet the rules as laid down by various regulatory bodies. A large proportion of

these regulations deal specifically with safety aspects of the design, specially when designing a new vehicle intended to carry passengers. Numerous disasters in the recent past kept reminding us how important safety considerations are and also indicated the inadequacy of the existing regulations. In some recent publications [6, 7] it has been suggested that designers should not be satisfied in designing only to the regulations. It is their professional duty to look at the safety aspects more closely and exploit different avenues and, if necessary, review the whole design process to ensure that safety of life and property is not put at undue risk. The authors support this positive attitude and feel that researchers must provide guidelines as to how these improvements should be made.

In this paper some concepts have been covered as a result of which a more reliable vehicle can be produced. This increase in reliability tied with other concepts covered here will improve the safety standards for marine vehicles.

Cost Analysis. Lately, the interest in cost after the purchase has grown tremendously among users. The designers and producers have good knowledge of the fixed cost of investment and expense of development and manufacture, but the operating and support costs must be forecasted. A way to determine these costs is through the application of a life cycle cost analysis.

Life cycle costs include the costs associated with all activities pertaining to research and development, design, test and evaluation, production, distribution, operation, maintenance and support and disposal costs.

Each component has a fixed cost that it contributes to the entire system giving a total life cycle cost.

Although it is difficult to state how certain costs will behave, it is possible to relate the factors that influence cost behavior. The most influential factors are: components reliability; maintenance efforts to restore opera-

tion and its support; unit cost of components; and the environment in which the system operates.

Integration of All Analysis

Designers are continually faced with the problem of choosing among alternative courses of action in designing, producing and operating the vessel. Many factors, some tangible and some intangible, must be considered before a decision is made.

Despite the fact that they have very different natures all these decision-making factors can be correlated to a single factor: life cycle cost. It is necessary to underline that this is not accounting costs (historical costs) which show what has happened under existing conditions. This is the future cost which represents what is expected to happen under an assumed set of conditions. This would answer an important question: What would happen if this was done? Relevant design, reliability, maintainability and supportability information are inputs to a life cycle cost model of the vessel under consideration and its operational environment. This is a projected figure of merit for the current design.

OPTIMIZATION CRITERION: LIFE CYCLE COST

As the reliability analysis determines the reliability of the system, the maintainability analysis quantifies the maintainability figures of the system, and the supportability analysis determines what resources are to be expected to maintain the system, the life cycle cost analysis determines a cost figure in the overall measure of merit based on the design, production/construction, operation, support, maintenance and retirement of the system.

At the end of one round through the design spiral, we get only one set of values. But what happens when design changes or a component has changed with different reliability and different maintenance requirement? The designer must recognize that one round through the spiral gives us only a static

view of the design. Part of the solution to this problem is utilization of life cycle cost which enables us to measure and quantify the changes made at a design stage against a different configuration. The whole decision making process during the design stage rests on the premise that the design can be quantified through a cost. Changes to the system have an overlying decision criteria that encompasses the key design parameters.

The design aims of high performance and reliability, low maintenance, and cost have a mechanism to trade-off each goal against the others. Alternatives in design are evaluated in each of the steps of analysis and are quantified through the life cycle cost analysis.

In any design alternative, varying factors assist the decision making process. For example, one alternative component might perform the same function with a higher unit cost, but has a significantly lower failure rate and demands more highly qualified technicians for maintenance than the alternative. The common denominator through this process is the decision making cost: life cycle cost.

Effectiveness Factors

In order to quantify the effectiveness factors of the system under consideration it is necessary to consider the following:

- * System performance/technical parameters: capacity, delivery rate, range, volume, speed, weight and similar;
- * System operational and support parameters: availability, capability, operational readiness, reliability, maintainability, and so on;
- * System life cycle cost: research cost, design cost, production cost, operation and maintenance cost, retirement and disposal cost.

Thus, figures of merit, FOM, which quantify the effectiveness of the system should establish a relationship between the above men-

tioned categories. Some possible figures of merit are mentioned below:

$$\text{FOM} = \frac{\text{availability}}{\text{life cycle cost}}$$

$$\text{FOM} = \frac{\text{reliability}}{\text{life cycle cost}}$$

$$\text{FOM} = \frac{\text{system capacity}}{\text{operational range}}$$

or other.

The benefit of the effectiveness of FOMs is particularly appropriate in the evaluation of two or more alternatives when decisions involve design and operational parameters. Each design configuration (D, in figure 3) is evaluated in a consistent manner employing the same criteria for evaluation which cover the whole life cycle horizon of the system under consideration.

CONCLUSION

This paper has examined some new concepts for inclusion at the conceptual stage of design of a marine vehicle in order to minimize some of the deficiencies currently present in ship design practice.

The notion of design for life cycle was discussed, by first looking at the current trends in ship design and looking at some shortcomings there-in.

Reliability, Maintainability, Supportability and some other related concepts and their application to ship design were discussed, in a qualitative manner. A quantitative approach requires much elaboration which is outside the scope of this paper, and has already been carried out in a series of lecture notes in connection with short courses for the industry at the University of Exeter.

Some software has already been developed by commercial firms [6], and work has recently been completed at the Center for Industrial Reliability and Cost Effectiveness at the University of Exeter, to develop an integrated software package for life cycle system

design which can be custom made to be applied to ship design.

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