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WAYS TO REDUCE COSTS OF SHIPS

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Specialist Team on Ship Costing

Participating Nations: Belgium, Canada, France, Germany, Italy, Netherlands, Norway, Portugal, Spain, United Kingdom, and United States

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For other restrictions, see paragraph 5 of the Introduction Section.

NORTH ATLANTIC TREATY ORGANIZATION

MILITARY AGENCY FOR STANDARDIZATION (MAS)

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1. ANEP 49 (Edition 2) – "WAYS TO REDUCE COSTS OF SHIPS" is a NATO/PFP UNCLASSIFIED publication.

2. ANEP 49 (Edition 2) is effective upon receipt. It supersedes ANEP-49 (Edition 1), which should be destroyed in accordance with local procedures for the destruction of documents.

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H.J. ERIKSEN
Rear Admiral, NON
Chairman, NSA

RECORD OF CHANGES

CHANGE DATE	DATE ENTERED	EFFECTIVE DATE	BY WHOM ENTERED
24 October 2000	24 October 2000	Edition 2 Release	NG/6 STSC

FOREWORD

This Allied Naval Engineering Publication (ANEP) was developed by the Specialist Team on Ship Costing (STSC) established under Naval Group Six (NG/6), formerly Information Exchange Group Six (IEG/6) of the NATO Naval Armaments Group (NNAG). The ANEP addresses cost reduction and cost avoidance throughout all phases of a ship's life cycle and emphasizes the need for careful consideration in the following major areas:

- determination of capability requirements,
- cost-conscious decision-making process,
- new technology advances,
- application of commercial standards and practices,
- manpower reduction,
- effective design specifications, acquisition practices and construction methods,
- effective cost management techniques,
- cooperation and teamwork between government and industry and between governments, and
- forward-looking program planning and management.

The ANEP derives from the IEG/6 working paper titled "Ways to Reduce Cost of Ships," reference (a). The working paper, published in June 1995, was prepared by an NG/6 Ad Hoc Working Group (AHWG) consisting of individuals with expertise in ship cost estimating and analysis, and including individuals with background in ship design, construction, operation and support. The original AHWG was renamed as the STSC and in November, 1997 the NG/6 tasked the STSC to prepare a working paper focusing on:

Trends and practices among NATO Nations regarding ship acquisition and ownership cost reduction, emphasizing:

- manpower reduction (military personnel) reduction, and
- use of commercial standards and commercial practices, and
- to make recommendations for updates to ANEP-41, "Ship Costing", and ANEP-49, "Ways to Reduce Costs of Ships".

Subsequently, WP/9, reference (f) was published in 1999 and the NG/6 tasked the STSC to incorporate its recommendations into the aforementioned ANEPs. Edition 2 of ANEP 49 incorporates the WP/9 salient recommendations.

Active participation in the development of the working papers and ANEP 41 and 49 was provided by the following nations: Belgium, Canada, France, Germany, Italy, Netherlands, Norway, Portugal, Spain, United Kingdom and United States.

EXECUTIVE SUMMARY

There is a common need among NATO navies for cost reduction in all phases of a ship's life cycle to achieve the most effective fleet acquisition and operations to meet mission requirements. In recognition of that need, this ANEP attempts to reduce the multitude of documentation that exists on ship cost reduction into a single reference document on the subject. It summarizes and evaluates information produced by NATO nations and provides an integrated view of the NATO team, which produced it. Its intended audience includes ship designers, cost estimators, decision authorities and others involved in the ship acquisition process. Major areas having potential to reduce ship costs are highlighted, leading to overall conclusions and guidance for the future.

Ship design is a complex undertaking and involves many compromises between requirements; design options; and the associated tradeoffs between cost, mission and operational effectiveness. The cost reduction techniques described herein are not universally applicable to all ship types in all situations. Likewise, the quantitative data presented derives from various sources and may not apply in all situations or circumstances.

The mission needs are the basic cost drivers in naval ship acquisition and ownership. Thus, close scrutiny of the specific requirements, which are determined necessary to meet the mission needs, is the first step in cost reduction. The ship designer aims to satisfy the needs with an effective design through the exploration of alternatives to meet the requirements. To make the best choice(s), an analysis of the cost and operational effectiveness and the affordability of each option should be performed early and continuously in the design process. As part of this process, the budget constraints, investment costs, technologies, production aspects, life-cycle requirements and risks must be considered. A crucial aspect of the design development stage lies in the cost impact of associated decisions on subsequent life-cycle phases. Eighty percent or more of a ship’s life-cycle cost may be predetermined by the end of the design development phase. Thus, it is essential that sufficient effort be invested to ensure that informed and cost-effective decisions are made.

Technological innovations should either enhance performance or lower acquisition and ownership costs. Opportunities for cost reduction associated with technology advances include: new materials; information technology; computer-aided design, engineering, manufacturing and logistics support; advanced production techniques and ship automation. The total time to acquire a combatant ship is lengthy and can span a period of ten years. This can lead to changes in technology and the threat definition, and hence, significant changes in costs. The application of information technology and automation hold significant potential for in-service phase cost reduction in the future. Through the use of virtual prototypes, virtual reality, and common electronic databases, simulation-based design and virtual prototyping (SBD&VP) and simulation-based acquisition reduce risks, minimize costs in all phases of a ship's life cycle, and allow for a paperless acquisition and ownership process.

A major challenge in warship design is the need for early exploration of cost reduction solutions that consider the entire life cycle. To achieve more affordable specifications, increased interaction is required between the designer and the requirements generator, e.g., fleet operator, to relate the cost impacts of the requirements. Cost savings of up to 30% in acquisition and 15% in life cycle have been achieved through the use of commercial standards and practices. Further opportunities for cost reduction exist in the areas of: production efficiency, minimizing design changes, value engineering, control of margin allowances, product and process standardization, inter-operability and through-life flexibility.

Many acquisition process factors heavily influence ship acquisition and ownership costs. A key element of the acquisition process is the choice of acquisition strategy and contracting methods. The contracting options must contend with issues such as: laws, regulations and treaties; industrial base, socio-economic and national concerns; international cooperation; environmental aspects; competition; quantity ordering; types of tenders, contracts and subcontracts; and cost, schedule and technical risk. Each of these areas includes numerous options with associated cost implications, which may or may not be appropriate due to technical, legal or political reasons; hence, the procedures and solutions vary among NATO nations and are heavily dependent on policy. Nonetheless, a cost-conscious decision process is invaluable to the goal of cost reduction in weighing the alternatives.

Production is one of the key elements in cost-effective naval ship procurement. Modern product-oriented or integrated design and construction practices have resulted in more efficient ways to acquire ships -- resulting in increased modularization, prefabrication, pre-outfitting and improved life-cycle support and mission flexibility. Modern methods define the ship as a set of interim products, which are subsequently grouped and standardized using principles of group technology. The approach requires increased communication between the design, procurement, planning and production functions. This fosters better teamwork among all functional organizations, development of multi-skilled work forces and continuous product and process improvement. The benefits of these improvements have not been fully realized and hold significant potential for further ship cost reduction. Although requiring substantially increased initial engineering and planning, an overall ship acquisition cost savings in the range of 10% to 15% can be expected. A similar range of savings can also be anticipated for the industrial effort of the in-service phase.

Operations and support costs may constitute 60-80% of the life-cycle cost of naval ships. Ultimately, these costs are dependent upon the operational deployment of a ship, the scenarios in which it is to operate -- environment, duration and tempo. However, to reduce and control these costs, their consideration must be integrated into the planning process at an early stage of ship design. An integrated logistics support plan, electronic data management, and continuous configuration control are helpful tools for effective organization and management of the operations and support cost elements. Training simulators, condition-based maintenance and possibilities for international cooperation, including joint training, can, inter alia, contribute to cost reduction.

Throughout the acquisition process, effective management techniques must be utilized in order to control cost, schedule and technical risk. These techniques are especially important in the design phase, where the preponderance of life-cycle costs is influenced. Some effective techniques during this phase include: design reviews, cost reviews, options analysis, resource controls, return on investment and cost-benefit analyses, change control and configuration control. During the production phase, contract incentives, statistical process control and contractor performance measurement systems are additional means to effectively manage costs. An integrated logistics support plan, considered from the beginning of the program, is key to effective cost management in the in-service phase.

Cost Reduction Guidance

* Mission needs should be scrutinized to remove non-essential requirements and ship design alternatives should be evaluated from the total-life-cycle-effect viewpoint considering cost, operational and mission effectiveness. Over specification should be avoided and near-term cost reduction measures should be resisted, if not justified from a through-life perspective.

* A concerted effort, close liaison, and teamwork by all parties, both government and industry, is needed to produce cost-effective naval ships which meet all requirements.

* New technology applications generally require an initial investment before benefits can be realized; they should be evaluated on the basis of cost and operational effectiveness and risks presented.

* To fully exploit its potential to achieve cost reduction, the design process should maximize use of design planning for production, commonality and standardization of products and processes, and commercial standards and practices. However, mission effectiveness and human safety must not be unduly compromised.

* Contracting practices, at all levels, should be carefully chosen and implemented to encourage efficiency and mitigate risks to industry and government; design changes after the construction contract award should be minimized.

* The transition to greater use of commercial standards and practices must be carefully monitored to minimize potential disruptions that could offset near-term savings and jeopardize future performance of mission requirements. Careful planning and implementation, study of design trade-off alternatives, and coordination within and across nations, must be undertaken as an ongoing process to evaluate options and progress.

* A full understanding of all affected navy in-house and supporting industry costs is essential to making useful comparisons when assessing the shift to increased use of commercial standards, practices and contracting strategies.

* Personnel (military manpower) costs are a major element of the in-service cost of a warship. Navies must move to more lightly manned ships to offset the increasing cost of manpower and the shrinking population of candidates. The goal should be to "right size" the crew complement to minimize cost while maintaining needed capabilities without compromising safety.

* Effective cost management and cost control measures, and continuous process improvement must be employed in all life-cycle phases to ensure cost avoidance.

* Investments in cost accounting systems and costing tools by both government and industry are necessary to develop the databases necessary for effective economic assessments.

* International cooperation offers potential for cost reduction in all phases of a ship's life cycle although the collaboration process itself may increase costs.

The Way Ahead

Toward the continuous goal of effective resource utilization among the navies of the NATO nations, life-cycle costs should become a more decisive factor in the acquisition decision process. More design emphasis needs to be placed on cost reduction in the In-Service phase. Ship cost estimating techniques for use in the ship design process should be improved.

This ANEP represents a substantial research effort by the NATO nations and should serve to aid ship designers, cost estimators, planners, managers and others involved in ship acquisition, operations, support and ownership. To ensure the character of a living document, the ANEP will be updated periodically.

WAYS TO REDUCE COSTS OF SHIPS

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LIST OF FIGURES

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INTRODUCTION

1. Background

The chronology of the development of this ANEP is provided in Appendix 1. The terms and definitions used herein are consistent with reference (b), ANEP-41 on Ship Costing. Selected other terms and definitions as used herein are contained in Appendix 2.

2. Aim

The aim of this ANEP is to provide emphasis and guidance to ship designers, naval staff planners, project managers, decision authorities and others on potential areas for cost reduction in naval ship acquisition, ownership and operation, which they may influence. This document is only a guide. Thus the data and suggestions contained herein should not be interpreted in an absolute or dogmatic fashion. It is emphasized that the national cost specialists or cost experts should be consulted and utilized as an inherent part of the decision process.

3. Acquisition Process and Program Costs

a. NATO Phased Armaments Programming System (PAPS). The phases and milestones of the NATO PAPS are described in Allied Administrative Publication number 20, reference (c). Broadly, each design and development phase or cycle progressively produces:

– a more detailed expression of requirements (sometimes associated with cost targets),
– a more detailed proposal for a system solution (successively involving system design, development, trials...) with a cost estimate or a negotiated price for the program.

There are eight program milestones and seven intervening program phases in the NATO PAPS. PAPS concentrates on the milestones and not the intervening phases. The milestones are the points in the weapon system life cycle where past work is validated and future work is agreed upon. The milestones are signified by the following documentation:

(1) Mission Need Document (MND),
(2) Outline NATO Staff Target (ONST),
(3) NATO Staff Target (NST),
(4) NATO Staff Requirement (NSR),
(5) NATO Design and Development Objective (NADDO),
(6) NATO Production Objective (NAPO),
(7) NATO In-Service Goals (NISEG), and

(8) National Disengagement Intention (NADI).

The MND signifies the conclusion of the mission analysis and long-term forecast planning and the commencement of the first program phase. The other milestone documents are produced, respectively, at the end of the seven phases listed below:

(1) Mission Need Evaluation
(2) Pre-Feasibility
(3) Feasibility
(4) Project Definition
(5) Design and Development
(6) Production
(7) In-Service

b. National Practices. The national practices of many nations; e.g., Canada, France, Germany, Italy, the Netherlands, Spain, the United Kingdom, the United States; are broadly similar to the NATO PAPS -- in particular when fully applied to major ship programs. However, simplified processes may be used for less demanding programs such as patrol craft, auxiliary ships, hydrographic research ships, etc.

c. Inherent Concerns. The full acquisition process, applied to a naval program for a combatant ship, has a total time span in excess of ten years. This means that:

(1) The cost estimating basis, technology basis and even the threat definition or mission role assumed at the beginning of the process (and, indeed, well into the process) may change or become obsolete or irrelevant during the process.
(2) Decisions, often major ones, are nonetheless made on this basis and therefore sometimes become simply wrong and costly.
(3) Engineering proposals, together with their cost estimates, which are accepted in the early phases tend to be reconfirmed in the following phases. Radical reconsideration leading to cost savings may be precluded in the follow-on phases. Even worse, some important military requirements may be decreased to fit within the budget before it has been demonstrated that they are unaffordable on the basis of a sound cost analysis.
(4) Because of the length of the process, changes are unavoidable. Changes are usually costly from an engineering point of view and maybe even more costly from a contracting point of view.
(5) Because of the economic, business and technical complexities involved and the far-reaching consequences associated, cost estimating and analysis for decision making should be undertaken with the assistance of trained and experienced professional analysts.

4. **Document Scope**

a. International Complexity. In the current environment of reduced budgets, nations are keenly aware of the need for ship cost reduction in all phases of the life cycle. It is understood that each nation has different methods and policies by which programs are managed, costs are calculated, ships are designed and constructed, program approvals are obtained, and ships are operated. Notwithstanding these complexities, this document attempts to reduce the multitude of literature that exists on ship cost reduction in the various NATO nations into a single, broad (yet focused) discussion on the subject.

b. Areas of Ship Cost Reduction. Ways to reduce cost fall into the following major categories:

- determination of capability requirements at the lowest level of effectiveness;
- cost-conscious decision process throughout the ship design stages, particularly in the early-design stages;
- application of new technology advances such as decreased manning through automation, improved design and construction solutions, materials and processes, and improved maintenance and modernization provisions;
- utilization of cost effective design specifications, acquisition practices and construction methods;
- application of effective and efficient cost management techniques;
- maximization of cooperation and teamwork between government and industry;
- cost avoidance achieved through forward-thinking program planning and management throughout the full spectrum of a ship's life cycle (program initiation though the in-service phase and final disposal; and
- use of multinational cooperation to share, *inter alia*, in design development and non-recurring costs.

c. As a Reference Document. In addition to highlighting potential areas for cost reduction in ship design, acquisition, operation and support, this ANEP serves as a reference document for ship designers, cost estimators, decision makers and others involved in the acquisition process, in the following areas:

- ship cost reduction methods, techniques and processes;
- proven alternative design, acquisition and construction practices;
- suggestions and guidelines pertaining to cost reduction in ship acquisition and ownership;
- cost reduction expertise and experiences of the respective navies of the NATO nations;
- information on cost control and cost management functions;

- cost trends from actual ship programs; and
- impact of design practices on ship costs.

d. Applicability to Ship Types. Although the information and data from which this paper derives is principally from surface ship programs, the cost reduction methods generally apply to all ship types.

5. **Restrictions**

a. General Availability of Information to Nations. Per the agreement set forth in the Terms of Reference for the AHWG (now STSC) in preparing this ANEP, information collected will not generally be available to all NATO nations or other nations as a matter of freely exchanged information with respect to the following:

- sensitive, commercial-in-confidence information;
- special arrangements amongst governments and national companies; and
- property and intellectual rights.

b. Limitations of Information to Specific Nations. The reference materials collected as part of the development of this ANEP were distributed to the respective national participants of the STSC during the course of this work. Most of this information is contained in published journals and is therefore available to the public; however, some of the materials have only been presented to the STSC or the NG/6 and may contain information or data considered sensitive by the respective nations. Therefore, the latter are restricted to use within or among the respective NATO navies who participated in the development of this ANEP (listed in the Foreword), unless approval is otherwise obtained from the originating nation of the material and NG/6.

6. **ANEP Organization**

This ANEP is divided into eight chapters, plus the appendixes. Chapter A describes the mission needs and requirements determination process and the impact on ship cost. Chapter B discusses the impact of technology on cost. Chapter C discusses the relationship between the ship design process and cost. Then, Chapter D describes the effects of the acquisition process on ship's cost. Next, Chapter E examines the relationship between production processes and cost. Ship's operations and support effects are described in Chapter F. Cost management is discussed in Chapter G. Conclusions are laid out in Chapter H. The appendixes contain supporting background information.

7. **Remarks on Data Use**

This document provides general information in terms of percentages or ranges of cost reduction -- generally speaking, specifics are not included due to constraints on data exchange.

Caution should be applied when using the figures contained in this material, as the quantitative values do not apply universally. The material contains information which indicates trends or potential for cost reduction but the specific circumstances of each nation or program must be brought to bear in the respective cost analyses and decision-making processes. Experienced cost analysts should be consulted wherever possible.

LIST OF REFERENCES

a. "Ways to Reduce Costs of Ships" (Working Paper), NATO IEG/6 on Ship Design, Specialist Team on Ship Costing, June 1995.

b. "Ship Costing," ANEP-41 Edition 2, NATO Naval Armaments Group Allied Naval Engineering Publication (NATO Unclassified), NATO International Staff - Defence Support Division, July 1992.

c. "Handbook On The Phased Armaments Programming System (PAPS):
Volume 1: PAPS Framework and Procedures
Volume 2: PAPS Related Activities and Management Considerations,"
(NATO Unclassified), NATO Naval Armaments Group Allied Administrative Publication (AAP-20), NATO International Staff - Defence Support Division, February 1989.

d. "Final Report to Information Exchange Group Six (IEG/6) on ANEP-41 Methodology," Ad Hoc Working Group on Ship Costing (NATO Naval Armaments Group Information Exchange Group Six), May 1992.

e. "Maritime Environmental Protection Strategy," AC/259-D/1572, AC/141-D/702, AC/141 (SWG/12)D/9, NATO Naval Armaments Group, 11 March 1994.

f. "Trends In Manpower Reduction and The Use Of Commercial Standards, Practices and Contracting Strategies To Reduce Costs Of Naval Ships" (Working Paper), NATO NG/6 on Ship Design, Specialist Team on Ship Costing, June 1999.

LIST OF ABBREVIATIONS AND ACRONYMS

AAP	Allied Administrative Publication
ABS	American Bureau of Shipping
AFNOR	Francaise de la Normalisation (French Standard)
AHWG	Ad Hoc Working Group
ASHRAE	American Society of Heating, Refrigeration & Air-conditioning Engineers
ASTM	American Society of Testing Materials
ANEP	Allied Naval Engineering Publication
BE	Belgium
BV	Bureau Veritas
CA	Canada
CAD	Computer-Aided Design
CAE	Computer-Aided Engineering
CALS	Continuous Acquisition and Life-Cycle Support
CAM	Computer-Aided Manufacturing
"cap"	Application of a Cost Ceiling
CAPS	Conventional Armaments Planning System
CBA	Cost-Benefit Analysis
CBM	Condition-Based Maintenance
CCG	Canadian Coast Guard
CFSR	Contract Funds Status Report
CM	Corrective Maintenance
CNAD	Conference of National Armaments Directors
Const.	Construction
Coop.	Cooperation
COTS	Commercial Off the Shelf
CPAF	Cost Plus Award Fee
CPFF	Cost Plus Fixed Fee
CPIF	Cost Plus Incentive Fee
CPR	Cost Performance Report
CSA	Canada Standards Association
C/SCS	Cost/Schedule Control System
C/SCSC	Cost/Schedule Control System Criteria
C/SSR	Cost/Schedule Status Report
CWBS	Cost/Work Breakdown Structure
D&D	Design and Development (phase)
DDG	Guided Missile Destroyer

LIST OF ABBREVIATIONS AND ACRONYMS (Cont'd)

DIN	Deutsche Industrie Norman (German Standard)
DMKM	DMKM-Afdeling Schebo (Netherlands)
DNV	Det Norske Veritas
DoD	Department of Defense (U.S.)
DoDD	Department of Defense Directive (U.S.)
DTC	Design-To-Cost
e.g.	For example; such as
etc.	Et cetera
EC	European Community
EU	European Union
EUROLOG	Logistics Subgroup within the Framework of the EUROGROUP of NATO
EVM	Earned Value Management
F	Feasibility (phase)
FAS	Fueling-at-Sea
FES	Funktionseinheitensystem = Functional Unit System (German)
FFP	Firm Fixed Price
FMECA	Failure Mode and Effect Criticality Analysis
FPEP	Fixed Price with Escalation Provisions
FPI	Fixed Price Incentive
FR	France
GE	Germany
GFE	Government Furnished Equipment
GFI	Government Furnished Information
GFM	Government Furnished Material
GSS	General System Specification
HCPC	Harbor/Coastal Patrol Craft
IA	Investment Appraisal
i.e.	that is
IEEE	Institute of Electrical and Electronic Engineers
IEG/6	Information Exchange Group Six (now Naval Group 6)
IETM	Interactive Electronic Technical Manuals
ILS	Integrated Logistics Support
IMO	International Maritime Orginization

LIST OF ABBREVIATIONS AND ACRONYMS (Cont'd)

Inter Alia	Among other things (Latin)
Int'l.	International
In-S	In-Service (phase)
IPPD	Integrated Product and Process Development (teams)
IPT	Integrated Product Team(s)
ISO	International Standards Organization
IT	Information Technology
LCC	Life Cycle Cost
LPD	Landing Platform Dock
LR	Lloyds Register
MAS	Military Agency for Standardization
MCDV	Maritime Coastal Defense Vessel
MEKO	Mehrzweckkombination = Multi-role Combination (ship design - German)
MIL-HDBK	Military Handbook
MNC	Major NATO Commander (SACEUR, SACLANT)
MND	Mission Need Document
MNE	Mission Need Evaluation (phase)
MoU	Memorandum of Understanding
M&S	Modelling and Simulation
MTBF	Mean Time Between Failure
MTTR	Mean Time To Repair
NADDO	NATO Design and Development Objective
NADI	NATO Disengagement Intention
NAPO	NATO Production Objective
NATO	North Atlantic Treaty Organization
NAVSEA	Naval Sea Systems Command (U.S.)
NBC	Nuclear/Bacteriological/Chemical
NDI	Non-Developmental Item
NFR-90	NATO Frigate Replacement for the 1990s
NG/6	Naval Group Six
NISEG	NATO In-Service Goals
NL	Netherlands
NNAG	NATO Naval Armaments Group
NO	Norway
NPV	Net Present Value

LIST OF ABBREVIATIONS AND ACRONYMS (Cont'd)

NSR	NATO Staff Requirement
NST	NATO Staff Target
O&S	Operations and Support
ONST	Outline NATO Staff Target
OPV	Offshore Patrol Vessel
PAPS	Phased Armaments Programming System
PD	Project Definition (phase)
PF	Pre-Feasibility (phase)
PM	Preventive Maintenance
PODAC	Product-Oriented Design and Construction
POL	Petroleum, Oil and Lubricants
Prod	Production (phase)
PWBS	Product Work Breakdown Structure
RAR	Rules and Regulations (Norway)
RAS	Replenishment-at-Sea
RBS	Readiness-Based Sparing
RCM	Reliability-Centered Maintenance
RMA	Reliability, Maintainability and Availability
SACEUR	Supreme Allied Commander Europe
SACLANT	Supreme Allied Commander Atlantic
SAR	Search and Rescue
SBD	Simulation Based Design
SBDVP	Simulation Based Design and Virtual Prototyping
SOLAS	Safety On Board for Lives at Sea
SPC	Statistical Process Control
spec	Specification
SSC	Sea Systems Controllerate (U.K.)
STSC	Specialist Team on Ship Costing
STANFLEX	Standard Flexible (ship design - Danish)
Subs	Submarines
Tech.	Technology
U.K.	United Kingdom

LIST OF ABBREVIATIONS AND ACRONYMS (Cont'd)

UPC	Unit Price Cost
U.S.	United States
VA	Value Analysis
VE	Value Engineering
vs.	Versus
yr.	Year

CHAPTER A

MISSION NEEDS AND REQUIREMENTS

1. Mission Needs

a. Mission Needs and the Ship Designer. The basic cost driver in the development, acquisition and ownership of any weapon system (including naval ships) is the mission needs. Generally, the mission needs are determined at high levels and, to a large extent, outside the influence of the ship designer; however, the ship designer plays a primary role in determining the actual ship design architecture, specifications and associated systems to meet the given needs. In this way, the ship designer plays a significant role in determining how the mission needs will be met in terms of the selection of possible ship designs.

b. Causes and Process. The need for weapon systems, e.g., naval ships, is generally determined as a result of national defense policy, changing military threats and obsolescence. Other needs may be determined by such factors as coastal patrol, law enforcement, and humanitarian service, rescue capability and the like. Still other needs may be due to treaty agreements between nations. For NATO activities, the NATO Phased Armaments Programming System, as described in reference (c), provides a framework for the NATO Military Authorities to clarify "their role in armaments planning, which primarily is to initiate weapons systems development by identifying mission needs." Additionally, individual nations have their internal processes and policies for the acquisition of weapon systems.

2. Translation of Mission Needs into Requirements

a. Determining the Requirements. Once the mission needs of a nation are determined, the means to accomplish the mission must be determined in the form of requirements; e.g., new weapon system, upgrade of an existing system, cooperative engagement between a nation's military services or coordinated efforts of two or more nations. National military requirements are generally determined, *inter alia*, by long-term planning and mid-term defense plans. Influencing factors include doctrine, tactics, training, infrastructure, existing shortcomings and desired additional operational capability.

b. Weighing Cost and Operational Effectiveness. The projected mission needs are initially expressed in broad operational terms. From these, the system-specific performance objectives and requirements evolve. There may be several or many alternatives, which satisfy the mission requirements. In fact, the difficulty does not lie in the drafting of early engineering solutions or costing these. But rather, the difficulty is much more with assessing the military value of performance differentials versus the costs. Hence, an initial (and subsequently at each ensuing program milestone) exhaustive analysis of the cost and operational effectiveness of an appropriate range of the alternative solutions should be performed in order to make the best selection. It is essential that a sufficient amount of effort be expended on this analysis to reach a proper decision but that the time is not overly prolonged. The process should also provide a framework for subsequently establishing, minimizing and controlling costs.

c. Economic Consequences of Decisions. Regardless of the mission needs determined by the respective nations, it is widely understood that a majority of the costs of a weapon system is determined in the early phases of ship design development. Indeed, as seen in Figure 1, 80% or more of a ship's life-cycle cost may be determined; i.e., *fait accompli*, by the end of the design development phases. It is essential, therefore, that the effort during the design development phase be complete and not abbreviated in an attempt to save money, lest the consequence of greater expense (in the long term) results from inadequately understood and specified requirements.

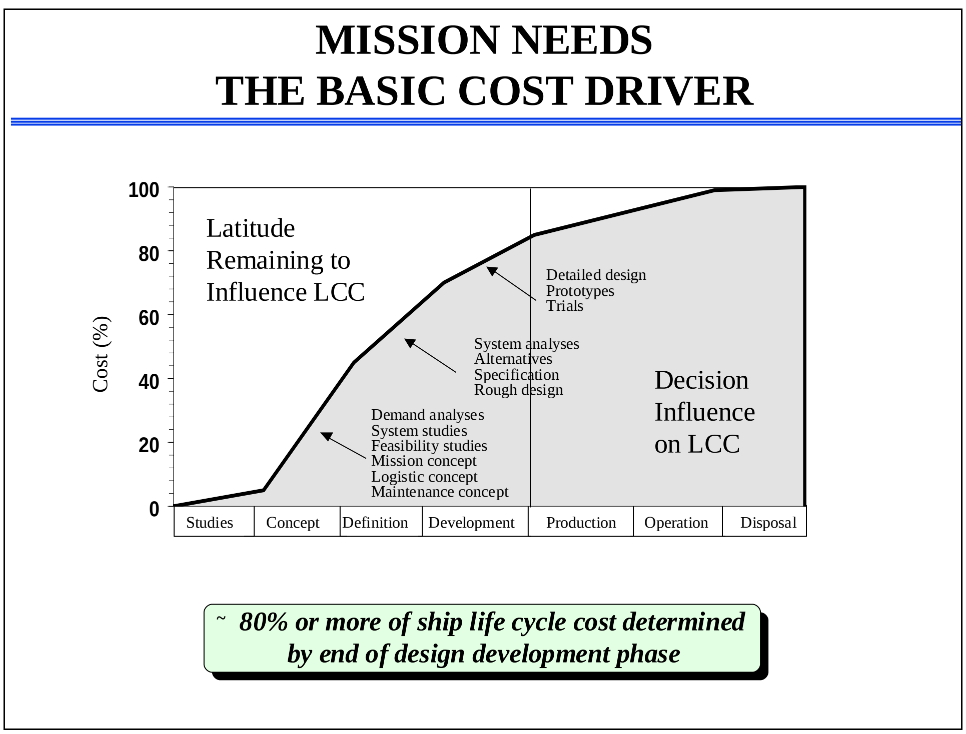

Figure 1

3. Affordability

a. Affordability Requirement. After the basic weapon system characteristics (e.g., ship type and principal characteristics) have been initially decided, the costs must be weighed against the realities of budget affordability (in effect, affordability becomes a requirement). Additionally, the impact of specific design decisions throughout the engineering phases should be carefully studied and monitored to determine their impacts on both the acquisition and in-service costs of the ship. Tradeoff decisions are usually inevitable, e.g., it may be necessary to delay, or give up entirely, certain capabilities in order to stay within the budget constraints. In this regard, downstream product improvement, e.g., mid-life conversion or upgrade, may be an acceptable alternative and should thus be allowed for in the initial design. More discussion on affordability is contained in other chapters as it pertains.

b. Affordability Analysis. In order to perform the affordability analysis, it will be necessary to model the design alternatives. Necessarily, the cost models will usually be parametric in nature at the early stages (e.g., based on major performance characteristics of a proposed ship) and in some cases may rely on analogy. The models will become more detailed (engineering bottom-up oriented) as the design details evolve. To the extent practicable, the more detailed models should take into account the impact of production processes and other industrial factors or requirements.

c. Choice of Military or Commercial Standards and Practices. (Also, see Chapters C and D and E)
One prominent issue when confronted with the reality of affordability is the need for military standards versus commercial. Although sometimes at the expense of operational and performance capability, studies, see Figure 2, have shown that savings of up to 38% in acquisition and 25% in life-cycle can be achieved through the use of commercial standards on navy ships.

However, to advocate greater use of commercial standards and practices requires an understanding of the similarities and differences between the commercial and military product environments, and the in-service fleet support implications. First, the degree of similarity between the product environments depends upon on the type of system or ship as a whole, and on the individual subsystems and components that comprise the overall system or ship. Commercial and military products are generally most similar at the component and subsystem level where the opportunity for substitution is greatest. Second, the government may potentially experience life cycle cost savings or cost avoidance from the use of commercial standards and practices, but may lose some control over the ship design and construction process as a result. This could have long-term implications on in-service fleet support strategies and associated costs that cannot be readily predicted. Thus, the choice should be carefully and continuously evaluated.

Regarding the results shown in Figure 2, the studies take into account military requirements (e.g., ship survivability, signatures, etc.) as well as regulatory standards and contracting practices. A study for the U.S. Department of Defense has assessed the regulatory cost premium for military practices to be about 18% for weapon system procurement. In this study, over 100 cost drivers were reviewed with the finding that the military specification for quality assurance is the largest regulatory cost driver, accounting for one-tenth of the premium. Though the U.S. study did not account for differences due to military features such as signature reduction and shock hardening, it does support the findings of the other studies of Figure 2.

Based on these studies, see reference (a), it is conservatively concluded that the cost difference of military versus commercial standards, practices and requirements is about 30% for acquisition and 15% for life-cycle (of a ship).

Potential Cost Savings from Use of Commercial
(In Lieu of Military) Standards and Practices

Study *	Sail-Away	Acquisition	In-Service	Life-Cycle
Canadian Frigate (Design Study)	35%	38%	16%	25%
German Type 423 Reconnaissance Vessels	**	30%	**	**
Italian Landing Platform Dock (LPD) SAN GIORGIO Class	**	25%	**	**
French Frigate FLOREAL (Commercial Standards) Compared with LA FAYETTE (Military Standards)	**	34%	**	**

* See Appendix 3
** Not stated

Figure 2

4. Changes in Requirements

a. The Time Element. Due to the long time period required for a ship's design and construction, changes in requirements are inevitable during this phase. Additionally, changes in requirements will continue through the in-service phase. To the extent that such changes can be anticipated, i.e., ships designed to accept later changes, additional costs to a program can be minimized, reduced or avoided. This may also cause excess design or over-design of some parameters initially, e.g., additional space, volume or system capacity, which may appear as a marginal up-front investment. However, if weighed on a life-cycle basis, a significant return on investment may result. This will need to be carefully considered during the design phase (see Chapter C).

b. Control Over Change. Changes may evolve due to numerous reasons such as changing threats, policy, et cetera -- as earlier discussed. Other changes in requirements evolve due to changes in law and regulations (e.g., environmental compliance) and technological innovations. While the ship designer may have little control over the introduction of the former types of changes, it may be necessary to defer technological innovations when cost constraint is dictated by the budget.

5. Other Factors

a. Infrastructure. Another parameter, which may affect requirements, is considerations of the industrial base infrastructure, which is of national interest. In this case, developing or sustaining the industrial base may in effect become a requirement and in turn this will significantly affect costs.

b. Variables. There are a number of other options and factors within the realm of the requirement discussion which have a significant effect on the costs of ships. Some of these may lie within the sphere of influence of the ship designer and some not. These include:

- new ship(s) versus modernization of existing ships;
- reliance on sister services - Army, Navy, Air Force, Marines;
- cooperation with other nations' forces;
- fleet user requirements, e.g., naval policy;
- operational environment and operational tempo;
- design policy, e.g., margins;
- speed and endurance;
- operational suitability;
- safety and survivability;
- reliability, maintainability and availability;

- habitability;
- interoperability; and
- logistics support requirements (e.g., maintenance and stock policies).

6. Life-Cycle Cost (LCC) Composition and Its Relationship to Ship Design Development

a. Cost Data. This section contains relative cost breakouts for the three major life cycle phases of a ship: Design and Development, Production and In-Service. The cost breakouts are from various sources, either as taken from the research literature used in developing reference (a), or as provided separately by the authors of this document based on the experience of their respective nations. For the Harbor/Coastal Patrol Craft (HCPC) design study example, the figures are from the ANEP-41 validation exercise performed by the prior IEG/6 AHWG on Ship Costing. The exercise was completed in May 1992 and the report is listed as reference (d).

b. LCC Breakdown. The life-cycle cost of a ship is composed of all costs that are incurred over its full life. This includes both the industrial and the government effort associated with the development, procurement, operating and support of the ship. For the HCPC design, the relative magnitude of these costs (excluding disposal) is as follows:

Design and Development	2% (excluding combat systems)
Production	43% (ten ship program)
In-Service	55% (20 year life)

This breakdown is graphically displayed in Figure 3. The design and development phase where the least money is spent (typically under 5%) is critical in the determination of the subsequent phase costs (typically over 95%) of a ship's life cycle.

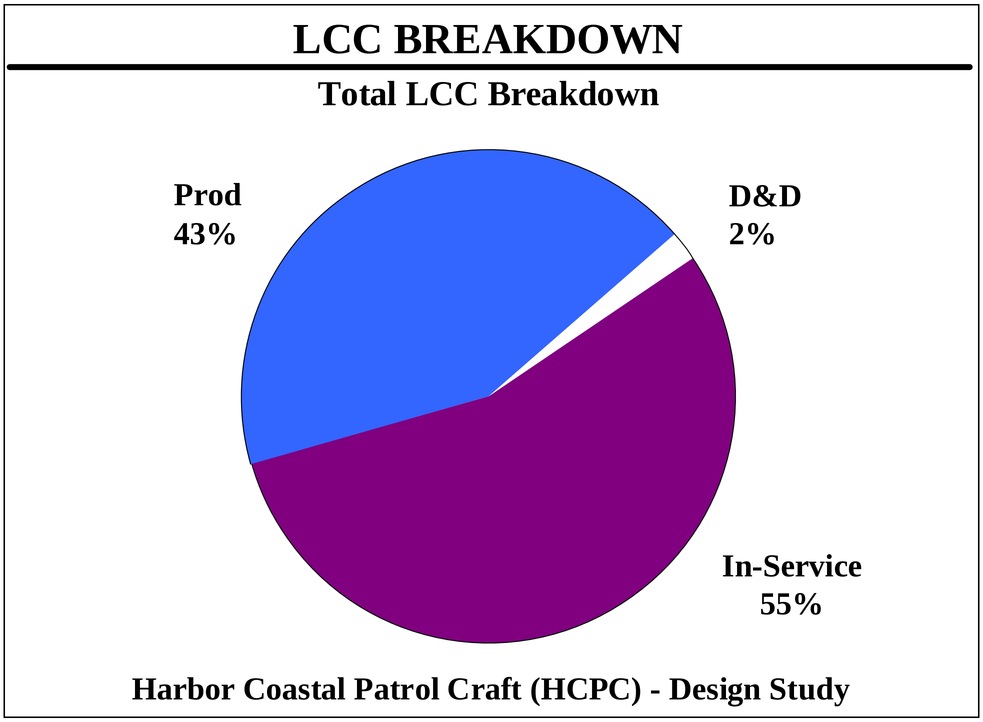

Figure 3

c. Design Phase Costs. The design development phase costs are generally a function of the complexity of the proposed ship and the challenges of the technology which must be incorporated for the ship to fulfill its intended purpose, i.e., its mission. The important factor in this stage, however, is not the actual cost of the design development phase itself, but rather, the impact on the cost of the subsequent phases that are caused by decisions from the design development phase. As already mentioned, as much as 80% of a ship's total life-cycle costs are determined by decisions made in the design phase (indeed in the early stages of design development prior to the actual construction drawing development).

d. Production Phase Costs. The production phase costs are also driven by the technological requirements of the design as it affects the actual construction and delivery of the ship. But other programmatic matters such as industrial factors (e.g., tooling and facility changes, training), quantity of ships to be built, lead time required for materials, and the program acquisition strategy heavily influence the costs. In the production phase, the proportion of production cost between platform and payload is approximately as indicated in Figure 4.

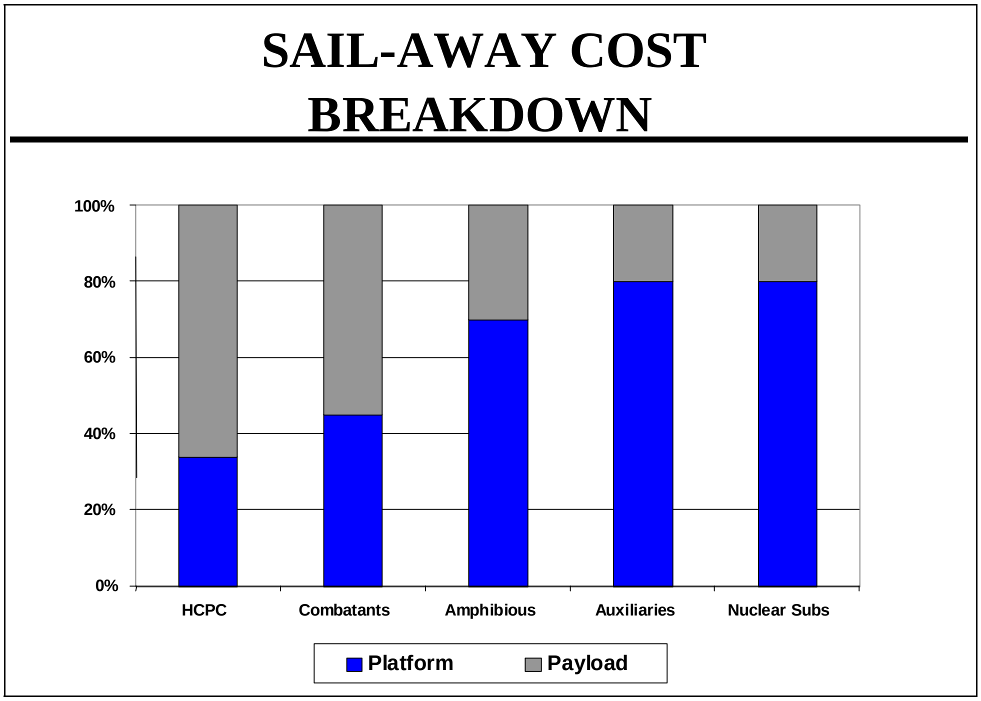

Figure 4

e. <u>In-Service Phase Costs.</u> The in-service phase costs are generally a function of the operational tempo, operational environment, maintenance requirements, ship alteration or modernization, operational personnel and the supporting infrastructure, fuel and training. For the HCPC design, the breakout of these costs is as follows:

Personnel (e.g., manning)	27%
Consumables (e.g., fuel, oil, lubricants)	16%
Direct Maintenance (e.g., overhaul, modernization)	36%
Sustaining Investment (e.g., spares, repair parts)	14%
Other Direct Costs (e.g., trainers, simulators)	6%
Indirect Costs (e.g., base operations)	1%

These costs are graphically depicted in Figure 5, highlighting the relative magnitude of the cost elements:

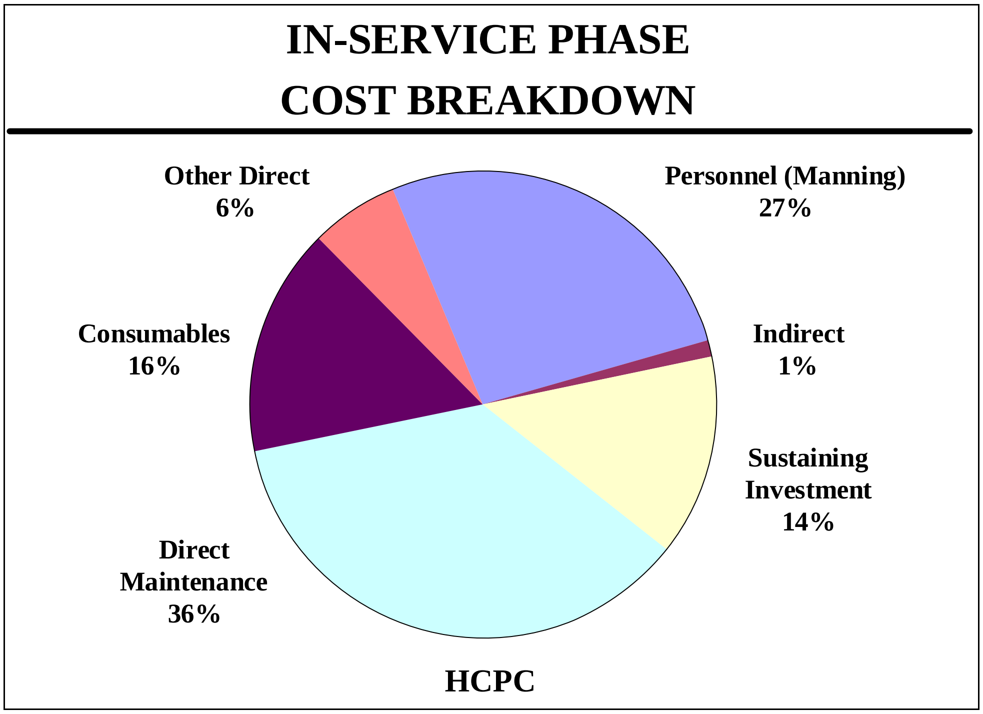

Figure 5

Personnel (military manpower) costs shown in Figure 5 depict direct costs only. Indirect personnel costs, if added, would nearly double the personnel costs. Therefore personnel could possibly constitute the largest cost driver. A more detailed discussion of personnel costs is included in Chapter F.

7. Latitude to Influence Costs of Requirements

a. Payload. A ship's payload is selected with the ship's intended use in mind (e.g., mission need). Therefore, using armament as an example, a reduction in the number and type of weapons to be carried will, presumably, leave the ship unable to fulfill her role (unless there is a fundamental change in operational requirements). As a result, subsequent cost reductions may only be possible to the degree that:

- the weapon manufacturer can reduce costs through productivity gains or increased sales volume,
- improvements can be effected by the ship detailed design engineers and production planners, or
- the government can leverage the commercial sector by using commercial standards and practices, e.g., accepting commercial products.

Again, the importance of sufficient up-front investment to ensure that decisions are made on an informed basis, which considers both the operational effectiveness and the affordability of the options, is noted.

b. Platform Dependency on Payload. The payload suite of a ship also affects or drives requirements in the hull, machinery and electrical areas of the ship's platform. For example, the combat suite, weapons and/or cargo require space, power, heating, cooling, ventilation, magazines, safety devices, fire-fighting provisions, manning and associated accommodations and so on, which the ship's platform must provide. In many cases, the structure and extent of the auxiliary systems are largely governed by the payload suite installation and, to the extent that these requirements are firm, reductions in platform costs may be limited. However, the ship designer should always consider the ship design from the perspective of total-systems engineering. That is, the ship designer should seek to find the best technical and economic balance between the payload and platform choices.

c. Other Naval Staff Requirements. The requirements that the Naval Staff specifies concerning ship's performance may/will drive costs. These include speed, endurance, replenishment-at-sea capability, shock resistance, survivability (vulnerability), safety, operations in specific sea states (e.g., helicopter) and ship's signatures. These needs will influence or dictate the hull size, shape and strength, power of the main engines and the amount of fuel to be carried. These demands may override or increase the requirements on the hull presented by the payload suite. Factors such as fuel efficiency and logistics impacts must be considered. The ship designer will have choices of alternatives to meet the requirements and these will affect costs, e.g., diesel engines vice gas turbines.

d. General Design Factors. There are a host of factors which are not specifically directed by the Naval Staff but which are necessary to the operation of the ship. Examples are environmental compliance, anchors, cables, lifeboats, gangplanks, stanchions and steering gear, to name a few. The size, range and scale of these items are closely linked to the size and required performance of the ship. The ability of the ship designer to affect these may be limited by the imposed policy or legal requirements.

8. Summary

a. Up-front Scrutiny. Notwithstanding market conditions, economic factors and political requirements, the mission and operational requirements are principal drivers of the costs of a ship throughout its life-cycle phases. It cannot be overemphasized that the mission and operational requirements must be closely scrutinized if costs are to be greatly reduced. It is essential that the up-front investment be sufficient to ensure properly informed choices.

b. Process Discipline. Ship costs can be reduced by: careful ship design and component selection, refining production methods, sensible procurement practices and minimizing contract changes during the construction period. To achieve this, however, requires a harmonious and disciplined process of policy makers, ship operators, designers and industry working together.

c. Cost Effectiveness and Operational Suitability. The need for the specified operational requirements must be constantly examined to determine the minimal level of effectiveness, e.g., need for military or commercial standards. Likewise, the spectrum of available alternatives to satisfy these requirements must constantly be reviewed and analyzed to determine the best solution of cost effectiveness and operational suitability. This assessment should take into account the life-cycle costs of the entire project, including the total military force structure if appropriate.

d. Ever-Present Cost Awareness. Total systems engineering and an ever-present cost consciousness and cost awareness are among the foremost requirements of a ship designer and must be part of all associated activities.

CHAPTER B

TECHNOLOGIES

1. Introduction

a. Technology Impacts. Technology innovations, in the framework of ship cost reduction, are understood as the application of practical or industrial "art-like" novelties (with controllable risk) to products and processes throughout the phases of a ship's life cycle. In the Feasibility, Project Definition, and the Design and Development phases of a ship's design evolution, the benefits of technology are probably most profound in contributing to the efficiency of the design. Technology applied to the Production phase most often results in reduced process costs and improved quality, or both. Additionally, much technology is incorporated with the intention of reducing the In-service phase costs for operations and maintenance.

b. Technology Drivers. Technological innovation is a result of different driving principles such as:

- innovation, to improve capabilities, enhance performance or lower costs,
- standardization, e.g., of effective solutions,
- interoperability and information management,
- technological challenges, e.g., solutions to particular problems,
- manufacturing and production improvements,
- environmental requirements, safety and health needs,
- productivity improvements,
- speed of processing,
- improved product quality,
- national goals and defense requirements,
- economic forces and competition, and
- cost reduction.

Whatever the reason for the technologies, this chapter deals with their impact on ship costs, both in the initial acquisition and in the operations and ownership aspects that follow. The following paragraphs discuss these impacts and a number of specific technology areas relative to ship cost reduction.

2. Costs

a. Cost Visibility and Risk. The impact of technology on ship cost is not always directly visible. Often, the impact is inherent in the chosen solution of the design or specifications. During the design phases, the most cost-effective solution fulfilling the requirement(s) is chosen based on engineering judgment or analysis of state-of-the-art technology. The cost impact of new technology is made visible only by comparing it to the current or previous solution and by assessing its affordability or cost benefits. As a matter of good business practice, technology solutions should always be checked for their cost and operational effectiveness and thereby create cost visibility as part of the ship design process. Due to the substantial uncertainty that generally surrounds the introduction of new technology, the analysis should also indicate the associated risk of the technology application. Methods of mitigating the risk and proving the technology include simulation modeling and the development and testing of actual prototypes. Additionally, conservative approaches such as an incremental design progression, "design-a-little/build-a-little," may prove effective. In any case, nations generally have their respective development and operational testing procedures to identify and control the risks and costs to acceptable limits.

b. Cost Effectiveness and Affordability. The introduction of new technology should improve capability or enhance performance at an acceptable cost, or lower acquisition and ownership costs. Care should be taken to avoid inserting more technology than needed to fulfill a ship's current mission or the anticipated mission during its life. If the introduction of new technology results in more or better performance than required, further investigation should be undertaken to determine if the extra performance is worth the investment. Comparing the improved solution to existing or previous solution(s) or other alternatives can make this assessment. and other solutions. New technology may be required to solve a safety problem or to meet a new policy (such as a new environmental policy).

c. Investment Cost. The performance enhancement, capability improvement or cost reduction resulting from the introduction of new technology must always be balanced against the resources in cost and time necessary for its development as indicated in Figure 6. For ships, this effort must generally be viewed as a long-term investment to be earned back with each application. Prototyping and simulation are effective techniques in realistically assessing and reducing the investment costs. Additionally, acquisition techniques can be employed to reduce the cost exposure such as: milestone approval requirements, limited production approval, gradual technology insertion via block upgrades (versus new ship starts), dual-use applications (commercial and military), inter-service (army, navy, air force, marines) cooperation or international cooperation.

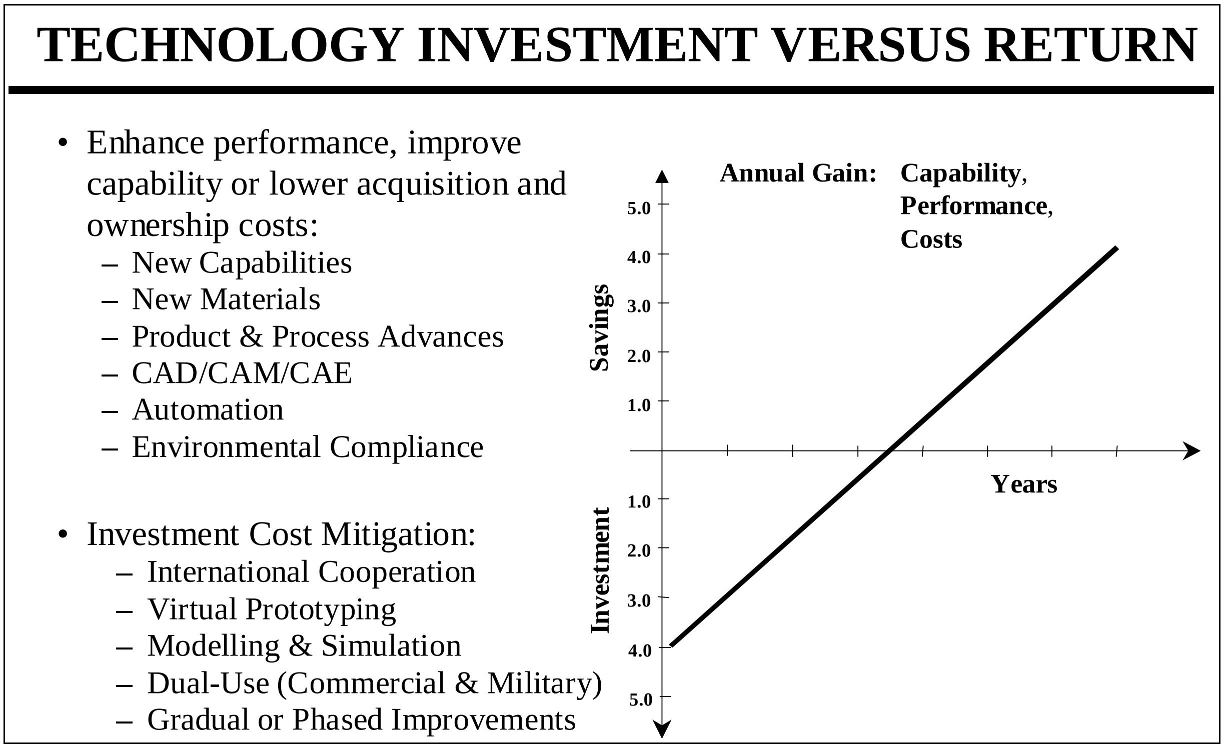

Figure 6

3. Technology Areas

a. Cost Reduction Potential. A subjective overview of the potential magnitude for ship cost reduction in eight technology areas is given in the Figure 7, in relation to the NATO PAPS phases. These areas have been chosen, following a survey of available literature, as being the most likely to offer worthwhile cost reductions. In almost all instances, the savings potential is the result of greater investment (an added cost) in the earlier phases for research, engineering and manufacturing development. These technology areas are each discussed in the following paragraphs.

RELATIVE COST REDUCTION POTENTIAL OF TECHNOLOGIES
(by NATO program phases for ship)

	MNE	PF	F	PD	D&D	Prod	In-S
New Materials				x	xx	xxx	x
CAD/CAM/CAE	x	x	xx	xx	xxx	xx	xx
Automation					x	xx	xxx
Software			x	x	xx	x	xxx
Environmental							xxx
Design/Const.			x	x	xx	xxx	x
Int'l. Coop.			x	xx	xxx	xx	x
Future Tech.		x	xx	x	x	xx	xxx

Figure 7

where,

x = Potential Savings
xx = High Potential Savings
xxx = Very High Potential Saving

and,

MNE = Mission Need Evaluation
PF = Pre-Feasibility
F = Feasibility
PD = Project Definition
D&D = Design & Development
Prod = Production
In-S = In-Service

b. New Materials. The benefits of the application of new materials are gained in the production process and during the In-service phase of the ship. New materials are often implemented during the Design and Development phase. Insertion at this stage, however, is not always cost effective or may pose cost risk as experience with production application of the new material may not yet have occurred. Cost reduction is reached when the new material is cheaper to produce and or when application of the product takes less labor or machine time, etc., and the investment costs are recouped. From the point of view of recoupment of investment costs, new materials can pay back the investment cost as savings are realized in the production and maintenance of the item or as efficiencies are gained in the operation cycle -- energy consumption, personnel, training, etc. The development cost of new materials will always have to be earned back in the production process, the operations phase, or through exploitation of the product in subsequent or serial applications.

c. CAD/CAM/CAE. Computer-Aided Design (CAD), Computer-Aided Manufacturing (CAM) and Computer-Aided Engineering (CAE), through the last decennia, have followed a gradual to explosive evolution. As well as the higher level of possibilities of the use of the computer that has been reached, a wider acceptance is noted in all areas of industry -- engineering, manufacturing, production, administration and management. From a ship cost reduction point of view, the use of CAD/CAM/CAE is beneficial in the following ways:

– reduced cycle times,
– less time in design and production,
– increased accuracy,
– reduced rework and changes,
– increased responsiveness,
– more efficient management,
– greater flexibility,
– better quality and quality management, and
– fewer but higher qualified personnel.

These computer-aided tools and methods also permit the optimization of ship design through visualization of the product including elements of virtual reality, and facilitate changes by the customer prior to commitment to production.

d. Simulation-Based Design and Virtual Prototyping (SBD&VP). The use of modeling and simulation allows the ship designers to perform multiple iterative assessments in the life cycle process before building any prototypes or initiating operations. Figure 8 illustrates the virtual life cycle of a ship wherein the use of SBD&VP will enable the following:

- conduct warfare and cost analysis to generate or revise ship requirements,
- design the virtual ship, with heavy reliance on visualization for functional analysis,
- provide efficiencies in the manufacturing processes,
- construct a ship prototype without bending metal or cutting steel,
- assess the virtual ship to ensure that performance requirements can be met,
- operate the virtual ship in realistically simulated environments to provide training for operators,
- perform mission rehearsals and logistic simulations, and
- build and maintain a design validation history.

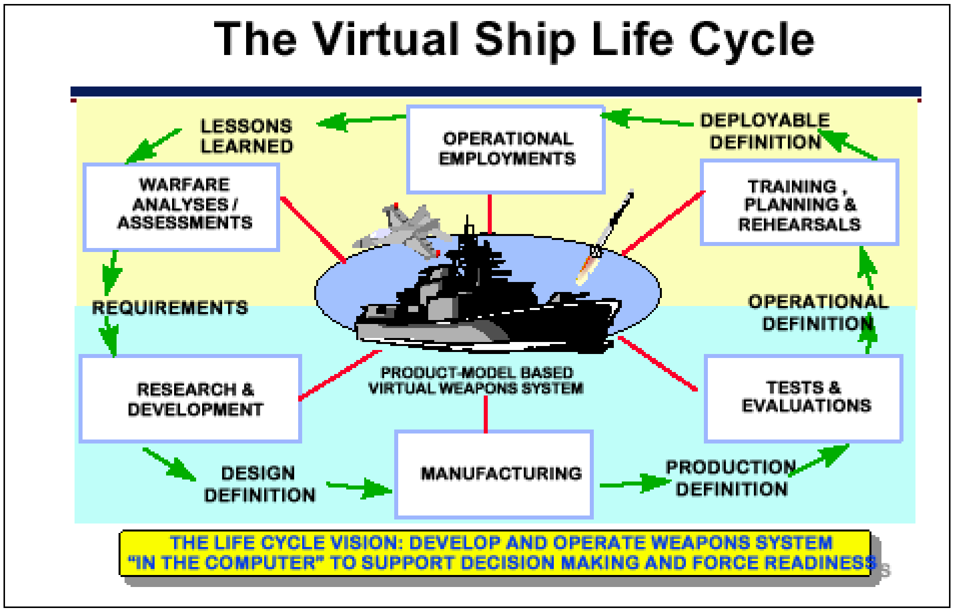

Figure 8

The use of SBD&VP, including virtual reality and common electronic databases, requires considerable up-front investments, however, risks can be reduced and life cycle costs minimized. This broad and multi-dimensional concept supports the full life-cycle process for decision-making and force readiness assessment. The technology provides a far-reaching and cost effective tool for assessing ship design capability, affordability, upgrade-ability, scale-ability and flexibility.

e. Automation. Whenever a process can be clearly defined and automated, personnel can be reduced and replaced by the automation of the process. The speed and repetition which are characteristic of automation along with improved quality and accuracy have led to its beneficial implementation. Automation normally implies an investment which will have to be "earned back" through the benefits of reduced costs of personnel and improved efficiency, quality and accuracy in the product. Reduced ship's manning requirements, with the attendant benefit of reduced personnel costs and ship living quarters and services, is one of the principal cost reduction benefits of automation.

f. Software. Reference (b) provides a definition of software (computer). Essentially, it is a pre-defined set of instructions and associated data that are stored in a computer (or disk, tape, etc.) that are used to execute a function or functions. In modern warships, software is an essential part of the operational effectiveness of naval ships, combat systems, weapons, command and control, tactical and strategic operations, communications, support infrastructure and so on. In the design and manufacturing process, software application has contributed to production efficiencies. However, it is expensive to develop and costly to acquire and maintain.

The development of software as an integral part of the naval ship design, very much depends on technology development; this is particularly evident in the development of combat system software and ship control systems automation. This type of software cannot be bought "off the shelf" and represents a large manpower effort with a high level of risk in its development. Generally, the costs to produce software depend on the complexity of the functions to be performed and increase exponentially as the number of lines of code to be integrated increase. The utilization of software metrics, e.g. lines of code produced per unit of time, by function, by type, by configuration item, et cetera, is an effective means of assessing progress and predicting and controlling costs. Experience also makes it abundantly clear that more time should be spent up front finding errors. The cost of finding and correcting a software problem in the early design phase is insignificant compared to the cost of finding and correcting that same problem once the software has been delivered.

Notwithstanding instances where commercial software may not satisfy the military requirement, the use of commercial software should be exploited wherever possible as an opportunity to reduce costs. Also, in the design of software, it is wise to provide an open architecture to permit ease and flexibility of later upgrades, and minimize compatibility and interface problems and maintenance costs.

g. Environmental Impact. The impact of environmental considerations on ships is incorporated or imposed through the ratification of laws and regulations of the respective nations -- following (peacetime) activities in environmental control and preservation of global resources. Reference (e) provides the strategy for environmental protection agreed upon by the NNAG. Navies (governments) are willing to abide by these laws and regulations, inter alia, to prevent "negative" publicity and, consequently, provide a "good" example to the public. Compliance with environmental requirements is expected to increase some costs in naval ship programs. However, the ultimate cost to the environment itself should improve and, hence, the cost to governments and society may be reduced. Nonetheless, there are direct and significant cost reduction benefits to ships:

- investment in environment-friendly (green) technology ships or associated products and systems is less demanding on resources (natural or energy) and, hence, may reduce the cost of production; and

- where reduction in material or energy is concerned, the choice of an environmental friendly solution is beneficial from a life cycle perspective in that the solution is more efficient with respect to consumables and replacements.

Moreover, the protection and conservation of the environment should be moulded into an attitude towards a reduction of global resources in general. In the "macro" sense, cost reduction (including ships) in the future is directly dependent on the availability of resources. A condition, which should be guarded against, is that it is not a natural phenomenon of design to invest its efforts based on the minimal use of readily available resources.

h. Design and Construction Techniques. As previously indicated, there are many advantages of new technologies to ship design and construction. In this section, the advantages of advanced ship design and construction methods as currently practiced are discussed. These benefits manifest themselves in the areas of improved management, design and production techniques as discussed below.

(1) Management Techniques. Typical advantages of the use of the computer are evident in terms of the use of CAD/CAM/CAE to assist in integrating the design, manufacturing, product flow, and product-oriented design and construction methods. Feedback from production into the design of a ship increases production efficiency, prevents repetition of mistakes and allows the designer to improve on quality and producibility.

(2) Design Techniques. It has become widely recognized that ship design decisions made in the early stages of a program can largely predetermine and, in effect, fix the major portion of the program budget requirement. Therefore, it is increasingly important to perform a thorough analysis of ship designs and their cost implications to ensure the "right" decisions at these early stages. Computer applications and modeling techniques can help in this regard. Many nations are investing more heavily in this area to develop better analysis tools and techniques. Also, increased accuracy in design, as a result of computer technology, has permitted smaller margins and enabled design for production improvements. However, to reduce costs, changes in the design after contract award must be prevented or minimized.

(3) Production Techniques. Contemporary generic shipbuilding strategies are worked out and made possible by the use of a product-oriented approach in ship production, resulting in modularity, standardization, zonal outfitting and process simplification as discussed below.

Modularity allows a number of sub-components to be assembled into a larger (repeatable) subassembly. Increased efficiency and greater flexibility by using standardized building blocks in construction are a result.

Standardization decreases the number of different or unique components used in the product. It reduces the number of types of like items, components and modules to be designed, produced and procured. Consequently, there is an associated reduction in the requirement for spare parts.

Zonal Outfitting employs a product-oriented work breakdown structure, rather than system-oriented. The aim is to perform the maximum amount of work during the most efficient stage of construction; i.e., maximize the opportunity to increase the overall productivity in the construction of a ship. Pre-outfitting in the shop or off-board the ship and modularity allow for higher production efficiency, and may permit the use of less volume in the ship. However, the design and engineering effort to implement zone outfitting is higher than that of a system-oriented approach.

Process Simplification denotes a building and procurement strategy based on an advanced product-oriented management approach which permits: standard designs of modules, a higher level of common equipment procurement, and parallel assembly of modular units and interim products. The concept promotes a factory-like working environment (wherein the functions of design and production are integrated) with a much increased level of prepackaging and ship pre-outfitting, as compared to earlier practices which largely consisted of a non-integrated, piece-by-piece (or "stick-built") design and production approach.

The combined approach and application of the above topics to ship design and construction is referred to as "commonality", indicating a synergistic approach to management, design, production and procurement aimed at producing an affordable navy fleet.

i. International Cooperation. One of the ways nations are dealing with affordability of defense systems is the "pooling" of technologies and resources in collaborative programs. This offers the advantages of leverage in the technology development end of program acquisition and economies-of-scale in the production and in-service support phases. International cooperative programs, during the pre-feasibility, feasibility, design and development and production phases, make it possible to benefit from the available technology of the different partners under an (data) exchange agreement. It is possible to execute a common development program using the technology centers of the different partners. Very often these programs are performed with "closed purses", meaning that the technology exchange is evenly divided between the partners based on work content (does not involve money payments).

A very special form of collaborative program would be to commonly execute the design and development phase including the building of a common prototype. As a program reaches the production phase of a class of ships, or even the in-service phase, international cooperation is less evident. However, ship cost reduction is feasible there also--for instance, common procurement of spare parts, common training programs and facilities. Even common operations can be thought of, e.g., NATO or EU, with the general objective of cost reduction and savings in operations.

j. Future Technology. The impact of future technology may occur in any of the phases of a ship's life cycle. Further enhancements in design technology are expected in CAD/CAM/CAE (with the visibility of results occurring primarily in the production phase) and automation (where reduced shipboard manning may manifest itself in the operations and support phase). Up to the present, the in-service phase is still a relatively unharvested area in ship cost reduction; therefore, substantial potential exists for operations and support cost reduction advances, making the in-service phase worthy of a much greater effort for future technology focus. It must be recognized, however, that in-service cost reductions often require greater up-front cost investment, and consequently do not always turn out favorably in an investment appraisal, due to discounted cash flow analysis. Greater use of information technology (e.g. digital data access, management and use) and modeling and simulation techniques are expected to facilitate improvement in concurrent engineering, enhance decision making capability, increase operational effectiveness and lower training costs.

4. Summary

Technologies generally have great potential for reducing the costs of ships, in addition to offering better and more effective solutions to (technological) problems. Cost reduction potential, associated with technology advances, exist in all phases of a ship's life cycle. Technology advances are expected to continue in all the design phases, where advanced computer techniques have benefited ship design, and during the production phase, where the full benefit of the design effort generally occurs and where advances in manufacturing and production automation and process techniques are realized. The in-service phase is an area that is deemed to have great untapped potential for continued cost reduction as a result of technology application. International cooperation in the technology area is gaining in popularity for its cost reduction benefits and potential for improving the products associated with ship acquisition, operations and support.

CHAPTER C

DESIGN

1. Introduction

a. Definitions. Reference (b) defines "design" as:

"The application of scientific and engineering efforts to:

(1) Transform an operational need into a description of system performance parameters and a system configuration;
(2) Integrate related technical parameters and ensure compatibility of all physical, functional, and program interfaces in a manner that optimizes the total system; and
(3) Integrate reliability, maintainability, safety, survivability, human engineering, and other such factors into the total engineering effort to meet cost, schedule, supportability, and technical performance objectives.

The design effort culminates in the production of the detailed specifications, drawings, inspection and testing criteria, and other technical documentation required for the construction, testing, and acceptance of the delivered ship."

b. Design Role. The above definition describes one creation and two integration (or management) functions, from which it can be concluded that design has a unique role in the overall warship planning process within the triad of: capability requirements, costs and risks. These inter-dependencies require a broad approach in addressing the question of possible cost reductions resulting from a ship's design. “Design” is more than the art of producing blue prints; it is the skill of transforming requirements into capabilities and balancing these capabilities versus the associated costs and risks.

c. Objective. The pressure on warship designers has changed over time from producing the best ship to producing the most cost-effective ship, and now, to producing the best ship that can be provided for a given amount of money. Against this perspective and within the framework and terminology of the NATO PAPS, reference (c), the objective of this chapter is to discuss:

- the three inherent functions of design,
- the influence of design on ship costs, and
- the opportunities and potential for ship cost reduction associated with design.

2. Design Practices

a. Policies and Procedures. There are no standardized policies or procedures for the performance of the design effort in NATO; practices vary from nation to nation. However one of the following general options, or a combination of several, is likely to be used for creation of a ship design:

- by government agency ("in-house"),
- by a contractor under supervision of government staff,
- standard design, modified to suit a particular requirement or customer (modularity philosophy, e.g., the German MEKO/FES concept, the Spanish Frigate F100), or
- by a contractor to civil standards (generally applicable to naval auxiliaries only).

b. Responsibility. Associated with design authority, one of the leading questions is: "Who bears responsibility if the ship does not work satisfactorily?" With merchant ships, the situation is fairly clear -- ships are designed to the safety standards required by the government of the country of registration and the rules of an accepted classification society. This society checks and endorses the design, supervises and surveys the build process, and certifies the ship upon completion. This process and the associated measures render the ship insurable. If the vessel is lost due to poor design, bad quality of construction, lack of maintenance or poor seamanship, the insurance company pays. For warships and other naval vessels, practices are quite different. These ships are not insured and if the ship suffers or causes damage or is lost as result of poor design, the navy or other government agencies must pay. Whatever design practices are followed, the fact that the government of the respective country has responsibility for its naval ships underscores the importance and responsibility of the designer.

3. Nature and Stages of Warship Design

a. Nature. The nature of warship design is pithily caught by the description: "A warship is engineering's greatest compromise." Since the majority of a ship's procurement and in-service costs are set during the early stages of its design, the ship designer plays a central part in affecting these costs.

b. NATO PAPS. As previously mentioned, armament planning is a national responsibility with national processes and procedures. However, to facilitate the discussion on design, the NATO PAPS is again used as a common frame of reference. The process is initiated by the definition of a military requirement, which is formally stated in the Mission Need Document (MND). The phases and milestones of this process are described briefly in the following paragraphs in the order in which they occur, taken from reference (c).

c. Mission Need Evaluation. This phase marks the beginning of the work and responsibility of the designer. Here, broad technical, financial and schedule considerations will be defined. Early dialogue between the designer and the user (operations/conceptual specialists of the navies) can help to avoid interpretation difficulties and illuminate cost driving requirements. Technical solutions must be weighed carefully and objectively to avoid bias.

d. Pre-feasibility. The main thrust of this phase is to conduct a preliminary survey of alternative technical solutions and to identify the most promising concepts for further evaluation.

e. Feasibility. An in-depth evaluation of the most promising technical concepts occurs during this phase and results in a staff requirement.

f. Project Definition. In this phase, a single system design will be considered in detail. The main objective here is to develop further particulars of the complete system specification, create initial subsystem specifications, and consider design approaches. The result will be an agreed set of specifications and a proposed program that can be used as the basis for the next phase.

g. Design and Development, Production and In-Service. During this phase, the detailed engineering for the selected technical approach will be conducted. Detailed documentation, manufacturing and logistic data is compiled as a prerequisite for the Production phase, and as necessary to support the technical readiness, field capability and logistic support required for the In-Service phase.

h. Framework Flexibility. The structure of the PAPS process is a systematic and flexible framework for promoting cooperative programs on the basis of harmonized military requirements, recognizing the sovereignty of nations as well as the authority delegated to the different NATO agencies.

i. Design Continuum. The level of design in each of the above described phases is governed by the design definition required at the end of the phase and should be limited to the minimum necessary to provide for the next step in the process, at an acceptable level of risk. Thus all steps in the design process are built upon preceding steps and form a design continuum.

4. Correlation of Design Activities with PAPS Phases

a. Integration of Diverse Elements. Although it involves a rather detailed discussion, it is important to delineate the related objectives, activities and results of each design phase to provide an insight into the basic functions of design. Through a combination of technical engineering, planning and management skills, the transformation of operational needs into performance and technical parameters is made. This process requires the integration of diverse elements to achieve a total engineering effort leading to a ship design that meets both the operational and technical requirements and the cost and schedule objectives. In the following paragraphs, the design activities, which occur during the different phases of PAPS, are discussed by outlining the objectives, processes and products of each along with a profile of the activities. This provides a background against which the scope for cost reduction can be identified.

b. Mission Need Evaluation. In this, the initial phase, design activities center on concept exploration studies. The objectives of the activities are to:

- define a series of feasible platforms with associated production costs which approach initial performance requirements,
- achieve a balance between operational requirements and production costs, i.e. to determine the operationally most cost-effective solution,
- identify the major technical risks with each of the considered design options,
- provide definition of alternative concepts to the level of detail required for a rough cost estimate, and
- select candidates from the options defined for further considerations in feasibility studies,
- develop rough cost estimation models, and
- broad diagrammatic or ship arrangement drawings.

The processes involved are:

- analyses and studies utilizing synthesis, parametric or other models, and
    - empirical estimating techniques and rough cost estimating models.

The products of this phase are an Outline NATO Staff Target (ONST) and range of concept level ship descriptions with associated:

- definition of payload, speed, range, endurance,
- number and structure of complement,
- general ship geometry (broad diagrammatic and ship arrangement drawings),
- type/number/power of machinery,
- number/kind of propellers,
- installed electrical power,

- an indication of major design tradeoffs,
- weight breakdown and gross space allocation, and
- Initial rough cost estimate.

A typical profile of activities of this phase could be characterized as:

- clarify the mission need document,
- consider similar national and other needs, harmonize where possible,
- consider broad timing, technical and economic implications,
- initiate considerations on standardization, logistics, training, and infrastructure,
- develop terms of reference and work statement for next phase, and
- emphasize relative costs, consistency and accuracy versus absolute results.

c. Pre-Feasibility and Feasibility. Much of the work of the MNE phase will serve as a basis for the following two phases, pre-feasibility and feasibility, the activities of which can be summarized as feasibility studies. A national or multinational project group could be created to identify technical solutions and to conduct the studies required. The objectives in this phase are to:

- provide technical baselines for new naval ship designs,
- develop definition of the selected ship concepts in sufficient detail and a more refined cost estimate, possibly setting a design-to-cost target,
- provide a firm baseline for project definition, and
- determine initial resolution of major technical risks identified in the previous phase.

The processes for these phases are similar to the previous phase. Study activities will increase and sub-groups may be established and work in parallel. The processes include:

- calculation or "design" of major and critical systems,
- ship sized on an absolute basis, compared with the baseline from the previous phase,
- major sub-system tradeoffs,
- development of space and weight budgets,
- evaluation and resolution of major technical risks,
- refinement of cost estimating model, and
- subsystem cost estimating and analysis.

The products of these phases are condensed into a NATO Staff Target (NST) for the pre-feasibility phase and NATO Staff Requirement (NSR) for the feasibility phase. Associated products are:

- detailed design baseline,
  - refined cost estimate,
  - logistic support and maintenance philosophy,
  - life cycle cost considerations,
  - testing concepts, and
  - Documentation.

The maintenance and monitoring strategies of the operational phase are most effective when determined and implemented during the design phase. Establishment of system and/or equipment parameters indicating performance allows for incorporation of the monitoring equipment into the design.

A typical profile of activities in these two interrelated phases could be:

- develop list of alternative technical approaches,
- evaluate applicable completed, ongoing or planned national, NATO or other studies,
- determine if additional studies are needed,
- determine how studies should be funded and run,
- select most promising concepts for further study,
- identify critical technologies of each concept and develop assessment criteria,
- identify areas of risk associated with each concept,
- consider appropriate standardization, logistics, training and infrastructure factors,
- develop initial estimates of schedule and unit life-cycle costs for each concept,
- develop management plan for the project,
- recommend preferred solution, and
- develop Memorandum of Understanding (MoU) for next phase.

d. Project Definition. Whereas the phases described so far serve an exploratory purpose, PD is devoted to the creation of a design for an optimum and complete system including specifications and program plans necessary to define the design and development program. Financial and industrial factors increase in importance. The objectives of the PD phase are to:

- provide the technical and functional baseline,
- achieve a complete engineering description of an integrated system,
- achieve functional definition of subsystems and their optimized integration,
- select final ship characteristics design criteria,
- provide a basis for the establishment of design-to-cost goal, and

- reduce risks to an acceptable and manageable level.

The related processes to this important design activity are:

- design-to-cost trade-off analyses,
- design review and selection,
- intensive ship system integration and optimization analysis,
- combat system integration with ship systems,
- ship entity characteristics selection,
- configuration management, and
- risk reduction exercises.

A "risk" is to be interpreted here as an event with a negative impact on a program in terms of performance, cost or schedule. The "measure" of a perceived risk is sometimes taken as the "product of its probability times its consequence in cost or delay". Risk analysis is a method intended to identify risks, as far as possible, in order that adjustments to the program plan, including cost and schedule options, can be made, should the risk materialize.

The condensed product of this work is the milestone NATO Design and Development Objective (NADDO). Individual products are:

- design baseline,
- system engineering management plan,
- logistic support/maintenance/training plans,
- documentation of all specifications,
- test and evaluation requirements/plans,
- simulation requirements, and
- risk management plan.

The profile of typical activities would be:

- determine time schedule for development, manufacture and delivery,
- identify critical components,
- draft specifications,
- determine assessment criteria,
- perform initial design and experimental work,
- identify compatibility problems and integration and remedial measures,
- determine considerations for standardization,
- analyze possible tradeoffs between performance, time and cost,
- reassess staff requirement,
- finalize selection of performance data,
- determine cost management plan,

- assess industry proposals for full development and production,
- finalize specifications,
- receive contractor proposals for the design and development phase,
- prepare development objective, and
- investigate risk areas and plans to manage them.

e. Design and Development. The last planning phase prior to production is D&D. It requires design-engineering work aimed at full validation of the technical approach and ensuring complete system integration to the point where production contract action can be taken. The objective of this phase can therefore be summarized as the provision of a contractual baseline. The processes involved and the related products are:

- adoption of management and cost plans,
- selection of contractors and other development authorities,
- preliminary design work,
- further validation of standardization, logistic support, training and infrastructure aspects,
- trials of components, subsystems, sub-assemblies, etc.,
- optimization studies,
- system design completion,
- prototypes, test and proof, contractor and user trials,
- agree final technical characteristics,
- amend specifications, finalize technical description and performance criteria for contract action,
- draft cost plan, production program for production MoU,
- prepare life-cycle cost estimate,
- prepare work for next phase, draft NATO Production Objective (NAPO),
- prepare archive of documentation for use in next stage, especially for quality control and common support arrangements.

f. Production and In-Service. In these phases, there will also be design activities but to a much lesser extent than in the previous phases. However, as the design proceeds, the ship designer should continue to look for cost reduction opportunities, particularly in the production process and regarding operations and support. Performance monitoring data collected during the operational phase is used to support the maintenance strategy and refine the design when necessary, or to improve efficiencies.

5. Cost and Work Breakdown Structure

a. Necessity for Structure. A warship acquisition requires a diverse range of functions and technologies that have to be integrated into design process as a whole. A project cost and work breakdown is essential to effectively managing this process. Such a structure is necessary also to provide the level of visibility and sensitivity to assess costs.

b. NATO Cost/Work Breakdown Structure. To enhance a common understanding, provide a framework of discussion for international programs, and enable a comparison with national practices, ANEP 41 delineates the NATO Cost/Work Breakdown structure (CWBS) for ships. This structure represents a hierarchy of elements arranged at four levels:

- Level 1, total project,
- Level 2, common elements and unique elements,
- Level 3, hardware, software, design and support services, and programmatics, and
- Level 4, major subgroups of the level 3 elements, e.g., ship systems, engineering and support services, etc.

6. Design Process Challenges

Ship design is very complex in nature and involves, as the previous considerations indicate, a variety of algorithms and heuristic processes and many imponderables. It would be an illusion to believe that the problem of ship cost reduction could be solved by producing a checklist of design tools and recipes which could be applied at the various phases and steps of the PAPS process. However, national and international experiences in ship design suggest some general challenges for the future:

- the need for greater options exploration at the earliest stages of the design process,
- the need for greater use of Modeling and Simulation (M&S) techniques and Simulation Based Design (SBD) in the earliest stages of the design process,
- the need for a more systematic approach to ship design,
- the need to exploit all available tools,
- the need to manage an increasingly complex, if not unstable, design process, and
- the need to give greater weight to control of operations and support costs by the design process.

7. Cost Reduction

Within the design process, the following considerations, methods and techniques should be addressed in the search for cost reduction.

a. Cost Driver Focus. Average acquisition unit costs of warships have steadily increased over the past several decades, even after adjusting for the effects of inflation.

This is attributable to a number of causes such as ship size and complexity, safety requirements, survivability, combat system capability, environmental compliance and production rates. To continue to acquire modern warships with capability upgrades in today's fiscally conscious environment, increased emphasis on affordability is unavoidable. Design tradeoff analyses and affordability assessments should focus first in the high cost-driver areas. In conjunction with this, there is the need to pursue overall process improvement initiatives and disciplined engineering approaches. In addition to the above, engineering and design attitudes must change regarding traditional practices. Nations may have to make sacrifices in their efforts to design ships with complete autonomy; that is, ship capabilities will doubtless have to be tailored to specific mission scenarios relying on other friendly ships or forces for augmentation in the areas of capability shortage such as survivability and sustainability. Design margin policies may have to be reduced.

Based on the literature survey presented in reference (a), a typical surface combatant breakdown is as follows: initial acquisition 23%, modernization 13%, maintenance 21%, personnel 37%, fuel 4% and design support 2%. For ship acquisition, propulsion and auxiliary systems, combat systems, combat system integration and requirements for infrastructure support comprise the high cost areas. Other features such as survivability, sustainability, habitability and future growth margins should be constantly assessed so that the associated costs are known to the decision-makers in determining their affordability. Cost models need to be established to assess the costs of performance features during the design process, particularly in view of the fact that the majority of the costs of a ship are dictated by early design decisions.

b. Integrated Product and Process Development Teams. Ship Design requires a high degree of teamwork amongst representatives from government agencies, the fleet operators and design and engineering specialists within the respective navies and industry. Such teams are sometimes referred to as Integrated Product and Process Development (IPPD) teams and are generally credited with significantly contributing to ship cost reduction and cost avoidance in addition to product and process improvements. In order to create the necessary cost consciousness and to take advantage of the synergism resulting from close proximity of functional experts, it may also be beneficial to have collocated ship design teams made up of personnel from all disciplines involved in ship acquisition including representatives from both industry and the government. Whatever the physical location of the team participants, it is necessary to have a real-time link between the design and engineering, cost estimating and analysis, and program decision-making personnel. In this way, continuous visibility within the design team and to higher management on the change in ship cost as the ship design proceeds can be effectively achieved.

c. Resource Control Approach. (See also, Chapter G) In the contract design phase of the U.S. Navy DDG-51 program, higher authority set a unit cost target for the lead and average follow ships. The approach used to achieve the cost goal was to establish a resource control process wherein functional managers of the design team were allocated design budgets for their respective ship subsystems. As the design for the subsystems was then developed, the design managers were provided real-time cost estimate feedback on the impact of their design changes so that cost-effective solutions could be chosen.

d. Design Specifications and Standards. There are many ways by which the cost of ships may be reduced through design tradeoffs. Some suggestions from industry are: use commercial specifications and practices, seek steady production rates (quantities, volume), apply firm designs or standard designs, reduce testing and inspection requirements, permit less stringent specifications, simplify designs, and reduce documentation and reporting requirements. One of the essential things to do is to let the "requirements setters" know what the cost of their specifications are so that they can sort out the softer requirements from the hard ones in order to stay within the affordability constraints. Another possibility is to review the standard design criteria, which is applied. The design margin policy should be carefully scrutinized for possible reduction as a result of other design decisions such as more standard parts, simpler designs, better space arrangements, design-for-production, et cetera, which may enable the margin reduction.

There are some key themes that emerge as common issues affecting the business case for the application of commercial standards and practices to naval ship acquisition and ownership. Chief among these is the need to consider all life cycle cost implications arising from the use of commercial standards and practices. Much of the available evidence indicates that significant cost reductions are possible during the acquisition phases. However, the use of commercial standards, practices, and contracting strategies bears implications for in-service (operation and support) costs as well. Furthermore, the use of commercial standards and practices requires an increased understanding of variable indirect costs at all stages of the ship’s life cycle, to enable meaningful and fair cost comparisons between options. Additionally, there is an increasing need to be able to relate these costs to the key functional parameters of the ship (such as survivability, capability, flexibility, etc.). The use of commercial standards, practices, and contracting strategies must be accompanied by informed analysis. This will enable the full cost implications to be considered in the business case when applying the various cost reduction techniques. Tools such as cost-benefit, return on investment, and breakeven analysis are useful in determining the most cost-effective solution to balance the cost reduction measures with the needed military effectiveness and safety requirements.

e. Initial Acquisition versus Life-Cycle Costs. In making choices on the cost effectiveness of design tradeoffs, it is important to look at the entire life-cycle implications of each tradeoff. It is very possible that a decision on the cost effectiveness of a design alternative which is attractive based on an initial ship acquisition cost basis may not be the right decision on a life cycle cost basis. There are documented cases where an up- front investment, which causes a cost increase in the acquisition phase, then more than makes up the difference through substantial savings in the in-service phase; e.g., increased automation to yield reduced manpower, increased ship size resulting from modular design in order to yield ease of payload change-out in the in-service phase, and increased structural weight as a result of applying commercial standards. Additionally, these increases in ship size and weight along with improved efficiencies in construction methods (zone-oriented/product-oriented) may enable reduced margin allowances.

f. Cost Data and Cost Modeling. To facilitate the decision-making process, it is necessary to have good cost modeling tools. This generally requires a substantial investment on the part of nations to obtain but without it one is helpless to understand the costs. In order to have such models, it is necessary to collect historical costs. Therefore, it is necessary to require contractors to provide periodic and meaningful cost data reports. Again, this is an up-front investment (increased cost) with the potential for high payback downstream.

g. Design-To-Cost. In times of financial stringency it has become common practice, to apply rigid price ceilings to warship projects. Design-To-Cost (DTC) is a means to achieve the goal of staying within given limits. It is not a process but an aim, which can be reached by application of certain methods and techniques to reduce risks and costs, such as close scrutiny in the following areas:

- design tradeoffs,
- common procurement opportunities,
- contracting practices (competitive tendering/bidding),
- value engineering analysis,
- production processes, build strategies,
- management methods,
- design commonality,
- crew reduction via automation,
- quality control and assurance, and
- test, trial, and acceptance procedures.

Application of the DTC approach commences with the development of military requirements and their translation into mission need documents, staff targets/ requirements, etc. Marginal reductions in the anticipated capabilities may often result in considerable savings without jeopardizing the overall mission of the respective weapon system. The greatest potential for this lies, of course, in the areas of ship propulsion/ machinery/hull and weaponry/combat systems. An early dialogue between the demander (customer) and the provider can help prevent technical and financial risks and avoid excessive costs or cost overruns.

h. Value Engineering. Value Engineering (VE) is a process, originally developed and used in industry to identify substitutes for products that were too expensive. Since then, VE has additionally been recognized as a means to be applied to production, organizational, and information processes. VE is a systematic, heuristic approach to solving problems where deterministic processes and algorithms do not work. VE can be applied to assist in the development of alternatives in all phases of the life cycle of warships. Other management tools such as work-study, cost effectiveness analysis, and cost-benefit analysis, can also be enhanced or supported by VE.

The prevailing phenomena of VE are:

- organization/breakup of a problem/task/project into functions,
- assessment of value/cost and its allocation/distribution to these functions,
- identification of lower cost alternatives, purposely applying creative thinking.

The objective of VE is to achieve the essential functions at the lowest cost consistent with the needed purpose, performance, reliability and maintainability. The structure, definitions and terms may vary with nations, but VE generally consists of following consecutive steps or phases:

(1) prepare the project,
(2) analyze the object,
(3) describe the requirements,
(4) develop solutions,
(5) determine solution(s), and
(6) implement solutions.

(The above structure is based on the German industrial standard Deutsche Industrie Normen (DIN) 69910. A similar French standard is the Francaise de la Normalisation (AFNOR) NFX 50-150 to 50-153)

Appendix 4 describes the above steps in further detail.

i. Design for Production. The term “design for production” refers to the idea of performing the design functions always with the production phase (manufacturing construction, assembly, and test) in mind--to ensure the producibility and cost effectiveness of the design. Design for production philosophy should be taken into account in the early design phase in order to avoid costly mistakes (design changes and rework) or to reduce the cost of producing the ship. This requires an understanding of ship construction techniques, capabilities, production efficiencies, work flow, material lead times, scheduling and the like. (Refer to Chapter E.)

j. Eliminate/Reduce Changes. The result of ship development and construction will reflect the latest proven technology, threat and societal conditions. In order to achieve this, contract changes are inevitable. Although changes can significantly improve ship development, attention must be placed on budgeting and scheduling to mitigate exposure to potential cost increases. Ideally, changes should be avoided because shipbuilding depends on a network of time dependent planning and scheduling. It is clear that this network phenomenon is related to the kind and magnitude of the changes. Agreements in contracts made in early stages of the process are inevitably susceptible to the risk of financial penalties where equipment is envisaged with extensive or projected delivery times. Generally, changes impact all parties to the agreement: the contractor (shipbuilder, subcontractor or supplier) and the customer (navy).

Contractually, change is anything considered beyond the contractor's scope. In quest of improving technical performance, changes may range from major proposals in war-fighting capabilities to minor alterations like deck covering alternatives. In shipbuilding, changes are typically incurred to modify product specification(s), reduce weight, reduce cost, substitute materials, improve environmental compliance, and improve safety. Attention must be paid to communication between the shipbuilder and subcontractors as well, particularly to ensure vendor delivery of the subcontracted item is on time and in good condition. When delivery on schedule is not possible, the shipbuilder may have to request a change in the terms of the contract. The same is true regarding delivery of government furnished items to be installed by the shipbuilder.

(1) Managing Change.

(a) Change Understanding and Categorization.
Based on the literature survey of reference (a), the key factor in managing change is understanding and organization. This process makes clear what kind of driving forces (originating sources) are involved. The identification of the value (of a change) which is added to the overall program is then to be acknowledged. A better understanding of the scope of change(s) can be achieved with a change category scheme identifying the characteristics of each change. Some schemes may require identification of multiple categories applicable to each change. Source-based category schemes require only one category to be identified per change: the source of the change. Establishing a change category scheme is seen as essential to providing the necessary insight and organization to effectively manage change. The steps in establishing such a scheme may be relatively basic:

- review change proposals to determine change sources (customer driven, contractor driven, user driven, etc.),
- determine categories of each change for tracking purposes (e.g., payload changes, platform changes, etc.),

- analyze changes for scope, cost and overall impact to the program, and
- analyze changes for major cost drivers by source and by category.

(b) Block Upgrade Concept.
Another effective management technique, especially for capability improvements, is the "block upgrade" concept of management. Using this technique, design changes are collected as a block for insertion in new construction programs upon the introduction of a new contract buy (or lot) of ships, or as budgets permit. In this way ships of a program (or class) which are currently under construction are not impacted during the construction phase albeit retrofits may be necessary.

(2) Relative Cost of Changes. Based on the literature survey of reference (a), perhaps the major category of change costs (40% or more) are changes that contribute to new ship capabilities and those improving existing capabilities. Second in financial ranking are ship design functional improvement changes. Many of these are outside of the program manager's control, e.g., user driven (fleet requirements or changing mission needs).

Analyzing data by ranking shows that some categories that are low in financial ranking are high in difficulty of management ranking; for example, unpredicted or unexpected timing of changes in Government Furnished Equipment (GFE), cannibalization of equipment, etc. Often, expensive changes are easier to manage because a program manager who decides when and how the changes are incorporated into the ship control them.

(3) Timing of Changes. It is clear that the longer is waited, the more it will cost to insert a change into a ship design. Experience says it is more cost effective to incorporate changes in ships, which are under new construction rather than to wait until the ship is in service. Some estimates indicate that changes cost two to three times more after a ship is put in service. Thus, the inference is that changes should be eliminated or minimized on ships that have been transferred to the fleet. Changes reflect the dynamics of the threat, technology or society. Design of naval ships is usually a long-term activity that is driven by decisions in an early phase of the acquisition process. It is also well known that changes occur during the actual ship construction wherein it is necessary to re-design. Such changes can have far-reaching effects when a ship is under construction, for example, when previous subcontractor orders have to be canceled.

(4) Cost Impacts.

(a) Technological Innovation. In relation to technological innovations, greater risk (and hence potential for changes) is introduced when new systems appear that have not been used previously. However, technological innovations that improve communications, enhance product visualization, and facilitate concurrent engineering, such as today’s information technology explosion, can greatly reduce any negative cost impacts of these changes.

(b) Early-Design Decisions. It is clear that decisions made in the early-design phases have a great effect on downstream program progress, and to a large extent predetermine future financial requirements. It is emphasized that decisions having the greatest cost impact are made in early stages of a ship program and therefore, program managers must be attuned to this fact. Decisions must be considered carefully and, in many cases, changes must be effected in the early phases (even if at a greater initial cost), in order to achieve greater savings in the in-service phase of the life cycle. The advantage of effecting a change during the early stages of a program is that the magnitude of the change is primarily limited to ship re-design and review of the associated contracts and specifications.

(c) Far-Reaching Scope. The impact of changes influences diverse areas of work due to the multi-disciplined character of a shipbuilding project. Therefore, as construction progresses, changes will result in greater financial penalties because of the network phenomenon of the process.

k. Crew Reduction versus Automation. Manpower (Military Personnel) is expensive. Reducing the crew of a warship is therefore a challenge, which can -- if successfully mastered -- significantly contribute to reducing LCC. Reduction of the ship’s complement affects a considerable number of issues such as the initial acquisition savings from reductions in personnel costs, catering costs, ship services and less fuel due to reduced ship size and power. But it can also be expected, during the operation phase, that further life cycle cost savings will occur.

There are limits to the reduction of personnel and less obvious offsetting costs which can reduce apparent savings. For sustained operations (months or weeks rather than days) there must be sufficient personnel to man and operate sensors, weapons and command, control and communications equipment as well as be prepared for Nuclear, Bacteriological, and Chemical (NBC) defense and damage control without degrading the overall fighting capability of the ship. This has been a dominant argument since World War II; however, its relevance is decreasing with the growing importance and capabilities of microprocessors and their application to all areas and functions under the heading of "automation". It should be noted, also, that automation is a tradeoff that generally requires expensive initial investment.

The overall tendency for the future will be a smaller but higher qualified and more skilled complement. In order to retain this highly qualified and well motivated personnel force, which is very expensive due to the required training alone, the reduced crew must be well fed and provided with comfortable living quarters, so that serving on board warships will be attractive and not a punishment. Higher standard living quarters means that space cannot be reduced in the same way as personnel. Additionally, having fewer junior ratings will leave the ship short of hands for cleaning, painting and day-to-day low level maintenance. However, the latter problem can be partially alleviated by the introduction of materials which are easy to clean and rust resistant and the use of interior designs which avoid dirt and corrosion traps. Further, the lack of or decrease in maintenance staff will result in more upkeep by exchange of equipment and the attendant increased costs for replacement or reconditioning ashore.

Some other impediments to the achievement of cost savings from the reduction of the ship's complement are as follows:

- cultural barriers within the naval staffs toward big reductions in crew size,
- increased investment for technical substitutes (automation),
- increased space allowances for improved living quarters, and
- increased equipment maintenance costs through "up-keep by exchange."

Notwithstanding these limitations, the impact of the reduction in personnel numbers afforded by the use of more automation should lead to an overall reduction of life cycle cost for navy ships. Figure 9 below provides a summary of the last 4-5 decades experience among NATO nations in reducing crew size for frigate, destroyer and cruiser surface combatants. The trend is derived from a simple plot of data from the second half of the twentieth century. The crew complement total is plotted at the first in-service year for the first of class ship. Reductions have been evolutionary from both a technical and cultural point of view. There is no indication for a particular breakthrough. In most cases it was merely a welcome side effect of new technologies such as less manpower intensive diesel and gas turbine propulsion replacing steam, advances in weaponry, and the introduction of more automated systems. Nonetheless, the cumulative effect of such changes has resulted in a rather significant overall downward trend.

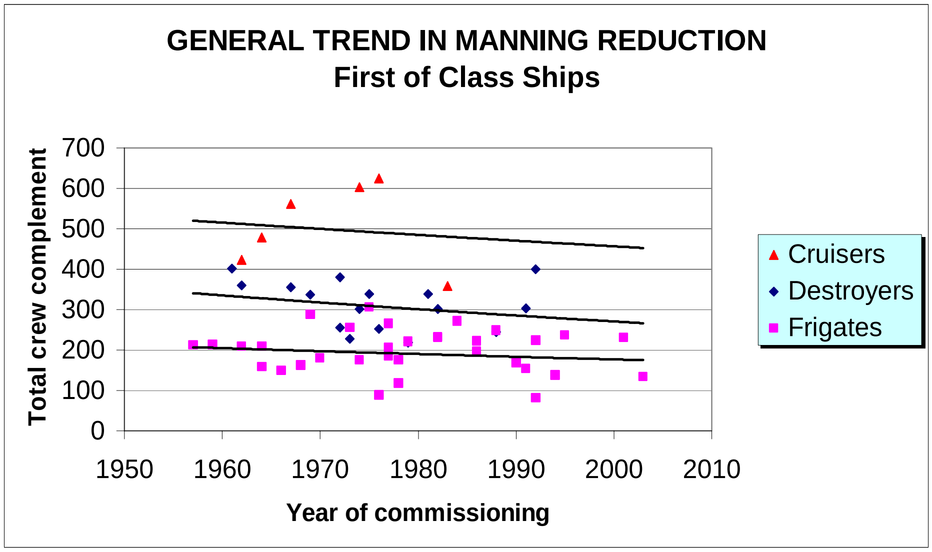

Figure 9

l. <u>Reliability Analysis.</u> In the context of cost reduction, "Reliability Analysis" is defined as a process comprised of two elements: "reliability" and "availability". Closely associated with these two elements is the element of "maintainability". A brief definition of these terms is as follows:

Availability: The expected part of a time interval that the ship/system/equipment is functioning.

Reliability: The probability that the ship/system/equipment is functioning at a point in time.

Maintainability: The degree of ease or difficulty with which the ship/system/equipment is maintained. Its scope includes all aspects of the logistics associated therewith.

To facilitate effective reliability analysis, the work is best carried out in the early design phase and it is important to work in a group where the members have different technical knowledge, i.e., within topics like mathematical/statistical analysis, system knowledge, cost estimating, project management, etc. It is also a condition that reliability data are available. Below are some examples of the uses of reliability analysis and why it makes it possible to save money.

(1) The design process should include a Reliability, Maintainability and Availability (RMA) study of the Mission Need Evaluation results. Sufficient data has been published or exists to generate a mathematical estimation of the Mean Time Between Failure (MTBF) and Mean Time to Repair (MTTR) for most, if not all, mission critical equipment. By

modeling mission needs against equipment reliability, trade off decisions can be made during the design phase. This will allow balance between required mission reliability and overall cost of design, and also help to avoid costly design changes during construction. Analysis of overall system and individual equipment reliability will also allow decisions to be made for life-cycle logistic support and maintenance strategy.

(2) The mission critical equipment identified by the reliability study will indicate which systems and equipment require performance monitoring to support reliability and/or Condition-Based Maintenance (CBM). Early identification of the conditions to be monitored will allow designers to accommodate this in design. Also, the results of the reliability study will enable a better understanding of spare parts requirements. A Readiness-Based Sparing (RBS) approach can then be adopted which can help to reduce depot maintenance inventories while increasing overall systems availability.

(3) A tool to provide the right solutions. Performing a reliability analysis may provide the right solutions, because it will reveal the weak and the good parts of a ship/system. This makes it possible to decide where redundancy or specific maintenance is necessary. For example, if one can expect only 80 % availability of the driving unit of a ship, then something may have to be done in order to increase the ship availability above that point, i.e., have a standby driving unit or maybe use another kind of driving unit.

(4) A tool for assessing whether the level of reliability is acceptable. If a system’s required operational performance is 95 % or better, this can be verified by performing an availability analysis.

(5) A tool for assessing cost effectiveness. In setting demands for ship equipment, a reliability study can help determine the cost/benefit ratio of various design options to meet the imposed requirements.

(6) A basis for development of safe and effective procedures for the operation and surveillance of an equipment or a process. Nothing is more expensive than accidents. In most accident cases, costs related to damage of the ship are only a part of the total costs. Other costs such as bad public relations, the psychological effect on the staff involved, etc. can exceed the costs directly related to damage. In accidents with loss of human life, this aspect is especially important.

(7) A vehicle to help improve the total understanding of the system. By performing a detailed reliability analysis, the understanding of how the

different systems interact will improve. Because the different "system experts" give expert information about the different systems processes and functions, the reliability analyst can base the evaluations on better and more comprehensive information.

To achieve a reliable estimate for the ship/system/ equipment availability, high quality data is essential and must not be neglected in managing ship acquisition, support and operations. Other important subjects/components which a reliability analysis may/should consist of are:

- Failure Mode and Effect Criticality Analysis (FMECA) - A method to detect failure modes of the different parts of the system, their effect and criticality

- Maintainability study - A study of a maintenance program for the operational phase. This includes detection of parts exposed to wear, etc.

- Reliability study - In connection with operation requirements such as: "the probability of failure before 1000 hours must not exceed 5%", find whether these are satisfied or not.

- Measure of importance of different parts of the ship - Detect the most vulnerable parts of the ship or system.

- Reliability program - Establish a set of tasks aimed at meeting the operational requirements concerning availability and reliability.

m. Investment Payback. Often during the design phases, a decision has to be made on an up-front investment, which will cause a cost increase in the acquisition phase. Usually such an investment will have to be justified on the basis of substantial savings in the in-service phase such as the following:

- increased automation to yield reduced manpower,
- increased ship size resulting from modular design in order to ease payload change-out in the in-service phase, or
- increased structural weight as a result of applying commercial standards.

Additionally, these increases in ship size and weight along with improved efficiencies in construction methods (zone/product oriented) may enable reduced margin allowances.

n. Commercial Standards and Specifications (Also, see Chapters A and D) The use of commercial or civilian standards may be applied in warship design as a cost saving matter. However, careful judgement must be brought to bear when making such design decisions. Even in peacetime, warships take extra risks (operate in threatening environments). They routinely carry explosives in considerable quantities, they indulge in dangerous maneuvers calling for special skills such as replenishment-at-sea, and operate in confined and shallow waters; they practice minesweeping, landing on beaches, operating aircraft, etc. Generally the decision to use or not to use a military standard or specification, as opposed to commercial, should rely on the knowledge and approval of the ship design requirement authorities.

Commercial standards cover a wide area. They range from rules for the classification of ships drawn up by societies such as Lloyds Register, through national and international standards sponsored by bodies such as ISO (International Standards Organization) and CSA (Canada Standards Association), to shipbuilder specific standards used only in certain shipyards. Commercial standards are already in use in many areas of ship design and construction. Experience shows that significant acquisition cost reductions are possible from their use with minimal effect on performance characteristics. Generally, the greatest opportunity for the application of commercial standards is at the component or sub-component level, and there are many opportunities for further expansion, notably in the in the combat system area, which makes up about 50% of the procurement cost of a complex surface combatant.

Lessons learned from the use of commercial standards indicate that there are some key constraints and considerations that must be taken into account when applying and advocating their use. Constraints include production volumes, reliability, maintainability and availability, safety and the ability to meet military performance requirements. Therefore it is essential that commercial standards be applied correctly after careful consideration and where clear benefit can be derived from their use. Military and safety requirements should always take precedence, but solutions to satisfy these should always be set against their cost. Thus it is necessary to make tradeoffs between commercial and military standards that are taken in full light of the cost and mission effectiveness implications.

(1) Commercial Standards – Definition, Purposes, Categories and Limitations.

Various NATO NG/6 working papers refer to commercial standards as *standards, as used in civil (merchant navy) shipbuilding.* A standard for either a naval or merchant ship specifies elements which will be applicable to many ships, thereby ensuring a common rule or basis for comparison and quality, but also saving efforts and costs if properly applied. Standards may be categorized as two types:

(a) Pure *requirement* standards, such as stability, shock resistance, environmental, accommodation, and habitability standards.
(b) Combination *requirement and imposed solution* standards like paint, lifeboats, electrical grounding, or standard equipment.

Pure requirement standards are too often applied without regard to their cost impact. Standards may be rigidly put to use in a wholesale manner to all ships, whether or not the requirement for which a standard is adopted has been adequately described. In some cases, the criteria used (including costs) when choosing the imposed solution lack adequate documentation, including the date the requirement was imposed. As a result, when new – and more economical – solutions are identified; the existing, often obsolete standard remains unchanged.

The danger common to both types is that when more than one standard applies to the same subject the standards are not ranked by increasing requirements and costs, absolute or relative. Another cautionary note in selecting commercial standards is to remember that a merchant ship standard is not necessary lower than a military, as witnessed by the different habitability standards for crew living quarters and hotel facilities.

(2) Sources of Standards

A mix of Standards as shown in Figure 10 influences specifications for naval ships. Military standards are developed by the respective national military organizations while Commercial standards for ships are developed by a variety of sources:

- ♦ Classification Societies.

  - Lloyds Register (LR), American Bureau of Shipping (ABS), Bureau Veritas (BV), Det Norske Veritas (DNV) or others
  - International non-governmental organizations -- International Maritime Organization (IMO), Safety Onboard for Lives at Sea (SOLAS), International Standards Organization (ISO), etc.

- ♦ Recognized Commercial Standards.

  - National government authorities -- Coast Guard or Standards Organizations
  - Technical associations and societies -- Institute of Electrical and Electronic Engineers (IEEE), American Society of Testing Materials (ASTM), etc.

- ♦ Other Standards.

  - Shipyard standards -- individual shipyard's own or industry standards

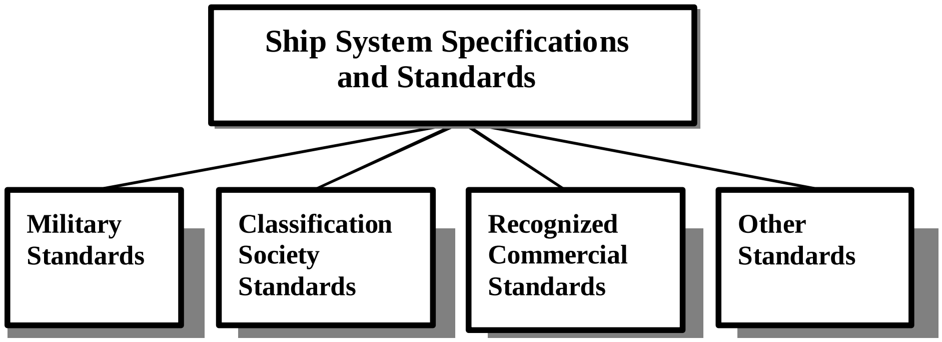

Figure 10 - Standards and Practices

(3) <u>The Way Ahead</u>.

(a) <u>Selection.</u> The decision to use commercial or military standards in ship design, construction, and shipboard electronics is mainly influenced by:

- operational requirements and safety;
- survivability;
- reliability, maintainability, availability (RMA);
- length of life cycle;
- documentation and testing;
- availability of the applicable commercial standard item; and
- acquisition, operating and support cost.

Critical life cycle cost considerations should include:

- determining long-term configuration management responsibility;
- assuring long-term vendor support for replacement items and spare parts, maintenance, and crew training;
- government access to data rights for commercial software and processors to allow future competition, facilitate future upgrades and incorporate new technologies; and
- interoperability issues (component, system, and ship, fleet, joint and allied).

(b) <u>Tailoring to Needs.</u> Even the strongest proponent of commercial standards and practices emphasize that *one size will not fit all.* The differing needs of the defense and commercial worlds have produced different levels of progress in a range of technologies so that a mix of military and commercial standards and practices must be tailored to the type of system being acquired.

(c) Cultural Issue. The use of standards in naval ship design must undergo a cultural change. Standards should be developed and used to for their true purpose, namely to save effort and cost. This means specification of true requirements (with adequate documentation) as well as careful avoidance of rigidity and use of obsolete standards. Competition in the merchant ship industry has forced commercial shipyards to design exclusively to pure requirements with cost as the driving factor. Many times in the past, naval ships have been technically designed and optimized to the requirement wherein solutions were described in terms of specifications such as length, displacement and equipment selection. To achieve a similar reduction in cost, naval ship design should consider these commercial practices, where length and displacement are almost never a requirement. Future designs of combatants must focus on the pure requirements and cost-effective solutions. A very important step towards this end is a thorough Naval Staff management process at the beginning to determine, through rigorous cost and effectiveness review, the pure requirements. Evolution should be considered as much as possible to mitigate the cost of acceptable solutions, and revolutionary type solutions applied only when needed and possible, at an acceptable degree of technical, financial and time risk.

Application of commercial or military standards is a matter of balancing requirements and capabilities versus the cost savings over the life cycle of a warship. Experiences, see Appendix 3, indicate that the use of commercial standards and practices has resulted in cost savings in various naval ship programs, especially in the initial procurement phase. Whether the promising initial savings can be confirmed and maintained during the entire life-cycle is a matter that needs careful observation and additional investigation. Significant savings in the area of risk management, through government-industry cooperation in the production of effective standards and affordable products, should be the aim as well.

o. Margin Allowances. Very closely linked to the standards issue is the question of margin allowances, which is also seen as a potential cost driver. Margin Allowances in ship designs are provided to increase the probability of success of the design by providing some level of flexibility, which is anticipated to cover emergent requirements during the design, construction and operational life for the ship. Said another way, margins incorporated in a ship design are provided to ensure the operational utility of the ship and its subsystems in consideration of the uncertainties and changes which may be encountered during the design and construction period and during the operation of the ship over its life. Margins include, *inter alia*, allowances in the ship design for volume, weight, power, cooling and vertical center of gravity. Two common categories of margins are described below:

(1) DESIGN AND CONSTRUCTION MARGINS are provided to cover problems of the design, and changes in the design requirements during the design and construction period of the ship. Allowances may be made for extra space, endurance, accommodations, structural strength, ship stability, propulsion power, electrical power, etc., so that a certain amount of change in the physical characteristics can be tolerated without having to enlarge the ship.

(2) FUTURE GROWTH MARGINS provide for anticipated future installation of items that are unneeded, unavailable or unaffordable at the time of initial construction.

A third category may be added based on the literature survey of reference (a):

(3) ASSURANCE MARGINS are employed to maintain the specified operating capability, offset progressive and predictable degradation of ship subsystems and equipment, and account for the uncertainty in the loads and demands that will be imposed during the life of the ship.

Looking at weight margins alone, national practices vary substantially. Figure 11 provides a comparison of the weight margin allowances for some of the NATO nations. The margin percentages shown are generally for conventional hull designs and vary depending upon the ship size, type and mission.

Surface Ship Weight Margins (Percentage of Light Ship Weight)								
Category	**CA**	**GE**	**FR**	**NL**	**NO**	**SP**	**U.K.**	**U.S.**
Design & Construction	2%-8%	7%	8%-10%	10%	5%-10%	5%-8%	15%	3.2%-12.6%
Future Growth		6%	0.4% /yr.	1.5%	3%-7%	5%-10%	8%	5%-10%
Figures shown are dependent on ship size and type and vary depending upon the particular mission, hull type, or critical design factors.								

Figure 11

Compounding effects of margin policy can be observed for eight types of margins employed in the design of a ship (based on the literature survey presented in reference (a)): space, accommodations, weight (acquisition), weight (future growth), vertical center of gravity, endurance power, sustained power and electrical power. Applying a range of values depending on policy, indicates that a wide variance in the ship platform procurement costs can result as shown below:

Policy	Platform Cost Impact
Low	5 to 20%
Medium (typical)	10 to 40%
High	15 to 60%

Considering this substantial range of impact, margin policy warrants close scrutiny when designing a ship.

The greatest flexibility to reduce or eliminate margins is with the Future Growth category. For example, if a ship is designed for a shorter life, the need for future growth is reduced. However, reducing Future Growth Margins will reduce a ship's flexibility and adaptability and may increase the costs of modernization and conversion during the In-Service phase.

Assurance Margins can be reduced to the extent that loss of performance in the "as-built" ship can be tolerated. Again, if a ship is designed for a shorter life, the corrosion allowance can be reduced or eliminated and the provision for long-term maintenance, spares and re-fits can be reduced. Assurance margins are generally selected for each part of the ship separately, with little consideration for the synergistic effects on the ship's performance as a whole. Therefore, it may be possible, through careful selection of these margins, to increase the ship's overall performance while reducing the ship size and cost.

In theory, Design and Construction Margins, which are not needed during the design and construction of the ship, may be deleted prior to delivery of the ship. In practice, however, this may not be practicable and would probably require a reiteration of the design, which might be costly in itself. Nonetheless, if more ships will be acquired of the same design, it may be worthwhile to adjust the margin to reflect this experience.

Case studies have also indicated the benefits of zone-oriented or product-oriented design and construction methods, when applied during the early stages of ship design. The improved construction methods may permit reduced margin and volume allowances as a result of the following examples:

- More efficient subsystem and space arrangements,
- Better organization of piping runs and reduced piping run lengths,
- Reduced ventilation duct sizes (cross sectional area),
- Improved paths for equipment removal and maintenance,
- More direct routing of wire-ways.

Other factors that may permit a reduction in margin policy are the elimination or reduction of:

- Changes in requirements during the design and construction phase,
- Contract changes after the ship construction award,
- Outdated specifications and design and construction practices.

p. Commonality. (See also, Chapters D and E) Considering design as a part of the planning and management process, commonality is a promising candidate for a more systematic approach to ship design, to exploit all available tools and manage the design process", based on the literature survey presented in reference (a). Commonality refers to a synergistic combination of modularization, equipment standardization and process simplification, aimed at cost reduction in both the initial acquisition costs of ships and the operation and support costs of the in-service phase. A policy of increased commonality is intended to reduce costs through increased cost consciousness in the early stages of ship acquisition planning relative to ship design, construction and ownership. The concept requires that a ship be designed for efficiency in the production process and for simplicity and flexibility in the in-service phase. Under this concept, naval ships are designed and built using common modules comprised of standard components and possibly would entail standard type platforms. These common modules and components are used across ship types and are integral with the philosophy of standardization, distributed system architecture and ship construction build strategies. In addition to increased use of standard modules and components, this concept embodies simplified ship specifications and common approaches to ship construction strategy across ship classes. Its use is applicable for combat systems, command, control, communications and computers, hull and habitability systems, machinery and ship service systems. Another potential benefit is the increased outfitting efficiency due to the shift of more work to an "in-shop" type environment. Commonality can even extend across national boundaries by designing and building ships with common equipment and to common standards, thus increasing the size of production orders and reducing the range of spares and support requirements.

q. International Design Pools. (See also, Chapter D) Notwithstanding national politics and concerns, the challenge of reducing ship costs could greatly benefit from international design pools, e.g., NATO community, European Community (EC) or multinational teaming agreements. Such agreements could produce NATO or EC ship design pools wherein the talents of the participating nations could be leveraged to maximize the formulation and realization of design methods and tools for reducing ship costs.

8. Summary

a. Policy and Procedures. Design policy, procedures and practices vary between nations and even within NATO, despite the existence of some remarkable common policy documents. Policy and procedures are not an end unto themselves; they must be of help and not an obstacle. When formulating or instituting new or revised policy, one should ask: Do we need more policies or do we just need better coordination and cooperation among the parties and consideration of alternatives to achieve the desired result? If there is a need for further or revised policies and procedures, it should always be kept in mind in producing them, that they must aim for a common, flexible and realistic framework that recognizes the creative and iterative nature of ship design and its complex management functions. Design is not a rigidly prescriptive process, and the procedures followed must be flexible and accommodate change.

b. Ship Design of the Future. Is the policy of commonality with functional equipment units and standard configured hulls the promising way of the future to an affordable fleet? Many questions remain open. Is the classical ship designer, who would optimize performance without regard to cost, a thing of the past? Design, free of almost all constraints -- in the sense of an art, is certainly history, if indeed, it ever existed. In the context of modern ship acquisition, ship design of the future will be more and more an assemblage of functional units or elements to provide the best ship obtainable for a given amount of money. Simulation-Based Design and Virtual Prototyping (SBD&VP) is a promising and supporting concept down the road to achieve this goal.

CHAPTER D

ACQUISITION PROCESS

1. Introduction

The purpose of this chapter is not to describe the different formal acquisition processes used by NATO and the member nations; rather, it is to analyze the different aspects and alternatives of the acquisition process with emphasis on cost reduction in the following areas:

- Industrial Base
- Contracting Practices
- Risk Mitigation
- Military versus Commercial Practices
- Data Requirements

2. Industrial Base

a. Role, Influence and Options. A country's industrial base is a key part of its defense capability. In the ship procurement process, it is with the industrial base that the design intent is converted into hardware. Increasingly too, ship design responsibility is being placed with industry so that industry has a further involvement in defining the design intent. Clearly then, the workings of the industrial base have great scope for influencing costs. For a complex artifact such as a naval warship, the customer does not have an absolute knowledge of the cost and, therefore, seeks to obtain (from his dealings with industry) assurance that he has obtained a fair and reasonable price.

b. Desired Characteristics of the Industrial Base. It is suggested that the government agency seeking to procure naval ships should look for several key characteristics in the industrial base available to it. Note that it is assumed in the first instance that only the national industrial base is relevant. However, should it prove unsatisfactory in some way, then it might be necessary to turn to other countries. The decision to do so would have significant political implications and would, therefore, be unlikely to be made solely within the acquisition organization. Nonetheless, the following are suggested as being the most important characteristics of an effective industrial base:

(1) possesses the required technical capability;
(2) produces work meeting the requirement the first time;
(3) has a realistic program or business plan and adheres to it;
(4) produces on time and within budget;
(5) can do the work for an acceptable price; and
(6) is forward looking, willing to develop new techniques to benefit itself and

the customer.

The first four characteristics may be described as "cost negative" in that shortcomings in them are likely to lead to upward pressure on costs, either by resulting in more money having to be paid by the customer (depending on contract type), or by forcing the firm to spend its own money in order to recover. The other two (related) characteristics are "cost positive" in that they offer the possibility of reducing costs, albeit, they rely on the first four being present as a prerequisite.

c. Competition, Business Volume and Risk. (See also, Chapter D, paragraph 3.c. (5) and 3.d.) It is recognized that an effective method of obtaining an acceptable price from industry for any task is through competition. In some cases, competition may be the only way to achieve sufficient incentive for firms to seek to reduce costs by eliminating practices that do not contribute to the end product but only inflate the price. It is noted, however, that going to competition is generally more expensive in the required management effort within the acquisition organization, to set up, organize and execute, than going to a sole source. Nonetheless, the potential savings to be made from competition for hugely expensive capital items like naval ships are such that the extra investment in management effort is well worthwhile.

In order to have successful competitions, the industrial base has to be sufficiently broad that there are enough competent firms. At the same time, the prospect of winning warship orders must be attractive enough that firms will tender. Firms will also want to have a reasonable chance of winning orders frequently enough to make the cost and effort of bidding worthwhile. Ideally, they should have sufficient other sources of work that winning any one order is not essential to their survival. Otherwise, they will be tempted or forced to bid low for the work with a good chance of consequent cost over-runs, going out of business, or having to look for ways to recoup their losses, to the detriment of the customer.

Too wide a range of firms, on the other hand, in relation to the volume of business, will lead to inefficiency in the competitive process, e.g., from the sheer management effort involved. Shipbuilding, particularly naval ships, is a specialist business. It may be tempting to spread the competitive net wider to seek a better price, but this must be weighed against the risk of achieving satisfactory contract completion. If the firm selected is not fully aware of the difficulties involved; then, when it is too late to back out, much more effort and cost may be incurred in an attempt to correct the situation. Further, if a number of firms are used, without being given some constraints, the resulting ships are likely to differ significantly in details of equipment and layout leading to extra cost and difficulty in support and operation.

Associated with the above points is the question of risk. Ideally, the industrial base should have firms which not only are technically capable and willing to bid, but are also sufficiently financially viable to accept the risks involved (both of getting it wrong and of failing to win enough orders). This element of risk can then be shared between government and industry through various contracting options. The various contracting options are discussed later in this chapter.

d. Production Improvements, Process Improvements and Innovation. Competition in the market place will provide a stimulus to efficiency and, hence, cost savings as a first step. There are further savings to be made, and a competitive advantage to be gained, by developing improved production techniques, for example, better welding methods, modular construction, etc. The procurement agency will, therefore, wish to see firms in the industrial base that actively pursue such innovations.

The industry, on the other hand, will be looking to make sufficient profit on its contracts to enable it to develop and introduce new techniques. These require up-front investment before there is a payback. If government does not wish to pay for development, either alone or in partnership, it would be short sighted not to make some allowance in its contract pricing for firms to be able to reinvest for the future.

e. Secondary and Tertiary Suppliers. A balance has to be struck between pursuing the benefits of competition, and the risks of damaging the industrial base through over-keen pricing and frequent changes of suppliers, with the attendant risks to the reliability of completing contracts and the quality of the product. It is worth noting a trend in other industries, i.e., automobile, to form close liaisons with key suppliers, offering them continuity of orders in return for a lower price together with a joint effort to improve productivity.

3. Contracting Practices

a. Contract Scope. Different nations may include different items in contracts for ships; thus the costs and scope may not be comparable. Additionally, the unique accounting and financial practices of the nations contribute to differences in the stated ship costs; e.g., taxes, cost of money, revenue dependency, social costs, etc. Depending on the nation or the program within a nation, the Unit Price Cost (UPC) of a ship may include the following categories of work: hull, main and auxiliary machinery, equipment, weapon systems, outfitting, setting-to-work, and trials. Consumables (ordnance, countermeasures, etc.), fuel, stores, spares, ammunition and aircraft are generally not included in the initial ship production contract.

The UPC should not be confused with the government's budget for a ship program. In the U.S., ship procurement budgets are accounted for on a "full-funding" basis where the unit cost of a ship is referred to as the "End Cost". The end cost includes all costs necessary for a delivered ship, i.e., the complete ship platform and combat system suite, testing, and trials; whereas, in the U.K., budget costs tend to include only the UPC items mentioned above. Therefore, the end cost of a ship includes all the items of the U.K. UPC plus: the detailed design effort, initial spares for new items introduced into the fleet inventory by the ship's design, on-board spares, in-house government support (e.g., laboratories) and fuel for trials. Personnel costs of the government program office and supporting headquarters personnel, consumables, fuel, stores, spares, ammunition and aircraft required as part of the ship's load-out and fleet operations are not included in either case. Therefore, when comparing costs, whether they are contracts or budgets, one should always examine the scope of work included very closely. ANEP-41 provides the NATO framework and methodology for effectively doing this.

b. Contracting Options. The variations in the practices of placing orders for warships, as used by NATO navies, have many options. A number of these are delineated below.

(1) Design:

(a) Designed "in-house" by government staff (e.g., NAVSEA, SSC, DMKM, etc.);
(b) Designed by a contractor under the close supervision of government staff;
(c) Standard design modified to suit a particular requirement or customer (e.g., MEKO Frigate); or
(d) Designed by a contractor to civil standards (e.g., auxiliary vessels).

(2) Ship/Combat Systems and Weapons or Platform/Payload Split:

(a) Buy the ship platform and payload wholly from one contractor (whole ship or total package procurement);
(b) Buy the ship platform from a shipbuilder and the payload items from another contractor(s) and have the shipbuilder install the payload items; or
(c) Buy the platform from a shipbuilder, the payload items from another contractor(s) and install payload items at another location (e.g., a government dockyard).

(3) Quantity Ordering:

(a) Order ships one at a time;
(b) Order ships in batches of two or more, up to the entire class requirement, from one shipbuilder;
(c) Order ships on an annual basis with contract options for follow-on buys (firm and option contract buys);
(d) Order from one shipbuilder only (sole source); or

(e) Order from more than one shipbuilder (dual source or multiple sources).

(4) Contract Types:

(a) Cost Plus;
(b) Firm-Fixed Price;
(c) Fixed Price with Escalation Provisions;
(d) Fixed Price with Incentive Provisions;
(e) Mixed Firm-Fixed Price/Cost Plus (e.g., fixed-price with cost plus for trails and setting to work);
(f) Fixed Price Incentive with Compensation Adjustment (e.g., Escalation, Fringe Benefits and Energy pass-through clauses); or
(g) None - a government dockyard builds the ship (e.g., allocation).

(5) Tenders:

(a) Non-competitive procurement (from one shipbuilder only, e.g., sole source);
(b) Competitive procurement (two or more sources);
(c) Prime Contractor (one lead contractor with instructions regarding the type and scope of sub-contracts); or
(d) None - where government dockyard will perform the work.

(6) Sub-contracts:

(a) By the shipbuilder using competitive tender;
(b) By the shipbuilder using a nominated supplier (single source);
(c) By the government at an agreed cost to the shipbuilder;
(d) By the government at no cost to the shipbuilder, e.g., Government Furnished Material (GFM), Government Furnished Equipment (GFE), Government Furnished Information (GFI); or
(e) By a third party, e.g., another government under one of many possible exchange arrangements.

c. Discussion of Options. A limited discussion of the above variations in contracting methods is provided below. However, it should be noted that it might not be possible for some methods to be used in certain areas of procurement, due to technical, legal or political reasons.

(1) Design:

(a) Post Delivery Responsibility. In contracting for the ship design effort, one of the leading questions is "Who has design responsibility?" Put another way, "If the ship does not work satisfactorily, even though the standards of workmanship and operation are good, who pays to make things right?" Moreover, "If, because of a design related matter, the ship sinks or breaks in two, who gets the blame?"

In the merchant ship world the situation is clearer. Ships are designed to the safety standards required by the government of the country of registration and to the rules of an accepted classification society, e.g., Bureau Veritas (BV), Safety-of-Life-at-SEA (SOLAS). The classification society checks and endorses the design, supervises and surveys the build process, certifies the ship upon completion and thus renders the ship insurable. If, subsequently, the ship is lost, be it due to poor design, bad quality of construction, lack of maintenance or poor seamanship, the insurance company pays.

For warships and other naval ships (auxiliaries, small craft, rescue vessels, harbor craft, stores tenders, etc.), practices are quite different from that of the merchant ship world. Generally, naval ships are not insured. Thus, if the ship suffers or causes major damage or is lost, as a result of its design, we the taxpayers (or our navies) must pay. The governments of the respective countries have responsibility for the design, construction, maintenance, repair and operation of its respective naval ships. Whatever contracting practices are used must recognize this fact.

(b) Use of Commercial Standards in Warships. The use of commercial or civilian standards may be applied in warship design as a cost saving measure. However, careful judgment must be brought to bear when making such design decisions. Even in peacetime, warships take extra risks. They habitually carry explosives in considerable quantities; they indulge in dangerous maneuvers calling for special skills such as replenishment-at-sea, and operate in confined and shallow waters practicing minesweeping, landing on beaches, etc. Generally, the decision to use or not to use a military standard or specification (as opposed to commercial) must be made with the knowledge and approval of the cognizant ship design requirements authorities.

(c) "In-House" Performance versus Contracting for the Design Effort. However much design work is contracted out by the government (or navy), the responsibility remains with the government and the scope of possibilities for seeking cost reductions by means of invoking cheaper civil standards is limited. It may even be in the interest of the government to have its own ship design office where the complexity and volume of associated work justifies it or where specialized work so dictates. However, there is generally less cost risk to the government, in a stable ship design scenario, to pass on the design and engineering responsibility to the shipbuilder to avoid later contract claims as a result of late delivery of GFE/GFI/GFM or faulty design work.

(2) Platform/Payload Split:

(a) Batch Buys. It is a generally understood premise that volume buys or rate production can reduce the unit cost of an item, e.g., making things in large batches is cheaper than small batches and similarly small batches are cheaper than making things individually. Relative to ship platform and payload costs, the payload tends to be procured in large batches (e.g., to fit more than one class of ship) while the platform portion tends to be ordered separately in smaller numbers.

(b) Programmatic Factors. The choice of contracting options relative to platform/payload split likely depends on factors other than cost:

- whether the same weapon system(s) is/are to be fitted in more than one ship class,
- the extent and complexity of the weapon systems and whether or not specialized facilities available only at certain industrial activities are required for installation and setting to work, and
- whether or not the weapon system(s) are to be procured from another country.

(c) Total Package Procurement. Whole ship or total package procurement has had some success in cases where the ship is acquired from a government dockyard or the ship is of a simple kind, e.g., an offshore patrol vessel.

(d) Design Process Influence. Except to the extent that the design process can influence the quantity, volume, or rate of production and hence the choice of contracting method, the latitude for adjusting contracting practices is controlled by other factors.

(3) Quantity Ordering:

(a) Design Impacts. The decision to buy ships and associated payload items in various quantities can be influenced by design considerations but may involve many other factors. If the design is fixed or stable it may be more conducive to volume buying, whereas, if the design will evolve from ship to ship, it may be more cost effective to buy in smaller lots or even singularly. These are generally matters of requirements setting and acquisition strategy.

(b) Industrial Base and Sociopolitical Influence. Industrial base and regional unemployment considerations may also be of a national or multi-national concern, which might also dictate the selection of a quantity option.

(c) Other Pertinent Factors. Although not intended to be all inclusive, other factors to be considered are competition or lack thereof, contract termination liability, pre-planned product improvements or capability upgrades, adaptability to changing requirements, contractor financial health and viability and life-cycle support.

(4) Contract Type. Contract selection is based principally in consideration of how the financial risks associated with the construction (attributable to technical or cost uncertainty) of a ship are shared between the government and the shipyard.

(a) Cost Plus. This type of contract is generally used for level-of-effort type work or new designs where the risk of cost overruns is too great; where costs cannot be predicted with a sufficient degree of certainty, e.g., lead ships and ship overhauls. In this type of arrangement, the contractor is reimbursed for actual costs plus a level of fee that may be based on a fixed rate or based on an award fee or incentive arrangement. For a Cost Plus Fixed Fee (CPFF) contract, the fee is fixed according to the level stated in the contract. For a Cost Plus Award Fee (CPAF), the award fee is determined by the contractor's performance against the criteria stated in the contract. For a Cost Plus Incentive Fee (CPIF) type contract, a sharing ratio is generally agreed upon between two levels of fee, a minimum and a maximum, where the contractor is stimulated to a higher rate of profit return for more efficient performance in accomplishing the work and controlling costs. The latter type contract has been used for ship overhaul work.

(b) Firm Fixed Price (FFP). In this type of contract, the risk to the government is minimized. It is used where costs can be predicted with a high degree of certainty such as repeat buys in ship production runs where previous deliveries have been made or relatively simple ship designs using commercial specifications. This type of contract may also be appropriate where the government announces a Circular of Requirements which outlines the basic requirements for a ship and leaves it to the competing shipyards to determine the design details and bid price. A selection is made without a negotiating process.

(c) Fixed Price with Escalation Provisions (FPEP). This type of contract is the same as FFP except it contains a clause permitting reimbursement for inflationary costs or costs beyond the control of the builder (e.g., energy). The escalation reimbursement may be based on actual inflation experienced by the contractor or it may be determined by an agreed upon index and formula.

(d) Fixed Price Incentive (FPI). This type of contract is often used for complex warships where technical or cost uncertainties limit the contractor's ability to estimate the cost of completing a contract. This type of contract involves a Target Cost, Target Profit, and Ceiling Price. The Ceiling Price is the maximum amount the government will pay. Up to the Ceiling Price, costs are shared between the contractor and the government based on a negotiated cost-sharing ratio.

(e) Mixed Contracts. It is also possible to have contracts that contain both cost plus and fixed price items. The same logic for application as described above would then apply at the contract item level.

(f) Fixed Price Incentive with Compensation Adjustment. This type of contract is the same as FPI but with the provision for adjustment based on such things as inflation, social costs and energy pass-through. The latter costs can be based on actual costs incurred, an agreed index capturing inflationary trends and an associated formula for calculation.

(g) Contract Changes. Any of the above contracts could be modified during the course of execution as agreed to the mutual interests of the parties. However, contract changes are generally disruptive and costly and should be avoided.

(h) Government Dockyard Sourcing. In this case there may not be an actual contract, but rather a work agreement/work request/work order. Arguably, in this case, the cost to the government may be the lowest. That is, if you consider that the workforce is already in place to respond to emergent fleet requirements for industrial services, there are inevitably peaks and valleys in the workload. In this case, an order to build a new ship could smooth out the government dockyard workload at an incremental cost that may be substantially less than contracting with private industry for the new ship. Some nations have also used the government dockyard sourcing method for lead ship construction in times where the commercial workload was sufficient to carry the private yards.

(5) Tenders. As used here, the term "Tenders" applies to the process of solicitation, bidding, and contract award for a ship, i.e., sole-source versus competitive acquisition strategy. Some options for tendering are delineated below.

(a) Single Source (Sole Source) Tender. Only one contractor is involved. In this case the contract price is determined by the prevailing limitations of the nation regarding profits, the actual scope of work and the historical cost correlation for similar work in the past. The contract type is a primary vehicle to control costs and provides incentive to the contractor to provide a quality product at a fair and cost-effective price.

(b) Competition. There must be more than one contractor available and willing to do the work and, preferably, on a sustained basis so that the competition is there for subsequent buys, i.e., the losing contractor is still there for future tenders. Generally, for competition to be effective the following conditions apply:

- the order must be substantial in terms of quantities of ships, system components and equipment,
- there must be a sufficient industrial vendor base that is genuinely capable of fulfilling the required orders,
- unsuccessful bidders must have sufficient alternative work to sustain them until follow-on orders are made, and
- the buyer, the government, must be able to define the product (e.g., ship) in sufficient detail so as to be considered producible by the competitors.

(c) Prime Contractor. Some nations have successfully utilized a prime contractor concept wherein the government contracts with one main contractor, the prime, and provides sufficient instructions regarding the type and scope of sub-contracts by the prime. In this case, considerable competition leverage may be gained at the second and third tier of vendors. This method could contribute to the risk mitigation of the government by placing responsibility on the prime. It could also alleviate the necessity for the government to retain a large acquisition oversight workforce and may contribute to regional workforce employment objectives.

(6) Sub-Contracts: The government controls the shipbuilder through the contract requirements, specifications and contract incentives. Generally, the shipbuilder controls his sub-contractors without interference by the government. However, the selection of equipment by the shipbuilder affects not only the acquisition cost of the ship but also the

life-cycle costs of the ship. Therefore, the government must be careful to apply contract provisions which address:

- the cost of new spares (or new range of spares)
- the cost of training units and operators,
- the cost of producing handbooks and documentation,
- component/equipment interchangeability between ships, and
- spares sustainability.

d. Competition in Contracting vice National Concerns. Regarding competition for military work, questions which a nation must keep in mind are:

- whether to exploit competition?
- whether to rely on a single contracting method?
- whether to utilize a policy of multiple contracting types?

Some considerations relevant to these questions are delineated below

(1) Policies. Military contracting is a national responsibility wherein procedures, policies and experiences vary widely from nation to nation. The effectiveness and efficiency of contracting in the sense of cost reduction may, however, be hampered by:

- national policy and/or sociopolitical actions, and
- national and international legal requirements as well as national buying practices.

(2) Contracting. The essence of contracting is:

- to establish legal agreement between the parties on the work or services to be performed, including the terms and conditions,
- to maximize leverage from competition and contract incentives,
- to carefully select the contract type with appropriate consideration of risk,
- to maximize the benefits of learning, and
- avoiding contract changes which increase costs.

(3) Cost Risk. The main objective of contracting in the context of cost reduction is how to arrange for a financial risk sharing between the navy (or governmental contracting agency) and the producer (shipyard, coordinating management agency, etc.). Regarding risk sharing and related consequences for contracting, there is no single answer because of the complexity of factors involved. Risks may vary considerably with the kind of project to be contracted

and with national practices, procedures and the complicated legal issues. Consequently, a very differentiated approach to this question is dictated. This will generally lead to specific solutions for particular cases, e.g., a standard single contract with certain changeable clauses commensurate with the risk involved.

(4) Limitations and Ramifications. Competitive bidding is a promising approach to save costs, at least from the user's (navy) point of view. It has become even more attractive in the EU after implementation of the Maastricht treaties. However, potential medium term savings could be offset by severe long-term penalties. Relentless competition is the most successful means to eliminate rivals. In times of limited investment resources for armament production, many able firms with considerable know how -- which takes days to destroy but many years, if ever, to restore -- would have to quit, thus narrowing or endangering the national industrial base and favoring establishment of monopolies. This possibility underscores the limitations and consequences of competitive bidding/contracting as the single policy for contracting.

(5) Sociopolitical Concerns. National or regional interests and political considerations (economy, labor, social, and defense) will determine how much real competition is acceptable and wanted. Prior to permitting an annihilation of competitors for some questionable short term savings, it is necessary to determine - both nationally and internationally via consultation and cooperation - how much national or allied (in the case of the EU, how much European) industrial base is necessary to support the common defense needs and how can it be developed to the benefit of all.

e. Commonality. (See also, Chapters C and E)

(1) Key to Long-Term Affordability. Considerations on ship cost reductions require an overall approach, looking at the ship as a system in the entirety of its life cycle. Cost savings that are sought after are thus related to design, acquisition, construction, operations and support. Commonality in this sense refers to a synergistic combination of the three elements "modularization", "equipment standardization", and "process simplification" and is therefore one of the keys to long-term naval ship affordability.

(2) Philosophy. The general philosophy of commonality is that naval ships will be designed and built, using common modules, comprised of standard components. The individual modules will be used across ship types/classes. Dominating features are standardization of equipment at as many levels as possible, distributed system architecture and a generic construction strategy. A potential benefit of using common modules and standard components is an increase in outfitting efficiency due to the shifting of more work to an "in-shop"

or "in-shop-like" environment.

(3) Modularization. "Modularization" involves the assembly of components or equipment into larger subassemblies to enhance production and life-cycle efficiency. These modules may offer improvements for space arrangements, shock mounting and noise isolation as well. Cost reduction benefits attributed to modularization include:

- flexibility in using basic building blocks during ship construction, e.g., standard modules and standard module interfaces;
- ease of design integration (into overall ship design);
- flexibility for maintenance and upgrade; ease of removal and installation;
- better defined contractual boundaries;
- broadening of competition for work grouped as a package;
- broader base for builder make or buy decisions;
- increased pre-outfitting and associated efficiency;
- reduced construction time;
- interchangeable elements;
- flexibility to introduce new technology (mid-life conversion/ growth potential); and
- reusable design across ship classes.

(4) Equipment Standardization. "Equipment standardization" is aimed at reducing the number of different items required to support ship ownership (operation and support) with the attendant benefits of reduced requirements for parts inventory, documentation, warehousing and materiel control; e.g., infrastructure streamlining and efficiency. Cost reduction benefits accrue from the following aspects of equipment standardization:

- wide application of fewer equipment and component part designs;
- less variation in performance prediction and physical characteristics;
- fewer customized parts and greater potential for application of commercial items;
- smaller spare parts population;
- less training, fewer courses and schools;
- improved interface control;
- improved configuration control;
- simplified maintenance infrastructure; and
- improved cost estimating, budgeting and procurement for fleet maintenance.

(5) Process Simplification. "Process simplification" portends the cost benefits of the implementation of strategies, policies and procedures to enable:

- streamlined military specifications, contract specifications and standards;
- standard designs for equipment modules and components;
- increased quantity procurement, e.g., at the fleet level or on international (alliance/coalitions) level;
- reduction in the number of equipment's requiring support;
- more efficient assembly of major components and ship systems;
- a parallel process for equipment assembly and test;
- ease of maintenance and modernization;
- increased use of digital data across disciplines and boundaries of engineering; and
- common ship construction approaches.

(6) National Experiences. The concept, based on the three elements discussed above, requires that a ship be designed for efficiency in the production process, and simplicity and flexibility in the operation/support phase of ship ownership. Some national approaches to commonality are already far beyond an experimental stage and have revealed promising results, e.g., Danish STANFLEX 300/3000 concept and German MEKO/FES. The German MEKO/FES cites cost savings of 5% in acquisition and 10% in life cycle, compared to conventionally built ships, based on the literature survey of reference (a). The French Navy in the use of modularity applied to propulsion plants of surface ships cites acquisition cost savings of 25%, based on the literature survey of reference (a), compared to conventional practices, achieved although some additional costs were incurred. The additional costs were due to greater technical effort and accelerated component buying but were less than 5% compared to conventional practices.

(7) Approach to Commonality. Realization of commonality is a long-term venture, very complex in nature, including processes, as well as procedures, hardware, software and a change of mind towards the philosophy of warship design and construction. Hence a broad national and international consultation and cooperation is a must. The key to achievement of the objectives of commonality, namely significant LCC reduction of modern warships and an affordable fleet, is a structured incremental approach with steps to:

(a) develop and demonstrate cost-effective commonality-oriented practices including ship architectures, common modules and build strategies;

(b) develop the process from concept to implementation (define specifications; develop, evaluate and test prototype; establish configuration control); and

(c) determine the acquisition strategy for module and commonality-based ship acquisition, ship class implementation, and fleet support.

Sub-tasks related to the realization of commonality are:

- the determination of the ship architectural fit for common modules,
- development of prototype modules,
- the quantification of cost benefits resulting from modularization, and
- configuration management of the modules.

Candidates to broaden the base of commonality include, *inter alia*, the following areas:

- simplified ship specifications,
- hull designs, hull sections,
- accommodation and habitability spaces,
- machinery and ship service systems (propulsion, electrical power generation/distribution, ventilation, fire fighting, damage control, auxiliary systems),
- combat systems, and
- command, control, communications, and computers.

f. Common Procurement/Purchases. Common procurement/purchases are related to ships and equipment with the aim of reducing individual unit costs through increasing the quantity of potential customers. The main question is how and where to find additional opportunities or partners. Some arguments have already been raised in context with this topic that the application of commercial standards, especially for equipment, may offer a broader basis for common procurement. Some possible partners or opportunities for common procurement/purchases are:

- another class of ship,
- another navy,
- another service, and
- a commercial user/customer (i.e., "dual-use" (military/commercial).

This common procurement/purchases approach requires thorough analyses and coordination. In some cases it may be easy to identify partners based on the same or comparable needs. In other cases it may be necessary to coordinate these needs on a common time axis, taking also into consideration national and international industrial, economic, and political constraints. Broadening the market for additional customers may well mean higher investments for interface design, development and management, which must be balanced against the expected benefits of producing larger quantities at lower costs. Notwithstanding the difficulty of implementation, the concept of common procurement/purchases offers an interesting and challenging area of possible cost reduction and should be taken into consideration at very early stages of the armament planning process.

g. International Cooperative Opportunities.

(1) Design and Development. Design and development and other nonrecurring cost items of complex weapon systems are extremely expensive and often unaffordable by a single nation. Hence international design pools are being formed. The benefits are considerable despite additional overhead costs that result from activities necessary to mutually interface between nations.

(2) Production. The potential benefits of international cooperation are also significant for production, since the “series” effect can be used to advantage if nations distribute production components efficiently. Applied to shipbuilding, this could mean that one yard produces forward sections, a second aft sections and a third could assemble the hull and do the outfitting -- as it was demonstrated in the European airbus production. Another method, referred to as "split series" production, might assign the complete hulls in the series to different yards, e.g., first to one yard, second to another and third to still another. Recent German naval procurement experiences have demonstrated the economic benefits of split series production among national yards, although additional costs for management, transportation and quality assurance were incurred.

(3) Operations and Support. International cooperation can also help reduce the costs of operations, support, training and logistics elements of life-cycle costs. Here too, nonrecurring costs can be shared and the potential exists for economic benefit from series production of larger quantities (lots, batches) of hardware and associated documentation as previous program examples like Tornado, HAWK/IHAWK missiles, howitzers and anti-tank missiles have demonstrated.

(4) NATO Alliance Experiences. International cooperation is a first step towards standardization in armament planning and procurement within the NATO alliance, a goal that still has not reached its full potential. It offers great opportunities in all phases of the life cycle of modern naval ships, but its realization too often fails due to complex national interests involved and lack of political will. Nonetheless, the merits of international cooperation have been proven in many naval programs, e.g., the GE/US rolling airframe missile, the BE/FR/NL "Tripartite" mine hunter.

In the area of training and operations, an example of international cooperation is the Belgian-Dutch mine warfare school at Ostend, which is also utilized by other NATO navies, and recently an agreement was reached for the operational integration of the Belgian-Dutch surface fleets into one command. Additionally, there are various NATO schools. In addition to promoting inter-operability, these ventures are significant steps in reducing the manpower, maintenance, operations and infrastructure costs of the participating nations.

h. Budgeting and Funding.

(1) Government Process. On one hand, government spending of most of NATO nations is usually approved on a yearly basis; on the other hand, contracts for military programs of a significant size extend, quite often, over a period of ten years or more. Budgeting is the process by which the program manager and higher authorities make funds available in terms of annual and multi-year contract authorizations and payments. Program progress is also reported, usually on a yearly basis as a minimum. This process has to follow national regulations. The cost of the budgeting process itself, if smoothly and successfully conducted over the program life span, has no impact on program costs (its cost in time and effort is not a significant portion of program costs and, in any case, though it may be controlled, to some extent it is unavoidable).

(2) Contingent Planning for Budget/Funding. Difficulties arise when defense yearly budgets are subjected to cuts against previous plans and have to be reflected in the programs through schedule delay, batch order shortening or both. Schedule lengthening inevitably leads to an increase in ship costs because some costs are directly proportional to time, e.g., management, and both the main contract and subcontracts may have to be amended, or the contractor may have to seek intermediate financing from banking institutions, with interest rates possibly in excess of the annual inflation rate. The situation may be worsened during production if appropriate clauses have not been included in procurement contracts, possibly resulting in legal suits. It is important to include such clauses although they may have a negative effect on the government negotiation strength and hence the contract prices.

4. Risk Mitigation (Also, see Chapter G)

a. Cost Management. Due to the potential for programmatic and cost risk in a ship acquisition program, it is imperative that effective design and cost management techniques are utilized early on and throughout the process. This requires a disciplined approach affording systematic analysis and timely feedback mechanisms that provide visibility into all areas of the process which can affect cost, schedule and operational requirements. The management process is complex and involves a large number of disciplines: acquisition policy, legal and regulatory requirements, engineering, design, cost estimating, budgeting, contracting, production planning and oversight, logistics and infrastructure requirements, testing, training, personnel, etc. The central responsibility in the management process generally rests with the individual in the government acquisition and support office referred to as the program manager or project manager.

b. Programmatic Risk. Types of programmatic risk fall broadly into the following categories, technical, program, schedule and cost. Technical risk refers to such areas as: technology not available in time to support the program schedule (e.g., software); government furnished drawings, specifications or information is incorrect or is provided late to the builder; the detail design of the ship contains flaws such as interference's between piping, wire-way or component locations; interfaces are incompatible between the ship platform subsystems/components and the payload/combat systems to be installed, thus necessitating rework or work-around solutions, or waiver approvals. Additionally, technical risk can be of the nature of an operational deficiency, for example, insufficient service life margin allowance. Program risk refers to risk of increased costs due to the impact of: changing requirements, changes in the market place (industrial base problems, supplier problems, unanticipated inflationary costs, construction worker strikes or labor union problems, union wage agreements), inclement weather, changes in the law or regulations, acts of God, et cetera. Schedule risk refers to slippage in the planned design and construction schedule due to any of the aforementioned risk variables. Cost risk refers to risk in the budgetary cost estimate associated with any of the aforementioned risk variables.

c. Program Management. The program manager must employ sophisticated management techniques in order to stay abreast of the programmatic risks and take the necessary corrective action. Types of tools employed include, *inter alia*, program decision milestones, program baseline documentation (objectives and thresholds), design configuration management, design tradeoff analysis, computer-aided design, computer-aided manufacturing, project work breakdown structures, contract change control, periodic program reviews, contract cost and schedule control (earned value management, contractor performance reports, cost and schedule status reports, funds status reports), affordability assessments, and multiple and flexible contracting methods.

d. Risk Mitigation Tools. In order to manage risk, the program manager may utilize a number of risk mitigation tools. Some of these are listed as follows:

- Selection of appropriate contract type, e.g., cost plus, firm fixed price, fixed price incentive, etc.;
- Build a little, test a little (gradual technology insertion as it matures);
- Pre-planned product improvement (anticipate state-of-the-art

technological improvements);

- Reserve space, weight, power and cooling capacity in the ship design for later (post-delivery) installation of equipment;
- Design Budget (provides a reservation in the design and construction schedule to accommodate the latest possible entry point, prior to ship delivery, for an item to capture the latest state-of-the-art technology);
- Block upgrade (collection of design changes for insertion into the program as a group at an opportune time, e.g., to be included in the next new contract);
- Economic adjustment contract clauses (to provide for inflationary changes, contract pass-through for certain cost elements subject to volatile price changes or changes beyond the contractor's control, e.g., energy, social security;
- Value engineering;
- Design-to-Cost, e.g., establish cost goal to be designed to, design budgeting;
- Comparative cost analysis of design alternatives, e.g., cost and operational effectiveness analysis;
- Cost-conscious design process, e.g., design for production;
- Standardization of components, equipment, subassemblies and processes;
- Group technology (matching classes of problems to sets of solutions);
- Design margin allowances (in anticipation of prediction errors, load or demand uncertainties, equipment obsolescence, and future space, weight, power and cooling requirements as well as wear and tear or degradation of ship subsystems during the In-Service phase; and
- Financial reserves.

5. Military Practices Compared to Commercial Practices (Also, see Chapters A and C)

The progressive military process, such as PAPs or the respective national military acquisition processes, is logical, systematic and extensive. But this exacts a price in time and cost on ship programs (usually more than ten years from the beginning to the first-of-class ship delivery). By comparison, commercial practices are short and simple: the future ship owner will issue competitively, a specification that is usually very simple and very short (commercial ships generally have simple functions and performance criteria). Shipyards will propose priced design offers that will serve as the technical specification of the ship to be built -- a detailed specification describing the different equipment, principal dimensions, guaranteed performances (speed, fuel consumption, usable load), principal plans, suppliers list to be consulted, and list of deliverables to be provided by the future ship owner. After contract award, the detailed design and construction period will rarely exceed two and a half years for the lead ship. Also, there are almost no logistics deliverables -- only the "as-built" plans, the standard documentation of the equipment suppliers, and very limited, "commercial-like" on-board spare parts. Commercial ship operators sometimes require one spare propeller or possibly just a single propeller blade, which is often the largest on-board spare to be provided. Compared to the military approach, the engineering and work preparation efforts for commercial practices applied in ship acquisition are very low.

6. Reduction in Contractor Data Requirements

a. Data Requirements. Military ship data requirements consist of a long list of topics concerning: material specifications, safety, product integrity, product quality, product (quality) assurance, item test and design verification, process verification, inspection systems, quality control, logistics support, management oversight, audit, documentation, contractor cost and schedule performance visibility, and contractor cost reporting. The reduction in contractor data requirements is a possible way of reducing the contract price and hence the cost of acquiring ships. However, in reducing the data requirements, a number of things must be taken into account including the safety of the ship and its operating personnel, the cost of ownership of the ship and associated logistics support, and the lack of visibility into management and budget issues.

b. Military Specifications. To a large degree, the data requirements of a contract are tied to the requirement of a military specification for an end item. As such, the need for data may be dictated by the need for the military specification. Usually the amount of documentation for an item procured to a military specification exceeds that of the same item procured to a commercial specification. Thus, to the extent that the military procurement can emulate commercial procurement practices, data costs can be reduced. The sheer number of pages of documentation for military specification procurement can exceed that of commercial procurement by ten or more times. To ensure the opportunity for cost reduction, the ship designer should attempt to avoid specification of requirements that unnecessarily preclude the use of commercial practices.

c. Standard Designs and Common Components. The use of standard designs and common components in ships can reduce the need for contractor data requirements. For example, in cases where the data has already been acquired for a prior procurement, the opportunity may exist to avoid additional data costs where there is no value added. This will also reduce the cost of maintenance of the associated data library by reducing the number of design items that must be supported. The use of non-military standards may further provide the opportunity for reduced data requirements and hence reduced costs.

d. Data Transmission Medium. The medium chosen for the transmission of the data may also affect costs. For example, electronic data transmission may reduce the cost of getting and maintaining data as well as providing a more effective means of retrieval of the data for later use. Electronic data transmission also offers the advantage of one-time data entry and near real-time data updates. There are, of course, many considerations associated with electronic data transmission which must be carefully worked out, e.g., common databases, standard data exchange formats, control of the data, safeguards against data corruption, et cetera.

e. Type of Contract. The type of contract selected may affect data costs. For instance, when entering into a firm-fixed-price contract, the government may forego the requirement for any cost performance reporting. Even where cost performance reporting is required, the reporting frequency, formats, variance thresholds, etc. should be continuously examined for the opportunity to reduce the inherent cost burden by only requiring that which is essential or necessary to the efficient management of the contract or to that which is substantially significant to the planning of future program acquisitions.

f. Need for Documentation. Excessive documentation requirements should be eliminated to reduce costs. Often a repeat procurement is made without a full review of the continued need for documentation or, technical data item managers may require that data be provided by a contractor without regard to its cost versus its value added. If the documentation is already available, costs may be avoided by not procuring it again. Likewise, if the cost of the data exceeds its value to the respective government, it may not be wise to require it. Therefore, data requirements should be continually reviewed for necessity, utility and value to the government. Notice, however, that the emphasis is on "value to the government" as sometimes the need for data is evaluated on the basis of its necessity to the current program only rather than considering the broader view of the value of the data to future programs or to the corporate requirements of the government.

7. Summary

To minimize the costs of ships, the project manager must:

- maximize quantities, batch sizes and production rate;
- maximize leverage from competition and contract incentives;
- carefully select the contract type with appropriate consideration of risk;
- maximize use of learning curve by limiting the design baseline changes, maximizing standard parts utilization, and minimizing the number of different parts in the life-cycle maintenance inventory;
- refrain from over specification, e.g., utilize commercial off-the-shelf versus military design where possible; and
- avoid contract changes.

The project manager will be constrained by:

- the need to meet operational requirements (which may dictate new and developmental features);
- the need to meet design responsibility (cannot compromise essential military requirements, personnel safety, etc.);
- legal requirements of the nation and international community as well as national buying practices;
- the capabilities and scope of the industry; and
- national policies and sociopolitical actions or requirements.

CHAPTER E

PRODUCTION

1. Introduction

a. Industry Motivation and Productivity. This chapter focuses on the industrial effort as it relates to ship acquisition and associated costs. Sustaining an adequate business volume and profit margin is the real motivation of industry, including shipyards. This basic motivation directly affects the productivity and efficiency of the production process. Cuts in naval defense budgets increase the need for improved productivity in the supporting industry to reduce the construction time and final cost of ships.

b. The Production System. Productivity is one of the key elements of an efficient production system. Any action or measure taken in one or more of the elements of such a system will induce effects, not only in the final product and its cost, but also in each of the other components of the system. Additionally, other external factors (technologies, regulations, etc.) have a direct effect on costs and affect how a product is manufactured, and distributed in the marketplace.

A production system consists of the following elements:

- engineering and design,
- planning, estimating and scheduling,
- production,
- logistics,
- purchasing,
- maintenance,
- process feedback, and
- management and control (cost, schedule and quality).

These elements interact synergistically in each other’s functional domain. Thus, improvement in productivity must take into account the impact of actions throughout the complete system as well as its component elements.

2. Industrial Approach

a. Industrial Strategy. From a market point of view, a manufacturing or construction firm's industrial strategy is its plan to obtain business and return a profit on a sustained basis. For shipyards and supporting vendors, the industrial strategy may be analyzed on the basis of a series of categories:

- production quantities,

- facilities and capital involved,
- schedule requirements,
- technologies employed,
- human resources required,
- quality level to be provided,
- management systems (and associated technologies) available, and
- organizational requirements.

b. New Industrial Technologies. New technologies impact directly on the choice of strategy to be chosen by a contractor. On one hand, choosing the correct strategy can result in the attainment of a privileged competitive position; on the other hand, to select the wrong strategy can lead to failure or even collapse.

New industrial technologies lead to new manufacturing processes, often very different from the traditional ones. Classic principles, which are now giving way to new techniques, are:

- enhancement of manpower performance by means of specialization,
- economy-of-scale by means of integration and concentration,
- functional organization of production processes,
- optimization by means of recurring production,
- control measures by individuals, and
- process engineering.

New techniques gaining in prominence are:

- information technology (electronic media leveraging),
- multi-functional, flexible and cooperative work approaches,
- specialized manufacturing plants -- by product (e.g., sub-plants),
- stock reduction (just-in-time material receipt),
- Integrated Product and Process Development (IPPD) teams,
- control by work team, group or area, and
- continuous process improvement.

These new principles are resulting a new way of designing, producing and distributing products. The aim of these principles is to globally increase the productivity of the industrial resources by reducing the design and manufacturing time and by orienting the engineering and design effort to facilitate production. The goal is productivity improvement, including the support activities, with a vision toward the overall system efficiency and economy.

c. Product Quality. In its broadest sense (including quality in designing, manufacturing, services, after-sales maintenance, etc.), product quality is the strong-arm for competitiveness. Therefore, the concept of total quality must be understood and implemented from the lowest control points up to the strategic objective established for all the components of the industrial organization. Simply stated, this approach employs continuous process feedback throughout all levels of the organization with employee empowerment to provide such feedback in the interest of achieving maximum production efficiency and ensuring the required product quality. Statistical process control is also an effective means of obtaining feedback and monitoring the process to determine the need for corrective action.

3. Industrial Processes and Productivity

a. Process Simplification. The first step in the course of improving the productivity is to simplify all industrial processes. From the materials flow to the design of jigs and tools, from the selection of equipment to production engineering, the trend is toward simplification in manufacturing and construction techniques. And in order to improve industrial efficiency, sophisticated methods are to be avoided that incorporate unnecessary risks and potential for production errors.

b. Process Advances. The naval shipbuilding industrial sector has traditionally been one of the more conservative sectors to adopt new practices. For example, the traditional mounting of all structural components, until recently, was carried out only in the yard slipway or dry dock (one by one) and essentially all outfitting was performed after the ship was afloat. However, in the last two decades of the twentieth century, as computerized technologies were incorporated in design and production processes, construction methods have evolved drastically toward those used in the aircraft industry. Modern shipbuilding techniques have evolved in the following areas:

(1) Increased Prefabrication. The majority of structural work is now carried out in workshops. The ship is divided into major hull blocks that are prefabricated in the workshop or a shop-like environment and are later transported to the slipway and joined together.

(2) Increased Pre-outfitting. Hull blocks are now outfitted with the various components and hardware elements that are to be mounted in them prior to movement to the slipway. The majority of hull outfitting is accomplished in this manner to take advantage of the easier access, down-hand welding, less congestion and less competition for the supporting services (electricity, air, welding, rigging, crane, etc.) required by the trades.

(3) Product-Oriented Design and Construction (PODAC) or Integrated Design and Production. Modern methods of ship construction employ PODAC techniques. Ships are designed to a product orientation keeping in mind how the ship will be fabricated and constructed. Hull construction, outfitting, insulating and painting progress simultaneously. The ship is

divided geographically into "interim" products. These interim products are standardized, as far as practicable, and fabricated by groups. This "group" technology takes advantage of the maximization of similar work through common workstations and tends to group work together according to common attributes. To the maximum extent, construction is modular and carried out in workshops. The assembly of the ship is then made on hull blocks. The hull-blocks are joined together and the ship is launched or put afloat with a high (70% or greater) degree of completion.

4. Integrated Design and Production

Integrated design and production or PODAC, as mentioned above, involves more effort and cost in the up-front engineering and planning efforts but the downstream savings in manufacturing result in an overall acquisition cost savings estimated to be in the range of 10 to 15 %. PODAC is an integration of the design, purchasing, production, logistic and management functions and is characterized by the following attributes.

a. Pre-defined Build Strategy. Definition of a construction strategy (or build strategy) to:

- enhance the liaison among the functional areas of design, procurement, planning, production, and industrial services;
- provide coherent planning of drawings, materials, equipment, tasks and facilities;
- ease the control and tracking of the construction work;
- improve productivity;
- reduce the construction cycle (construction period length); and
- improve the quality of the product.

b. Product Work Breakdown Structure (PWBS). Definition of the ship as a set of interim products:

- hull-blocks,
- sub-blocks,
- bulkheads, decks, sub-assemblies, and
- modules (such as workshops, equipment modules, piping, living quarters, berthing, sanitary spaces, etc.).

c. Leveraging Commonality. (See also, Chapters C and D) Standardization and organization of products and processes to be able to fabricate or perform them by groups:

- standard components,
- standard modules, and
- grouping of common or similar work for common process lanes (leveraging repeatable processes or activities).

The organization of alike work in this manner is referred to as “Group Technology”, based on the literature survey of reference (a). “Group Technology” is an effective means for the organization of alike work by looking for manufacturing commonality, matching classes of problems to sets of solutions, and ignoring differences in design details; interim products (parts, subassemblies, and assemblies required to build ships) are grouped by the problems inherent in their manufacture. Ship designers are guided by the product-engineered build strategy in so grouping the information. The build strategy, in this context, is imposed at an early design phase, ideally prior to the development of the design on which the industrial contract is to be based.

d. Aligning Work to Most Efficient Environment. Shifting to a factory-like work environment:

- maximizing the amount of work (production activities) in workshops, and
- orienting work for the easiest position for performance of the fabrication and manufacturing processes.

e. Summary. The integrated design and production concept developed for commercial use enables the shipbuilder (if applied for naval ships) to also shift many tasks, normally accomplished onboard or at the slip-ways to workshops or to a more productive work environment off-board the ship (i.e., pre-outfitting). Work onboard is considerably reduced. The effect is to significantly increase productivity and product quality. Additionally, since module pre-fabrication and hull-block pre-outfitting are carried out simultaneously, the ship’s construction period is shortened overall. Experience in commercial shipbuilding shows that total work progress of 80% at ship launching is achievable.

5. Learning Curve Maximization

a. Background. The learning effect in the various activities associated with the manufacturing of products is an established phenomenon. The first attempts to describe the effect find their origin in World War II in the production of airframes for fighter planes. In principle, learning is the effect which describes the fact that the repetitive nature of certain activities (e.g., the direct labor involved in producing an item) tends to reduce the necessary amount (cost) of that activity to produce the same item in succeeding instances. This is reflected in the direct labor time spent (labor learning) as well as in the production strategy used (organizational learning).

Generally, the learning effect will be more noticeable for labor-intensive ways of production than for machine-dominated ways of production. For example, a learning effect of only 10% might be achieved where the direct labor content is 25% (in terms of cost) in the production of a product, but up to 20% might be achieved in an instance where the direct labor content is 75%.

In naval shipbuilding, direct labor learning effects of between 90% and 95% can be routinely expected on a total ship construction basis. Depending on the method of production of the shipyard and the number of similar ships to be built, even greater learning can be achieved. Learning rates in the 80-90% range are not uncommon.

The total effect of learning can be divided in four parts:

(1) gaining experience with the product and the production team,
(2) gaining experience with the method of production,
(3) quantity effects of producing a large number of serialized products with the same method (in fact, the theoretical learning-effect), and
(4) the maturity of the design of the product as the project progresses.

Very often it is assumed that the learning-effect "just happens". However, with small series production quantities, as in shipbuilding, careful and dedicated management is necessary to get the maximum effect.

b. Theory of the Learning Effect (Parameter Calculation). The learning effect is not a specific number that relates just to production labor; it is also related to the type of product and the way it is produced. Therefore, more attention is being given to the determination of learning (from production statistics) by product type. In theory, learning curve is based on the assumption that the amount of labor needed to produce a quantity of item decreases by a fixed percentage each time the number of items produced doubles.

Mathematically this relation is expressed as:

Y = a * (X) ^b, where

Y	=	Average time to produce X units
a	=	time required to produce the first unit
X	=	Number of units produced
b	=	the measure (%) of learning

If plotted on a logarithmic scale, the relation between X and Y is a straight line, where the (negative) gradient is a measure of the amount of learning experienced.

c. The Application of the Learning Effect. Experience curve benefits (learning) are not always automatic. The learning effect does not just happen to you. It often requires management initiative or stimulus. Its effects need to be recognized and carefully incorporated in the planning and management of the production of a product. Only through this process, can the full benefits of learning be realized. Further, the larger the impact of the production effort on the future investment of labor, funding, marketing, etc., the more management must invest its effort in the project to be certain that the benefits are realized. This is particularly important in naval shipbuilding where serialized lots generally run in small quantities. Management still wants the full benefit of learning in production even though ship production runs of up to forty units do not approach the size of production runs experienced with aircraft or missiles or many commercial products. The cost savings are still significant.

A mitigating effect on learning is also experienced when changes are introduced into production runs; e.g., an intermediate redesign is performed and incorporated. This process, common in serial production of navy ships, is necessary to keep pace with ongoing technological innovations. It further reduces the size of the production run of identical ships. Thus, shipbuilders cannot base their learning curve projections on as large a series of ships as originally planned. Therefore, shipyards must seek to maximize the benefits from learning in the early phases following the insertion of such technology innovations.

History has proved that a strategy based on a dedication to getting the full benefit from learning can be stifling to innovation, may force volume increases, and may leave the producer and customer with an obsolete product. Therefore, management must be attuned to this fact. Innovation should always be considered important from a management point of view, as well as the avoidance of product obsolescence. However, from a production efficiency and learning curve maximization point of view, the following methods may result in cost savings.

<u>Increased Standardization</u> - less changes and fewer unique parts will allow lower margins and a larger production volume; production processes can be more effectively optimized to take advantage of major reductions in costs that result from the repeating of process activities.

<u>Production Technology Application</u> - advanced or modern production sequencing and process lanes are more adapted while leaving room for specialization.

<u>Decreased Production Supervision</u> - direct supervision is becoming of lesser importance as responsibility is delegated to specialists in production.

<u>Economy-of-Scale</u> - like items (equipment, components, parts) should be aggregated so that the full benefit of economy-of-scale can be obtained.

<u>Material Purchasing</u> - material procurement should be optimized for the most efficient sources.

<u>Flexible Workforce</u> - specialization at the worker level may maximize learning effects;

however, product quality must be monitored; alternatively, job-rotation could improve job satisfaction and result in a better product.

6. Summary

a. Industrial Sector Motivation. A sustained and adequate business volume and profit margin are basic motivators of the industrial sector. Continuous productivity improvement is a key element for industrial success and cost reduction. New technologies and techniques are essential ingredients to productivity improvement.

b. Integrated Design and Production.

(1) Product-Oriented Design and Construction. The concept of product-oriented design and construction is a break from the traditional sequence of executing shipbuilding and related tasks, implying that design must, to an extent, be subordinated to the construction method.

(2) Optimizing Human Resource Performance. As the use of shipbuilding resources is more flexible, integrated design and production optimizes the performance of human resources. It gives the workers an integral vision of the product, makes them responsible in the context of the shipbuilding process as a whole, and gives them more autonomy -- thus stimulating initiatives, cooperation and creativity. It improves working conditions, communication and human relations, again resulting in an increase in productivity.

(3) Organizational Flexibility. One of the main advantages of the integrated design and production method is that it inserts flexibility into the organization of the shipyard. The flow of information is more dynamic as it is mainly horizontal and almost in real time. As the organization becomes more flexible, integrated design and production mobilizes the internal labor market and eliminates the borders between trades, breaking undesirable cultural habits.

(4) Expected Cost Savings. Integrated design and production methods have a price in terms of increased engineering and planning efforts required up-front in the process. However, as the methods demand a more precise technical definition of the product, the actual computer-aided systems for designing and manufacturing, together with advanced product-oriented ship construction techniques, permit an overall acquisition cost reduction estimated to be in the range of 10 to 15 %.

c. Learning Phenomenon. As a management tool, the learning phenomenon can be expected to occur in a project, and therefore be "planned" to happen by management. It takes into account the effect of human labor and innovation. It should become part of the management strategy for the development of cost-efficient production. Its effects can be evaluated for expected performance versus actual results. However, the benefits of learning are not always automatic and often require management initiative or stimulus; for example, through a policy of increased use of standardization but only to the extent that innovation and creativity are not stifled.

CHAPTER F

OPERATIONS AND SUPPORT

1. Introduction

This chapter addresses all costs of the In-Service phase. These costs are defined and described in reference (b), ANEP-41, which provides the NATO framework and definitions of the associated cost categories. These categories indicate the wide spectrum of potential cost drivers and hence areas for cost savings and are listed below:

- Personnel (pay and allowances for personnel assigned to the ship);
- Consumables (petroleum, oil, lubricants, spare parts, stores and equipage);
- Direct Maintenance (depot, intermediate maintenance activities, basic overhaul, mid-life modernization and component repair);
- Sustaining Investment (replenishment spares, modification and refit programs, software support and support equipment);
- Other Direct Costs (engineering and technical services, update publications and documentation, second destination transportation, leasing and storage, trainers/simulators, charter/harbor fees, rents and utilities, operation of helicopters, handling of government owned stores; and
- Indirect Costs (personnel acquisition and training, training facilities, platform and payload land-based test sites, support personnel for bases, depots, medical facilities, support installation infrastructure, headquarters and other command facilities, transportation and logistics supply - supply ships for replenishment of fuel, stores, POL, ammunition, etc.)

2. Operations and Support Costs

The term "Operations and Support" (O&S) costs as used herein refers synonymously to the In-Service phase costs listed above. O&S costs vary from ship type to ship type and according to the operational scenario. O&S costs form a major portion of ship program costs and may comprise 60-80% the total life cycle cost of naval ships. This fact should be borne in mind through all phases of a ship program, starting with the formulation of the mission needs and then transforming these requirements into ship capabilities. In essence, a major part of the O&S requirements and related cost are already determined at the beginning of a program, e.g., with the "Mission Need Document (MND)", which is the starting point and baseline of all following phases and tasks. Since the life span of a ship is very long (thirty years is not uncommon) and may vary by ship class, O&S costs are often considered on a cost per ship per year basis for practicality. However, when performing a cost-benefit analysis, care should be taken to determine the actual (or representative) in-service cost profile (based on industrial maintenance periods and operational profile of the ship) in order to properly determine the net present value and cost benefit ratio.

3. Operational Deployment Impacts

a. The NATO Alliance. Looking at the O&S cost categories from a operational view suggests a subdivision into three areas:

- Operational Deployment,
- Training (individual, unit and fleet training), and
- Logistic Support.

These category subdivisions are elements of the overall NATO defense planning process. O&S costs related to these areas are very much dependent on national policies, requirements and limitations. Operational deployment of NATO naval forces is based on common doctrines, procedures and standards where inter-operability is of prime importance. Its day-to-day practice and success is reflected in the exercises of the Standing Naval Forces as well as other exercises. However, most of the time during their life, ships remain under national command, following national operational deployment policies and patterns.

b. Cost and Operational Effectiveness. To achieve the maximum effectiveness (both from a mission and a cost point of view) it is obviously important that military ships be deployed (or employed) consistent with the Operational Requirement(s) for which they were designed and outfitted. A ship is usually designed through a project effort that tries to join together high performance with high reliability, for particular operational conditions and missions -- not an easy compromise, especially if economic constraints are applied. Given the affordability constraints, it is ultimately impossible for each ship to tackle all possible mission scenarios with the same reliability and effectiveness.

c. Operational Planning. Improper utilization of ship assets, once delivered to the fleet, could produce the following problems regarding costs:

- waste of those resources invested during the design and building of the ship(s), for the study and for the realization of a ship able to face particular conditions (but afterwards utilized in a different way);
- higher cost for maintenance because the operational scenario is different from that initially planned; and
- higher cost for logistic support (spares) as a consequence of disruption to the maintenance cycle and associated organization.

Therefore, considering the aforementioned concerns, it is imperative that the "real" future activities of the ship(s) are well defined by the Naval Staff.

d. Integrated O&S Planning and Management. Operational deployment, training and logistic support are interdependent. Training and logistic support requirements are derived from the operational deployment policy. Answers to the following questions serve to largely define the operational deployment of a ship:

Under what scenarios, in what areas and how long is the ship to operate?

What will be the operational tempo?

What are the modes of operation and what consequences will they have on technical and operational readiness, availability, operational/training/ maintenance programs and schedules, and support requirements?

What are the skills and experience of the complement?

What are the requirements for individual, unit and fleet training, to achieve and maintain combat readiness? How many sea days are necessary?

These considerations must be taken into account at an early stage of the planning process for a new ship. Ideally, they should be reflected in an integrated O&S plan. This plan should include certain management and organizational aspects:

(1) How to cost-effectively organize operations, training and support.

(2) Life-cycle cost reduction, through technical aspects, by:

- application of automation technologies, e.g., data acquisition, management and use;
- electronic technical manuals and electronic classrooms;
- modularization of sensors/effectors and equipment's;
- use of modeling and simulation for tactical and technical training onboard and ashore; and
- design for reliability, maintainability and availability.

(3) Combining management and technical aspects such as:
- common procurement programs,
- standardization of components,
- common training,
- common logistic support,
- combining national fleet headquarters, and
- international cooperation.

Many of these items are addressed in more depth in the Allied Administrative

Publication Number 20 (AAP-20), reference (c).

4. Ship Types and Missions

O&S costs are unique to the type of ship and the associated mission(s) as illustrated by the following two examples:

a. Surface Combatant/Large Off Shore Patrol Vessels (OPV)

- long and isolated missions,
- numerous and skilled crew to perform second and third level maintenance,
- spacious workshop areas, and
- large areas devoted to spare parts storage.

b. Patrol Craft

- short missions,
- small crew tasked only for operational managing of the ship, and
- no areas devoted to workshops and limited areas devoted to spare parts storage (provided by shore facilities at the end of short at sea periods).

5. Maintenance Policy and Techniques

a. Policy. To illustrate the impact of operational policy, two types of maintenance philosophy are highlighted below.

(1) Periodic, Preventive Maintenance. Periodic maintenance activity requiring a long period for industrial availability of the ship in order to perform the work -- 6-12 months or more (mid-life modernization will typically be longer), where major maintenance of the ship and overhaul of all equipment is performed. Maintenance on this basis does not necessarily require that the ship be increased in size to accommodate the overhaul work.

(2) Condition Monitored Maintenance. "On condition maintenance" (governed by condition monitoring or running time) where short work periods are performed, as required to sustain mission capability or as the opportunity arises -- and where all the other equipment-related maintenance is deferred, e.g., overhaul of major items.

In the first area noted, the entire ship will be inoperative for a long period. This will permit the possibility of disassembling all the equipment and components that are usually not well maintained due to space problems. In order to achieve this task, it is not necessary to dedicate a large space allowance for maintenance around these types of equipment -- in the interest of having a smaller ship and possibly less expensive shipbuilding cost. However, it should be noted that a smaller ship does not necessarily connote lower construction costs, as a more densely packed space may be harder or more time consuming to assemble and test.

In the second area of discussion, in order to allow a complete and quick overhaul of each piece of equipment, and without making the ship inoperative, it is necessary to design sufficient maintenance access spaces to allow the easy replacement of the equipment. Obviously a ship designed according to this criteria is more expensive to produce but may result in lower through-life cost because maintenance by substitution involves:

- low intervention time,
- easier (and cheaper) repair in the shore based facilities.

In both of the cases discussed, a design tradeoff analysis considering both the initial production costs and the in-service maintenance and ownership costs should be performed to assist the decision process.

b. Need for Improved Maintenance Techniques. There is a need for maintenance techniques that are more directly related to the state of equipment than before. This is different from reduced maintenance resulting from design investment in more reliable machinery, longer lasting materials, etc. Modern diagnostic methods (e.g., onboard sensing of equipment condition) are now starting to allow the introduction of Reliability Centered Maintenance, vice time-based maintenance, so that equipment can be repaired with more confidence when it needs to be, rather than when it is just felt prudent to do so. Other methods could also be developed to allow reduction of maintenance costs without loss of reliability. Again, early design process consideration should be given to this area for maximum benefit, which might require up-front investment for a later return.

c. Development of an Effective System/Equipment Performance Monitoring Program. A thorough knowledge and assessment of actual equipment/system condition in relation to its designed condition is the most logical basis for maintenance decisions. Equipment condition is a broad term that includes static parameters, such as size and shape, and dynamic parameters, such as speed, temperature, pressure, flow, voltage, etc. While the individual ship’s force is in the best position to know the condition of ship and equipment/systems, the complexities of modern design and engineering dictate that specialized assistance and equipment be used to determine the condition of much of the systems and equipment. This specialized assistance is best provided by active monitoring of critical systems and equipment utilizing state-of-the-art, non-intrusive, instrumentation. Assessment of the collected data will determine the operational performance and material condition of the equipment/system and enable recommendations for maintenance accomplishment, design improvements, ILS revision, etc. to be made. This will also ensure unnecessary maintenance is not performed. Essential elements of an effective program include:

- State-of-the-art monitoring equipment and methods capable of collecting operational data by non-intrusive means;
- Monitoring procedures (which collect consistent, repeatable data) that reflect actual equipment condition;
- Analysis methods and procedures, including the use of expert systems, to generate engineering recommendations to optimize maintenance effectiveness; and
- Trained and experienced teams of personnel to collect and analyze data.

6. Follow-on Support

a. Main Categories. Activities and actions for the development of logistics support in collaborative and other new weapon and equipment projects are indicated in the following paragraphs:

- supply management;
- maintenance, repair and overhaul management; and
- arrangements for quality assurance.

The activities and actions suggested for these logistics categories by EUROLOG guidelines, for the development of logistics support for collaborative and other new weapon and equipment projects, are indicated in the following paragraphs.

b. Supply Management. Determine/provide/perform:

- allocation of responsibility for the procurement of materials, spares, etc., devise appropriate arrangements for cost sharing;
- a facility to ensure that modification programs are fully agreed and coordinated by all participant nations so as to maintain a common configuration and the ability to interchange main equipment, sub assemblies and modules between national weapon systems;
- assessment of the range of materials, spares, etc. required to support the weapon or major equipment concerned at used, maintenance and

supply levels;
- naming, identification, classification and numbering in the NATO codification system for equipment, spares, tools, and accessories to be held at every level and/or by each participant;
- identification of the size, location, funding and custodian of the common pool of materials, spares, etc;
- the need for an agreed priority system for each participant's requirements and arrangements for exceptional requirements (i.e.: for combat operational requirements);
- procedures for distribution of supplies, including time scales for requisition and delivery, methods of handling, transportation, special cases for security and other special requirements;
- planning of follow-on support arrangements and the method of forecasting future requirements, including periodicity of replenishment demands and identification of individual items;
- exchange of management and supply information and of engineering information affecting supply;
- disposal of excess or obsolete stocks;
- accounting procedures and automated data processing considerations;
- demands on preservation and packaging procedures, including the examination of the necessity and the scope of reusable containers;
- achieving a concept for the disposition and supervision of a stockpile circuit for interchangeable articles; and
- determination of value standards (especially for high value items);
- preparation for cross servicing.

c. Maintenance, Repair and Overhaul Management. Determine/provide/perform:

- the definition of tasks and their division between central and national resources;
- provision of common technical publications, and other supporting documentation;
- required test equipment, inspection facilities and tools;
- estimates of consumption of spares for individual maintenance, overhaul and repair tasks;
- provision of spare parts to support repair lines;
- estimates of costs of maintenance, overhaul and repair;
- training requirements regarding maintenance, overhaul and repair;
- provision of special tools and equipment; and
- exchanged of information, including systems effectiveness, defects, modification and improvements;

(Note: The need for accurate estimates is emphasized in this area due to the high percentages of LCC involved.)

d. Quality Assurance Agreements. Determine agreements on quality assurance level and extent of quality assurance for:

- equipment, spares, tools, and accessories provided for the first fits and for common national stocks, and
- maintenance, overhaul and repair tasks.

7. Integrated Logistic Support

a. Need for Early and Continuous ILS. The operations and support of naval ships is very complex and costly. Many decisions at initial stages of the design may have severe consequences or impacts on the in-service phase of the life cycle. ILS is a disciplined management approach, affecting both government and industry, aimed at optimizing LCC. It considers all support elements to influence equipment design and determine support requirements to provide supportable and supported equipment. The major goals of ILS are:

- influence the design early enough to be effective,
- develop support resource requirements,
- acquire resources, and
- provide the required In-Service support at the optimum LCC.

For the design and production effort, the ILS approach should be integrated and must cover the entire life cycle, starting from the very beginning of PAPS. This overall perspective for logistics support is gaining momentum in some nations through a strategy called “Continuous Acquisition and Life-Cycle Support (CALS)”. CALS facilitates the concurrent engineering process and offers great potential for reducing acquisition and in-service costs through leveraging of the current state-of-the-art in Information Technology (IT) as seen in Figure 12.

CONTINUOUS ACQUISITION AND LIFE-CYCLE SUPPORT (CALS)

- The transition from paper-intensive, non-integrated weapon system design, manufacturing, and support processes to a highly automated and integrated mode of operation
- The acceleration of the use of digital data in technical information systems and the associated reduction in business process cycle times and cost of operations
- The creation of a uniform capability to electronically receive, use, manage, and distribute technical data products in a digital media.

Acquisition, managing, and using technical data in standardized digital forms

Figure 12

Examples of CALS results thus far include:

- Electronic Classrooms
  - reduced paper
  - increased trouble shooting opportunity
  - improved scores, reduction in attrition
  - reduced training time

- Interactive Electronic Technical Manuals (IETM)
  - reduced paper
  - automated and relational databases
  - real-time updates

- Readiness - Based Sparing (RBS)
  - reduced inventory requirements
  - increased operational availability

Additional discussion of CALS is contained in Chapter G.

b. ILS Applied to Technical Activities. A coherent, integrated and early planning approach is the cornerstone for effective management and cost reduction in the operations and support of a naval ship. Thus, a disciplined, unified, and iterative planning and management approach should be applied to the 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,
- acquire the required support, and
- provide the required support during the operational phase at minimum cost.

c. Process Management. As in the other phases of a ship's life cycle, the goal of the In-Service phase is to deploy a system which satisfies the need in a timely manner, at an affordable cost, and with the necessary support to operate and sustain the system in the most economic way. To effectively manage this process, it is necessary to establish and maintain a balance among the costs and the system effectiveness. The costs are the resources required to acquire, produce, operate, support, and dispose of the system. The system effectiveness is the degree to which the system can be expected to achieve its intended mission(s), within a given amount of money. Early and continuous ILS planning and management is a critical aspect of this process.

d. Elements of ILS. ILS can be subdivided into ten major elements:

(1) Maintenance Planning - The process conducted to evolve and establish maintenance concepts and requirements for the lifetime of the naval weapon system.

(2) Manpower and Personnel - The identification and acquisition of military and civilian personnel with the skills and grades required to operate and support the weapon system or ship over its lifetime, at peacetime and wartime rates.

(3) Supply Support - All management actions, procedures and techniques used to determine requirements to acquire, catalog, receive, store, transfer, issue, and dispose of secondary items. This includes provisioning for initial support as well as replenishment supply support.

(4) Support Equipment - All mobile or fixed equipment required to support the operation and maintenance of the weapon system or ship. This includes associated multi-use end items, ground handling and maintenance equipment, tools, metrology and calibration as well as test equipment. It includes the acquisition of logistics support for the support and test equipment itself.

(5) Technical Documentation/Data - Recorded information, regardless of form or character (such as manuals and drawings), of a scientific or technical nature. Computer programs and related software are not technical data, whereas, documentation of computer programs and related software are. Also excluded from inclusion under the term technical data are financial data or other information on contract administration.

(6) Training and Training Support - The processes, procedures, techniques, training devices, and equipment used to train civilian and active duty and reserve military personnel to operate, and support the weapon system or ship. This includes individual and crew training, new equipment training, initial, formal and on-the-job training, logistic support planning for training equipment, and training device acquisition and installation.

(7) Computer Resources Support - The facilities, hardware, software, documentation, and manpower needed to operate and support embedded computer systems.

(8) Facilities - The permanent or semi-permanent real property assets required to support the weapon system or ship. Facilities management includes conducting studies to define types of facilities or facility modifications/improvements, environmental requirements and equipment.

(9) Packing, Handling, Storage, and Transportation -The resources, processes, procedures, design considerations and methods to ensure that all system, equipment and support items are preserved, packaged, handled and transported properly. This includes environmental considerations and equipment conservation requirements for short and long term storage and transportability.

(10) Design Interface - The relationship of logistics-related design parameters to readiness, availability and support resource requirements. These logistics-related design parameters are expressed in operational terms rather than as inherent values and specifically relate to the system readiness objectives and support costs of the system.

e. Operational Feedback to ILS Planning. The objective of ILS planning during the development of a ship or naval weapon system is to ensure that readiness objectives are met and sustained through the in-service phase, including the post-production period. The first empirical measure of system readiness occurs when the naval ship or weapon system is operationally deployed. Experience gained from this period is then used to adjust the logistic support resources previously programmed. Planning deferred until the problems are encountered will have severe limiting effects on the total effectiveness. Therefore, material and performance deficiencies must be detected and corrected as early as possible in the O&S phase.

f. Training. The cost of crew training is changing rapidly with the advent of today's computer technologies. These capabilities require an up-front investment in software and hardware; however, the return on investment rapidly prevails. This is clearly demonstrated via the experience to date resulting from the existence of electronic classrooms, electronic technical manuals and simulation facilities. This capability has the following benefits to name a few:

- shortened training time and reduced costs,
- decreased demand for onboard training with the associated reduction in risk and operational costs,
- near real time update of technical information,
- increased possibilities for trouble shooting training in the classroom environment, and
- increased operational availability and readiness.

8. MANPOWER (MANNING) REDUCTION

Manpower (military personnel) reduction is an interdependent element of ship design and a significant means to limit life cycle costs of naval ships. Conceptual and technical changes offer demanding challenges in future warship design and operation with consequences in numbers, required skills and structure of personnel.

a. General. There are a number of cost impacts associated with reduced manning. First is the direct monetary value of wages, benefits and training. Estimates of the personnel portion of the life cycle costs for surface combatant are 25% or more, so that any saving in this area is significant, and directly calculated. There are numerous personnel related hidden costs as well, ranging from the incremental impacts on ship weight, to services (heating, ventilation, water, sewage, hotel/recreation services, etc.), to training, to post-military service costs (pensions). Cost savings can only be achieved, if the associated planning of crew reduction is incorporated into the total ship design, acquisition and ownership as an integrated process.

b. History and Trends. There are many ongoing efforts to assess the cost of naval personnel, especially as they relate to cost of ownership of naval ships.

Personnel or manning costs are critical life cycle cost driver, representing as much as 50% of operating and support costs in naval ships. Extensive research is in progress (in varying degrees among NATO navies) to develop personnel cost databases for capturing direct personnel costs and variable indirect costs.

Notwithstanding a generally recognized downward trend over the last 50 years, technology developments promise further reductions in the future, possibly of breakthrough proportions (another 25-30% or even more depending on the ship type and nation). Future reductions may result from more deliberate paradigm shifts in the use of manning to operate the ship, e.g., regarding exploitation of information technology, improved materials and processes, associated improvements in combat operations and operations other than war, damage control techniques, and ship husbandry. Although navies are reluctant to abandon contemporary traditions, further manning reductions in warships will likely involve revolutionary policy modifications and substantial elimination of political constraints. However besides the reduction potential in performing standard functions and tasks by the support of new or emerging technologies, new and additional tasks may be accomplished calling for more crewmembers and/or changed qualifications.

c. Personnel Cost Considerations. The elements and structure included in the cost of navy personnel vary from nation to nation, but there are some generic categories that can be addressed. Personnel costs are composed of *direct* and *variable indirect costs.* Savings attributable to any reduction in crew numbers depend on the ability to affect both categories. Common definitions have not been established among the NATO nations but, as a reference, Figure 13 provides a broad definition of the elements contained in each of these categories. The elements are typically associated with expenditures related to salary, health care, pensions, specialization service pay, allowances, training and permanent change of station costs. Most of these costs can be categorized as only one type, either direct or variable indirect. The costs associated with training however, can be allocated to both depending on the type of training involved, namely specific/specialized or general training. The term Full Cost of Training (FCT) refers to the sum of direct and variable indirect training costs.

Figure 13 also illustrates the relative magnitude of the elements and shows the significant proportion of the total that is made up of variable indirect costs. Thus, to reflect the true costs affected by a decision involving the design of a ship and its operation, the variable indirect costs of manpower must be considered. Figures III-1 and III-2 of Appendix 3 give a more detailed view of the elements contained in the direct and variable indirect costs for the U.S. Navy, respectively.

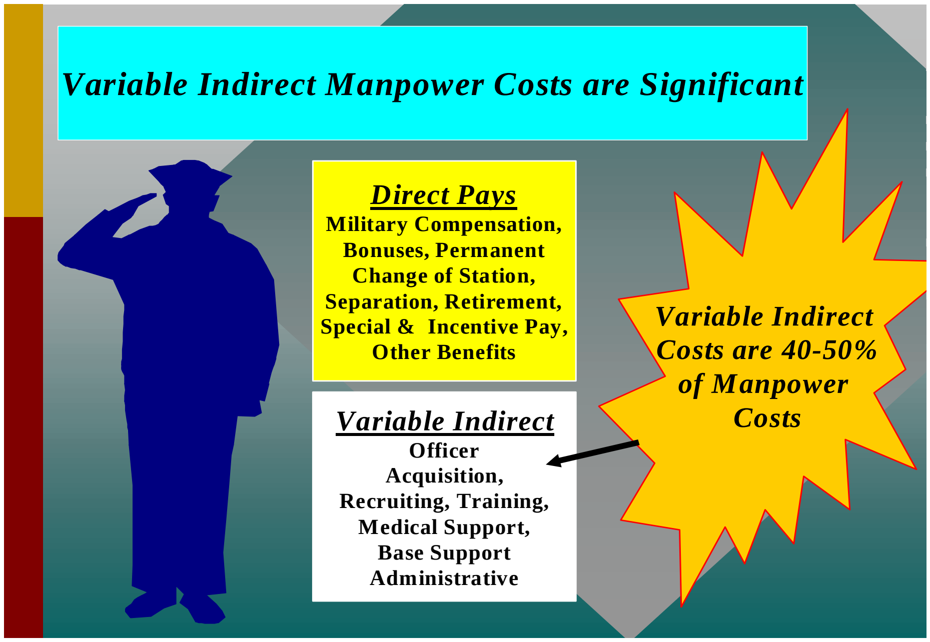

Figure 13

d. Determining Manpower Requirements and Discussion. Methodologies to determine manpower requirements for NATO surface combatants are explicitly described in the ANEP-20 series. For new ship designs standard tools such as functional analysis, task analysis, design work study and system trade-off studies are applied, individually or in concert to investigate the man-machine workload requirements and distribution.

Besides functional and task analyses, the key issue is Workload Determination. Workload refers to the amount of work, in terms of accountable and tangible output performance, that can be identified and adequately described for the purpose of work measurement and cost accounting. It compares available working time in terms of billets with the workload requirements derived from existing or anticipated technical and organizational concepts or measures. It can be closely linked to role plan analyses, since a role plan does not consider the workload at, but rather allocates persons to individual stations.

Simulations offer also a broad spectrum of application in determining or validating manpower requirements. Based on operational scenarios, assumed technical and organizational concepts and measures are tested along operational and functional flow diagrams and the number of personnel available. A typical application of this method would be the evaluation of a damage control scenario, covering defined hits and damages to be successfully engaged and controlled with a given amount of personnel and equipment.

The overall work to be performed on board, reflected as functional tasks and activities, can be arranged in three categories.

Type 1 Activities – These activities are aligned to the basic function Operate or Fight and are scheduled, regular and contain elements that are most easily automated. Reducing manpower for Type 1 activities prejudices the capacity to conduct Type 2 and 3 activities.

Type 2 Activities – These activities determine the ability to Sail/Sustain with operational effectiveness, which is imperative for navies.

Type 3 Activities – These activities allow the ship to Survive by responding to the unexpected and unusual as well as covering off-ship activities.

A more descriptive array of the three types of activities is found in Figure 14.

Savings from Type 1 activities can be achieved by automation and other technologies. Future savings in manpower, in addition to Type 1 reductions from automation and other technologies, will also require a tradeoff of operational capabilities by, *inter alia* identifying ways to reduce the crew involvement in Type 2 activities while maintaining essential Type 3 capability. It comes down to balancing essential performance and safety requirements with affordability constraints, in a holistic total ownership cost context, where manpower is a major cost driver. The transition to smaller crew size may imply a greater necessity for shore support. Thus ships of the future have to be prepared for ease of work onboard, i.e., by low-level corrective maintainance and appropriate level of redundancy in the design.

Manning goals should be set in the design process. During the initial concept phases it is nearly impossible to analytically describe the tasks that the crew will be required to perform once underway. However the crew is a significant factor regarding the size and cost of the ship. Crew size has to be targeted at the outset (early design phase) since manning is a basis for the ship design itself though the actual crew workload will evolve during the design phase. Because of this situation, the iterative approach is often taken. An initial crew-size objective and margin is chosen, generally based on observation of long-term experience. This progressive method may be effective, but there are no guarantees that the early stage design crew-size objective will be the correct target. It is also fair to say that this approach may inhibit a real breakthrough.

Types of Ship Activities		
Type 1	**Type 2**	**Type 3**
Scheduled, Regular	Expected, Irregular	Unscheduled, Emergency
Command	Fault Diagnosis	Manual Control

Ship Control & Safety	Fault Repair	Fire-fighting
Machinery Control	RAS	Damage Repair
Weapon Control	Store Ship	Accidents
Rounds & Patrols	Team Training	Emergencies
Maintenance	Sea Boats	Aid to Shipping
Administration	Guarding	Boarding
Food Preparation	Ship Husbandry	SAR
Laundry	Navy Days	Aid to Civil Authority
Logistic Supply	Visitors	Disaster Relief
Cleaning	Ceremonial	

Figure 14

e. Manpower Reduction – Possibilities and Constraints. Historically, the merchant ship approach has been to take maximum advantage of automation to reduce crew size to an absolute minimum and transfer the biggest portion of maintenance and husbandry ashore. In cases of need, competitive corrective maintenance ashore is requested. The use of automation in combination with reliance upon functions ashore is an option for manning reduction in naval ships. But a more radical approach to operational policy may be required to effect significant change in naval ship manning. For a combatant during battle conditions almost the entire crew is stationed in three groups of actions:

- ship and combat system operation,
- manning of manual control positions of critical equipment, and
- damage control parties.

In this condition, the ship is used with maximum automation, but manned for manual control because of the emphasis given to simultaneous performance of all functions in a degraded mode. The approach presents a delemma. First, at no time are all functions per-formed simultaneously, so a large portion of the crew is under-employed for long periods of time. In case of a severe hit, the crew members who are assigned to take over manual control in the damaged compartments are likely to be disabled, while the crew in the undamaged compartments are likely to remain under-employed as the automatic controls may continue to function normally if they are robustly designed. In this situation a more efficient organization should be possible given careful analysis of safety and policy issues.

Observations in the field of manpower reduction reveal that initiatives and activities are often directly or indirectly constrained by traditional bureaucratic policies, procedures, and processes. Every nation has developed its own organisational, operational and logistical principles and practices. These have evolved from domestic and foreign policy, military experience or even geographic considerations. NATO requirements for multinational cooperation sometimes create additional constraints. As a result, the need for a *cultural change* has been articulated. This need for a change fits well into the widespread initiatives for lean management, public-private partnership in defence and application of commercial standards and practices.

Contemporary ship acquisition programs have set challenging goals for manning reduction, but smaller is not always better. The desire to minimize the complement for reasons of cost and candidate personned avialability has to be balanced with the mission and tasks. The ship is designed with emphasis on the basic functions of a naval ship to operate/fight, to sail/sustain and to survive. Moreover, sailors are to be provided a certain quality of life onboard the ship which must not be sacrificed. Approximately 15% of a warship's crew is dedicated to sustaining this quality of life standard through morale building, food service, recreation, etc. Additionally, margins in manpower for the ship's crew are necessary to allow for embarking and support of more personnel to suit mission requirements and enabling naval ships to adapt flexibly to mission needs and to avoid costly subsequent construction changes.

f. Summary and Conclusions. Manpower costs constitute 40-60% of the in-service cost of a major surface warship and is a major cost driver. Navies must move to more lightly manned ships to not only offset the increasing cost of manpower but to also deal with the shrinking population of personnel candidates. The goal should be to "*right-size*" the crew complement to minimize cost while maintaining needed capabilities, without compromising safety.

Although technology and automation offer opportunities for reduced manning, doctrinal constraints impose limits that affect, if not determine, manpower levels. Since these constraints vary with nations, it is not feasible to provide guidance with upper and lower boundaries, either fixed or generic. Nations will need to individually pursue workload reduction initiatives and reduce or remove doctrinal constraints to achieve real manpower reduction.

Manpower reduction as means to reduce LCC of naval ships is a very complex issue. It involves all the design and operational aspects with associated processes of the basic functions of a warship to fight/operate, sail/sustain and to survive. NATO and national policies, doctrines, guidance publications and technology developments must be considered continuously. Husbandry, damage control, fueling-at-sea/replenishment-at-sea (FAS/RAS), and additional operational requirements are some of the prominent mission, task and function areas that drive manpower requirements. Notwithstanding endeavors towards manning reduction, contingencies and emerging operational needs may make it necessary to even consider increases in future ship complements.

New technological developments regarding sensors, effectors, communications, data processing and distribution have triggered significant advances in the basic function operate/fight. These advances must now also be applied to the other basic functions sail/sustain and survive, so that all three merge as an integrated ship management system that maximizes crew efficiency and consequently manning reductions.

9. Collaborative Programs

As learned from the 1980's NFR-90 Program study, see literature survey presented in reference (a), significant potential for In-Service cost savings lies in the following areas:

- common training,
- common procurements and standardization of components,
- shared test facilities,
- integrated logistics support and spares operations, and
- shared automatic test equipment, central data management, etc.

10. Summary

a. In-Service Phase Costs. Operations and Support costs constitute a major portion of a ship's life-cycle costs. Major cost drivers and dependencies are depicted in Figure 15.

OPERATION & SUPPORT

- In-Service Phase Costs May Constitute Up to 60-80% Of LCC
- Costs Heavily Dependent On:
  - Peacetime and wartime operational scenario and tempo
  - Mission and Policy Requirements built into the ship designs
- Cost Drivers Connected To:
  - Personnel Cost (Manning)
  - Early design stage planning
  - Up-Front investment
  - Level of automation
  - Equipment standardization/ Configuration control
  - Continuous Acquisition and Life Cycle Support (CALS)
  - Integrated logistics support
  - Design flexibility provisions
  - Ease of maintenance and upgrade
  - Environmental compliance
  - Training

Figure 15

b. Military Requirements and Policy Definitions. A clear definition of military requirements and a realistic assessment of operational deployment, training and logistic support policies form the basis of efficient operations and support management. These policies and their consequences need to be carefully considered and integrated into the design and planning process of a naval ship at the very earliest stages of a program.

c. Estimating Life Cycle Costs. Starting from the initial design, construction and management activity, continuing through the period of attaining a technically proficient crew, and finally to the shore-based and onboard technical and logistic support -- all of these items have to be taken into account to estimate the total life cycle costs of the ship (design, building and management).

d. Deployment Cycles, Maintenance Monitoring and Quality Standards. The duration and frequency of operational deployment cycles, the means of maintenance monitoring, and the standards of quality (of the design, materials, components, workmanship and operative plans), are key factors in influencing the costs of the In-Service phase. Additionally, the logistics support policy of the entire navy (not just a class of ships) and the influences of international cooperation significantly affect the costs.

e. Decision-Making. Maximum leverage for cost savings can only be attained through a heightened awareness of all involved in the process, through early and continuous cost evaluation and execution to plan throughout the program phases. This includes the requirements setters (e.g., Naval Staff), the fleet operators (together with Naval Staff, in right-sizing crew numbers to minimize cost while maintaining capabilities without jeopardizing safety), engineers, designers, logisticians, financial planners and, most importantly, the project managers. Effective cost analysis to support the design tradeoffs can significantly aid in the decision making process.

f. Technical Data Management. The acquisition, management and use of technical data in standardized digital form holds great potential for In-Service phase cost reduction.

CHAPTER G

COST MANAGEMENT

1. Introduction

a. Delivering Effective Warships. The cost of warship acquisition and ownership is an ongoing concern. As a consequence, to control the cost, many governments have opted to impose cost constraints in many ship acquisition projects. Whether cost constraints are imposed or not, the likelihood of ensuring that effective warships are designed and built to meet the mission requirements is greatly enhanced if:

(1) effective cost management techniques are utilized from the early design phase,
(2) effective contract management and program cost and schedule control systems are employed, and
(3) necessary cost visibility is provided through effective accounting systems extending throughout a ship's life cycle.

b. Design Phase and Ongoing Cost Management. The formal application of cost management techniques is essential in a project as complex and far-reaching as the design, procurement and operation of a warship -- as much to prevent the uncontrolled escalation of costs, as to bring about cost reduction. These techniques must be applied appropriately at every stage of the project, but are most important during the design phase. It is here that at least 80% of the life-cycle costs are committed.

2. General Principles and Techniques

a. Early Assessments. As previously mentioned, a major part of a ship’s life cycle is committed during the design phases. Therefore, it is important for cost reduction awareness that cost assessments be performed early-on in conjunction with the design development. To this end, cost models should be carefully employed as an adjunct to the design tools employed. Over-estimation during the design development can lead to unnecessary reduction in capability and even project cancellation and should be avoided as much as under-estimation.

b. Design Reviews. A general technique, which should be used, in any case as good management practice, is to regularly scrutinize the design as it develops, and the resulting cost estimates. The basis and composition of the cost estimates should be queried, to establish that the assumptions are reasonable, given the stage of development, and have been thought through. Comparison with previous projects should be used whenever possible, making justifiable extrapolations, until the design is sufficiently developed to allow detailed cost estimates to be prepared. This technique will reveal any unclear thinking or inadequate research, and identify areas of risk where uncertainties need to be investigated further.

c. Cost Reviews. As the design develops, cost reviews, as part of normal design reviews, should be used as part of the process of assessing the design against the requirement, and thus establish whether the product is over-designed. For example, have extra features been introduced or have margins not been reduced in line with better definition?

d. Estimating Methods. Related to the scrutiny of design is the scrutiny of the estimating methods used. How accurate are they? Are they relevant to the type of ship being studied? A sound cost estimate involves the determination of many factors involved in a project such as the project definition and cost/work breakdown structure, a database and models from which to predict costs. The actual process and methodologies vary from nation to nation. Reference (b) describes the process and associated factors in more detail for a NATO ship program.

e. Design-To-Cost.

(1) Cost Goal. One of the techniques used to address cost reduction is the application of a cost goal (sometimes a firm cost “cap” or “ceiling” is used). In this case, the cost goal is utilized to limit the cost or arbitrarily force the cost down. Generally, this method will result in trade-off studies to assess the cost impact of changes to the design against the operational benefits. This may employ an Investment Appraisal (IA) to compare the cost of various options to meet the operational requirement.

(2) Scrutiny of the Requirements. The cost goal may be seen as a blunt weapon but it has proven effective in concentrating the efforts of operations requirements staff, ship designers and builders on what is essential and what is less so (by causing a close scrutiny on all aspects of the military requirement). Used carefully, a cost goal can direct effort to developing alternative and cheaper ways of meeting the requirement, although possibly at some increase in development costs.

(3) Search for Cost-Effective Solutions. Trade-off studies and IA's are related to cost goals but should be conducted, nonetheless, in order to explore alternatives, from a design and cost point of view, to see if more cost-effective solutions can be found. It should never be assumed that the first solution that comes to mind cannot be done better or more economically. Therefore, a formal program of trade-off studies should be pursued as an engineering discipline, whether or not there is a cost target.

(4) Affordability versus Capability. A cost “cap” should not be applied prematurely; i.e., before sufficient design work has been done to identify the realistic costs of meeting the initial requirements, and of the possible tradeoffs. Only then can affordability and capability be balanced in an informed manner.

f. Cost Budgets. A further cost management technique that can be applied as the design develops is to apply a cost budget to individual weight groups or to equipment. This is a further discipline on individual design areas, to look carefully at their own parts of the design, rather than relying on other areas to bail them out if they are insufficiently rigorous. This approach requires a strong project manager to enforce the discipline and also an experienced one to recognize the danger of sub-optimization in a particular area.

g. Up-Front Investment. Again, in the design phase, the possibility to "spend-to-save" will need to be examined. Money spent up-front is generally not a popular option. However, greater reliability, maintainability, availability, redundancy, and higher quality in the product may well give a positive payback in terms of reduced life-cycle costs (less spares required, fewer breakdowns, less time out of service, etc.). Such investments will need to be thoroughly justified by a through-life investment analysis, and strongly argued against those who are more concerned with the acquisition cost only.

h. Contract Incentives. Cost management in the production phase depends, *inter alia*, on the type of contract. For example, with fixed price contracts, the opportunity for cost management will likely be limited first to keeping an eye on the shipbuilder's spend profile, and second to resisting pressure for changes (whether inspired by the customer or by the shipbuilder). Regardless of the contracting type, there will be limited scope for cost reduction, unless the shipbuilder has a contractual incentive to reduce the overall cost and price.

3. Contract Cost and Schedule Control Systems

a. Early Warning Systems. For most warship construction contracts, there is a considerable cost risk to the respective government as to whether the ship will be delivered on schedule, on cost, and meeting all the technical and performance requirements. Therefore, the respective governments to obtain assurance that their contractors have acceptable management systems should utilize management tools. The contractor management system(s) should provide valid cost and schedule data and enhance the Project Manager's visibility into the projected cost at completion of the contract, with early warning of impending cost increases.

b. Cost/Schedule Management Systems. A good cost management system should determine a cost that mirrors the manufacturing process, identifies waste, isolates cost drivers, and provides visibility into cost reduction/performance improvement opportunities. Various cost/schedule management systems are available, such as:

(1) Cost/Schedule Control Systems Criteria (C/SCSC);
(2) Cost Performance Reports (CPR);
(3) Contract Funds Status Report (CFSR);
(4) Cost/Schedule Status Report (C/SSR); and
(5) Earned Value Management System (EVMS).

These systems may be applied independently or collectively depending on the contract size (in terms of cost), risk associated or other compelling factors. Currently, the above systems are all used in the U.S., and Canada and Spain use C/SCSC.

c. Product-Oriented Design and Construction. New approaches are increasingly being adopted to better reflect how the work is actually accomplished. An example of this is the Product Work Breakdown Structure (PWBS) in which the information is grouped to exactly anticipate the parts, sub-assemblies and assemblies, i.e., the interim products, required to build ships. Progress reporting and cost collection, in this case, are product and process oriented so that managers have a more tangible means of corroborating work completed in order to forecast work remaining and resources required for completion.

4. Techniques During the Design and Production Phases

a. Resource Control Approach.

(1) An example of the early-stage-design cost management approach is the Resource Control Team methodology implemented for the U.S. Navy DDG-51 program, based on literature survey of reference (a), which proved to be an effective mechanism in achieving the cost goal and combat capability. The resource control approach was applied in the contract design phase and provided the necessary cost visibility to establish a real-time link between design engineering, cost estimating and program decision making.

(2) The resource control or a similar approach involving real-time cost engineering can be applied for controlling the cost of future warships, e.g., to meet the production cost constraint. This approach involves three key characteristics:

(a) engineering discipline in the design team,
(b) vigorous system engineering, and
(c) visibility throughout the design team and higher levels of

management of the evolving cost of the ship.

(3) The resource control approach is essentially a closed-loop feedback control process of:

(a) establishing budgets,
(b) reviewing the design for conformance to the budgets, and
(c) making decisions to change the design where design features exceed the established budgets.

b. Contract Change Control. Change can significantly improve products, but it must be prudently controlled, budgeted and scheduled. Based on the literature survey of reference (a), one method of management of contract changes is the "source-based" change categorization scheme developed and implemented, to enable the program manager to maintain an overview of change order causes and status, on the U.S. Navy Aegis cruiser program. Developed as an outgrowth of the automated configuration management database, this change categorization scheme provides data and information to provide an awareness from several standpoints:

- originating source,
- cost on a per ship basis, and
- categories of cost drivers.

This key information provides the program manager with essential knowledge needed to manage contract changes.

c. Risk Mitigation. (See Chapter D, same topic)

5. In-Service Phase Opportunity

a. Dynamic Nature of In-Service Phase Costs. Cost management should be implemented through the entire life cycle of the ship and not just the production phase -- although the maximum effort must be made in the Project Definition and Design and Development phases. After the initial Design and Development has been completed, the life cycle cost of a ship, to a great extent, can be viewed as two parts: the more or less fixed acquisition costs and the variable, often hard to predict, operating and support costs.

b. Design Impact and "Spend-to-Save". During the In-Service phase, cost management is contained in meeting the various operating budgets -- crew costs, fuel, spares, etc. These costs, in theory, are known or can be estimated in advance based on the design of the ship and the likely operating profile. There is limited scope for cost reduction in a planned way, except where this has been provided for by "spend-to-save" measures during the design phase. Associated with this approach, however, is the need for continuous Investment Appraisal to assess the possible alternatives?

c. Impact of Operations Tempo and Political and Economic Factors. In-Service costs are particularly sensitive (or vulnerable) to political and financial pressures to cut costs -- for example, resulting in reduced maintenance, less time at sea, unfilled berths, etc. They are also liable to upward pressure due to unforeseen maintenance, unscheduled operations, etc. Thus, to a great extent, in-service phase cost reduction tends to be reactive, operating costs being seen as a convenient source of savings when pressures dictate.

d. CALS Concept. Continuous Acquisition and Life-Cycle Support was discussed in Chapter F and is one of the promising cost management strategies to emerge in the past decade with the broad objectives to:

- improve the management and efficiency of ship
- operating and support systems,
- reduce cycle times,
- improve fleet support, and
- improve support technologies.

Through, *inter alia*, the process of information technology leveraging, onboard, equipment/system condition monitoring, readiness-based sparing, electronic classrooms and electronic technical manuals, the implementation of CALS is expected to result in savings of up to:

- 10-15% in hardware costs,
- 40% in documentation costs, and
- 30% in training costs.

The CALS approach is now being progressively implemented in several navies, based on the literature survey of reference (a). Information available tends to confirm the achieve-ability of the above savings. CALS is not a panacea; however, it is one of the promising contemporary concepts which holds potential for effectively dealing with a changing environment and serving as a tool for cost reduction in ships.

6. Summary

a. Life Cycle Cost Management. Cost management should be implemented through the entire life cycle of the ship and not just the production phase. Figure 16 depicts many cost management tools and techniques, which are shown in the life-cycle phase with which they are mainly associated. However, these techniques may be employed in any of the life-cycle phases.

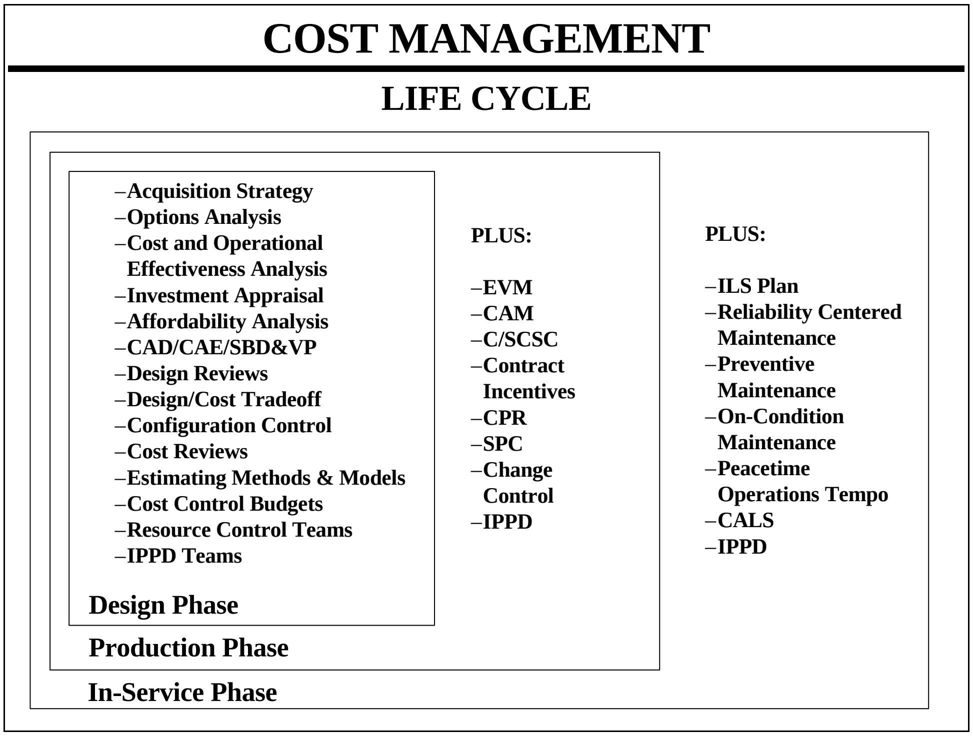

Figure 16

b. Maintenance Cost Elusiveness. The impact of the accounting system used is as important as any other factor in this area. It must provide information to enable the fleet's management to control maintenance in an efficient manner. Over-maintenance is as expensive as under-maintenance and the need exists for more accurate means to determine maintenance requirements; e.g., condition-based and reliability-centered assessment systems.

c. Total Program Perspective. Notwithstanding the fact that many influences result in cost increases in ship acquisition programs (political pressures, economic constraints, mission requirements, etc.), effective cost management can limit or mitigate the adverse cost impact of these factors. Ship designers, program managers, fleet operators, and others involved in the process must be keenly attuned to this fact and ever alert to look ahead through proven and innovative cost management techniques. A total program life cycle perspective, essential feedback and control systems, and knowledge of potential outcomes, risk areas, timeliness of corrective action, consequences of contracting mechanisms and change control are essential elements of the process. But to be effective, the management tools must be integrated into an overall process which encourages communication, allows managers and workers to track program progress and permits prompt corrective action before problems become large. Intense up-front planning, leading to an integrated product and process approach, wherein open communications and an ever-present cost awareness are embodied, is the key.

CHAPTER H

CONCLUSIONS

1. General

There are numerous areas with potential for reducing the acquisition, operations and support costs for naval ships, and where the NATO countries can cooperate to facilitate these improvements. Moreover, a concern for cost-effective ship design, construction, operations and support needs to be molded into the attitudes of the entire naval ship acquisition community as part of its day-to-day approach. The methods for ship cost reduction should be applied in all phases of the ship project life cycle.

Not all cost reduction techniques described in this ANEP will be applicable to all ship types in all situations. Each situation should be evaluated on a case-by-case basis to derive the maximum benefit. Indeed, there are synergistic effects among the techniques and some of these may counteract or degrade the effects of others. In any case, the use of cost reduction techniques must never be an excuse for decreasing quality or degrading safety.

The quantitative data presented in this document derives from various sources and, while believed to be accurate for specific situations described, may not be directly applicable to other situations with different circumstances. Caution should therefore be exercised when using any quantitative figures that are cited.

2. Integrated Ship Design, Procurement and Support

In the post-cold war era of declining defense budgets, the cost of naval ships will continue to be a major concern of the NATO navies. In this context, ship design aims have changed from seeking the "best possible" technical solution to the search for the "most cost-effective" solution, i.e., avoiding over specification in selecting the design which satisfactorily meets the mission requirement(s). To achieve the most cost-effective (and affordable) naval ships, an <u>integrated ship design, procurement and support approach should be implemented continuously from the earliest stages of requirements definition throughout all phases of a project's life cycle</u>. As an inherent part of this approach, the following guidelines are suggested:

- a concerted effort by all parties is necessary to produce an effective and affordable ship; a close liaison between all those involved in the acquisition process is essential -- operators, designers, and industry cooperating as a team;
- the definition of the mission need requirements has a crucial impact on the life-cycle costs and must be closely scrutinized to remove all non-essential elements;

– capability requirements should be determined at the lowest acceptable level of mission or operational effectiveness, but retaining the necessary safety and survivability features; and
– all aspects of design, engineering and procurement should be fully integrated with the plans for production and in-service operations and support, e.g., design for production, consideration of in-service operations and support impacts, and feedback to the design function from production, the fleet operator and fleet support entities.

3. Emphasis on Total Life-Cycle and Mission Effectiveness

Design features and cost reduction techniques should be evaluated over the whole of a ship's life cycle to form a balanced view of their impact. A cost reduction action to lower the initial procurement cost of a ship, without regard to the impact on the in-service phase, may only serve shortsighted objectives and result in higher life cycle costs. Likewise, the impact on mission effectiveness and personnel safety must not be overlooked. Therefore, the greatest possible use should be made, at all stages, of cost-benefit analyses coupled with an assessment of the operational and mission effectiveness to enable strategic cost reduction decisions and resource utilization.

4. Significant Other Findings

Ship design is a complex undertaking and involves many compromises between requirements, design options, and the associated costs. This necessitates many tradeoffs between cost, mission and operational effectiveness. In this context, the following are significant findings, which are proffered as guidance on ways to reduce the costs of ships (while retaining essential mission capabilities, environmental and regulatory compliance features, and personnel safety features):

* Technology advances should be continuously sought and applied to improve design and construction solutions and processes, improve maintenance and modernization, and improve operational and mission effectiveness. The SBD&VP concept (in total or elements thereof) offers significant potential to reduce costs and risks, especially if applied in a total system approach to life cycle cost.

* New technologies have significant potential for reducing costs although an initial investment of resources is generally necessary before the benefits can be realized.

* Technology advances should be tested before implementation to evaluate their effectiveness and associated risks.

  * Military standards and practices, margin policies and contractor data requirements are significant cost factors and should be closely scrutinized.

  * Greater use of commercial standards and practices in naval ship design and construction can lead to substantial savings. Cost reductions of up to 30% in acquisition and 15% in life cycle can be achieved.

  * Increased commonality and standardization of products and processes should be pursued at the ship level, across classes of ships, at the fleet level and from an international cooperative viewpoint.

* Evidence indicates that experience curve benefits (learning) are not always automatic, but often require management initiative or stimulus. One of the most significant ways that this can occur is via the use of design modules for ships. With the standardization that results, production processes can be more effectively optimized to maximize work accomplishment at the most efficient stage and work environment, to take advantage of major reductions in costs that result from repeatable of process activities.

* Design changes should be minimized after contract award to minimize disruption to ship construction and to prevent cost increases. While there are many reasons why changes are considered necessary for navy ship acquisition, a significant reduction in acquisition costs can be realized by eliminating or substantially reducing changes once the construction contract has been awarded.

* A key element of the acquisition process is the choice of acquisition strategy and contracting methods. Contracting practices should be carefully chosen and implemented to encourage contractor efficiency and minimize or balance the risk between industry and government. The current systems do not always effectively encourage vendor efficiency, and often have a deleterious effect. Although each country has its unique contracting practices that are closely linked with the jurisprudence culture, the opportunity exists for nations to effectively cooperate in improving these practices by establishing communications links to share information concerning contracting improvement dynamics.

* Advanced ship construction methods have significant potential to reduce costs. Savings of 10 to 15% are considered possible using product-oriented or integrated design and production methods.

* Further development of the integrated logistic support approach should be pursued and implemented from the earliest design phases as an integral part of a concurrent engineering approach.

* Cost control measures should be applied in all phases to enable effective cost

management, mitigate risk, and promote continuous process improvement.

* International cooperation should be considered in all phases, *inter alia*, for its potential to be of economic benefit of the participating nations.

APPENDIX 1

CHRONOLOGY OF DEVELOPMENT

1. Background

In October 1992, Information Exchange Group Six (IEG/6) on Ship Design of the NATO Naval Armaments Group (NNAG) chartered an Ad Hoc Working Group (AHWG) of ship cost experts (later renamed, Specialist Team on Ship Costing) to:

a. collect and analyze information available in the nations on ship cost reduction,
b. summarize findings on the potential for cost reduction in the next generation of surface combatants, and
c. incorporate findings into a working paper, reference (a), on ways to reduce costs of ships, for use by ship designers and others involved in the ship acquisition process.

The NNAG endorsed the tasking at its regular meeting in December 1992. Upon completion of the working paper and presentation to the NNAG in June 1995, the recommendation to extend the working paper into an ANEP was approved by the NNAG.

2. AHWG Participants

The AHWG participants represent expertise from the nations principally in ship cost estimating and analysis but also include individuals with naval architectural background, industrial expertise and ship operational experience. Eleven nations were direct participants in the AHWG: United States (Chairman), Canada (Secretary), Belgium, France, Germany, Italy, Spain, Netherlands, Norway, Portugal, and United Kingdom.

3. Terms of Reference

Appendix 1 of reference (a) delineates the Terms of Reference for the performance of this work. The terms of reference was drafted to satisfy the basic task of providing guidance to ship designers on ways to reduce the costs of ships. However, the AHWG later expanded the tasking to extend to all parties involved in ship design, acquisition, construction and operation by including coverage perhaps beyond the immediate influence of ship designers (e.g., mission requirements, contracting practices, acquisition policy, et cetera), but where decisions made in the design phase will have an impact.

4. ANEP Development

The process for development of the working paper and subsequent ANEP is depicted in Figure 1-1.

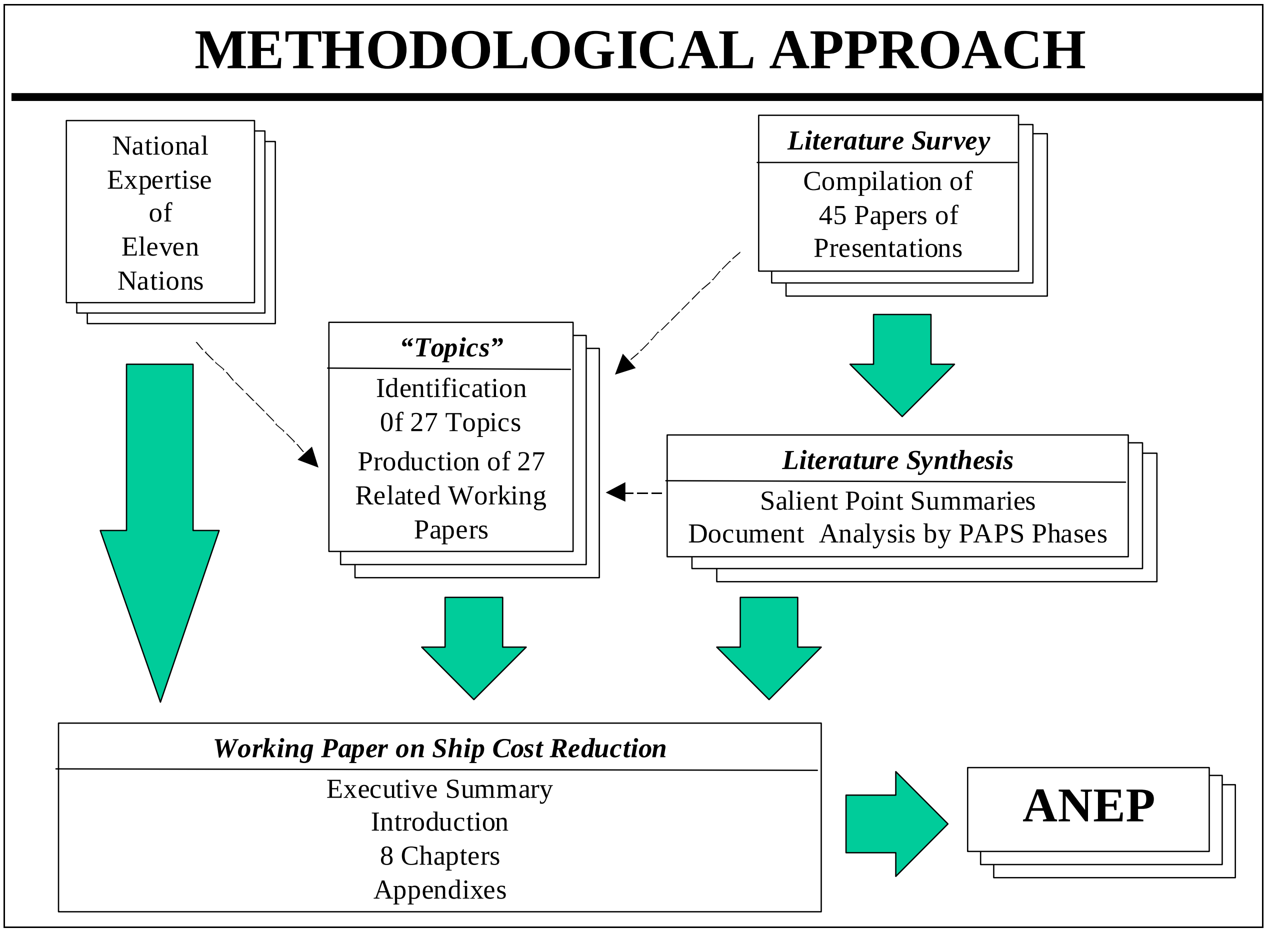

Figure 1-1

To produce the working paper and subsequent ANEP, the 27 major topic areas shown in Figure 1-2 were identified. Additionally, a survey of existing information having relevance to ship cost reduction was performed. A paper was prepared on each of the topic areas drawing upon a literature survey and national experiences. The topic papers are found in Appendix 3 of reference (a). Drawing upon the 27 topic papers, the salient points of papers found in the literature search and the expertise of the nations (AHWG members and other reviewers), the final working paper and the ANEP were produced.

MAJOR TOPIC AREAS

- Requirements (Mission)
- Procedures/Process to Establish Requirements
- Commercial vs. Military Standards
- Design-to-Cost
- Common Procurement/Purchases
- Technology Innovations
- Time and Decisions
- Contracting Practices
- Commonality
- Specifications/Project Definition
- Operations and Support Considerations
- Cost Management
- Value Engineering
- Eliminate/Reduce Change
- Crew Reduction vs. Automation
- Reduction in Contractor Data Requirements
- Production/Processes
- Reliability Analysis
- Risk Acceptance Level
- Margin Policy
- International Cooperation
- Standardization of Cost Effective Solutions
- Learning Curve Maximization
- Industrial Base Productivity, Competitiveness and Reliability
- Design/Cost Tradeoffs (Affordability Analysis)
- Use of Competition vice National Concerns
- Environmental Impact

Figure 1-2

5. ANEP Revision

At its November 1997 meeting, the NG/6 approved the reactivation of the Specialist Team on Ship Costing (STSC) with the United States as the pilot nation. NG/6 tasked (Decision Sheet AC/141(NG/6)DS/6) the STSC with the objective to review trends and practices among NATO nations regarding ship acquisition and ownership cost reduction (or possibilities to reduce costs) with emphasis in two primary areas:

- Manpower (military personnel) reduction, and
- Use of commercial standards and commercial practices.

The STSC findings are documented in Working Paper AC/141(NG/6)WP/9 which is reference (f) of ANEP 49, Edition 2. The STSC approach used in developing WP/9 and the proposed revisions to ANEPs 41 and 49 is reflected in Figure 1-3.

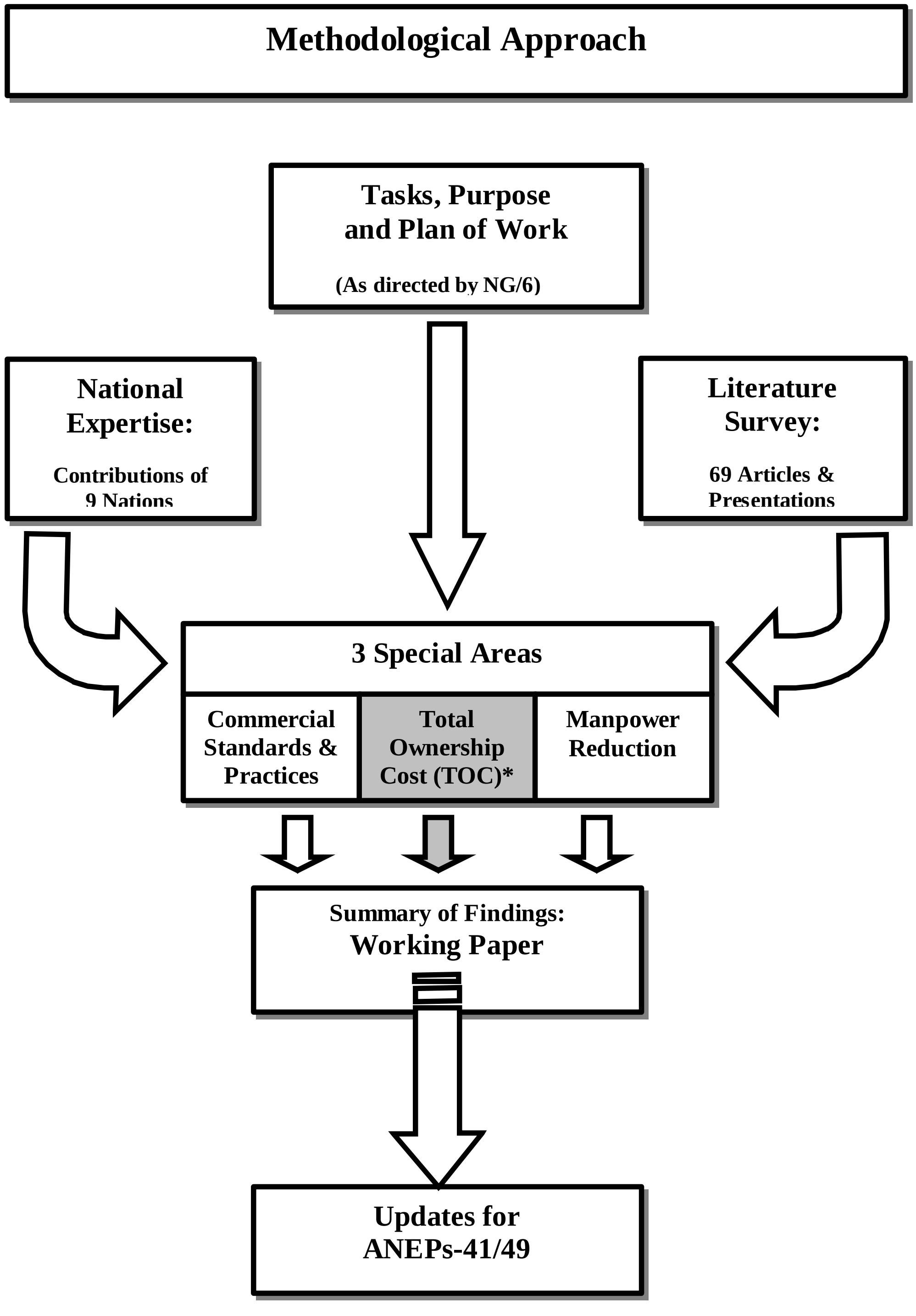
Methodological Approach
Tasks, Purpose
and Plan of Work
(As directed by NG/6)
National
Expertise:
Contributions of
9 Nations
Literature
Survey:
69 Articles &
Presentations
3 Special Areas
Commercial
Standards &
Practices
Total
Ownership
Cost (TOC)*
Manpower
Reduction
Summary of Findings:
Working Paper
Updates for
ANEPs-41/49

Figure 1-3

APPENDIX 2

GLOSSARY OF TERMS AND DEFINITIONS

Assurance Margins - Margin allowances provided to maintain the specified operating capability, off-set progressive and predictable degradation of ship subsystems and equipment, and account for the uncertainty in the loads and demands that will be imposed during the life of the ship.

Availability - The expected part of a time interval that the ship/system equipment is functioning.

Change Control - (1) A management process for introducing changes into a confirmed requirement (normally during the production phase) in a systematic way, to ensure that the benefit of the change is weighed against its cost and the disruption of the program. (2) Adhering closely to the original specifications and schedule to control design changes and avoid a big driver of cost increases. (3) Maintaining control of the design configuration of a ship or class of ships.

Commercial Contracting Strategies - Commercial contracting strategies, in the context of this paper, refer to commercial-like acquisition strategies applied to the defense sector for the design, acquisition, construction, operation, and support of a naval ship. The aim of such strategies is to reduce costs to the government without sacrificing mission capability, effectiveness, environmental complicity, and the safety of the ship and its crew.

Commercial Practices - The NATO NG/6 working paper, AC/141(NG/6-SG/7-INV) WP (98)2, “Implications of the use of commercial standards and practices on the vulnerability of surface ships,” defines commercial practices as: “the way the contractor applies the commercial standards to produce the ship.” For the purpose of this report, this definition is expanded to include any process or practice used in commercial shipbuilding, that may be applicable to naval surface combatants.

The U.S. Defense Systems Management College (DSMC) defines commercial practices currently in use as: the techniques, methods, customs, processes, rules, guides, and standards normally used by business but either applied differently or not used by the government.

Commercial Standards - The NATO NG/6 working paper, AC/141(NG/6-SG/7-INV) WP (98)2, “Implications of the use of commercial standards and practices on the vulnerability of surface ships,” defines commercial standards as: “standards as used in civil (merchant navy) shipbuilding.”

The commercial standards for ship construction are developed by a variety of sources such as:

(1) Classification society rules such as:
(2) Lloyds Register (LR);
(3) American Bureau of Shipping (ABS);
(4) Bureau Veritas (BV); and
(5) Det Norske Veritas (DNV).
(6) International Maritime Organization (IMO)/SOLAS.
(7) National government authorities such as Canadian Coast Guard (CCG), Canada Standards Association (CSA) and United States Coast Guard (USCG).
(8) Technical associations and societies such as Institute of Electrical and Electronics Engineers (IEEE), American Society of Testing Materials (ASTM), and American Society of Heating, Refrigeration and Air-conditioning Engineers (ASHRAE).
(9) Shipyard standards – individual shipyards' own standards.

Commonality - Commonality refers to a synergistic combination of modularization, equipment standardization and process simplification, aimed at cost reduction in both the initial acquisition costs of ships and the operation and support costs of the in-service phase. Increased commonality is intended to reduce costs through increased cost consciousness in the early stages of ship acquisition planning relative to ship design, construction and ownership. The concept requires that a ship be designed for efficiency in the production process and for simplicity and flexibility in the in-service phase. Under this concept, naval ships are designed and built using common modules comprised of standard components and possibly would entail standard type platforms.

Concurrent Engineering - A systematic approach to the integrated design of products and their related processes, including manufacture and support. This approach, ideally applied from the earliest stages of design development, considers all elements of the product life cycle from conception through disposal, including user requirements, quality, schedule and cost.

Continuous Acquisition and Life-Cycle Support (CALS) - Cost management strategy which facilitates the concurrent engineering process and offers great potential for reducing acquisition and in-service costs through leveraging of the current state-of-the-art in Information Technology (IT). Broad objectives to: (1) improve the management and efficiency of ship operating and support systems, (2) reduce cycle times, (3) improve fleet support, and (4) improve support technologies.

Cost-Benefit Analysis - A methodical process of determining the costs and benefits of a function/process/equipment, so that alternative solutions can be compared by examining a plot of cost against benefit. It will also reveal when diminishing returns set in. It is necessary to define cost and benefit numerically as far as possible to perform this process. See also "Operational Effectiveness."

Cost "Cap" - A (usually arbitrary) financial limit placed on the overall cost of a project, or of a part of it which is used as a management tool to force scrutiny of the requirements and of possible trade-offs. Also, the cost "cap" may be viewed as a cost goal utilized to limit the cost or arbitrarily force the cost down. Generally, this method will result in trade-off studies to assess the cost impact of changes to the design against the operational benefits and may employ an Investment Appraisal (IA) to compare the cost of various options to meet the operational requirement. See also "Design to Cost".

Cost Effectiveness - (1) A measure of the value of a function vis-a-vis the cost required to provide it. This can be simplistically given as a ratio of value/benefit to cost (assuming both can be so defined) and thus used to compare options. (2) A measure of the operational capability added by a system as a function of its life-cycle cost (DoD 5000.2, Part 15). (3) A measure of alternatives in terms of their marginal costs and benefits (DoD 5000.2, Part 8).

Design and Construction Margins - Margin allowances provided to cover problems of the design, and changes in the design requirements during the design and construction period of the ship. Allowances may be made for extra space, endurance, accommodations, structural strength, ships stability, propulsion power, electrical power, etc., so that a certain amount of change in the physical characteristics can be tolerated without having to enlarge the ship.

"Design-a-Little/Build-a-Little" - Refers to an incremental or gradual approach to technology insertion or design development; wherein, the aim is to control or mitigate risks (cost, schedule, technical or performance) associated with the introduction of the technological, design or process change. An example of this approach is the block upgrade method of technology insertion used in the U.S. Navy Aegis Shipbuilding Program, where design changes and product upgrades are collected and inserted into the design baseline of follow-on shipbuilding contracts as a block or group of changes.

Design-To-Cost (DTC) - (1) The practice of designing a system or product to a cost target or cost range, e.g., unit production cost, life cycle cost threshold, et cetera. The DTC goal can be in the form of average unit flyaway, rollaway or, in the case of ships, sailaway cost targets. Shipbuilders and GFM vendors can be provided with DTC contracting incentives to motivate them during the production phase. (2) A management concept that demands that cost be considered as a key design parameter during all phases of the acquisition process. DTC goals are established early to become part of the design trade-off process that examines other parameters such as schedule, performance and operational capability. (3) An acquisition management technique to achieve defense systems designs that meet stated cost requirements. Cost is addressed on a continuing basis as part of a system's development and production process. The technique embodies early establishment of realistic but rigorous cost objectives, goals and thresholds and a determined effort to achieve them (DoDD 4245.3).

Dual-Use - Refers to the development, application or use of technologies and products by both the commercial sector and the military sector, i.e., an item has a use in both sectors of the economy, military and commercial.

Future Growth Margins - Margin allowances provided for anticipated future installation of items which are either unneeded, unavailable or unaffordable at the time of initial construction.

Group Technology - The organization of alike work by looking for manufacturing commonalties, matching classes of problems to sets of solutions, and ignoring differences in design details; interim products (parts, subassemblies, and assemblies required to build ships) are grouped by the problems inherent in their manufacture. Designers are guided by a product-engineered build strategy in so grouping the information.

Interactive Electronic Technical Manual (IETM) - A paperless but functional equivalent of the conventional paper-based technical manuals; i.e., a technical manual stored or available in a digital medium which can be interactively shared or utilized.

Integrated Logistics Support (ILS) - A disciplined, unified and iterative approach to the management and technical activities necessary to:

(a) Integrate support considerations into system and equipment design;
(b) Develop support requirements that are related consistently to readiness objectives, to design and to each other;
(c) Acquire the required support; and
(d) Provide the required support during the operational phase at minimum cost.

[U.S. Department of Defense Directive 5000.39, "Acquisition and Management of Integrated Logistic Support for Systems and Equipment"]

Integrated Product and Process Development Team - A team approach towards systematically integrating and concurrently applying all the disciplines necessary to develop a product or process. The goal is to improve quality, productivity and flexibility while reducing development time, cycle time and costs.

Investment Appraisal - Refers to the assessment of goals and objectives to improve or enhance performance and capability, or to obtain these capabilities, weighed against the resources in cost and time for the development, and acquisition. An evaluation of the follow-on operation and support requirements associated and a return on investment analysis is also entailed.

Maintainability - The degree of ease or difficulty with which the ship/system/equipment is maintained. Its scope includes all aspects of the logistics associated therewith.

Margins - Allowances in ship designs provided to increase the probability of success of the design by providing some level of flexibility which is anticipated to cover emergent requirements during the design, construction and operational life for the ship. Said another way, margins incorporated in a ship design are provided to ensure the operational utility of the ship and its subsystems in consideration of the uncertainties and changes which may be encountered during the design and construction period and during the operation of the ship over its life.

Modularity - Refers to a ship design method which allows a number of sub-components to be assembled into a larger (repeatable) subassembly. Increased efficiency and greater flexibility by using standardized building blocks in construction are a result.

New Materials - This term, in the context of new technology, refers to the introduction or use of a new chemical composition or a new, alternate, or substitute material for a given application, e.g., composite material use for a deck-house vice the conventional use of steel or aluminum.

Operational Effectiveness - (1) The degree to which the ability of a force, to perform its mission, is improved or degraded by the introduction (into it) of a system, product, process or entity. (2) The ability of a system to fulfill a specified role. Operational analysis is used to assign a value to the system (e.g., measure of effectiveness), as the benefit side of a cost/benefit equation. (3) The overall degree of mission accomplishment of a system when used by representative personnel in the environment planned or expected (e.g., natural, electronic, threat, etc.) for operational employment of the system considering organization, doctrine, tactics, survivability, vulnerability, and threat (including countermeasures, initial nuclear weapons effects, nuclear, biological, and chemical contamination threats) (DoD 5000.2, Part 15).

Operational Suitability - (1) The value of a system for a specified role, as compared with other systems which can also carry out the role (may be described numerically or subjectively). (2) The degree to which a system can be placed satisfactorily into field use with consideration given to availability, compatibility, transportability, interoperability, reliability, wartime usage rates, maintainability, safety, human factors, manpower supportability, logistics supportability, natural environmental effects and impacts, documentation , and training requirements (DoD 5000.2, Part 15).

Process Simplification - Refers to ship design and construction procurement strategy based on an advanced product-oriented management approach which permits: standard designs of modules, a higher level of common equipment procurement, and parallel assembly of modular units and interim products. The concept promotes a factory-like working environment (wherein the functions of design and production are integrated) with a much increased level of pre-packaging and ship pre-outfitting, as compared to earlier practices which largely consisted of an un-integrated, piece-by-piece (or “stick-built”) design and production approach.

Product-Oriented Design and Construction - The practice of designing and building ships to a product orientation keeping in mind how the ship will be fabricated and constructed. Hull construction, outfitting, insulating and painting progress simultaneously. The ship is divided geographically into "interim" products. These interim products are standardized, as far as practicable, and fabricated by groups. This "group" technology takes advantage of the maximization of the processing of similar work through common work stations, and tends to group work together according to common attributes. To the maximum extent, construction is modular and carried out in workshops. The assembly of the ship is then made on hull blocks. The hull blocks are joined together and the ship is launched or put afloat with a high (70% or greater) degree of completion. Progress reporting and cost collection, in this case, are product and process oriented so that managers have a more tangible means of corroborating work completed in order to forecast work remaining and resources required for completion.

Reliability - The probability that the ship/system/equipment is functioning at a point in time.

Readiness-Based Sparing - An approach to spare parts provisioning which can be developed from reliability analysis early in the design phase, and continuing onwards, which can help to reduce depot maintenance inventories while increasing overall systems availability. In this approach, the determination of the level of spares holdings, onboard and at bases or depots, is numerically determined based on an engineering analysis of the likely failure rates.

Reliability-Centered Maintenance (RCM) - (1) An analytical process used to determine the maintenance requirements of any physical item during its operation, to maintain the reliability designed into the system. The result is a systematic blend of experience, judgment and reliability data to identify whether Preventive Maintenance (PM) or Corrective Maintenance (CM) is preferable. (2) A systematic approach for identifying preventive maintenance tasks for an end item in accordance with a specified set of procedures and for establishing intervals between maintenance tasks (DoDD 5000.39). (3) A maintenance philosophy based on a numerical assessment of the reliability of ship systems, so that maintenance is carried out when it is predicted to be needed, and not just when failure occurs, or on a time interval basis. RCM is often combined with equipment condition monitoring to adjust the predicted maintenance pattern.
Resource Control - (1) The management activity of deploying resources in an organized

manner to meet required tasks as efficiently as possible. (2) An early-stage-design cost management approach which adheres closely to a pre-defined cost target for a task, project or program by establishing a methodology to achieve the cost goals. The approach is essentially a closed-loop feedback control process of: (a) establishing budgets, (b) reviewing the design for conformance to the budgets, and (c) making decisions to change the design where design features exceed the established budgets. The approach provides the necessary cost visibility to establish a real-time link between design engineering, cost estimating and program decision making.

Risk Mitigation - Refers to actions, methods, techniques and processes to control or minimize the negative or adverse effects, or to ensure success of an entity, goal or objective, relative to the various kinds of risk: performance, technical, schedule and cost. Examples of this could be the use of modeling, simulation, prototyping cost/schedule control systems, systems engineering, etc.

Simulation-Based Design - Ship designs which are based on a process of conducting experiments with a model for the purpose of understanding the behavior of the system modeled under selected conditions or of evaluating various strategies for the operation of the system within the limits imposed by developmental or operational criteria. Simulation may include the use of analog or digital devices, laboratory models, or “testbed” sites. Simulations are usually programmed for solution on a computer; however, in the broadest sense, military exercises and wargames are also simulations (DoD 5000.2, Part 15).

Standard - A standard for either a naval or merchant ship specifies elements which will be applicable to many ships (thereby saving effort and costs if properly applied).
Standards may be categorized in two types:

Pure *requirement* standards, e.g. shock resistance, stability, environmental, accommodations, and habitability standards; and

Combination *requirement and imposed solution* standards such as paint, lifeboats, electrical grounding, and "standard" equipment.

Standardization - Refers to a ship design approach which decreases the number of different or unique components used in the product. It reduces the number of types of like items, components and modules to be designed, produced and procured. Consequently, there is an associated reduction in the requirement for spare parts. Standardization also involves the maximization of the use of common processes or activities to increase efficiencies from learning and group technology.

System-Engineering - The application of scientific and engineering efforts to:

(a) Transform an operational need into a description of system performance parameters and a system configuration through the use of an iterative process of definition, synthesis, analysis, design, test and evaluation;
(b) Integrate related technical parameters and ensure compatibility of all physical, functional and program interfaces in a manner that optimizes the total system definition and design;
(c) Integrate reliability, maintainability, safety, survivability, human and other such factors into the total engineering effort to meet cost, schedule and technical performance objectives.

[U.S. Military Standard 499A, "Engineering Management"]

In its simplest terms, systems engineering is both a technical process and a management process.

Value Engineering (VE) - VE is also more generally described as Value Analysis (VA). (1) The practice of determining the lowest possible cost for a specified process, product, project or service to reliably accomplish the intended function. VE is an organized effort to: (a) identify the functions of systems, equipments, facilities, procedures and supplies; (b) establish a value for those functions; and (c) achieve those functions at the lowest overall cost. (2) A method of engineering that systematically eliminates all costs that do not contribute to the value of the product, service or process. (3) A technique for identifying alternative means of satisfying a requirement, by systematic analysis of the requirement by its component parts, and the identification and determination of the lowest cost alternatives, by creative thinking.

Zonal Outfitting - Refers to a ship design and construction approach which employs a product-oriented work breakdown structure, rather than system-oriented. The aim is to perform the maximum amount of work during the most efficient stage of construction, i.e., maximize the opportunity to increase the overall productivity in the construction of a ship. Pre-outfitting in the shop or off-board the ship and modularity allow for a higher production efficiency, and may permit the use of less volume in the ship. The design and engineering effort to implement zone outfitting is generally higher than that of a system-oriented approach.

APPENDIX 3

SELECTED INFORMATION ON NATIONAL EXPERIENCES RELEVANT TO SHIP COST REDUCTION

1. General. This Appendix contains information on some national approaches and results to reduce costs of naval ship acquisition and in-service operation and ownership. It supports the findings that are mentioned in the various chapters of this ANEP. This information is based on the literature surveys and working papers contained in reference (a) and (f) of ANEP 49, Edition 2.

2. Manpower (Military Personnel) Cost Elements – United States.

   The elements of cost included or not included in the cost of navy personnel vary from nation to nation. The tables below (Figure 3-1; Figure 3-2) provide a delineation of these elements generally based on those of the United States Navy.

Direct Cost Elements for Enlisted and Officer Personnel	
Military Compensation Enlistment Bonus Reenlistment Bonus Special Pays Other Benefits	• Basic Pay, Allowances, Special and Incentive Pays, Retired Pay Accrual, Social Security, Permanent Change of Station, and other Miscellaneous Pays. Direct personnel costs apply to any Navy person, whether assigned to the direct forces or indirect (supporting) forces.
Permanent Change of Station (PCS) Costs	• Permanent Change of Station • Categories of Moves: - Accession - Training - Operational - Rotational - Separation
Separation Costs	• Movement from last permanent duty station to point of separation, including movement from overseas.
Retired Pay Accrual	• Contributions to Military Retirement Fund for both officers and enlisted.
Non-Navy (paid by MoD or other Agency)	• Veteran's Benefits (e.g., continuing education, member/dependent medical support)

Figure 3-1

Variable Indirect Cost Elements for Enlisted and Officer Personnel	
Recruiting Training (General) Medical Support Administrative Activities	• Those costs associated with acquiring (recruiting), training (inclusive of basic training through initial skill training to arrival at the member's first duty station), locating (costs borne while member is in that temporary travel and training status) and supporting (base operating support, administrative support and medical support) the direct personnel and the indirect (supporting) personnel who themselves must be acquired, trained and located.
Officer Acquisition	• Military training and indoctrination for officer candidates as part of a college curriculum or post-baccalaureate program, and preparatory training for selection to such an accession program (includes Naval Reserve Officer Training Corps). Includes college instruction to enrolled baccalaureate degree seeking students covering tuition, fees, books and administrative costs of the program.
Training (Specialized Skills)	• Resources used to develop curricula and train a workforce of officer and enlisted personnel to man and support the operating force platforms and their installed weapons systems. Enlisted personnel receive broad career-field and Naval Enlisted Classification ratings upon completion of initial and advanced training programs in the areas such intelligence, cryptologic/signals and nuclear power operation.
Individual's Account	• A Defense Planning and Programming Category of manpower that includes military personnel who are not considered force structure manpower and consists of transients, patients, prisoners and holdees (TPPH), students, trainees and cadets. • TPPH - Transients (T). This category contains only the transient program element, and consists of active duty military personnel in travel, leave enroute or temporary duty status (except for training) while on PCS orders. - Patients, Prisoners and Holdees (PPH). This category contains only the Personnel Holding Account program element consisting of active duty military personnel dropped from the assigned strength of an operational or training unit for reasons of medical, disciplinary or separation non-availability. - Students, Trainees and Cadets/Midshipmen. This category contains active service officer students, active enlisted students, active enlisted trainees, service academy cadets and midshipmen and active officer accession students not assigned to a specific unit or activity.
Base Support	• Includes activities that predominantly support operating forces. Base support includes operation of utility systems, public works services, base administration, supply operations, base services such as transportation and security, personnel support functions, bachelor quarters operations, morale, welfare and recreation operations, disability compensation and environmental and hazardous waste management.
Non-Navy (paid by MoD or other Agency)	• Veteran's benefits (e.g., continuing education, member/dependent medical support)

Figure 3-2

3. <u>Manning Reduction Through Automation – Germany.</u>

A study by the German Navy, reference III-a, using a "reference frigate" as an example, found that the life cycle costs decrease by DM 26 million per ship (1992 currency) for a reduction of the crew by 50 persons (averaged over 10 ships with a life cycle of 25 years) as shown below:

Initial Investment Cost (increase)	=	+ 14.0
Ship Size Reduction	=	- 10.0
Increased Maintenance (.8/yr x 25)	=	+ 20.0
Crew Size Reduction (2/yr x 25)	=	- 50.0
Life-cycle savings	=	- 26.0

4. Commercial Practices – United States.

What are commercial practices? The following eight areas have been defined by U.S. DoD program managers, reference III-b, as distinct practices viewed as commercial practices:

i. Past Performance: Uses previous performance on government contracts as a source evaluation factor.

ii. Best Value: Determines contract award on a range of evaluation factors besides simply lowest price, such as quality, life-cycle support, life-cycle costs and other relevant factors.

iii. Commercial Warranties: Rather than special, government-unique warranty requirements, the acceptance and use of standard commercial product warranties or purchase of extended product warranties.

iv. Government/Contractor Cooperation and Relationship: A cooperative and mutually beneficial relationship between government and its contractors characterized by reducing government oversight, establishing long-term partnerships, and including contractor or industry participation in program Integrated Product Teams (IPT).

v. Performance Specifications: Defines the government's requirements in terms of performance. Gives the contractor more flexibility to reduce costs and enhance support. In addition, shifts ultimate responsibility for performance to the contractor.

vi. Commercial Specifications and Standards: Requires the same design, production, management, and accounting practices in government contracts as are currently used in the commercial marketplace. (In 1994, the U.S. Secretary of Defense mandated this practice for DOD.)

vii. Streamlined Contract Administration: Fundamental drive to simplify government acquisition processes by streamlining internal policies and reducing contract data deliverables. Electronic data interchange has shown results in this regard.

viii. Commercial Off-The-Shelf/Non-Developmental Item: Use of products developed and available in the commercial sector (COTS), and use available products and items which do not require further developmental investment (NDI).

5. Impact of Military Requirements on Platform Costs - France.

A French study (reference III-c) compares the frigates LA FAYETTE (to military standards and practices) and the FLOREAL (to commercial standards and practices) and dissects the cost differentials into categories of military requirements as it applies to platform costs. The summary results are shown in Figure 3-3. The ships have vastly different missions and military payloads and differ by a factor of about three in terms of unit production costs. Of this, the analysis shows that 34% overall is due to specific military requirements.

Impact of Military Requirements on Platform Costs

(Percentage Increase): French Frigates (LA FAYETTE vs. FLOREAL)

Platform Cost Element	Shock Resistance	Signature Reduction	Vulnerability Survivability	Service Life	Other	Total
Hull	+7.8	+5.1	+9.4	+1.7	-	+24.0
Auxiliaries & Outfitting	+4.5	+6.7	+11.1	+1.4	+6.9	+30.6
Electrical Plant	+8.0	+4.2	+22.8	+7.6	-	+42.6
Propulsion	+10.7	+22.8	+9.0	+4.1	+2.9	+49.5
Total Platform	+7.1	+9.1	+11.8	+2.9	+3.1	+34.0

Figure 3-3

6. Impact of Military Requirements on Platform Costs – Germany.

Figure 3-4 illustrates the effects on cost of pure commercial standards versus a combination of commercial and navy specifications versus pure navy specifications. Specifically the charts, per reference III-d, show the per unit cost variation as achieved for commercial pipe installation and hull painting.

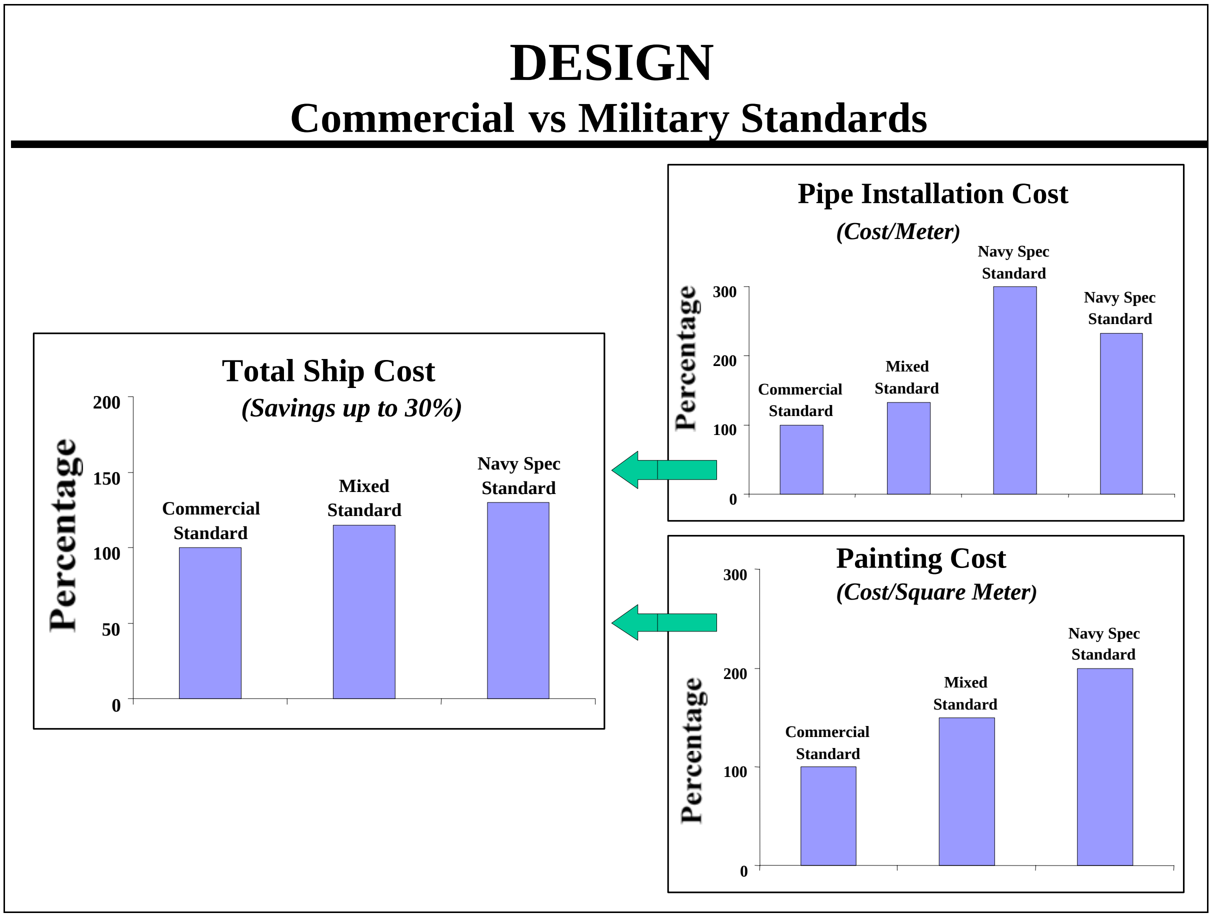

Figure 3-4

7. <u>List of References</u>

III-a "Possibilities to Reduce Costs in Naval Ship Construction and Resulting Technical Consequences," Burmeister, H.P., Presentation at IEG/6 meeting, November 1992.

III-b "Commercial Practices – Dilemma or Opportunity?" by LCDR Michael H. Anderson, USCG and Dr. Eric Rebentisch, *<u>Program Manager</u>*, (Defense Systems Management College Press)Volume XXVII, No. 2, DSMC 143, March-April 1998.

III-c "An Analysis of Military Requirements Influence on Ship Costs – Platform Portion – By Comparison of Frigate Classes 'FLOREAL' and 'LA FAYETTE' Costs," Vialatte, P and Cottin, Y, (unpublished), May 1995.

III-d "Application of Commercial Standards in Naval Ship Construction," Scheel, H., (Presentation to IEG/6 Ad Hoc Working Group on Ship Costing), Hamburg, Germany, February 1993.

APPENDIX 4

VALUE ENGINEERING PROCESS STEPS

The tasks to be performed in the respective VE steps or phases are described below:

(1) Prepare the project:

- select moderator, analyze mission, define tasks, identify goals, objectives, conditions to be met;
- develop targets/target hierarchy;
- determine scope of analysis;
- develop project organization; and
- determine sequence of events/project plan.

The moderator coordinates, rather than commands, the team and ensures that all team members start with the same status of information/knowledge of the project and that mental obstacles and reservations which may preclude one from escaping common tracks and "traditional" patterns of thinking are removed.

(2) Analyze the object:

- identify the object to be analyzed/evaluated;
- gather object-related and relevant information; collect cost data;
- determine and structure functions;
- evaluate factors and premises affecting solutions; and
- allocate cost to functions.

Besides fact gathering, the decisive task in this phase is to break down the object into functions and to structure these functions into a logical hierarchy. Through the identification and allocation of functions, it will be apparent if and where "nice-to-haves" have crept in. A matrix, in which functions and cost per function(s)/sub-function(s) are compiled, shows the relationship between costs and functions of the object. The evaluation of the functions, in context with the object, may lead to the conclusion that some can be eliminated because they are costly and not essential to the mission.

(3) Describe the requirements:

- evaluate gathered information;
- determine required functions;
- establish premises; and
- determine cost targets and allocate these to the established functions.

The establishment of required functions is based on those which have been developed in the preceding phase. With the establishment of cost targets and their allocation to functions, each individual function will reflect a certain value within the object.

(4) Develop solutions:

- Identify existing solutions
- develop new solutions
- evaluate and modify existing solutions

Whereas the analytical effort of the process is concentrated in the requirements description phase, the essence of this phase is creativity.

(5) Propose solutions:

- establish assessment criteria;
- assess solution ideas/proposals;
- condense ideas/proposals to solutions;
- assess solutions; and
- prepare solutions for decision.

This phase serves primarily to condense and to filter solutions and to prepare them for decision. The decisive criterion upon which to select a solution is to what degree the established targets are met. The findings of this phase are compiled into a report as a basis for decisions. At the end of this phase, the client will decide which solution or combination of solutions is/are selected for implementation.

(6) Implement solutions:

- plan implementation in detail;
- implement solution(s);
- monitor implementation; and
- conclude the project.

In contrast to many other processes, VE does not end with the decision. The assigned responsibility remains valid until the project is formally concluded with a final report. Alterations or changes may require revisions or even a new start of the whole process.

VE may also be more generally described as Value Analysis (VA). References (IV.a) and (IV.b) give some examples of application of VE techniques to commercial shipbuilding in France.

(7) List of References

IV.a “La consruction navale n’est pas encore morte!.” Petitdemange, C., L’A.V. Dans L’Economie, La Valeur no. 36.

IV.b “C.C.o.: Oui a l’avenir d’un grand Chantier naval,” Vivier, F., 4th congres de l’A.F.A.V., April 1986.