1381-22 (4-EAM-2575)

U.S. NAVAL AUXILIARY, AMPHIBIOUS, MSC AND MINEHUNTING TYPE VESSELS DETAIL DESIGN COST ESTIMATING MODEL

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U.S. NAVAL AUXILIARY, AMPHIBIOUS, MSC AND MINEHUNTING TYPE VESSELS DETAIL DESIGN COST ESTIMATING MODEL

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1.0 INTRODUCTION

During the last 10 years, Gibbs & Cox, Inc. has developed a number of ship construction cost models for the Naval Center for Cost Analysis (NCA). These models include the following:

- Revised Destroyer/Cruiser Construction Model [Reference (1)]
- U.S. Naval Vessels (Auxiliary and Amphibious Ships) Construction Cost Model [Reference (2)]
- Revised Follow Ship and Follow Yard Construction Cost Model [Reference (3)]
- Ship System Modernization Cost Model [Reference (4)]
- Cost Model : Follow Ship and Follow Yard [Reference (5)]
- Cost Model: U.S. Naval Vessels (Destroyer Type) [Reference (6)]
- Cost Model: U.S. Naval Vessels (Auxiliary and Amphibious Ships) [Reference (7)]
- U.S. Naval Vessels Detail Design Cost Estimating Model [Reference (8)].

In the lead ship construction models, ship construction labor and material costs are estimated using cost estimating relationships (CER's) developed from historical data provided by various shipyards, and based on a modified two digit ship's work breakdown structure (SWBS).

One element of the ship's construction cost that is not fully included in these models is the cost for engineering detail design. In the previous auxiliary and amphibious ship construction model these engineering costs are identified under SWBS Group 800. This study provides a method for estimating total engineering costs for U.S. Naval auxiliary, amphibious, MSC and minehunting type vessels and includes data from various shipyards including Bath Iron Works, Ingalls Shipbuilding, Avondale and NASSCO. The model consists of three basic elements: a historical data base for ship detail design costs, a set of CER's to determine total ship detail design labor and material costs, and a brief summary of the analysis performed to derive CER's used.

This model is based primarily on historical detail design costs and selected shipyard construction data for recent U.S. auxiliary, amphibious, MSC and minehunting type vessels. The model is similar to detail design cost estimating models previously developed for NCA, and is intended for use in conjunction with the auxiliary and amphibious construction cost model. Included in the data base are engineering and shipyard production data for the following auxiliaries and amphibious ship classes, as well as similar ships within the Military Sealift Command (MSC) inventory and cost estimates provided by shipyards for use in previous models:

Amphibious Warfare Ships

LHD-1 Class Amphibious Assault Ships
LSD-41 Class Dock Landing Ships

Auxiliary Ships

AOE 6 Class Fast Combat Support Ships
AO 177 Class Oiler (Conversion)

Military Sealift Command (MSC) Ships

T-AO 187 Class Oilers
T-AGS 45 Class Surveying Ships

Shipyard Estimates

T-AGOS 19 Class SWATH Ocean Surveillance Ships (BIW)
7100 Ton SWATH (BIW)

In addition, data for two classes of Mine Warfare Ships are considered in this model. These include:

Mine Warfare Ships

MCM 1 Class Mine Countermeasure Ships
MHC 51 Minehunter (Coastal)

All cost estimating relationships in this model are related to shipyard production and engineering costs and are developed at the whole ship level. A CER for estimating total engineering labor manhours was derived based on lead ship production manhours. A CER for estimating engineering material costs was derived and related to the engineering manhours costs.

An additional CER for estimating aggregate follow ship engineering costs was developed based on lead ship engineering costs. Both the data base and the CER's are provided to NCA in hard copy in this report and on floppy disk using Lotus 1-2-3 Release 3.

Engineering design is handled differently by different shipyards. In many yards, most of the work is performed by the yard, while in other cases, the yard is supported by an independent naval architect or a group of independent naval architects. As such, the cumulative effort is often performed by a number of organizations using different accounting systems. In addition, each yard structures its engineering activities to meet its specific production needs. The total engineering labor encompasses the various engineering activities within the yard, including detail design and production engineering. The shipyard typically reports all the engineering costs to the Navy as a single item: under SWBS Group 800 - Integration/ Engineering (Shipbuilder Response). These cumulative costs represent the engineering cost data used in development of the CER's and are, therefore, the costs estimated by the CER's.

The remainder of this report consists of four chapters. Chapter 2 presents a brief summary of the engineering design process. Chapter 3 discusses the data base. Chapter 4 presents the cost estimating relationships. Chapter 5 provides conclusions and recommendations.

2.0 DETAIL DESIGN PROCESS

2.1 Introduction

In this section a summary of the detail design process is presented to provide insight into detail design. The purpose of detail design is to convert the Navy definition of the ship, as contained in the contract design technical package, to the products necessary to construct a ship, including:

- Purchase specifications for equipment.
- Working drawings for fabrication and installation of structure, outfit, piping, cabling, propulsion systems, electrical systems, and distributive systems such as heating, ventilation and air conditioning.
- Parts list for components
- Bulk material ordering data (steel plate, pipe, etc.)

Detail design also produces supporting documentation in response to the contract data requirements list (CDRL) including:

- Calculations
- Weight reports
- Integrated logistic support data

- Planning and scheduling data
- Cost/performance reports
- Technical manuals
- Selected Record Drawings (Ship information book, propulsion operating guide, etc.)

The level of detail and comprehensiveness of a detail design package are to an extent dependent upon the information required for a shipyard to define the ship to a sufficient level of detail to build the ship, and to an extent on the deliverables and other information required by the client or regulatory approval agency. Typically, a government agency will impose greater deliverable submittals and reporting requirements than a commercial client. Also, typically, a highly complex ship, such as a surface combatant, will require significantly more design effort to define the ship, than will a less complex ship such as an oil tanker.

The detail design process discussed in the following paragraphs reflects a comprehensive design for the U.S. Navy, in a shipyard using zone construction with extensive preoutfitting. This is presented to indicate the activities involved in detail design, and is considered representative of activities that would take place during detail design of a complex U.S. Naval ship.

The first step in detail design is to extend the contract design at a whole-ship or total system level. Typically, the following major products are developed during this phase:

- Purchase specifications

- Compartment and access (C&A) drawings, space arrangements
- Producibility input, design standards
- System diagrams
- Scantling drawings
- Accepted weight estimate
- Design review input

The purchase specifications for major vendor-furnished information (VFI) are critical elements in the detail design process. Late or incomplete VFI (along with ECP's) is one of the leading causes of cost increases and schedule delays. The technical requirements to prepare the purchase specifications are generally derived from the system diagrams and ship specifications leading to the following sequential products:

- Purchase specifications defining technical and contractual requirements for vendor furnished equipment. These may be issued in two phases: inquiry specifications to determine available sources and to obtain preliminary proposals, and the final specification.
- Purchase orders authorizing the vendor to begin development of the equipment, including design drawings, materials lists, performance data, etc.
- Release for manufacture, authorizing production.

- Final VFI (interface control drawings).

The C&A's are an expansion of the contract design general arrangements and provide locations for all bulkheads, decks, accesses and other principal features. The size and type of all hatches, scuttles, doors, etc. are also identified. The C&A's serve as a key configuration control tool throughout detail design. Space arrangement drawings again expand on the contract design drawings and include machinery, combat system and selected operational spaces. These drawings begin as the arrangements backgrounds for the design control process described below. After they are iterated and refined during the design process, they are formalized as space arrangement drawings identifying all major and minor equipment and major system runs.

The producibility and design standards input is essential early in the process, and includes the following:

- Producibility manual defining recommended production principles and techniques to enhance producibility, including unit breaks.

- Standard details including structural and foundation details, pipe hangers, pipe connections, cableway hangers, joiner details, standard fittings, penetrations, etc.

- Drawings and list formats

- List of standard bulk materials

System diagrams, including the contract design piping and HVAC diagrams, are developed in detail, although still at the diagram level, including all duct and pipe sizes, fittings, instrumentation, control components and materials. Calculations are developed in accordance with the ship specifications to optimize the design. Cable block diagrams and wiring connection lists are also prepared by system.

The contract design midship section and scantling drawings are expanded to reflect unit breaks and major details such as transitions of double bottoms, bow and stern framing, machinery foundations, local built-in tanks, etc.

The accepted weight estimate is submitted early in the contract to define the contractual limits on light ship weight and vertical center of gravity.

The contract will establish a schedule for formal design reviews, generally monthly, as well as quarterly program reviews. In addition, periodic, less formal liaison visits are recommended to address specific technical issues. Typically, the detail design effort should begin with an intense review of the contract package to identify open issues, questions, inconsistencies, etc. However, recent shipbuilder involvement in contract design has reduced the importance of such post-contract reviews.

During the next phase of detail design, compartment level arrangements, structure and distributive system arrangements are developed and integrated, including precise location of system runs that were previously at the undimensioned diagram level. This can be done manually or by computer. In the manual process, the following procedures are followed:

- Priority routing drawings are developed for each deck identifying constraints on running systems (e.g., noise limits, locked spaces, shock and blast areas, etc.) and blocking out primary system runs.

- Overlays are prepared indicating equipment locations, structure, removal routes, and access/maintenance envelopes.

- Teams of designers representing piping, cabling and HVAC negotiate optimum routes for system runs, modifying equipment arrangements, etc. as required.

- An interference check is run to identify and resolve all interferences between systems, equipment and structure.

- The final system overlay is the key configuration control tool for subsequent development of the detail design.

The next major phase of the detail design process results in production of zone-oriented working drawings providing all details necessary to fabricate and outfit the ship. Each drawing is limited to a specific design zone or, in some cases, groups of contiguous zones. Zone drawings are developed for the following major categories:

- <u>Hull</u>
  - Structural units
  - Closure lists
  - Foundations
  - Uptakes, intakes
  - HVAC installation
  - Hull outfit installation
  - Joiner, furniture fabrication
  - Insulation, deck covering
  - Weapon system installation

- <u>Machinery</u>
  - Shafting

    - Piping installation
    - Valve operating gear
    - Pipe hangers
    - Label plates

- <u>Electrical</u>
    - Electrical equipment installation
    - Cabling deck drawings
    - Installation degaussing, main cableways, transits, stuffing tubes
    - Lighting system

The development of zone and functional drawings overlaps, with iteration as required to suit design development.

The zone design drawings are used as the basis for production drawings that are oriented to specific trades within the shipyards. For example, a zone piping installation drawing that defines all piping in a zone will be broken out into individual pipe pieces as input to the pipe shop. Likewise, HVAC zone installation drawings will be broken down into individual duct fabrication drawings as input to the sheet metal shop. The total number of drawings for all phases of detail design can be well over 3000.

As with the other phases of detail design, there is insufficient data to determine how much, if any, savings are realized through the use of CAD/CAM for detail design. There is general agreement that there will be substantial savings downstream during follow ship design and modernization.

2.2 Detail Design Contracting Methods

The development of detail design can be accomplished by the shipyard as part of the lead ship contract, or under a separate contract independent of the shipbuilding contract. In the former case, which is the more typical, the shipyard may use its own design staff, a design agent or a combination. In the case of a combination, the yard will normally concentrate on the later production-oriented phases with the design agent working up front. Alternatively, a major portion of a design may be broken off to give to the agent, such as the bow or superstructure zones, with the shipbuilder controlling the interface.

The advantages of having the shipyard develop the design are primarily related to liability. The yard can tailor the design to their production techniques and is responsible for developing a design that supports their production cost and schedule estimates. If the Navy supplies the design, there are potential problems with late, inaccurate or incomplete drawings and incompatibilities with yard-unique production processes.

On the other hand, the use of a separate contract for detail design offers the opportunity to begin detail design in advance of the lead ship contract, which minimizes design schedule compression. It also supports development of a design that is not uniquely tailored to one shipyard, if both lead and follow yards are selected simultaneously (similar to FFG 7 or SSN 21).

2.3 Detail Design Scheduling

The schedule for detail design is driven by conflicting factors. The shipyard will generally want to start pre-outfitting in highly complex areas such as the machinery box, since these areas drive the overall schedule. Further, these areas are the most difficult to design, since they are VFI-intensive and complex in terms of system layouts. Thus, production wants to advance the schedule for such areas, while design wants to stretch the schedule.

The use of pre-outfitting also creates significant problems in scheduling due to the basic incompatibility of the design process and the need for early design information to support pre-outfitting. For example, the yard would like to install back-up structure for foundations as part of structural unit assembly, early in construction. However, the sizing and location of that structure is dependent first on completion of design control, and second on receipt of final VFI to support foundation design. Inevitably, these two sets of requirements are out of phase, which often limits the extent of pre-outfitting that can be accomplished on the lead ship.

3.0 DETAIL DESIGN DATA BASE

3.1 Introduction

This report presents a procedure for estimating engineering design costs of U.S. Naval auxiliaries, amphibious, MSC and minehunting type vessels. The lead ship detail designs are used as the foundation for the design of all follow ships of the class, class upgrades, major variants of the class, and occasionally as a parent platform for a new ship class. As such, the initial high non-recurring costs on a lead ship detail design are, to a certain degree, amortized over the entire class of ships. On the other hand, detail design activity is ongoing during the period of construction of the class and its variants in order to incorporate changes. To develop a comprehensive data base on detail design, elements of the various aspects of design activities must be included, particularly major cost drivers such as lead ship design, ship conversion and major upgrade design. The data base developed for this model contains a good cross section of these design costs.

The data used in this study was derived from three sources: Shipyard Cost Performance Reports (CPR's), data provided by SUPSHIPS New Orleans, and data derived from the auxiliary and amphibious ship construction cost model. The first two sets of data, provided by NCA, represent return cost data for the ships listed in Table 3-1. The data derived from the auxiliary and amphibious ship construction cost model consists of design and construction cost estimates developed by Bath Iron Works for the T-AGOS 19 SWATH and a 7100 ton SWATH.

TABLE 3-1
SOURCES FOR RETURN COST DATA

SHIP TYPE	SHIPYARD	DATA SOURCE
Amphibious Ships		
LHD 1	Ingalls	Cost Performance Reports
LSD 41-44	Lockheed	Cost Performance Report
LSD 44-51	Avondale	SUPSHIP Data
LSD 44-51	Avondale	Cost Performance Reports
Auxiliary Ships		
AOE 6	NASSCO	Cost Performance Report
AO 179, 180, 178, 177, 186[(1)]	Avondale	SUPSHIP Data
[(1)] Ship Conversion		
MSC Ships		
T-AGS 45	Avondale	SUPSHIP Data
T-AO 187-189, 190, 193, 195, 197-204	Avondale	SUPSHIP Data
T-AO 191, 192, 194, 196	Penn Ship	Cost Performance Reports
Mine Warfare Ships		
MCM-1	Peterson Builders	Cost Performance Report
MCM-2	Marinette Marine	Cost Performance Report
MHC-51	Intermarine USA	Cost Performance Report
MHC-53	Avondale	Cost Performance Report

This engineering design model is similar to the surface combatant detail design model developed by Gibbs & Cox, Inc. for NCA [Reference (8)]. The model uses historical shipyard engineering and construction data to first relate engineering labor manhours to production manhours; second, to relate engineering material dollars to engineering labor dollars and third, to relate lead ship engineering costs to follow ship engineering costs.

The engineering cost estimating model is intended to be used in conjunction with the auxiliary and amphibious construction cost model [Reference (2)]. The construction cost model estimates lead ship construction costs using CER's from 22 cost groups based on the Navy's Ship Work Breakdown Structure. These CER's relate ship characteristics, such as weight, shaft horsepower etc., to labor and material costs derived from historical shipyard construction costs.

The data base developed for this model is intended to be a comprehensive set of data on the ships used to both provide sufficient data to develop the CER's for this model, as well as to provide NCA with a compendium of data on the ships for comparison purposes. The level of detail provided is based on the availability of the data and is intended to be consistent with the data required for the engineering design and construction cost estimating models. The data base is PC based and presented in Lotus 123 Release 3. Standard summary sheets have been developed to summarize the ship characteristics, ship 1 digit weight, labor and material cost data by SWBS, and a breakdown of the lead and follow ships engineering and production costs.

The ships characteristics and SWBS summaries are consistent with the parameters used in the construction cost model, albeit at the 1-digit SWBS level. This is because the shipyard cost performance reports do not report costs beyond the first digit level.

The breakdown of ship engineering and production costs are based on the most recent "estimate at completion" costs available to NCA from either the shipyard CPR's or SUPSHIP New Orleans. The data is summarized to highlight engineering versus production labor and material cost in manhours and unburdened dollars. Additional total contract data and original contract data is also provided to identify the multipliers needed for determining fully burdened costs.

Much of the raw cost data is business sensitive. As such, this data is only provided in the PC-based data base, and is not reproduced in this report. Costs presented in this report have been sanitized and are not considered business sensitive.

A summary of the data base for the ships used in this model is provided in the following sections. General ships characteristics and descriptive narrative are derived from Reference (9), except where noted. Cost data sources are provided in each data set.

3.2 LHD 1 Class Amphibious Assault Ships (Multi-Purpose)

The lead ship of the WASP Class amphibious assault ships was commissioned in 1989. The class consists of five ships: the fourth of which, LHD 4, will be commissioned in 1994. The general characteristics of the LHD 1 are shown in Table 3-2.

The WASP Class ships were designed as multi-purpose amphibious assault ships that combine the features of several previous amphibious ships. The LHD carries a complement of 1873 troops including 98 officers, and has a cargo capacity of 101,000 cubic feet, with an additional 20,000 square feet to accommodate vehicles. In addition, a 50-foot wide well deck accommodates up to three amphibious air-cushion vehicles (LCAC). The LHD has a HY-100 steel flight deck with two aircraft elevators and nine helicopter landing spots. The ship typically carries a mix of 30 helicopters and six to eight Harriers (AV-8B), but also has the capability to support the AH-1W Super Cobra, CH-53E Super Stallion, CH-53D Sea Stallion, U/CH-46E Sea Knight, UH-1N Twin Huey, AG-1T Sea Cobra, and SH-60B Seahawk helicopters. The LHD's bridge is two decks lower than that of an LHA, and command, control and communication spaces were moved inside the hull to avoid "cheap kill" damage. The ship is outfitted with ITAWDS and MTACCS combat data systems and a variety of air, surface, and navigation radar systems. Its armament systems include SAM, Sea Sparrow with two launchers, Vulcan Phalanx Mk 15 and 8-12.7 mm MG guns. Countermeasures include four Loral Hycor SRBOC 6-

TABLE 3-2
GENERAL CHARACTERISTICS OF LHD 1 LEAD SHIP

SHIP TYPE:	LHD 1 Amphibious Assault Ship
SHIPYARD:	Ingalls Shipbuilding Division
COST DATA TYPE:	Return Cost[1], Lead Ship, Lead Yard
COST DATA SOURCE:	Cost Performance Report, CORL A003, Issue No. 100 Contract No. N00024-82-C-2260, dated 13 March 1991

LEAD SHIP CHARACTERISTICS[2]:

Commissioning (year)	1989
Delivery (year)	1989
Displacement, Light Ship (LT)	27,965
Full Load (LT)	34,350
LBP (ft)	788
Beam (ft)	106
Draft (ft)	27
Depth at Side (ft)	91
Cubic Number (LxBxD)/100	76,010
Volume (cubic ft)	
Complement, Ship	1,077
Troop	1,873
Power Plant	Steam
SHP (HP)	70,000
Shafts/Propellers	2
Electric Plant	Steam/Diesel (Emergency)
Kilowatts	16,500
400 Hz KW	12,500
Other	

NOTES:

1. *All costs based on estimate at completion.*
2. *All data are from Ships Specifications and Janes' Fighting Ships 91-92.*

barrelled fixed Mk 36, SLQ 25 Nixie acoustic torpedo decoy system, and ESM/ECM SLQ 32 (V)3 combined radar warning, jammer and deception system. Power for the ship is provided by two Westinghouse geared steam turbines of 70,000 shaft horsepower.

Ingalls Shipbuilding Corporation (ISI) developed the detail design of the LHD and also built the lead ship. Follow ships are also being built by ISI.

The labor, material and detail design cost data developed for the LHD 1 were obtained from a cost performance report, CORL A003, Issue No. 100, Contract No. N00024-82-C2260. All costs are based on an estimate at completion. Labor costs in manhours are broken down by SWBS. Table 3-3 provides a summary of labor manhours costs for the LHD 1. A summary of unburdened labor dollars is provided in the PC-based data base.

Percent material costs are based on reported material dollars, compared to a labor cost, using the contract data provided. Table 3-4 provides a summary of the engineering cost relationships derived from the data base.

TABLE 3-3
LHD LEAD SHIP LABOR AND MATERIAL COST DATA

SWBS NO.	LABOR COST
	KMHRS
000	0
100	2,773
200	114
300	1,777
400	278
500	2,214
600	2,097
700	84
800	4,716
900	3,472
Other[1]	2,136
TOTAL	**19,661**

NOTES: (1) Includes: System Test and Evaluation, Project Management and System Engineering, Data, Fitting Out for Delivery, and Contractor Support

TABLE 3-4

LHD 1 ENGINEERING COST RELATIONSHIP

Engineering MHRS/Productions MHRS:	0.30
Burdened Engineering Material Dollars/ Burdened Engineering Labor Dollars	0.15

3.3 LSD 41 Class Dock Landing Ships

The lead ship of the WHIDBEY ISLAND Class, LSD 41, was built by Lockheed Shipbuilding and Construction Company and was commissioned in May 1985. The class consists of eight ships with five additional cargo carrying variants built to provide increased cargo-carrying capability. The LSD program was transferred to Avondale Shipyard beginning with the LSD 44. Avondale has been responsible for all subsequent design and construction activities for the program. The first cargo variant, LSD 49, was authorized and funded in FY 1988. The general characteristics of the LSD 41 are shown in Table 3-5.

The ships of the WHIDBEY ISLAND Class, LSD 41 through LSD 48, principally carry cargo and landing craft and are equipped with a removable helicopter platform above the docking well. The ships of this class are based on the ANCHORAGE Class (LSD 36 - LSD 40) design, but have a slightly larger docking well suitable for air cushion assault landing craft (LCAC). The WHIDBEY ISLAND Class has a capacity of 5000 cubic feet for marine cargo and 12,500 square feet for vehicles. It is also equipped with one 60 ton and one 20 ton crane. The cargo variant, LSD 49, is the first ship in the HARPERS FERRY Class. This variant represents a minimum modification to the LSD 41 design. It has 40,000 cubic feet for marine cargo and 13,333 square feet for vehicles, but only two LCACs. Other changes include additional air conditioning, piping and hull structure; the forward Phalanx is lower down and there is only one

TABLE 3-5
GENERAL CHARACTERISTICS OF LSD 41 CLASS SHIPS

SHIP TYPE:	LSD 41 Class Dock Landing Ship
SHIPYARD:	Lockheed (LSD 41-43) and Avondale Shipyards (LSD 44-51)
COST DATA TYPE:	Return Cost [(1)], Lead and Follow Ships, Lead and Follow Yards
DATA SOURCE:	1. Cost Performance Report, Contract No. N00024-84-C-2027, dated 31 March 1989 2. Revised Data Sheet Provided to NCA, dated 30 June 1991 3. Cost Performance Report, Contract No. N00024-80-C-2080, dated 28 June 1987 for LSD 41-43 4. Cost Performance Report, Contract No. N00024-85-C-2027, dated 30 June 1989 for LSD 45-48 5. Cost Performance Report, Contract No. N00024-88-C-2048, dated 31 December 1991 for LSD 49-51

LEAD SHIP CHARACTERISTICS[2]:

Commissioning (year)	1985
Delivery (year)	
Displacement, Light Ship (LT)	11,057
Full Load (LT)	15,685
LBP (ft)	609
Beam (ft)	84
Draft (ft)	20.5
Depth at Side (ft)	44'-6"
Cubic Number (LxBxD)/100	21,680
Volume (cubic ft)	
Complement, (Total Accommodations)	340
Power Plant	Diesel
SHP (HP)	41,600
Shafts/Propellers	2/CP Propellers
Electric Plant	Diesel (4)
Kilowatts	5,200
400 Hz KW	149
Other	

NOTES:

1. *All costs based on estimate at completion.*
2. *All data are from Ships Specifications and Janes' Fighting Ships 91-92.*

crane. There is approximately 90 percent commonality between the HARPERS FERRY and WHIDBEY ISLAND Class ships.

The LSD 41 carries a complement of 340 troops including 221 officers. The ship is outfitted with SATCOM SAR-1 and WSC-3 (UHF) combat data systems, and a variety of air, surface and navigation radars. Its armament systems include two GE/GD 20 mm/76 6-barrelled Vulcan Phalanx Mk 15 and two Mk 67 20 mm 8-12.7 mm MG guns. Countermeasures include four Loral Hycor SRBOC 6-barrelled Mk 36 and an ESM:SLQ32 intercept system. Power for the ship is provided by four Colt-Pielstick Type 16 PC25-V400 diesels with two controllable pitch propellers.

All costs for the LSD 41 data base represent an estimate at completion. The lead ship of the class and the next two follow ships were built by Lockheed Shipbuilding and Construction Company. The detailed cost data for these three ships is provided in the PC-based data base as obtained from the cost performance report, Contract No. N00024-80-C-2080. The data base for the LSD 41 contains only total costs in dollars. As such, it is not possible to identify a relationship between engineering and production manhours or engineering labor and material costs.

LSD 44 represents a lead ship in a follow yard, with Avondale Shipbuilding Industries as the sole yard for the remainder of the WHIDBEY ISLAND Class. The labor, material and detail design cost data for LSD 44 was obtained from a cost performance report, Contract No. N00024-84-C-2027. Similar cost data for LSD 45 through LSD 51 was obtained from the cost performance reports listed under data source in Table 3-5. All detailed cost data for the LSD 44 to LSD 51 ships is provided in the PC-based data base. A summary of the engineering cost relationships for LSD 44 is presented in Table 3-6.

TABLE 3-6
LSD 44 DETAIL DESIGN RELATIONSHIP

Engineering MHRS/Production MHRS:	0.35
Burdened Engineering Material Dollars/ Burdened Engineering Labor Dollars	0.12

Two sets of data for LSD 44 through 51 are contained in this study. The first, shown in Table 3-7, is based on Avondale CPR's. The second, shown in Table 3-8, are costs reported by SUPSHIPS New Orleans. For the lead ship engineering to production, and engineering material to labor cost ratios, the two data sets are reasonably close. Similarly, for the relationship between engineering design costs for the lead and follow ships, the two data bases are relatively consistent. There is a wide discrepancy, however, in the reported follow ship production costs between the two data sets. Adjudication of the differences in follow ship production costs is beyond the scope of this study, especially since there is good correlation between the data for the lead ship and engineering design relationships developed in this model.

TABLE 3-7
LSD 41 CLASS SHIPS: AVONDALE CPR LEAD AND FOLLOW SHIP MANHOUR COST DATA

SHIP	LABOR COSTS (KMHRS)		ENGINEERING/ PRODUCTION	FOLLOW SHIP/LEAD SHIP ENGR.	FOLLOW SHIP PROD./LEAD SHIP PROD.
	ENGINEERING	PRODUCTION			
LSD 44 [1,3]	1685	4255	0.40		
LSD 45 [3]	198	3773	0.05	0.12	0.89
LSD 46 [3]	120	3200	0.04	0.07	0.75
LSD 47 [3]	110	3017	0.04	0.07	0.71
LSD 48 [4]	92	2713	0.03	0.05	0.64
LSD 49 [2,4]	826	2777	0.30	0.49	0.65
LSD 50 [4]	48	2334	0.02	0.03	0.55
LSD 51 [4]	38	1874	0.02	0.02	0.44

NOTES:

1. *Lead Ship - Avondale Industries, Inc.*
2. *First Cargo Variant*
3. *Based on Cost Performance Reports, dated 30 June 1989:*
   Contract N00024-84-C-2027 for LSD 44
   Contract N00024-85-C-2027 for LSD 45-48
   Contract N00024-88-C-2048 for LSD 49
4. *Based on Cost Performance Report dated 31 December 1991*
   Contract N0024-88-C-2048 for LSD 49

TABLE 3-8
LSD 41 CLASS SHIPS: SUPSHIPS LEAD AND FOLLOW SHIP MANHOUR COST DATA

SHIP	LABOR COSTS (KMHRS)		ENGINEERING/ PRODUCTION	FOLLOW SHIP/LEAD SHIP ENGR.	FOLLOW SHIP PROD./LEAD SHIP PROD.
	ENGINEERING	PRODUCTION			
LSD 44 [1,3]	1710	4812	0.36		
LSD 45 [3]	203	4129	0.05	0.12	0.97
LSD 46 [3]	122	3891	0.03	0.07	0.91
LSD 47 [3]	92	3807	0.02	0.05	0.89
LSD 48 [4]	96	3768	0.03	0.06	0.89
LSD 49 [2,4]	743	3724	0.20	0.44	0.88
LSD 50 [5]	29	3610	0.01	0.02	0.85
LSD 51 [5]	28	3449	0.01	0.02	0.81

NOTES:

1. *Lead Ship - Avondale Industries, Inc.*
2. *First Cargo Variant*
3. *Actuals*
4. *Avondale estimate at completion*
5. *SUPSHIPS Estimate*

3.4 AOE 6 Class Fast Combat Support Ship

The ships of the SUPPLY Class were designed to provide rapid replenishment at sea of petroleum, munitions, provisions and fleet freight. The ships accommodate three utility helicopters and have a cargo capacity of 156,000 barrels of fuel, 1800 tons of ammunition, 400 tons of refrigerated cargo, and 250 tons of general cargo. The SUPPLY Class ships are outfitted with four General Electric LM 2500 gas turbines of 100,000 horsepower and can maintain a speed of 25 knots.

The lead ship of the class, AOE 6, was built by National Steel Shipbuilding Company (NASSCO) and was commissioned in 1991. Contracts have been awarded to NASSCO for construction of the AOE 7 and 8. The AOE 9 was cancelled. An RFP has been issued for construction of the AOE 10. The general characteristics of the AOE 6 are listed in Table 3-9. Cost data for the AOE 6 was obtained from a cost performance report and is provided in the PC-based data base. Table 3-10 provides a summary of the engineering cost relationships derived from the data base.

TABLE 3-9
GENERAL CHARACTERISTICS OF AOE 6

SHIP TYPE:	AOE 6 Fast Combat Support Ship
SHIPYARD:	NASSCO
COST DATA TYPE:	Return Cost[1], Lead Ship, Lead Yard
DATA SOURCE:	Cost Performance Report, ELIN B012, 48 Submittal, for Period 1 January 1991 to 27 January 1991

LEAD SHIP CHARACTERISTICS[2]:

Commissioning (Year)	1991
Delivery (Year)	
Displacement, Light Ship (LT)	20,500
Full Load (LT)	47,273
LBP (ft)	730
Beam (ft)	107
Draft (ft)	37'-0"
Depth at Side (ft)	66'-8"
Cubic Number (LxBxD)/100	52,076
Volume (cubic ft)	
Complement (Accommodations)	667
Power Plant	Gas Turbine
SHP (HP)	80,000
Shafts/Propellers	2
Electric Plant	Diesel
Kilowatts	12,500
400 Hz KW	60
Other	

Notes: *1. All costs based on estimate at completion.*
2. All data are from Ships Specifications and Janes' Fighting Ships 91-92.

TABLE 3-10
AOE 6 DETAIL DESIGN RELATIONSHIP

Engineering MHRS/Production MHRS:	0.37
Burdened Engr. Material Dollars/Burdened Engr. Labor Dollars	0.11

3.5 AO 177 Class Oiler Conversion

The AO 177 Class Oiler data is from the "jumboization" conversion of the AO 177 CIMARRON Class oiler. The ships of the CIMARRON Class were sized to provide two complete refuelings of a fossil-fueled aircraft carrier and six to eight accompanying destroyers. They carried approximately 120,000 barrels of petroleum products and are fitted with a helicopter platform aft. The lead ship was requested in FY 1975 but was not approved by congress. Subsequently, two ships were approved in FY 1976, one ship in FY 1977 and two ships in FY 1978. Fifteen more of this class were planned or proposed but were cancelled in 1979. All five ships of the class were built by Avondale Shipyards. Beginning in 1987 all the ships were jumboized, increasing their capacities from 120,000 barrels to 180,000 barrels. Funding for the first "jumboization," AO 179, was provided in FY 1987, second (AO 180) in FY 1988, third and fourth (AO 178 and 177) in FY 1989, and fifth (AO 186) in FY 1990. The builder, Avondale, constructed the conversion mid-bodies and had them ready for the ships when they arrived in the yard.

For the purposes of this model, the conversion of the AO 179 was considered a lead ship activity, with the other conversions considered follow ship activities. This is considered acceptable for the model, since all design and construction of the conversion is new construction, and all design work is directly related to the conversion construction work. This differs from a forward fit upgrade, where design modifications are incorporated into an overall follow ship construction. In these cases the relationship between design modification and construction activity cannot be easily related.

General characteristics for the AO 177 Class are provided in Table 3-11. Lead and follow ship manhour cost data is summarized in Table 3-12. This table provides cost ratios of engineering to production manhours, follow ship to lead ship engineering manhours and follow ship to lead ship production manhours. A summary of the engineering cost relationships derived from the data base for the lead ship is provided in Table 3-13.

TABLE 3-11
GENERAL CHARACTERISTICS OF AO 177 CLASS OILER

SHIP TYPE:	AO 177 Class Oiler
SHIPYARD:	Avondale Industries, Inc.
COST DATA TYPE:	Return cost[1], Conversion[2]
DATA SOURCE:	Data provided to NCA by SUPSHIPS New Orleans

LEAD SHIP CHARACTERISTICS[3,4]: (After Conversion)

Commissioning (Year) (Conversion)	1981 (1991)
Delivery (Year)	
Displacement, Light Ship (LT)	8,210
Full Load (LT)	26,110 (34,800)
LBP (ft)	582 (700)
Beam (ft)	88 (88)
Draft (ft)	35 (32)
Depth at Side (ft)	
Cubic Number (LxBxD)/100	
Volume (cubic ft)	
Complement (Accommodations)	217
Power Plant	Steam (Steam)
SHP (HP)	24,000 (24,000)
Shafts/Propellers	1 (1)
Electric Plant	(3)
Kilowatts	2500 KW Turbo Gen
400 Hz KW	
Other	

Notes:
1. *All costs based on estimate at completion.*
2. *Lead ship 179, Follow ships 180, 178, 177, 186*
3. *All data are from Ships Specifications and Janes' Fighting Ships 91-92.*
4. *This ship was lengthened.*

TABLE 3-12
AO 179 LEAD AND FOLLOW SHIP MANHOUR COST DATA

SHIP	LABOR COSTS (KMHRS)		ENGINEERING/ PRODUCTION	FOLLOW SHIP/LEAD SHIP ENGR.	FOLLOW SHIP PROD./LEAD SHIP PROD.
	ENGINEERING	PRODUCTION			
AO 179	199	766	0.26		
AO 180	30	686	0.04	0.15	0.90
AO 178	11	645	0.02	0.06	0.84
AO 177	10	674	0.01	0.05	0.88
AO 186	10	493	0.02	0.05	0.64

TABLE 3-13
AO 179 DETAIL DESIGN RELATIONSHIP

Engineering MHRS/Production MHRS:	0.26
Burdened Engr. Material Dollars/Burdened Engr. Labor Dollars:	Insufficient Data

3.6 T-AGS 45 Class Surveying Ships

T-AGS 45 is the lead ship of the WATERS Class surveying ships built by Avondale Industries. The ship was ordered in April of 1990 for the purpose of supporting the Integrated Underwater Surveillance System. The ship will carry a remote-controlled submersible. General characteristics of the T-AGS are provided in Table 3-14.

All data for the T-AGS 45 was provided to NCA by SUPSHIPS New Orleans and is based on an estimate at completion. Engineering manhours are 400 KMHRS and production manhours are 1643 KMHRS. No other data was provided. An estimated ratio of engineering manhours to production manhours is listed in Table 3-15.

TABLE 3-14
GENERAL CHARACTERISTICS OF T-AGS 45 CLASS SURVEYING SHIP

SHIP TYPE: T-AGS 45 Surveying Ship
SHIPYARD: Avondale Shipyard
COST DATA TYPE: Return cost[1], Lead Ship, Lead Yard
DATA SOURCE: Data provided to NCA by SUPSHIPS New Orleans

LEAD SHIP CHARACTERISTICS[2]:

Commissioning (Year)	
Delivery (Year)	
Displacement, Light Ship (LT)	7,000
Full Load (LT)	12,000
LBP (ft)	428'-7.5"
Beam (ft)	69
Draft (ft)	21
Depth at Side (ft)	37
Cubic Number (LxBxD)/100	
Volume (cubic ft)	
Complement (Accommodations)	95
Power Plant	Integ Dsl Elect
SHP (HP)	7,400
Shafts/Propellers	2 FP
Electric Plant	5 @ 2500 KW AC
Kilowatts	12,500
400 Hz KW	None
Other	

Notes:
1. All costs based on estimate at completion.
2. All data are from Ships Specifications.

TABLE 3-15
T-AGS 45 DETAIL DESIGN RELATIONSHIP

Engineering MHRS/Productions MHRS:	0.24
Burdened Engineering Material Dollars/Burdened Engineering Labor Dollars	Insufficient Data

3.7 T-AO 187 Class Oiler

There are 18 ships in the HENRY J. KAISER Class of Oilers. These ships, which have a cargo capacity of 180,000 barrels of fuel oil, are equipped with both port and starboard stations for underway replenishment of fuel and solids. The ships are capable of 20 knot speeds and have a range of 6,000 miles at 18 knots. Power is provided by two Colt-Pielstick 10-PC4.2V diesels. The ships are also fitted with integrated electrical auxiliary propulsion.

With the exception of T-AO 191 and T-AO 192, all ships of the class were constructed or are planned for construction by Avondale Shipbuilding Industries. The T-AO 191 and T-AO 192 were awarded to Penn Ship. Penn Ship went out of business in 1989 while both ships were under construction. The ships were towed to the Philadelphia Navy Yard and then were towed to Tampa Shipyards for completion. The ships required extensive refurbishing as a result of their sitting idle for months prior to towing to Tampa. Table 3-16 lists the general characteristics of the T-AO 187 Oiler.

Two sets of data are provided for the HENRY J. KAISER Class Oilers. The first is production versus engineering manhour data provided by SUPSHIPS New Orleans. The second is summary CPR data. The data provided is contained in the PC data base.

TABLE 3-16
GENERAL CHARACTERISTICS OF T-AO 187 CLASS OILER

SHIP TYPE:	T-AO 187 Class OILER
SHIPYARD:	Avondale Shipyards
COST DATA TYPE:	Return Cost[1], Lead Ship, Lead Yard
DATA SOURCE:	1. Data Provided to NCA by SUPSHIPS New Orleans 2. Cost Performance Report

LEAD SHIP CHARACTERISTICS[2]:

Commissioning (Year)	1986
Delivery (Year)	1986
Displacement, Light Ship (LT)	14,462
Full Load (LT)	41,225
LBP (ft)	677.5
Beam (ft)	97.5
Draft (ft)	36.0
Depth at Side (ft)	178,142
Cubic Number (LxBxD)/100	
Volume (cubic ft)	
Complement (Civilians)	96
(Navy)	21
Power Plant	2 Diesels
SHP (HP)	16,500 each
Shafts/Propellers	2
Electric Plant	2 ALCO Diesel Gen
Kilowatts	2500
400 Hz KW	
Other	

NOTES: (1) All costs based on estimate at completion.
(2) All data are from Ship's Weight Estimate and Janes' Fighting Ships 91-92.

The SUPSHIPS data for ships of the class built by Avondale is summarized in Table 3-17. The table provides cost ratios of engineering to production manhours, follow ship to lead ship engineering manhours and follow ship to lead ship production manhours. There was not enough information available for T-AO 191 and T-AO 192 to include them in this table.

Table 3-18 provides a summary of engineering cost relationships derived from the data base.

TABLE 3-17
T-AO 187 LEAD AND FOLLOW SHIP MANHOUR COST DATA

SHIP	LABOR COSTS (KMHRS)		ENGINEERING/ PRODUCTION	FOLLOW SHIP/LEAD SHIP ENGR.	FOLLOW SHIP PROD./LEAD SHIP PROD.
	ENGINEERING	PRODUCTION			
T-AO 187	782	2458	0.32		
T-AO 188	95	2252	0.04	0.12	0.92
T-AO 189	93	2087	0.04	0.12	0.85
T-AO 190	100	2013	0.05	0.13	0.82
T-AO 193	230	2157	0.11	0.29	0.88
T-AO 194	42	2065	0.02	0.05	0.84
T-AO 197	41	2232	0.02	0.05	0.91
T-AO 198	52	2087	0.02	0.07	0.85
T-AO 199	25	2047	0.01	0.03	0.83
T-AO 200	52	2067	0.03	0.07	0.84
T-AO 201	25	2007	0.01	0.03	0.82
T-AO 202	52	2027	0.03	0.07	0.82
T-AO 203	25	1967	0.01	0.03	0.80
T-AO 204	52	1987	0.03	0.07	0.81

TABLE 3-18
T-AO 187 DETAIL DESIGN RELATIONSHIP

Engineering MHRS/Production MHRS:	0.31
Burdened Engr. Material Dollars/Burdened Engr. Labor Dollars	Insufficient Data

3.8 T-AGOS 19 Class SWATH Ocean Surveillance Ships

The ships of the VICTORIOUS Class, T-AGOS 19 through T-AGOS 22, are ocean surveillance ships built by McDermott Marine, Inc. The T-AGOS 19 is a follow-on to the STALWART Class of ocean surveillance ships and is primarily used to support the SURTASS towed array surveillance system. The T-AGOS 19 ships are of SWATH design (small waterplane area twin hulled) giving them greater capability to operate in high latitudes under adverse weather conditions. The contract for the first SWATH ship, T-AGOS 19, was awarded in November 1986, and options for the next three were exercised in October 1988. These ships are outfitted with two Raytheon navigation radars, a UQQ2 SURTASS sonar and a towed array. They are diesel-electric powered and carry a complement of 34. General characteristics of this class are shown in Table 3-19.

The data used in this report is based on a bid estimate prepared by BIW and used in the Auxiliary and Amphibious Construction Cost Model. Table 3-20 provides a summary of the data by SWBS element. The cost data available for this ship is included in the PC-based data base. Table 3-21 provides a ratio of burdened engineering material dollars to engineering labor dollars based on an assumed $28/MHR burdened (no fee) labor rate.

TABLE 3-19
GENERAL CHARACTERISTICS OF T-AGOS 19 CLASS SWATH OCEAN SURVEILLANCE SHIP

SHIP TYPE:	T-AGOS 19 Class SWATH Ocean Surveillance Ship
SHIPYARD:	See Note 1
COST DATA TYPE:	Estimated[1], Lead Ship
DATA SOURCE:	BIW Letter to Gibbs & Cox, Inc. Subject: Parametric Shipbuilding Construction Cost Model, dated 18 January 1988

LEAD SHIP CHARACTERISTICS:

Commissioning (Year)	1990
Delivery (Year)	1990
Displacement, Light Ship (LT)	3,360
Full Load (LT)	0
LBP (FT)	190
Beam (FT)	93'-6"
Draft (FT)	24'-9"
Depth at Side (FT)	49'-6"
Cubic Number (LxBxD)/100[4]	8,794
Volume (cubic ft)	420,100
Complement (Accommodations)	34
Power Plant	Diesel Electric
SHP (HP)	1,600
Shafts/Propellers	2/Fixed Pitch
Electric Plant	Diesel
Kilowatts	3,320
400 Hz KW	30
Other	

NOTES:
1. *This data set is based on an estimate prepared by BIW. The actual ship was built at McDermoitt Marine, Inc.*
2. *Data provided as input to U.S. Naval Vessels (Auxiliary and Amphibious Ships) Construction Cost Model, Contract No. N00014-86-C-0796, dated September 1988.*
3. *Above data are taken from Ships Specifications and Jane's Fighting Ships 91-92.*
4. *This may not be realistic since this ship is a twin hull ship.*

TABLE 3-20
T-AGOS 19 WEIGHT AND COST DATA SUMMARY

SWBS NO.		WEIGHT (LT)	LABOR COST KMHRS	MAT'L COST ($K)
000	General Guidance			
100	Hull Structure	1,721	201	1,403
200	Propulsion Plant	66	15	1,817
300	Electric Plant	119	26	1,914
400	Communication & Control	46	11	1,053
500	Auxiliary Systems	340	73	5,587
600	Outfit & Furnishing	269	75	3,195
700	Armament	0	0	0
800	Integration & Engineering		360	1,137
900	Ship Assembly Support		185	1,369
TOTAL		**2,561**	**946**	**17,475**

TABLE 3-21
T-AGOS 19 DETAIL DESIGN RELATIONSHIP

Engineering MHRS/Production MHRS:	0.36
Burdened Engr. Material Dollars/Burdened Engr. Labor Dollars:	0.12[1]

NOTES: ***1. Based on assumed $28/MHR burdened (no fee) labor rate.***

3.9 7100 Ton SWATH

The 7100 Ton SWATH is a conceptual design of a SWATH ship prepared by BIW. The data for the 7100 Ton SWATH data base was provided by BIW as part of the Auxiliary and Amphibious Construction Cost Model. No detailed list of ships characteristics or mission description was provided by BIW for this report. The PC-based data base includes weight, labor costs and material costs by SWBS breakdown. A summary of the data is provided in Table 3-22. Table 3-23 provides a summary of the engineering cost relationships derived from the data base. In order to determine a breakdown of the engineering to non-engineering costs for SWBS Group 800, the percentage breakdown for these costs for the T-AGOS 19 SWATH data was used.

TABLE 3-22
7100 TON SWATH WEIGHT AND COST DATA SUMMARY

SWBS NO.		WEIGHT (LT)	LABOR COST KMHRS	MAT'L COST ($K)
000	General Guidance			
100	Hull Structure	2,812	591	5,694
200	Propulsion Plant	462	79	30,570
300	Electric Plant	336	240	5,773
400	Communication & Control	178	95	1,163
500	Auxiliary Systems	790	296	7,695
600	Outfit & Furnishing	447	432	3,490
700	Armament	143	15	37
800	Integration & Engineering		1,329	63,850
900	Ship Assembly Support		1,229	2,985
TOTAL		**5,168**	**4,306**	**121,257**

TABLE 3-23
7100 TON SWATH DETAIL DESIGN RELATIONSHIP

Engineering MHRS/Production MHRS:	0.26
Burdened Engr. Material Dollars/Burdened Engr. Labor Dollars:	Insufficient Data

3.10 MCM-1 Class Mine Countermeasure Vessel

MCM-1 is the lead ship of 14 ships in the AVENGER Class of mine countermeasure vessels. The contract for the prototype MCM was awarded in June 1982; MCM 2 in May 1983; MCM 3-5 in December 1983; and MCM 6-8 in August 1986. MCM 9 was funded in FY 1985 and MCM 10-11 in FY 1986. Contracts for MCM 9-11 were not awarded until January 1989. The last three ships of the class, MCM 12-14, were funded in FY 1990.

The hull of the ship is constructed of oak, Douglas fir and Alaskan cedar, with a thin coating of fiber glass on the outside, because of wood's low magnetic signature. MCM-1 and MCM-2 are outfitted with four Waukesha L-1616 diesels. A problem of engine rotation with the Waukesha diesels led to their replacement with low magnetic engines manufactured by Isotta-Fraschini of Milan, Italy for MCM-3 and follow. The AVENGER Class ships are equipped with a surface search radar and high frequency active minehunting sonars. Countermeasures include two SLQ-48, ROV mine neutralization systems including cable with cutter and countermining charge, SLQ 37(V)2, and magnetic/acoustic influence sweep equipment. The general characteristics of MCM-1 are listed in Table 3-24.

Details of the cost data are provided in the PC-based data base. Table 3-25 provides a summary of the engineering cost relationships derived from this data base.

TABLE 3-24
GENERAL CHARACTERISTICS OF MCM-1

SHIP TYPE:	MCM-1
SHIPYARD:	Peterson Builders, Inc.
COST DATA TYPE:	CPIF, Lead Ship, Lead Yard
DATA SOURCE:	Cost Performance Report, dated 28 October 1988 Contract N00024-82-C-2121

LEAD SHIP CHARACTERISTICS:

Commissioning (Year)	1987
Delivery (Year)	
Displacement, Light Ship (LT)	
Full Load (LT)	1,312
LBP (FT)	224
Beam (FT)	39
Draft (FT)	12
Depth at Side (FT)	
Cubic Number (LxBxD)/100	
Volume (cubic ft)	
Complement	
Power Plant	81
SHP (HP)	
Shafts/Propellers	2400 BHP
Electric Plant	2 Shafts, Bow Thruster
Kilowatts	
400 Hz KW	
Other	

TABLE 3-25
MCM-1 AND MCM-2 DETAIL DESIGN RELATIONSHIP

	MCM-1	MCM-2
Engineering MHRS/Production MHRS:	0.28	0.32
Burdened Engr. Material Dollars/Burdened Engr. Labor Dollars:	Insufficient Data	Insufficient Data

3.11 MHC Coastal Minehunter

The MHC-51 is the lead ship of the OSPREY Class of coastal minehunters. In mid-1986, a project to construct 17 minesweepers was cancelled because the design, which was based on a surface effect ship, failed shock testing. The Secretary of Defense then indicated that $120.1 million of FY 1986, funds would be used to construct the lead ship of a new MHC class based on the Intermarine Lerici class of minesweeper/hunters. A design contract was awarded in August 1986 followed by the award of a construction contract in May 1987 for the lead ship, MHC-51. Intermarine Sarzana established Intermarine USA in conjunction with Hercules Aerospace Corporation of Salt Lake City and purchased Sayler Marine Corporation in Savannah, GA. The company has updated that yard to support construction of the OSPREY. In October of 1989, Avondale Industries was named as the second construction source. Two ships were funded in FY 1990, two in FY 1991 and two more proposed in FY 1992 and in 1993. Twelve of the class are to be built, followed by eight lengthened MHC(V) versions.

The ships are constructed of heavy GRP (glass reinforced plastic) throughout the hull, decks and bulkheads, with frames eliminated. Main machinery is mounted on vibration dampers. The ships are equipped with navigation radars and high frequency active minehunting sonars. Both mechanical and modular influence sweep systems are being developed independently of the ship construction program. The general characteristics of the OSPREY Class are listed in Table 3-26. Details of the cost data used are provided in the PC-based data base. Not enough information was available to develop an engineering cost relationship for the MHC-51 at this time.

TABLE 3-26
GENERAL CHARACTERISTICS OF MHC-1

SHIP TYPE:	MHC-51 OSPREY
SHIPYARD:	Intermarine USA
COST DATA TYPE:	FPI, Lead Ship, Lead Yard
DATA SOURCE:	Cost Performance Report, dated 31 December 1991 Contract N00024-87-C-2136

LEAD SHIP CHARACTERISTICS:

Commissioning (Year)	1992
Delivery (Year)	
Displacement, Light Ship (LT)	
Full Load (LT)	851
LBP (FT)	188
Beam (FT)	35
Draft (FT)	9
Depth at Side (FT)	
Cubic Number (LxBxD)/100	
Volume (cubic ft)	
Complement	51
Power Plant	
SHP (HP)	2400 BHP
Shafts/Propellers	2 vs Propellers, Bow Thruster
Electric Plant	
Kilowatts	
400 Hz KW	
Other	

4.0 COST ESTIMATING RELATIONSHIPS

4.1 Introduction

In determining the parameters to consider as independent variables for the detail design cost estimating relationships (CER's), primary consideration was given to parameters that were used in the construction cost models previously developed for NCA. In this way, the detail design cost model can be used in conjunction with the construction models to develop a total lead ship design and construction cost. This also assures that the detail design cost model uses parameters available to NCA, and that the model is consistent with the level of detail used in the previous models.

In the construction cost models, general ship's characteristics such as weight, shaft horsepower, cubic number, length, beam, and complement are used as independent variables for algorithms within 24 cost groups representing SWBS Groups 100 to 900. Total construction labor costs in manhours and material costs in dollars are derived by summing the individual cost elements. The construction cost model also differentiates between SWBS Groups 100-700, which represent the construction activities, and SWBS Groups 800-900, which represent a variety of shipbuilder engineering and general support during construction.

The reason for this differentiation is because SWBS Groups 100-700 tend to follow reasonable and predictable trends, whereas SWBS Groups 800 and 900 are subject to change as Navy policy and support requirements change.

In particular, SWBS Group 800 includes elements such as:

- Design Support - specifications, weight, computer programs, engineering calculations, models and mockups, photographs, design/engineering liaisons, and lofting.

- Quality Assurance - tests and inspections, trials support, inclining experiment and trim dive, combat systems check-out, and certification standards.

- Integrated Logistics Support (ILS) Engineering - maintenance, support and test equipment, supply support, transportation engineering drawings and specifications, technical manuals and other data, facilities, personnel and training, and training equipment.

- Authorized repair planning and funding.

- Special Purpose Items - human factors, standardization,value engineering, reliability and maintainability (RMA) data management, and project management.

Over the past 10 years, Group 800 support has grown in response to the increased demand for project management support and increased focus on ILS, RMA, human factors and the like. With tightening budgets and the maturity of some of these support programs, it is likely that this growth will level off and costs decline.

SWBS Group 900 encompasses the general shipyard support services required for construction of the ship that do not fall within any of the previous SWBS Groups. Included in SWBS Group 900 are the following:

- Ship assembly identification.

- Non-Engineering Contractual and Production Support Services - assist ships force, insurance, trials support, delivery support, fire and flooding protection, tests and inspections support, weighting and recording, administrative contract data requirements, and fitting-out support.

- Construction Support - staging, scaffolding and cribbing services, temporary utilities and services, material handling and removal cleaning services, molds and templates, jigs, fixtures, launching, and drydocking.

As with SWBS Group 800, SWBS Group 900 costs have increased over the past 10 years. This growth is attributed, in part, to the general growth in support services to respond to Navy requirements, as well as the increased planning and coordination necessary for extensive pre-outfitted construction. The growth in SWBS Group 900 costs has not been as dramatic as SWBS Group 800 since SWBS Group 900 activities are primarily in support of construction activities within the yard.

The purpose of detail design is to convert the Navy definition of a ship, as contained in the contract design technical package, to the products necessary to construct a ship. The amount of activity related to the detail design is a function of the requirements of the Navy regarding deliverables and approvals for construction, and the needs of the shipyard to develop the products necessary to construct the ship. This relationship between the detail design and the ship construction activity lends itself well to using the ship's construction labor costs as an independent variable for estimating detail design labor costs. Since an estimate of a ship's construction labor costs is also a partial product of the ship construction cost models, use of the construction labor costs as an independent variable also relates the detail design labor costs to the ship's general characteristics used in the ship construction cost models. This connection to the ship construction cost model allows NCA to derive a total design and construction cost estimate from a single set of variables. Most of the data used in this cost model is derived from Cost Performance Reports (CPR's) submitted to the Navy by the various shipyards responsible for the construction of the ships. The breakdown of costs reported in the CPR's differs among the various yards, with some yards reporting by SWBS element, others by unit construction zones, and others by trades. In most cases, however, the CPR differentiates between construction, engineering and other costs; and between material and labor costs. The differentiation is not consistent or clearly defined in many cases. In those cases where it is not clearly defined production costs reported are assumed to represent SWBS Groups 100-700 and 900. The engineering costs reported are assumed to be part SWBS Group 800 costs, and other costs are assumed to be the remainder of SWBS Group 800 costs.

Given the nature of the data, the main emphasis of this detail design model is to relate the engineering labor manhours (partial SWBS Group 800) to the production labor manhours (SWBS Groups 100-700, 900) as defined in the construction cost model. Data is also provided with identified shipyard burdened labor rates for data engineering and production manhours. This allows NCA to develop an engineering manhour estimate as well as providing historical data to estimate total engineering costs in dollars.

Engineering design is a labor intensive activity. Material costs are primarily expenditures for supplies and equipment to support the design activity. These material costs are, therefore, related to manhour expenditures, and are a percentage of total labor costs. This differs from construction activities, where purchase of equipment and construction material is a large component of the total cost, and often independent of the manhours required to install on board a ship. For this reason, the engineering design model provides a factor that is multiplied by the engineering labor costs in dollars to estimate engineering material costs in dollars. This factor is based on a direct comparison of engineering labor dollars to material dollars reported in the CPR's.

The non-engineering SWBS Group 800 is identified in the CPR's and other data used in this model to a varying level of detail. Guidance is provided on the value of these costs as presented in the data base, as a percentage of engineering costs, in order to estimate a total SWBS Group 800 cost. In this way, the construction cost model can be used to develop an estimate of production costs (SWBS Groups 100-700 and 900). This model can then be used to derive an estimate of engineering costs, and these costs can be proportioned up to derive an estimate of total SWBS Group 800 costs. The total construction costs can be estimated by summing the production costs and total SWBS Group 800 costs.

The use of the two digit SWBS breakdown for estimating engineering costs is considered unwarranted in this engineering design cost model for the following reasons. First, the shipyards report all detail design costs under SWBS Group 800, and the data set did not support a SWBS breakdown. Second, approximately one half of the detail design activity, such as weight estimating or overall design management, is done at the total ship level. Third, the variability between SWBS groups is accounted for in developing the construction labor cost estimate and the assumption is made that, in general, there is a proportional relationship between the construction activity and design activity. As discussed in Reference (8), this assumption is correct at the total ship level and for most SWBS Groups, based on comparisons of Gibbs & Cox, Inc. design manhours for SWBS Groups 100-700, to equivalent construction manhours. For these reasons, the CER's are presented at the total ship level.

4.2 Relationship Between Lead Ship Detail Design and Construction Labor Costs

A plot of the relationship between the total engineering design labor manhours versus production manhours for the ships in the data base is shown in Figure 4-1. A best fitting line using the method of least squares regression, for the ship data points, plus zero/zero, gives a line with the following equation:

$$L = .31C + 35 \tag{1}$$

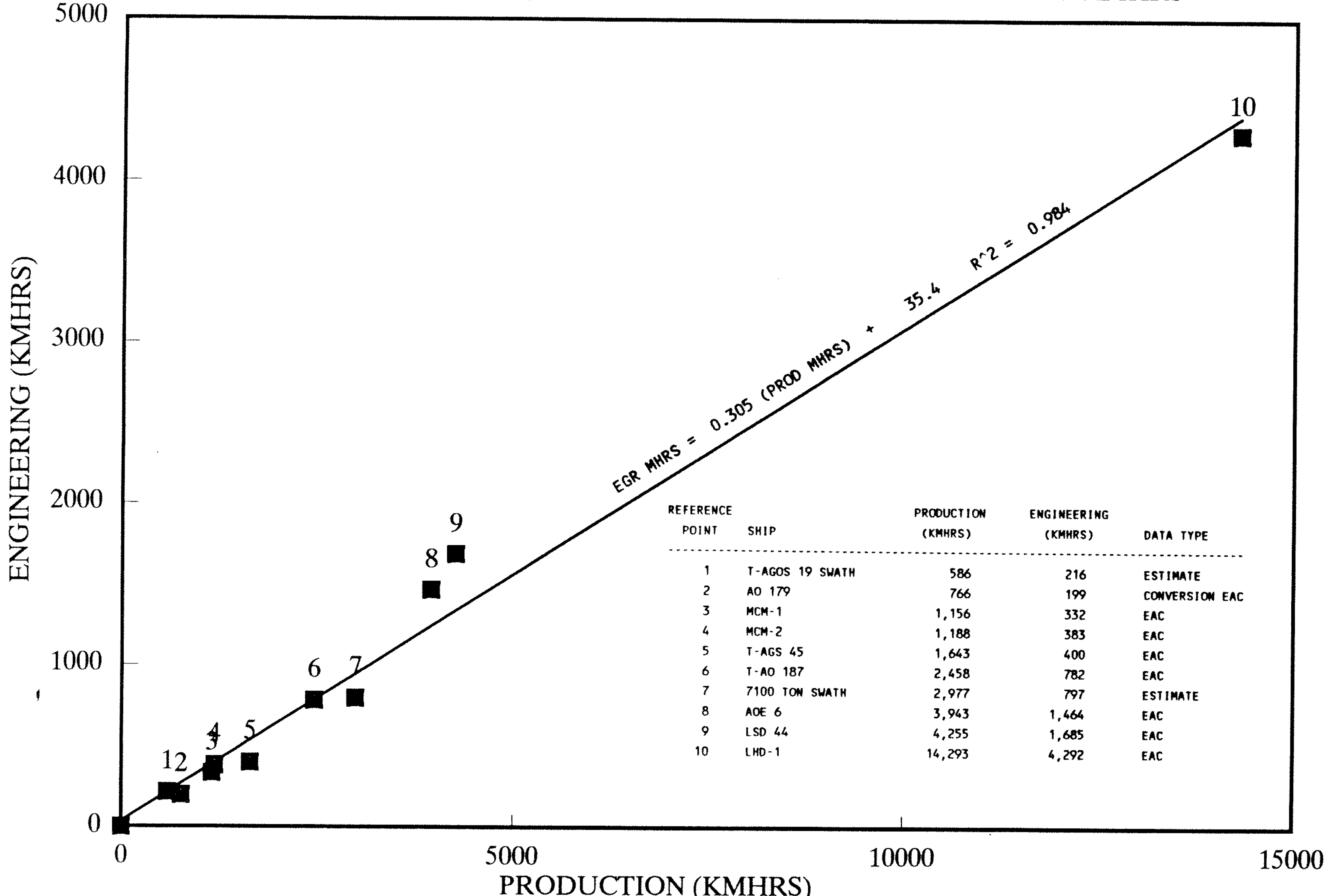
where (L) is the total engineering design manhours in (KMHRS) and (C) is the labor manhours in (KMHRS).

This equation has a coefficient of determination (r^2) of .984. The coefficient of determination is a measure of the fit of the regression equation to the data points. The value of r^2 ranges from 0 to 1.0, with 1.0 indicating a perfect fit, implying all data lie on the curve. Equation (1) is the primary CER developed in this model for estimating the detail design labor manhours. It supports the assumptions made in its derivation, and relates the detail design cost model to the construction cost model.

The relatively good correlation of the data is surprising, given the variety of ship types, data sources, the time span of the data set, and the estimates that were made to establish the data points. As additional data points are identified, it is likely more spread will occur in the data. This could also result in a series of CER's for the various ship types. However, the linear trend line appears to hold over the full range of ships considered.

A second CER was developed for use in determining engineering manhours as a function of lightship weight. A plot of the data is shown in Figure 4-2. As can be seen, this data is more dispersed than that shown in Figure 4-1. A best fitting line using the method of least squares regression, for the ship data points, including zero/zero, gives a line with the following equation:

AUXILIARY & AMPHIBIOUS SHIP ENGINEERING DETAIL DESIGN COST
ESTIMATING MODEL,ENGINEERING KMHRS VS. PRODUCTION KMHRS



REFERENCE POINT	SHIP	PRODUCTION (KMHRS)	ENGINEERING (KMHRS)	DATA TYPE
1	T-AGOS 19 SWATH	586	216	ESTIMATE
2	AO 179	766	199	CONVERSION EAC
3	MCM-1	1,156	332	EAC
4	MCM-2	1,188	383	EAC
5	T-AGS 45	1,643	400	EAC
6	T-AO 187	2,458	782	EAC
7	7100 TON SWATH	2,977	797	ESTIMATE
8	AOE 6	3,943	1,464	EAC
9	LSD 44	4,255	1,685	EAC
10	LHD-1	14,293	4,292	EAC

LSD data from Avondale CPR

FIGURE 4-1

AUXILIARY & AMPHIBIOUS SHIP ENGINEERING DETAIL DESIGN COST ESTIMATING MODEL, ENGINEERING KMHRS VS. LIGHTSHIP WEIGHT

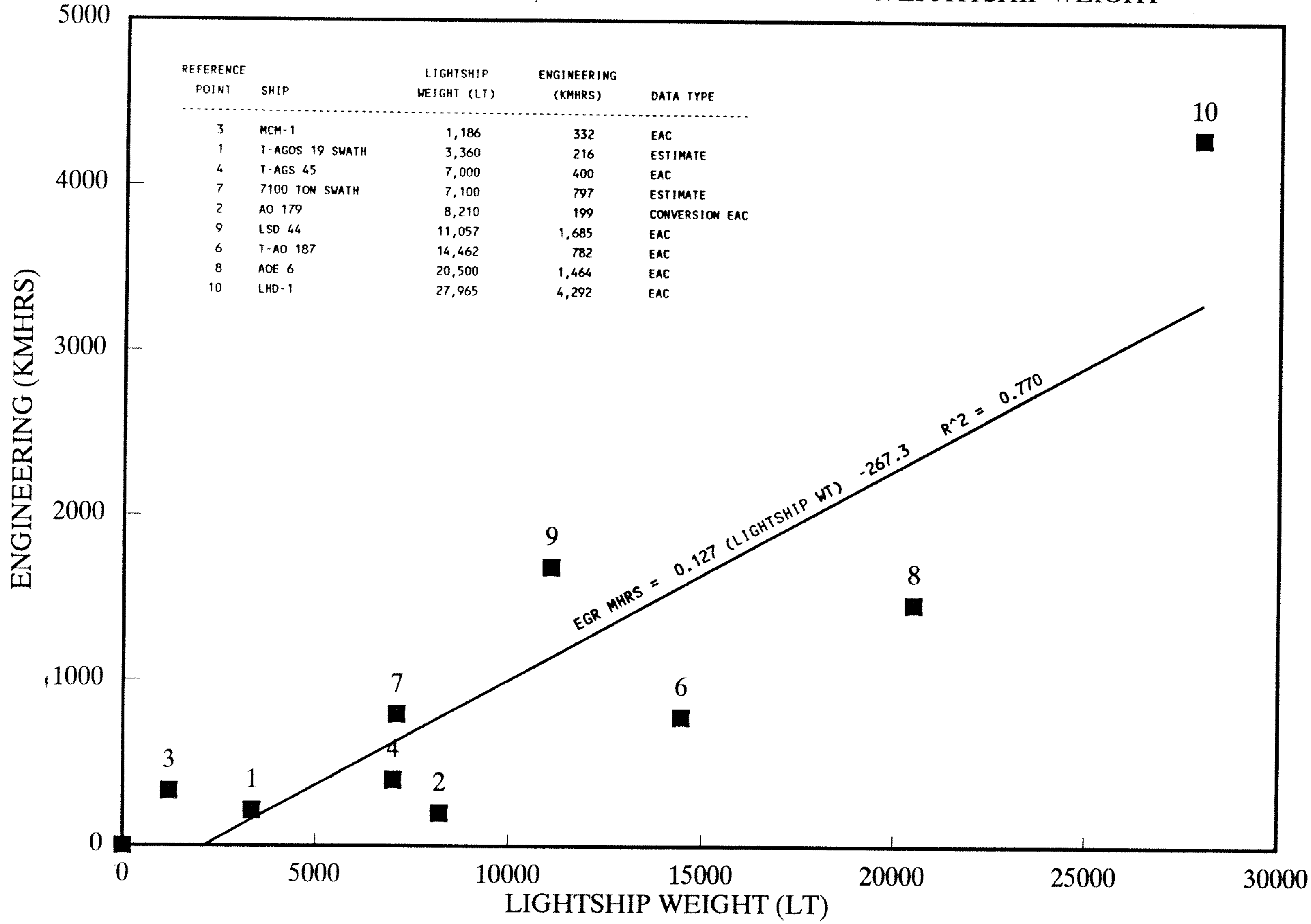


FIGURE 4-2

$$L = .13W - 267 \tag{2}$$

where (L) is the total engineering design manhours in (KMHRS) and (W) is the lightship weight in long tons.

This equation has a coefficient of determination (r^2) of .770. This lower value of r^2 reflects the greater spread of this data compared to that for Equation (1). For this reason, Equation (2) is considered a secondary CER to be used only if production manhours are unknown.

The distribution of data in Figure 4-2 does not indicate any discernible trends; however, as more data is identified, multiple CER's may become apparent.

As with the construction cost models, total labor costs, in dollars, are developed by multiplying the labor manhours by a labor rate provided by the user, as follows:

$$D = (L)(R) \tag{3}$$

where (D) is the engineering design labor dollars in ($K) and R is the labor rate in ($/MHR).

The model user can select a labor rate for use in Equation 3. The data base provides a number of historical shipyard labor rates for use in establishing a labor rate for use in Equation 3. The CPR data reports unburdened labor rates, which must be multiplied by the shipyard's burdens and then escalated to current year dollars in order to derive a fully burdened rate. Since the components of the labor rate are considered business sensitive, they are not presented in this report.

4.3 Relationship Between Detail Design Labor Costs and Material Costs

As noted previously, detail design material costs are primarily expenditures for supplies and equipment to support the design activity. They are reported in actual dollars expended during design. To develop a CER for this model, the material costs in dollars were compared to labor costs in dollars as reported in the CPR's. A summary of the percentage of material costs to labor costs for the ship considered is provided in Table 4-1. The data averages at 12 percent. Thus, the following CER should be used for estimating detail design material costs:

$$M = 0.12D \tag{4}$$

where (M) is the detail design material dollars in ($K).

Table 4-1
PERCENT OF DIRECT EXPENSE IN DETAIL DESIGN

SHIP	% MATERIAL COSTS	SHIPYARD
LHD-1	15%	ISI
AOE 6	11%	NASSCO
LSD 41	NA	LOCKHEED
LSD 44	12%	AVONDALE
AO 179	NA	AVONDALE
T-AO 187	NA	AVONDALE
T-AGS 45	NA	AVONDALE
T-AGOS 19 SWATH	12%	BIW (ESTIMATE)[1]
7100 TON SWATH	NA	BIW (ESTIMATE)
MHC-51	NA	INTERMARINE
MHC-53	NA	AVONDALE
MCM-1	NA	PETERSON
MCM-2	NA	MARINETTE
PROPOSED	12%	MODEL

NOTES: 1. Based on $28/MHR burdened (no fee) manhour rate

The number of data points available for material costs is less than that for engineering costs. However, the percentage seems to be relatively consistent over a variety of ship types at a number of yards. As more data is identified, this factor should be updated, as required.

4.4 Total Engineering Costs

The total engineering costs for the ship are the summation of the labor costs and material costs, as per the following equation:

$$T=D+M \tag{5}$$

where T is the total engineering costs in ($K). D is the total engineering labor dollars in ($K) and M is the total engineering material dollars in ($K).

4.5 Relationship Between Engineering and Other SWBS Group 8 Costs

As noted previously, engineering costs are a component of the SWBS Group 800 costs reported by the shipyards. Other SWBS Group 800 costs include project management, quality assurance, integrated logistics support, engineering, authorized repair planning, and special purpose items (such as human factors, standardization, value engineering, reliability and maintainability (RMA) and data management). Depending on the demands of the Navy program office, the contract requirements, and the accounting system of the shipyard, the costs can vary significantly.

The CPR and other data used in this study provide some guidance regarding the relationship between the engineering costs and the total SWBS group 800 costs. Table 4-2 shows the relationship between the engineering costs and total SWBS Group 800 costs where the data is sufficient to determine these percentages.

TABLE 4-2
RELATIONSHIP BETWEEN ENGINEERING COSTS AND TOTAL SWBS GROUP 800 COSTS

SHIP	*LABOR* $\left(\frac{ENGINEERING\ KMHRS}{SWBS\ GROUP\ 800\ KMHRS}\right)$	*MATERIAL* $\left(\frac{ENGINEERING\ (\$)}{SWBS\ GROUP\ 800\ MATERIAL\ (\$)}\right)$
LHD 1	79%	62%
AOE 6	79%	41%
T-AGOS 19[1]	60%	66%
LSD 44	57%	65%
MCM 2	65%	Insufficient Data

[1] *BIW ESTIMATE*

Given the limited data set, the variability of the data, and the uncertainty of which factors drive this variability, no firm cost estimating relationships can be derived from this information. However, by inspection, use of 65 percent for both labor manhours and material costs would be a reasonable approximation for the percentage of engineering costs to total SWBS Group 800 costs. Thus, there is no other information available to determine total SWBS Group 800 costs. The following equation should be used:

$$Total\ SWBS\ Group\ 800 = \frac{T}{0.65} \qquad (6)$$

where Total SWBS Group 800 costs are in ($K) and T are the total engineering costs in ($K).

4.6 Relationship Between Lead and Follow Ship Detail Design Costs

The engineering costs for the lead ship of a class are typically considerably more than those of the follow ships, since most of the nonrecurring costs associated with the design are accrued during the lead ship design. The follow ship design effort involves modifying the design to suit the follow ship designation and to incorporate changes that have been approved by the Navy. These changes can either be for the entire class, or a specific ship, and they can be for forward fit, backfit or both.

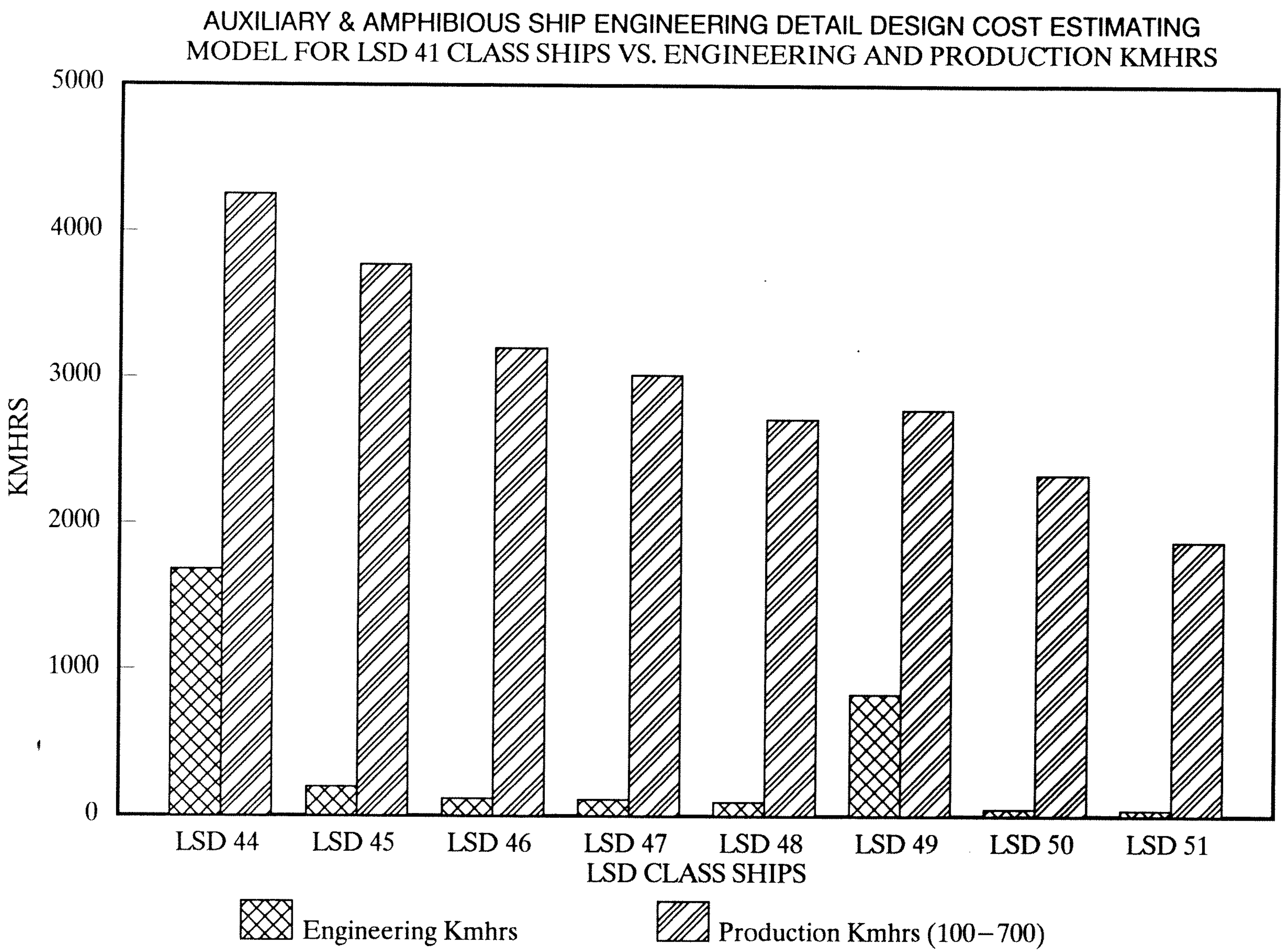
Often a number of shipyards are involved in construction of a class of ships. Design of the lead ship is typically done by the first, or "lead yard" involved, based on a competitive lead ship construction bid. The lead yard may also be awarded the role of maintaining the class design and incorporating class changes into the design. Additional shipyards, or "follow yards", are responsible for construction of subsequent ships in the class based on competitive bids. The detail design effort for the first ship in a follow yard can be as extensive as the lead ship of the class, since the design must be tailored to specific shipyard production methods. This is illustrated in the MCM-1 Class data.

In the data base there are examples of both lead and follow ships in a lead yard, and lead and follow ships in a follow yard. For the LSD 41 Class, there is data for the LSD 41-43 at Lockheed Shipbuilding and LSD 44-51 at Avondale Shipbuilding. Unfortunately, the Lockheed Data is not sufficiently detailed to assess engineering versus production costs. In this case, however, the entire program was transferred to Avondale, and as such, the Avondale data is representative of a lead yard contract. Data is also provided for lead and follow ships of the T-AO 187 Class Oilers built at Avondale. In addition, lead ship data is provided for the lead and follow yards for the MCM-1 Class Mine Countermeasure Vessels and the MHC-51 Class Coastal Minehunters. Again, unfortunately, the MHC-51 is not sufficiently detailed to assess engineering versus production costs.

Figure 4-3 shows the relationship between lead and follow ships for the LSD 44-51 at Avondale Shipyards, based on Avondale CPR data. A similar plot for the same ships based on SUPSHIPS data is shown in Figure 4-4. As noted in Section 3-3 there is a significant difference in the production costs reported; however, the engineering relationships are relatively consistent between the data bases. Both data sets show declining engineering costs for the follow ships, with a relatively significant design effort corresponding to the LSD 49, which was the lead cargo variant of the class. With the LSD 49 design included as follow ship, the aggregate engineering costs for the follow ships, divided by the number of ships built, is 8 percent for the Avondale CPR data, and 10 percent for the SUPSHIPS data. If the LSD 49 data is excluded, these percentages drop to 5 percent for each data set.

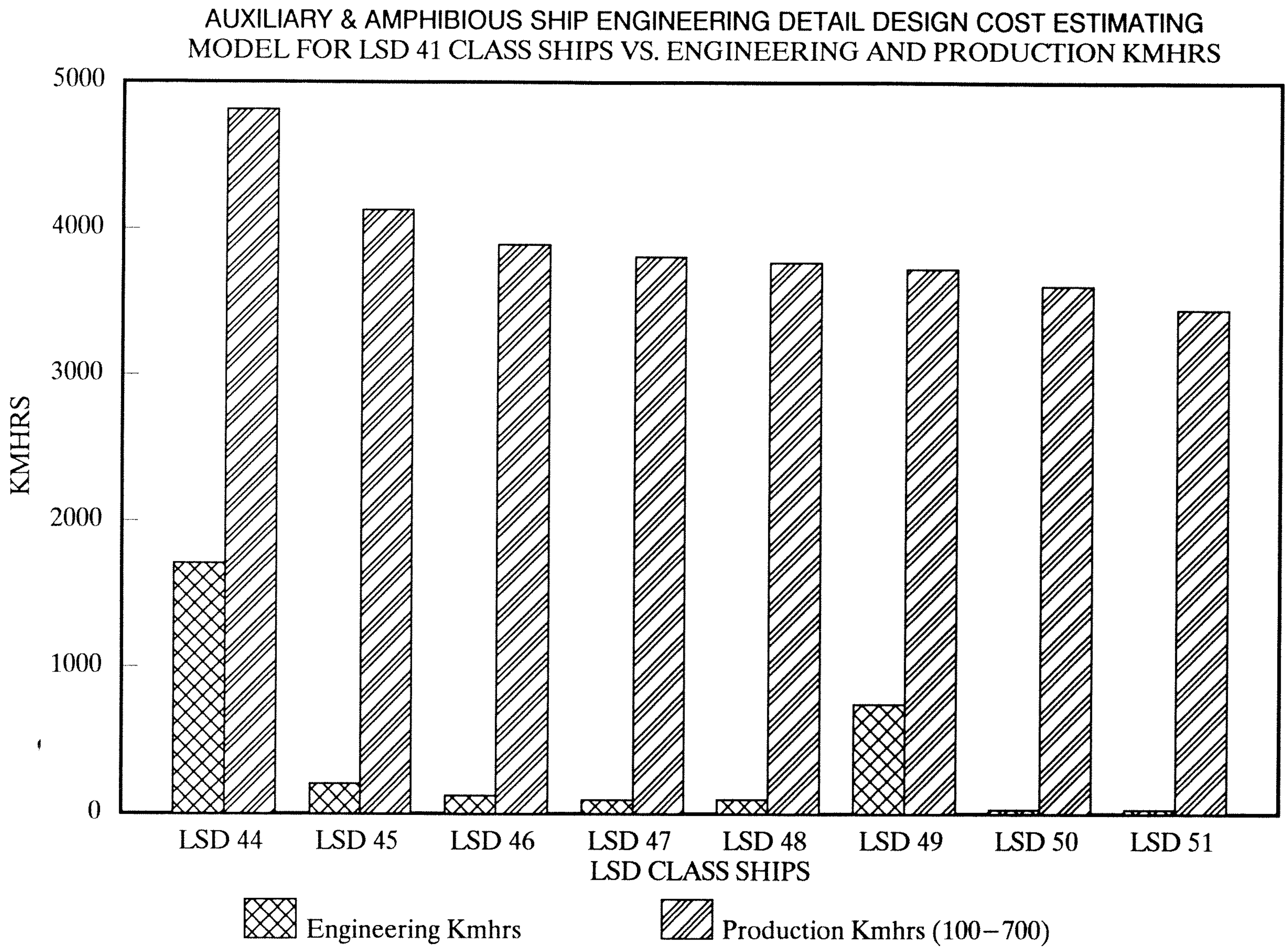
Figure 4-5 shows the relationship between the lead and follow ships for the T-AO 187 Class built at Avondale Shipyards. This data set shows the same declining engineering costs for follow ships. In this case, the aggregate engineering costs for the follow ships, divided by the number of ships built is 8 percent.

Figure 4-6 shows the relationship between the lead and follow ships for the AO-177 Class conversion. The conversion is incorporated as a backfit to existing ships, with the design costs assigned to the first ship receiving the change, and changes incorporated into other ships on an approved basis. For the T-AO 177 Class Oilers, the T-AO179 was the first ship to be jumboized, followed by the T-AO's 180, 178, 177 and 186. Although, these ships are conversions, the relationship between lead and follow ships is similar to that of a new ship, since all the design effort is related to the conversion. The data set shows that the aggregate engineering costs for the follow ships, divided by the number of ships converted, is 8 percent.



Data from Avondale Estimates at Completion

FIGURE 4-3



Data from SupShips

FIGURE 4-4

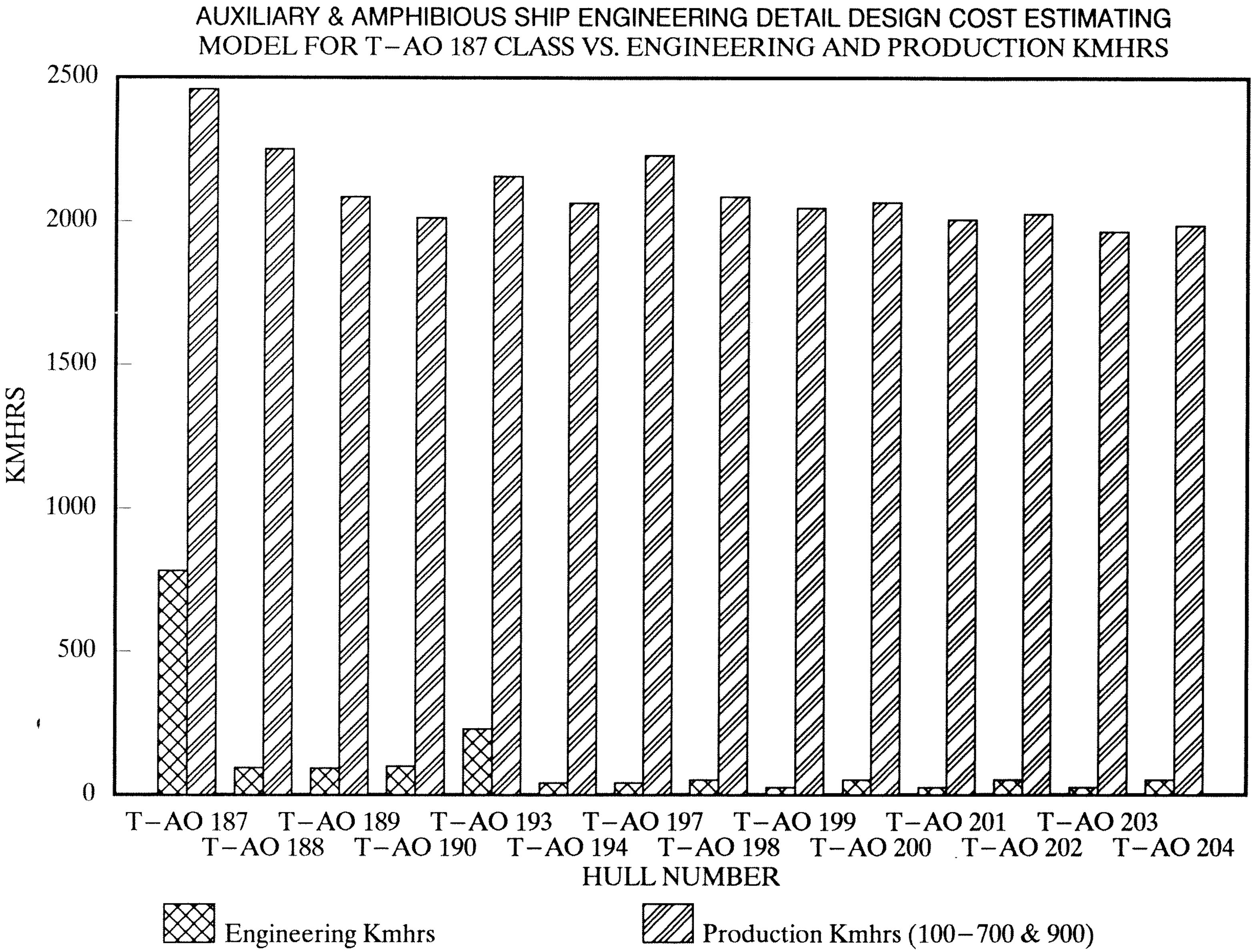

AUXILIARY & AMPHIBIOUS SHIP ENGINEERING DETAIL DESIGN COST ESTIMATING
MODEL FOR T-AO 187 CLASS VS. ENGINEERING AND PRODUCTION KMHRS
KMHRS
2500
2000
1500
1000
500
0
T-AO 187
T-AO 188
T-AO 189
T-AO 190
T-AO 193
T-AO 194
T-AO 197
T-AO 198
T-AO 199
T-AO 200
T-AO 201
T-AO 202
T-AO 203
T-AO 204
HULL NUMBER
Engineering Kmhrs
Production Kmhrs (100-700 & 900)

FIGURE 4-5

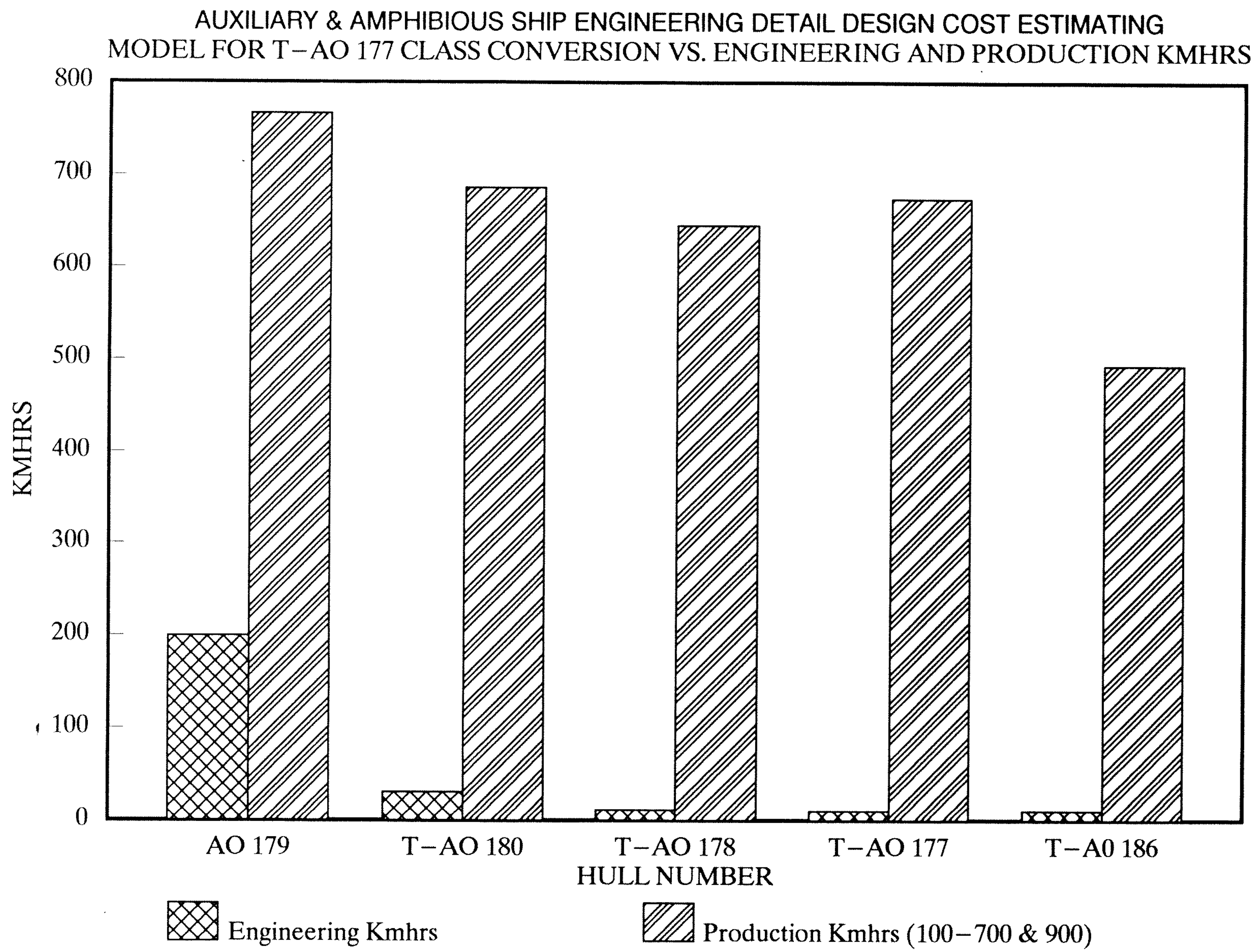

AUXILIARY & AMPHIBIOUS SHIP ENGINEERING DETAIL DESIGN COST ESTIMATING
MODEL FOR T–AO 177 CLASS CONVERSION VS. ENGINEERING AND PRODUCTION KMHRS
KMHRS
800
700
600
500
400
300
200
100
0
AO 179
T–AO 180
T–AO 178
T–AO 177
T–A0 186
HULL NUMBER
Engineering Kmhrs
Production Kmhrs (100–700 & 900)

FIGURE 4-6

This data indicates that an estimate of the total engineering costs for the follow ships of a class can be estimated using the following relationship:

$$F = .08(T)(N) \tag{7}$$

when F is the aggregate follow ship engineering cost in ($K), T is the total lead ship engineering costs in ($K), and N is the number of follow ships in the class. As shown by the LSD 44-51 data, there is wide variance between different individual follow ship costs; consequently, this relationship should not be used for estimating engineering costs for individual follow ships.

When the Navy groups a number of changes to a class and incorporates them as a forward fit to the class, the result is called a class upgrade. Design costs for the upgrade are assigned to the first ship that incorporates the changes, with all subsequent ships of the class receiving the upgrade changes. An example of this in the data base is the LSD 49 Cargo Variant of the LSD 41 Class Dock Landing Ships. There is no direct relationship between the engineering costs of an upgrade and the production costs of the ship for a number of reasons. The design effort is a combination of normal recurring design work for a follow ship of the class, plus the design changes to delete existing systems and add new ones. The construction effort is a mixture of the unmodified construction work for a ship in the class, plus the new work related to the upgraded system. The unmodified work will be affected by the learning curve based on the lead ship. The new work will be similar to a lead ship effort, and since it is a forward fit, there will not be a component of ripout or physical deletion of systems on the ship. This situation is shown in Figure 4-3 for the LSD 49 cargo variant. Although engineering costs for the LSD 49 are roughly nine times greater than the engineering costs for the LSD 48, the production costs are only two percent greater.

For the purposes of estimating an engineering cost for an upgrade, an approximation can be derived by making an estimate of the change required by the upgrade and treating this change as new design work. This approach was taken by Gibbs & Cox, Inc. in estimating design cost deltas for the DDG 51 Flights II, III and IIA Upgrades, where a zone by zone assessment was made to determine the percent of redesign necessary to incorporate the upgrade. This percent of redesign was multiplied by the lead ship engineering costs for the zone. The new design work cost was then the summation of these individual zone values. This new design work cost can then be added to the normal follow ship engineering costs for the remainder of the ship to derive a total engineering cost for the ship.

5.0 PROCEDURE FOR ESTIMATING LEAD SHIP DETAIL DESIGN COSTS

The cost estimating procedure for estimating lead ship detail design costs on this model is very straightforward. In summary the steps to be taken are as follows:

1. Develop a lead ship production manhour estimate (C) (SWBS Groups 100-700 and 900) using the amphibious and auxiliary ship construction cost model [Reference (2)].

2. Estimate the engineering detail design labor manhours using the following equation:

$$L = .31(C) + 35 \qquad (1)$$

   where (L) is the engineering design labor manhours in (KMHRS) and (C) is the production manhours in (KMHRS) estimated in Step 1. If the production manhours are unknown and a lightship weight is known, then an estimate of the engineering design manhours can be derived using the following equation:

$$L = .13(W) - 267 \qquad (2)$$

   where (L) is the engineering design labor manhours in (KMHRS) and (W) is the light ship weight in long tons.

3. Estimate the engineering detail design labor dollars using the following equation:

$$D=(L)(R) \tag{3}$$

where (D) is the engineering design labor dollars in ($K) and (R) is a labor rate in ($/MHR) provided by the model user.

4. Estimate the engineering detail design materials costs using the following equation:

$$M=.12(D) \tag{4}$$

where (M) is the material costs in ($K).

5. Estimate the total engineering detail design cost using the following equation:

$$T=D+M \tag{5}$$

where (T) is the total engineering cost in ($K).

6. An estimate of total SWBS Group 800 costs in $K can be derived using the following equation:

$$\textit{Total SWBS Group } 800 = \frac{T}{0.65} \tag{6}$$

7. If this model is being used in conjunction with the follow ship and follow yard cost model [Reference (3)], an aggregate engineering detail design cost for an entire class can be estimated by using the following equation:

$$F = .08(T)(N) \qquad (7)$$

where (F) is the total aggregate follow ship engineering costs in ($K) and (N) is the number of follow ships in the class. (This CER should be used only for large classes of ships. It should not be used to estimate individual follow ship detail design costs.)

6.0 CONCLUSIONS AND RECOMMENDATIONS

The detail design cost estimating model provides NCA with a model for estimating detail design cost of U.S. Naval auxiliaries, amphibious, MSC and minehunting type vessels. The primary accomplishments and conclusions derived from the modeling effort are as follows:

- Developed an extensive data base for lead ships, follow ships and major upgrades of the LSD 41, LHD 1, AOE 6, T-AGS 45, T-AO 187, MCM-1, and MHC-51 Class ships. The data base includes both labor manhours and material costs.

- Developed a CER for estimating detail design engineering labor manhours from an estimate of SWBS Groups 100 - 700 and 900 production labor manhours.

- Developed a CER for estimating detail design engineering labor manhours from the ship's lightship weight.

- Developed a CER for estimating engineering detail design material dollars from the estimate of detail design labor dollars.

- Developed a procedure for estimating total detail design costs and for integrating these cost with those derived in the lead ship construction cost model.

- Developed guidelines for estimating Total SWBS Group 800 costs from the total engineering costs.

- Assessed the follow ship engineering detail design costs and provided a recommended factor to be used in assessing aggregate follow ship engineering detail design costs for the class.

- Developed a PC based data base and model that contains all the data used in the model and the CER's developed. The PC data base contains business sensitive information not presented in this report. The data base is expandable to include new ships as the data is identified.

The base assumption used in the model, that there is a relationship between construction labor and detail design labor, appears to be valid for the range of ships investigated. It is recommended that future model development focus on identifying data from a variety of ship types and expanding the data base. This can be used to either revise the CER's developed in ship model or develop new CER's, as required.