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A PARAMETRIC COST MODEL FOR ESTIMATING OPERATING AND SUPPORT COSTS OF U.S. NAVY (NON-NUCLEAR) SURFACE SHIPS

by

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A PARAMETRIC COST MODEL FOR ESTIMATING OPERATING AND SUPPORT COSTS OF US NAVY (NON-NUCLEAR) SURFACE SHIPS

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ABSTRACT

With few effective decision-making tools to assess the affordability of major weapon systems, management of total ownership costs is continually misunderstood. Cost analysis provides a quick and reliable assessment of affordability. Because there is no standardized method for calculating reliable estimates of operating and support (O&S) costs (the principal component of total ownership cost), this thesis formulates a parametric cost model which can be used to determine the annual O&S costs of U.S. Navy (non-nuclear) surface ships based on known (or assumed) physical characteristics and manpower expectations. Source data for the cost model is obtained from the Navy Visibility and Management of O&S Costs (VAMOSC) database, a historical cost database maintained by the Naval Center for Cost Analysis (NCCA). Through standard regression and data analysis techniques, cost estimating relationships are developed for three major cost drivers: ship light displacement, ship overall length, and ship manpower. The formulated parametric cost model is a top-level and fairly reliable representation of average annual O&S cost, and it can be used by the DoD cost community to perform component cost analyses or independent cost estimates.

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LIST OF SYMBOLS, ACRONYMS, AND ABBREVIATIONS

α	Level of Significance for Hypothesis Testing
β_0	Intercept Parameter for Linear Regression
b_0	Estimate for the Intercept Parameter
β_1	Slope Coefficient Parameter for Linear Regression
b_1	Estimate for the Slope Coefficient Parameter
ε	OLS Regression Error
H_o	Null Hypothesis
H_a	Alternate Hypothesis
r	Coefficient of Correlation
R^2	Coefficient of Determination
$\forall$	For Every
ANOVA	Analysis of Variance
AOA	Analysis of Alternatives
CAIG	Cost Analysis Improvement Group
CCA	Component Cost Analysis
CER	Cost Estimating Relationship
CES	Cost Element Structure
CP	Cost Position
CRUDES	Cruiser/Destroyer
CSBA	Center for Strategic and Budgetary Assessments
CV	Coefficient of Variation
CYXX$	Constant Year Dollars for Year XX
DAB	Defense Acquisition Board
DoD	Department of Defense
DoDD	Department of Defense Directive
DoDI	Department of Defense Instruction
DoN	Department of the Navy
FY	Fiscal Year
ICE	Independent Cost Estimate
IID	Independent and Identically Distributed
IMA	Intermediate Maintenance Activity
IPT	Integrated Product Team
ISI	Information Spectrum, Incorporated
ISR	Individual Ship Report
LCC	Life Cycle Cost
LOA	Length Overall
MDAP	Major Defense Acquisition Program
MIS	Management Information System
NCCA	Naval Center for Cost Analysis

O&S	Operating and Support
OLS	Ordinary Least Squares
OSD	Office of the Secretary of Defense
POE	Program Office Estimate
PPBS	Planning, Programming and Budgeting System
R&D	Research and Development
ROM	Rough Order of Magnitude
SCP	Service Cost Position
SE	Standard Error (of Regression)
SGLI	Serviceman's Group Life Insurance
SIMA	Shore Intermediate Maintenance Activity
R&D	Research and Development
UIC	Unit Identification Code
USD(A&T)	Under Secretary of Defense for Acquisition and Technology
VAMOSC	Visibility and Management of Operating and Support Costs

EXECUTIVE SUMMARY

Pentagon officials face hard questions regarding operating and support (O&S) costs as each military service feels the impact of significant budget cuts in overall defense spending, especially in modernization funding. With few effective decision-making tools available to assess the affordability of major weapon systems, managing total ownership costs is difficult. For the U.S. Navy, estimates show that about 64 percent of the life cycle cost for a surface ship is attributed to O&S costs. Cost analysis provides a quick and reliable assessment of these costs for surface ships.

O&S cost estimates focus on the costs likely to be incurred by a major weapon system (such as a surface ship) under specified conditions. Although the cost analysis must consider historical costs, it should do more than merely extrapolate from past cost trends. The proper approach is to present normalized empirical data to show the relationship between an assumption and its related cost impacts. Because there is no standardized method for calculating reliable estimates of O&S costs—the principal component of total ownership costs—this thesis sets out to formulate a parametric cost model that can be used to determine the total annual O&S costs of U.S. Navy (non-nuclear) surface ships based on known (or assumed) physical characteristics and manpower expectations.

Source data for the cost model was obtained from the Navy Visibility and Management of O&S Costs (VAMOSC) database, a historical cost database maintained by the Naval Center for Cost Analysis (NCCA). Data for 417 U.S. Navy surface ships spanning thirteen years was obtained and normalized to constant 1998 dollars. Battleships and nuclear-powered ships were removed in order to achieve database parity. The class of battleships was removed because of its dissimilar hull construction with respect to all other ship classes, while removal of the classes of nuclear-powered ships was due to the (realized) higher maintenance and fuel costs as compared to conventional-powered ships (i.e., those with steam, gas turbine, or diesel propulsion plants). Ordinary least-squares regression and analysis of variance were performed in order to validate the assumption that total annual O&S cost was constant over time for a given ship class so that class-averaged cost data could be used.

Through standard regression and data analysis techniques, cost-estimating relationships were developed for three major cost drivers: ship light displacement, ship overall length, and ship manpower. These specific parameters were relatively easy to capture as independent variables for the cost model, which can be used by the DoD cost community to aid in performing component cost analyses or independent cost estimates.

The formulated cost model is a top-level and reliable representation of average annual total O&S costs. It should only be used for non-nuclear-powered ships. The cost model is specifically not intended to estimate the annual O&S costs of aircraft carriers, both conventional- and nuclear-powered (CVs and CVNs, respectively). Further, due to the limited scope of ship data available, it is recommended that this cost model be updated periodically in order to increase its reliability, effectiveness, and utility over time. Specifically, other cost drivers may need to be considered as should the development of a more versatile cost model so that an estimate may be calculated for any U.S. Navy ship (including submarines and CVs/CVNs).

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I. INTRODUCTION

In the early 1980's, the U.S. Navy began an effort to expand its fleet to 600 ships. This effort was initiated largely in response to an increased emphasis on the maritime role in the national military strategy as the Soviets embarked on a fleet expansion of their own. Towards the end of that decade, however, the Soviet Union began to collapse, signaling the end of the Cold War. Consequently, the attention of national military leaders was re-directed from the traditional "blue-water" threat to the littorals as new regional conflicts, for example Iraq's invasion of Kuwait in 1990, arose. After the Cold War, Defense Department spending took a downward turn under bureaucratic assumptions that the need for American military forces would be enormously reduced and military infrastructure would be greatly consolidated (Davis, p.26). Today, with fleet expansion a thing of the past, Navy leaders look to fleet modernization in order to meet the diverse challenges of the future.

The Navy stands at the threshold of a 21st-century revolution in the character and conduct of military operations through creative application of technology, innovative operational concepts, and new methods of organization. The bottom line is that the Navy must achieve 21st-century capabilities affordably in light of budgetary restrictions imposed by Congressional tightening of Defense Department purse strings. According to Chief of Naval Operations Admiral Jay L. Johnson, "...we must build our 21st-century ships at a cost below historical averages if we are to maintain the force structure our country needs." (Johnson, p.7) Cost, then, has become the primary factor in the decision-making process of fleet modernization programs for the U.S. Navy, specifically, and for the Defense Department, generally.

Over the next 10 years, the Department of Defense (DoD) plans to spend $260 billion on several new weapon systems procured through major Defense acquisition programs (MDAPs).[1] These include three new fighter aircraft, a new attack submarine, and a new fleet of surface combatants.[2] Many of these weapon systems will cost at least twice as much to procure as the systems they are designed to replace, exacerbating concerns about their affordability. According to estimates from the Center for Strategic and Budgetary Assessments (CSBA), an independent federal agency, it is expected that the mismatch between Defense modernization plans and the DoD budget funding will amount to approximately $26 billion. The Center speculates that one of the reasons for the nearly 10 percent budget gap is the Pentagon's historic tendency to underestimate the costs of buying, operating and supporting its weapon systems. "It's not just the eye-popping cost of new weapon systems that is squeezing the Defense Department, but the cost of operating, maintaining and then disposing of them." (Peters, p.15)

To better manage these runaway costs, Pentagon officials must focus on the expenses associated with owning the weapons (i.e., the operating and support costs), not

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[1] In order to be a MDAP, an acquisition program must either be designated by the Under Secretary of Defense for Acquisition and Technology (USD(A&T)) as such or estimated by the USD(A&T) to require eventual total expenditure for research, development, test, and evaluation of more than $355 million in FY96 constant dollars or, for procurement, a total expenditure of more than $2.135 billion in FY96 constant dollars.

[2] Such new programs include the DD-21 Land Attack Destroyer, the CVX Next Generation Aircraft Carrier, and the LPD-17 class of amphibious assault ships.

just the initial purchase price. The Pentagon's historic tendency has been to place primary emphasis on the areas of research, development and acquisition "...because they were tied to the budgets we were receiving, [and] people didn't ask too many questions in the area of operations and support." (Peters, p.15)

Now the hard questions regarding operating and support costs are being asked as the services feel the huge cuts in military spending, especially in modernization funding. In response, the Pentagon is embarking on renewed efforts to understand and reduce operating and support costs. Steven Kosiak, director of budget studies at CSBA, says, "By far the largest share of DoD's budget is absorbed by [operating and support] costs." For the Navy alone, estimates show that about 64 percent of the life cycle cost of a surface ship can be attributed to operating and support costs. In order to execute future modernization plans affordably, then, the Navy (and DoD as a whole) must understand and manage the total ownership costs of weapon systems. (Peters, p.16)

Hence, there is a need for an effective decision-making tool that assesses the affordability of U.S. Navy surface ships in terms of operating and support (O&S) costs. In the absence of a standardized method for calculating a reliable O&S cost estimate, this study establishes a procedure which can be used to determine the annual O&S costs of non-nuclear surface ships based on known (or assumed) physical characteristics and manpower expectations. The cost model is parametric in that a statistical approach is used to estimate the functional relationships between cost and some major cost drivers.

Generally, the bigger the ship, the more expensive it is to operate and support. Ship size characteristics, such as light displacement, length overall, and manpower, are relatively easy to capture as independent variables for the analytical determination of their functional impact on the dependent variable, total annual O&S cost. These three particular parameters are chosen due primarily to their ready availability and, as will be shown, their sensible functional forms. Moreover, manpower tends to have "...the most dramatic effect on determining O&S costs." (Ting, p.iii)

Once validated and documented, the cost model will provide budget planners and decision-makers with a fairly accurate and robust estimate of what it might cost to operate and support a ship, new or otherwise, from year to year. Further, the cost model can be used by the Naval Center for Cost Analysis (or any other agency in the Navy cost community) to aid in performing component cost analyses (CCAs) or independent cost estimates (ICEs) for new ship acquisition programs.

II. BACKGROUND

Background research and literature review was conducted in preparation for the formulation of the operating and support cost model. In this chapter, four key topics are examined in order to provide a better understanding of this area of study: (1) the nature of operating and support cost estimating; (2) current research and application of related cost models; (3) the Naval Center for Cost Analysis and its role in cost estimating; and (4) a description of the Visibility and Management of Operating and Support Costs database used for the development of the U.S. Navy surface ship cost model.

A. OPERATING AND SUPPORT COST ESTIMATING

Discussion on operating and support (O&S) cost estimating is obtained from the *Operating and Support Cost Estimating Guide* prepared by the Office of the Secretary of Defense (OSD) Cost Analysis Improvement Group (CAIG). As delineated in DoD Instruction 5000.2M and DoD Directive 5000.4, the OSD CAIG acts as the principal advisory body to acquisition milestone decision authorities on cost-related issues. The guide prepared by OSD CAIG is for use by all DoD components, and, as stated explicitly in the manual itself, "should be considered the authoritative source document for preparing O&S cost estimates."[3]

The life cycle cost (LCC) estimate is an important tool for measuring affordability. For major Defense acquisition programs (MDAPs), the LCC is composed of all costs

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[3] DoDD 5000.4 gives CAIG the authority for establishing criteria and procedures for preparing and presenting cost estimates of major weapon systems requiring a Defense Acquisition Board (DAB) review.

related to a major weapon system during its life span; these include research and development (R&D), production, operating and support (O&S), and disposal[4] costs. O&S costs typically exceed both R&D and production costs over a system's useful life (see Figure 1). Therefore, in assessing the total costs of two competing systems, the cost of operating and supporting each system should be a primary consideration. Moreover, independent review and validation of O&S cost estimates is critical for informed decision-making on the procurements of major weapon systems that will require a financial commitment to O&S cost demands for many years into the future.

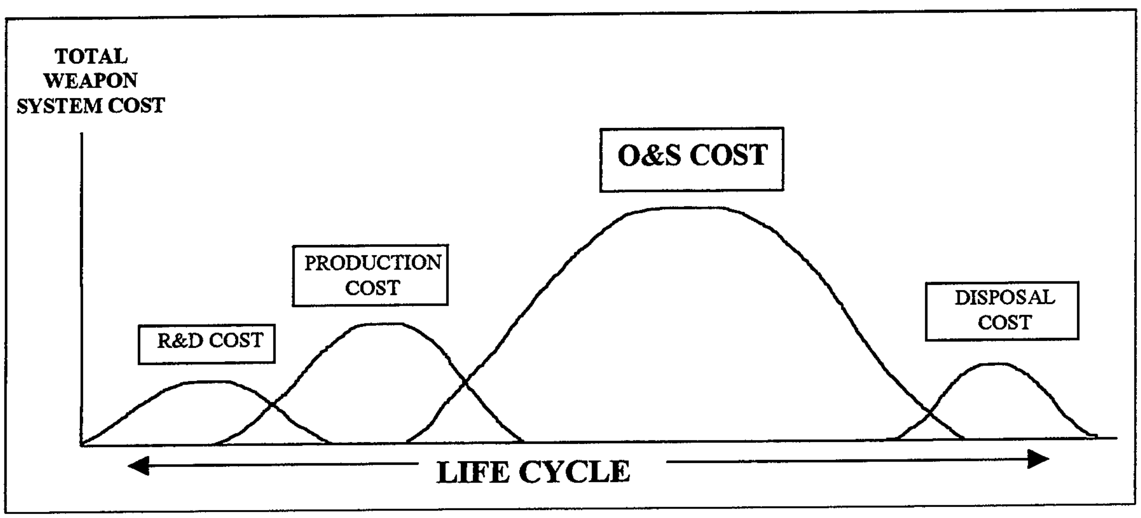

Figure 1. Illustration of Life Cycle Cost Component Distributions Within the Total Cost of a Major Weapon System. (OSD CAIG)

[4] Disposal costs include those expenditures associated with deactivating or disposing of a major Defense system after its useful life.

The LCC estimate, which is required to support the Planning, Programming, and Budgeting System (PPBS) among other things, serves as the basis for a program office's budget submittal in support of specific milestone requirements for a MDAP. In order to test the reasonableness of the program office's estimate (POE) for LCC, an independent agency within the DoD cost community prepares a component cost analysis (CCA) or independent cost estimate (ICE). The CCA/ICE functions as a crosscheck of the POE at each acquisition milestone decision. These independent estimates serve as a type of "sufficiency" review (in terms of evaluating the cost estimating methodology used and the extent for which critical cost factors are accounted).

The typical independent cost estimating process (see Figure 2) involves the creation of a cost Integrated Product Team (IPT) to discuss the scope of the CCA in order to develop the military branch Service Cost Position (SCP). The scope will be tailored to the needs and circumstances of the MDAP and range from the traditional "full-up" independent CCA, to an independent estimate of high cost/high risk elements, or an assessment of various POE methodologies. This process allows for close interaction of the cost centers with their service's comptroller staff and the designated program office in developing the SCP.

The OSD CAIG evaluates the CCA against its own ICE for the MDAP.[5] Following its review, the CAIG submits its cost position to the Defense Acquisition Board (DAB), a senior DoD corporate body for major weapon systems acquisition that provides advice and

[5]Generally, the ICE highlights only those elements of cost which contain a degree of risk that needs to be addressed.

assistance to the Defense Acquisition Executive (the Under Secretary of Defense for Acquisition and Technology) and the Secretary of Defense. The DAB makes the "go/no-go" decision for each program milestone based on the cost position and several other factors.

O&S cost estimates focus on the costs likely to be incurred by a major weapon system under specified conditions. Although the cost analysis must consider historical costs, it should do more than just extrapolate from past cost trends. The proper approach is to present normalized empirical data to show the relationship between an assumption and its related cost impacts. This thesis begins with such an approach.

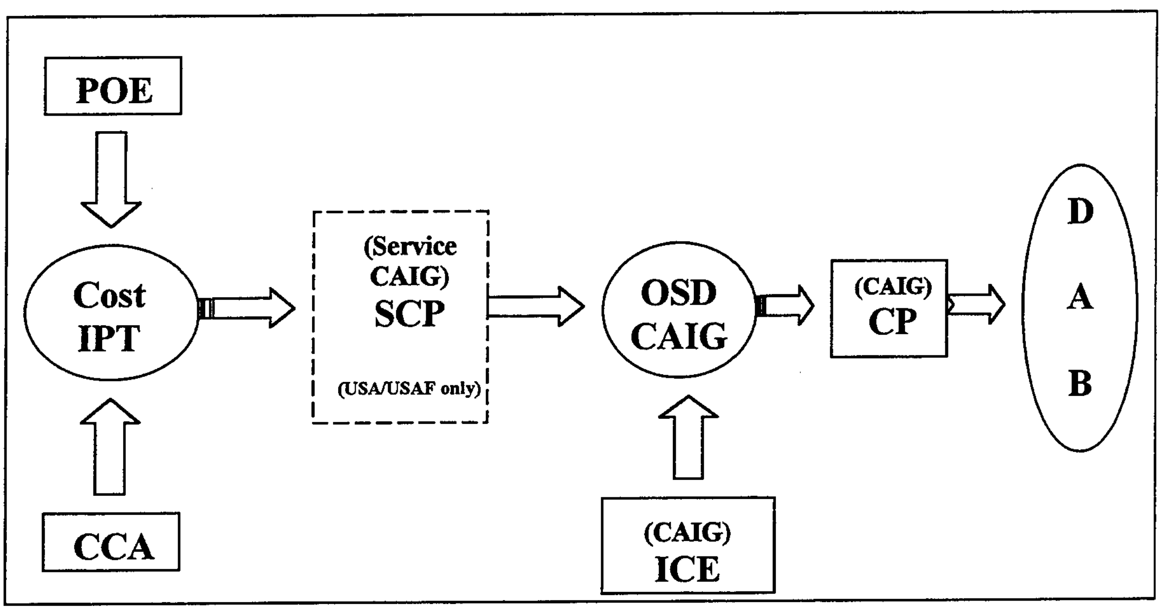

Figure 2. Flow Chart Representation of the Cost-Estimating Process. (OSD CAIG)

The objective of this study is to develop a robust O&S cost-estimating methodology for U.S. Navy (non-nuclear) surface ships that will generate a fairly accurate and reliable

O&S cost estimate for most new ship acquisition programs. The usefulness of the O&S cost estimate is determined by the definition of how the proposed major weapon system (in this case, a new ship) will be operated, maintained, and supported in peacetime. Hence, the assumptions, ground rules, and cost-estimating methodologies for both the reference and proposed system should be similar. This will enable the cost analyst to pinpoint differences in resource consumption that arise from differences in weapon system characteristics.

B. CURRENT RESEARCH AND APPLICATION

A Naval Postgraduate School thesis entitled *Estimating Operating and Support Cost Models for U.S. Naval Ships* by Chung-wu Ting (1993) analyzed O&S costs for U.S. Navy surface combatants using a combined database from three different sources.[6] Ting's thesis employed both accounting and structural methods to understand and authenticate the combined database and to determine basic relationships among O&S cost components. His accounting-oriented analysis used regression to model the constructive relationships among the data and determine its quality. He determined the combined database to be "...relatively accurate with the exception of nuclear submarines (SSNs) and nuclear aircraft carriers (CVNs)." (Ting, p. iii) His structural analysis set out to find relationships between O&S costs and the factors that affect it using structural equations, which revealed that, with exception to overhaul cost, there were strong relationships among the selected factors. The most significant of these factors, manpower, was found to have "the most dramatic effect

[6] As described in the reference, the database was constructed from three major sources: (1) *Visibility and Management of Operating and Support Cost - Ships (VAMOSC-SHIPS)*, March 1991; (2) *NAVSEA Historical Cost of Ships*, Naval Sea Systems Command, Cost Estimating and Analysis Division; and (3) *Jane's Fighting Ships*, 1988-1989.

on determining O&S costs." (Ting, p. iii) With respect to ship overhaul, Ting further suggested that the cost factor—overhaul—should be analyzed separately due to differences imposed by a 1985 policy revision to ship overhaul procedures on the calculation of overhaul costs. With his final objective to "provide a useful database for modeling the effects of changes in operational tempo upon O&S costs," he concluded that "generally speaking, the observations in this data set are valid for any further research except for certain types of ships (e.g., CVN and SSN)." (Ting, p. 4, 59)

Three other studies cited in Ting's thesis are mentioned here for the purpose of illustrating an apparent lack of more extensive research or application of an O&S cost estimating methodology like the one proposed by this thesis. One study, conducted by Terasawa, Gates and Shin (1993) categorized the same combined database used by Ting into eleven groups. The authors found that serial correlation and heteroscedasticity posed statistical problems for determining relationships among O&S costs. Another study, which also identified serial correlation, was conducted by the Institute for Defense Analyses (1989). Like Ting's study, differing ship overhaul costing procedures were identified as causing otherwise unexplainable statistical variations. Lastly, research from the Rand Corporation (1990) used averaged annual O&S cost data to develop a statistical model for U.S. Air Force aircraft. This model became the structural basis for the aggregate part of Ting's study, which modified the data for use with U.S. Navy surface ships.

The *Surface Combatant for the 21st Century* (SC-21) concept (now referred to as *Destroyer for the 21st Century* or DD-21) provided the framework for a major surface combatant (such as a cruiser or destroyer) performance-based life cycle model. Currently in development, it is being used by the Naval Surface Warfare Center (Carderock Division) in Bethesda, Maryland and sponsored by the Naval Sea Systems Command (NAVSEA) in Arlington, Virginia.[7] This cost model is sensitive to combat system performance parameters (for example, speed, firepower) for predicting the LCC of major surface combatants. The developers hope that the cost model will serve as a tool to provide a rough-order-of-magnitude (ROM) cost estimate of surface ship design concepts during the analysis of alternatives (AOA) process, or to investigate the cost implications of alternative mission requirements. The NAVSEA cost model primarily analyzes R&D and production aspects of the life cycle cost, and specifically excludes O&S costs.

Consequently, with no standardized O&S cost-estimating methodology currently available for U.S. Navy surface ships, O&S cost estimates are generated on an *ad hoc* basis through the Navy's cost community. Agencies like the Naval Center for Cost Analysis have become historical data collection points and analytical "think-tanks" for the determination and calculation of O&S cost estimates. This thesis aims to develop an O&S cost model that can be used by cost analysts (as well as "non-cost analysts") to generate robust annual O&S cost estimates for use in such various arenas as LCC estimates, AOAs, and force structure analyses.

[7] For further information on this performance-based life cycle model, contact the Naval Surface Warfare Center (Code 211), Carderock Division (HME systems), 9500 MacArthur Blvd., W. Bethesda, MD 20817.

C. THE NAVAL CENTER FOR COST ANALYSIS

By direction of the Secretary of the Navy, the Naval Center for Cost Analysis (NCCA) was established on October 1, 1985. Its mission is "to guide, direct and strengthen cost analysis within the Department of the Navy (DoN); to ensure the preparation of credible cost estimates of the resources required to develop, procure and operate military systems and forces in support of planning, programming, budgeting and acquisition management; and to perform such other functions and tasks as may be directed by higher authority." (NCCA) NCCA is one of four DoD cost centers which develop CCAs and ICEs for MDAPs.[8]

NCCA also maintains a working relationship with the OSD CAIG. This enables NCCA to remain aware of the cost risks in an MDAP, thereby permitting any concerns to be identified and resolved prior to the CAIG and Defense Acquisition Board (DAB) briefings. Lastly, one of NCCA's vital functions is to manage the DoN portion of the congressionally-mandated Visibility and Management of Operating and Support Costs program.

D. VISIBILITY AND MANAGEMENT OF OPERATING AND SUPPORT COSTS

The Visibility and Management of Operating and Support Costs (VAMOSC) database is one source of historical cost data specifically directed by DoDD 5000.4.[9] A historical data collection system, VAMOSC records O&S costs in a well-defined, structured

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8 The three other DOD cost centers are the OSD CAIG, the U.S. Army Cost and Economic Analysis Center, and the U.S. Air Force Cost Analysis Agency.

9 DODD 5000.4 requires that historical data be used to identify and allocate functional costs among major defense systems and subsystems.

approach for most DoD major weapon systems (a U.S. Navy surface ship is considered a "major weapon system"). One of VAMOSC's objectives is to enhance the visibility of O&S costs for these systems for use in DoD cost analyses. By authority of the OSD CAIG, validated VAMOSC data should be used to calculate the O&S costs of a major weapon system unless some other sources or databases are clearly more appropriate. The data is intended to be used as a basis for decisions concerning affordability, budget development, support concepts, cost trade-offs, modifications, and retention of current systems. The OSD CAIG, responsible for VAMOSC implementation and guidance, also encourages use of the data to develop cost estimates for future systems. (OSD CAIG)

The Individual Ship Report (ISR) of the Navy VAMOSC database which was provided for this study contained thirteen years of historical data for 417 individual ships distributed among 77 ship classes, and forms the basis for the data analysis and cost model formulation. The estimated total annual O&S cost for each ship is broken down into four primary component cost elements: (1) direct unit cost; (2) direct intermediate maintenance cost; (3) direct depot maintenance cost; and (4) indirect O&S cost. Appendix A illustrates the complete cost element structure (CES) defined by VAMOSC. A summary description of the four primary ship O&S cost components and their associated sub-elements follows from detailed discussion in *Navy VAMOSC Individual Ships Report (ISR)* for fiscal year 1995 (see List of References).

1. Direct Unit Cost

Direct unit cost captures the direct costs associated with the operation and support of an individual ship as identified by its unit identification code (UIC). It is computed within the Navy VAMOSC Management Information System (MIS).[10] Direct unit cost is the sum of personnel, material, and purchased services costs.

Personnel cost is the direct personnel costs at the organizational level. A key sub-element incorporated in this aggregation is manpower cost, which represents the employment cost of all active duty Navy personnel (both officers and enlisted) assigned to the ship as reported by the Defense Finance and Accounting Service—Cleveland Center from the Joint Uniform Military Pay System (JUMPS).[11] This cost includes base pay, allowances, other entitlements and government contributions to FICA and SGLI. This cost sub-element does not include the indirect costs of trainees, unassigned personnel, permanent change of station personnel, prisoners, patients, etc.

Material cost sums the costs of all materials utilized or consumed by the ship with the exception of materials utilized in the Intermediate and Depot level maintenance effort (these are reported separately within the direct intermediate maintenance and direct depot

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10 Some sources which provide the data include: Navy Cost Information System/Operations Subsystem (NCIS/OPS); Strategic Systems Programs (SSP), Naval Inventory Control Point (NAVICP) Mechanicsburg; Conventional Ammunition Integrated Management System (CAIMS); Defense Finance and Accounting Service – Cleveland Center; Naval Sea Logistics Center (LOGCEN); and Navy Energy Utilization Reporting System (NEURS). (VAMOSC-ISR, p. A-2)

11 The number of officers and enlisted personnel is an average reported by the Bureau of Personnel (BUPERS), and is calculated by adding the "on board for duty" personnel total at the end of each month of the fiscal year and dividing by twelve (results are rounded to the nearest whole person). Note: some MCMs have two crews; AD and AS manpower strengths include associated repair components. Other ships like CVs may have small detachments assigned to the parent ship which are included. In the case of officer and enlisted Marine personnel assigned to the UIC, the Commandant of the Marine Corps (Code M) reports manpower costs. (VAMOSC-ISR, p. A-3)

maintenance cost components, respectively). The materials accounted for herein include ship petroleum, oil and lubricants (POL), repair parts (non-aviation depot level repairables), supplies[12] (those not reported under Repair Parts), and training expendable stores[13] (purchased from procurement appropriations).

Purchased services cost covers the costs of services other than maintenance. These include printing and reproduction (the procurement of printing and publications not carried in standard government stock), ADP rental and contract services (rental of automatic data processing equipment and related contractual services which incorporate laundry services, rental of boats, and port services provided by other than Navy activities), rent and utilities (heat, light, power, water, gas, electricity and other services excluding transportation and communication services), and communications (long distance telephone/teletype services, postage, rental of post office boxes, and telephone installation charges).

2. Direct Intermediate Maintenance Cost

Direct intermediate maintenance cost includes the costs of material and labor expended by a tender, repair ship, or equivalent ashore or afloat Intermediate Maintenance Activity (IMA) in the repair and alteration of the ship. Computed within the Navy VAMOSC MIS, Direct intermediate maintenance cost is the sum of afloat maintenance labor, ashore maintenance labor, material, and commercial industrial Services costs.[14]

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[12] Includes all non-maintenance supplies and equipage used by the ship and the ships crew. Examples include items relating to health, safety and welfare of the crew, such as medical and dental supplies, radiation badges, fire protection suits, charts, maps, binoculars, etc. (VAMOSC-ISR, p.A-10)

[13] Includes the cost of ammunition, training missiles, and pyrotechnics expended by the ship in non-tactical operations and training exercises. (VAMOSC-ISR, p. A-11)

[14] Sources providing this data include LOGCEN, SSP, and Supervisors of Shipbuilding, Conversion and Repair (SUPSHIPS). (VAMOSC-ISR, p. A-16)

Afloat maintenance labor cost includes the costs of labor expended by a tender, repair ship or equivalent afloat IMA for the repair and alteration of the ship being tended. Similarly, ashore maintenance labor cost covers the costs of labor expended by a Shore IMA (SIMA). The costs of repair parts and consumables used by IMAs are included within the material cost sub-element. Finally, commercial industrial services cost captures the costs for accomplishing afloat and ashore intermediate maintenance actions by private contractors due to workload limitations at the IMAs.

3. Direct Depot Maintenance Cost

Costs associated with depot level maintenance performed for the ship by public or private facilities are classified as direct depot maintenance cost. These costs are computed within the Navy VAMOSC MIS using data provided by various sources.[15] Scheduled ship overhaul, non-scheduled ship repair, fleet modernization, and other depot costs are summed to obtain total direct depot maintenance cost.

The expenditures of scheduled depot maintenance support, for example Regular Overhaul (ROH) and Selected Restricted Availability (SRA), of ships in the operating forces incurred at both public and private facilities constitute scheduled ship overhaul cost. Non-scheduled ship repairs cost, in contrast, records the costs of depot level maintenance exhausted as a result of casualty, voyage damage, and other unforeseeable occurrences which remain beyond the repair capability of ship's force.

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15 The sources providing this data include: SUPSHIPS; SSP; Pacific Fleet Ship Repair Facilities (SRF) Yokuska and Guam; Fleet Modernization Program Management Information System (FMPMIS); Naval Aviation Depot (NADEP) North Island; NAVSEA; Naval Ordnance Station, Louisville; and Space and Naval Warfare Systems Command (SPAWAR). (VAMOSC-ISR, p. A-20)

Fleet modernization cost sums the costs of installing ship alterations and improvements (including military and technical), other support provided at ship depot facilities, and costs for Centrally Provided Material (CPM) used at public and private facilities.[16] Costs expended for the purchase of spare parts and other material required due to changes to the ship's Coordinated Shipboard Allowance List (COSAL) are also included. Fleet modernization cost is computed within the Navy VAMOSC MIS.[17]

4. Indirect Operating and Support Costs

Indirect O&S cost captures the costs of those non-investment services and items that are required by the ship after commissioning and launching to continue operations but which do not result in an expense against Fleet Operations and Maintenance, Navy (O&MN) appropriations. These costs are computed within the Navy VAMOSC MIS, and are calculated by summation of cost sub-elements training (professional skill classroom instruction for officers and enlisted), publications, engineering and technical services (services provided to the ship other than during IMA or depot availability), and ammunition handling (ammunition onload/offload transactions).[18]

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[16] CPM is the acquisition cost of investment funded material (Other Procurement, Navy (OPN) and Weapons Procurement, Navy (WPN)) used in accomplishing alterations under Fleet Modernization. (VAMOSC-ISR, p. A-40)

[17] Some sources providing this data include: SSP; FMPMIS; SUPSHIPS; SRF Yokuska and Guam; NAVSEA; and DFAS Charleston and Oakland. (VAMOSC-ISR, p. A-36)

[18] Some sources providing this data include: Naval Education and Training Program Management Support Activity (NETPMSA); Naval Inventory Control Point (NAVICP) Philadelphia; Naval Weapons Support Center (NWSC) Crane; Naval Sea Systems Command (NAVSEASYSCOM); and SSP. (VAMOSC-ISR, p. A-47)

III. DEVELOPING A PARAMETRIC COST MODEL

The need to re-engineer business processes and reduce acquisition costs in DoD led to a parametric cost estimating initiative. Consequently, in early 1994 the Joint Government/Industry Parametric Cost Estimating Initiative Steering Committee was formed to study the ways for enhancing the use of parametric cost estimating techniques. The cumbersome methods that evolved into the development of the "normal" cost-estimating processes of today are beginning to yield more efficient and less costly approaches to achieve the same, or superior, results. Overall, parametric estimating approaches have fit very well into the overall cost estimating process reengineering scheme within DoD. "Parametric techniques are a credible cost-estimating methodology which can provide accurate and supportable contractor estimates… and more cost-effective estimating systems." (Scott, pp. 2-4)

In this chapter, the parametric cost estimating process is discussed in terms of its definition and background, the collection, normalization, and evaluation of cost data, and the explanation of cost estimating relationships (CERs). The chapter concludes with a preview of the total annual O&S cost model methodology proposed for estimating the cost of non-nuclear surface ships, and the required documentation and validation of such a cost model.

A. THE PARAMETRIC COST ESTIMATING PROCESS

1. Definition and Background

As defined by the Joint Government/Industry Committee,[19] a *parametric cost estimate* is "...one that uses Cost Estimating Relationships (CERs) and associated mathematical algorithms (or logic) to establish cost estimates." (Scott, p. 2) Parametric cost estimating is a technique used by both the U.S. Government and contractors in the planning and budgeting stages of the acquisition process. DoD and NASA, for example, routinely rely on parametric estimates to form the basis of new project cost commitments to Congress. (Scott, pp. 8-10)

With origins dating back to World War II in response to increased demands for military aircraft, parametric cost estimating proved valuable during the late 1940's for the DoD and U.S. Air Force amid mounting pressures of changing technology in jet aircraft, missiles, and rockets. Recognizing the need for a "stable, highly skilled cadre of analysts" to assist with the evaluation of major Defense system alternatives, the military established the Rand Corporation circa 1950. A civilian "think-tank" for independent analysis, Rand's cost-estimating contributions to the aerospace industry were significant in terms of prolific cost studies and the development of the CER cost estimating tool (Scott, pp. 5-8). Then in 1994, the joint government and industry workshop on parametric cost estimating declared "...that valid parametric estimates are a useful and often cost effective estimating approach." (Scott, p. 9)

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[19] The Joint Government/IndU.S.try Parametric Cost Estimating Initiative Steering Committee authored the *Parametric Cost Estimating Handbook* (see List of References) to provide training and background information on the U.S.e and evaluation of parametric tools.

2. Collection, Normalization, and Evaluation of Historical Cost and Parametric Data

Parametric cost estimating requires an extensive database of historic cost and parametric data. The database offers the advantage of actual observations which show both expected and unusual cost expenditures as well as trends in the physical and performance characteristics of fielded systems. Thus, parametric cost estimates provide a realistic prediction of new weapon systems based on experience with similar existing ones. (U.S. Army Logistics Management College, pp. 1-11)

Once raw data is collected, closer inspection may reveal certain problems in terms of comparability and consistency among the systems. Correction of these discrepancies requires specific adjustments to neutralize the impacts of external influences prior to further analysis of the data. For instance, the cost data must be normalized to account for environmental impacts such as inflation. Also, the analyst must devise a mapping scheme between the historical cost element structure (CES) and the new system's CES. Other significant adjustments to both cost and parametric data that may be appropriate include adjustments for consistent scope (sample homogeneity), anomalies (unusual events), and improved technology. There may exist differences in major weapon system scope between the historical data and the estimate being made.

For example, if the systems engineering department made a comparison of five similar programs and then realized that only two of the five had design to cost (DTC) requirements. To normalize the data, the DTC hours were deleted from the two programs to create a consistent systems scope and definition for CER development. (Scott, p. 16)

A model derived from a homogeneous population of older and existing weapon systems will not yield a reliable cost estimate for a similar new weapon system unless its scope and definition are consistent with the model-based weapon systems. Additionally, the historical data should be adjusted for anomalies or unusual events if it is not reasonable to expect such extreme or outlying costs to be present in the new major weapon system. Finally, changes in technology may require adjustments to the data. Such adjustments admittedly will be a matter of judgment for proper application. (Scott, pp. 16-17)

After the historical data is normalized and reviewed for external impacts of content, quantity, and inflation, statistical evaluation is accomplished to determine the effect that selected predictors or drivers of cost impart. A cost driver or parameter is simply a physical, performance, or technological characteristic that is used to predict cost at a high level of aggregation (referred to as a "top-level" cost estimate). It is assumed that there exists a functional relationship between the parameters and the cost. It is this relationship which must be determined through statistical analysis.

3. Cost Estimating Relationships

Cost estimating relationships (CERs) are "...mathematical expressions relating cost as the dependent variable to one or more independent cost-driving variables." (Scott, p. 38) There are four common approaches to developing a CER:

- Analogy
- Industrial Engineering approach
- Expert Opinion
- Statistical/Parametric approach

The statistical or parametric approach is generally the preferred method of cost estimating. This method utilizes all available information on similar systems and derives an estimate of system costs. (U.S. Army Logistics Management College, p. 1-14)

For purposes of illustration, see Figure 3. At the two bottom vertices lie the database and its validated assumptions. As described in the previous section, the parametric approach requires an extensive database of historic cost and parametric data, and assumes that historic cost relationships will continue to hold true. With these foundations (legs) of the triangle intact, the actual parametric procedure begins at the apex. The fundamental tool of parametric cost estimation, regression analysis, sits here. The procedure consists of (statistically) fitting a line or function to a set of historical data and then substituting the appropriate parameter of the new system into the resulting equation.

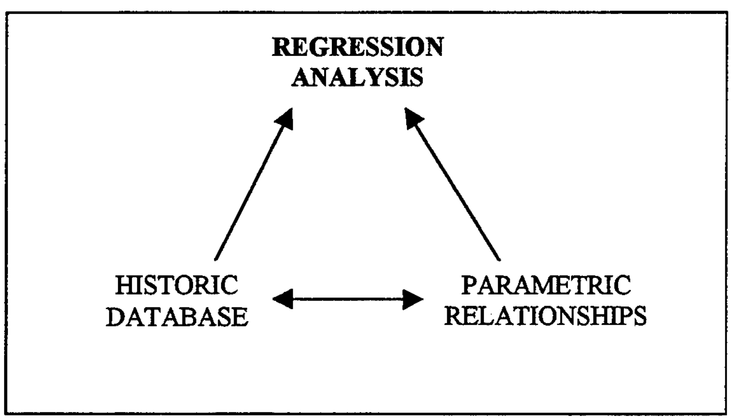

Figure 3. The Statistical Approach to Cost Estimating.

B. THE PROPOSED TOTAL ANNUAL O&S COST MODEL

A parametric cost model is defined as "...a group of cost estimating relationships (CERs) used together to estimate entire cost proposals or significant portions thereof." (Scott, p. 10) Parametric cost models clarify and define the linkage between cost and the major weapon system's physical, performance, and technical parameters. For the proposed parametric cost model developed in this study, cost is represented by the expenditure of total annual O&S dollars, and the major weapon system is a non-nuclear surface ship. The following paragraphs describe the cost model methodology, the documentation required for its use, and its validation by actual, historical observations.

1. Cost Model Methodology

This study constructs a parametric cost model for estimating total annual O&S costs for U.S. Navy (non-nuclear) surface ships based on one of three specific size (physical) parameters: light displacement, length overall (LOA), and manpower (a sum total of enlisted personnel and officers permanently assigned to the ship). A historic cost database[20] detailing the total annual O&S costs of over 400 ships is normalized for inflation, purged of battleships and nuclear-powered ships (due to their inherent dissimilarities from the rest of the sample—see Chapter IV for further explanation), and evaluated for consistent cost trend relationships (using linear regression, analysis of variance, and graphical techniques—also see Chapter IV).

The proposed cost model is a top-level representation of total annual O&S cost

[20] Navy VAMOSC database for FY1996.

constructed with high fidelity and grounded in history. With reference to the cost probability distributions of the key component cost elements, the model provides an interval estimate (based on the standard deviation of the distribution) of total O&S cost broken down into the matching four primary OSD CAIG O&S cost components: (1) direct unit cost; (2) direct intermediate maintenance cost; (3) direct depot maintenance cost; and (4) indirect O&S cost (recall the detailed explanation of these CES elements in Chapter II).

Once documented and validated, the model will require one of three inputs: (1) ship light displacement (measured in tons); (2) ship LOA (measured in feet); or (3) ship manpower (a sum of all shipboard personnel permanently assigned). Additionally, the user may input the particular ship category that best describes the ship (new or otherwise) for which he or she desires a complete estimate. This is necessary due to unequal component cost distributions among the various ship categories (see Chapter V). The surface ships cited in the analysis were grouped into twelve categories in order to calculate more robust cost estimates.

The model output is twofold. First, an interval estimate (bounded by the standard error of regression for the selected CER) representing total annual O&S cost per ship is calculated. Second, a corresponding CES break-out estimate based on the derived probability distributions of the desired ship category is computed as a percentage of the total estimate (see Table I for sample output).

ANNUAL TOTAL O&S COST	$100M (–27%, +33%)
DIRECT UNIT COST (52%)	$52M ± $8M
DIRECT INTERMEDIATE MAINTENANCE COST (12%)	$12M ± $3M
DIRECT DEPOT MAINT COST (27%)	$27M ± $5M
INDIRECT O&S COST (9%)	$ 9M ± $2M

Table I. Sample Output of a Total Annual O&S Cost Estimate with Component Cost Breakouts.

As a top-level model, this parametric cost model will give a reasonably good solution to the annual O&S cost of a proposed non-nuclear surface ship. The "complete" solution (per the CAIG's *O&S Cost Estimating Guide*) also requires the inclusion of four additional cost elements (these are contractor support, simulator operations, software maintenance support, and installation support) which are not accounted for in the VAMOSC database. For a more detailed cost estimate, these four cost elements would need to be estimated independently. Moreover, since the personnel cost reported in VAMOSC does not include accrued costs such as retirement costs of military personnel, this model will tend to underestimate total personnel cost. Figure 4 illustrates the methodology of the proposed parametric cost model.

2. Cost Model Documentation and Validation

The documentation of a parametric model should include the source of data used to derive the parameters, and the size and range of the database. Additional information that should be included in the documentation of a parametric model are: how the parameters were derived, what the model's limitations are, the time frame of the database, and how well the parametric model estimates its own database (measured by the coefficient of variation). All of this information should be located in the source document of a parametric model which should be read before the model is used in an estimate. By reading the source document, the strengths and weaknesses of the parametric model can be assessed and a determination can be made about any appropriateness for use. (Scott, pp. 25-26)

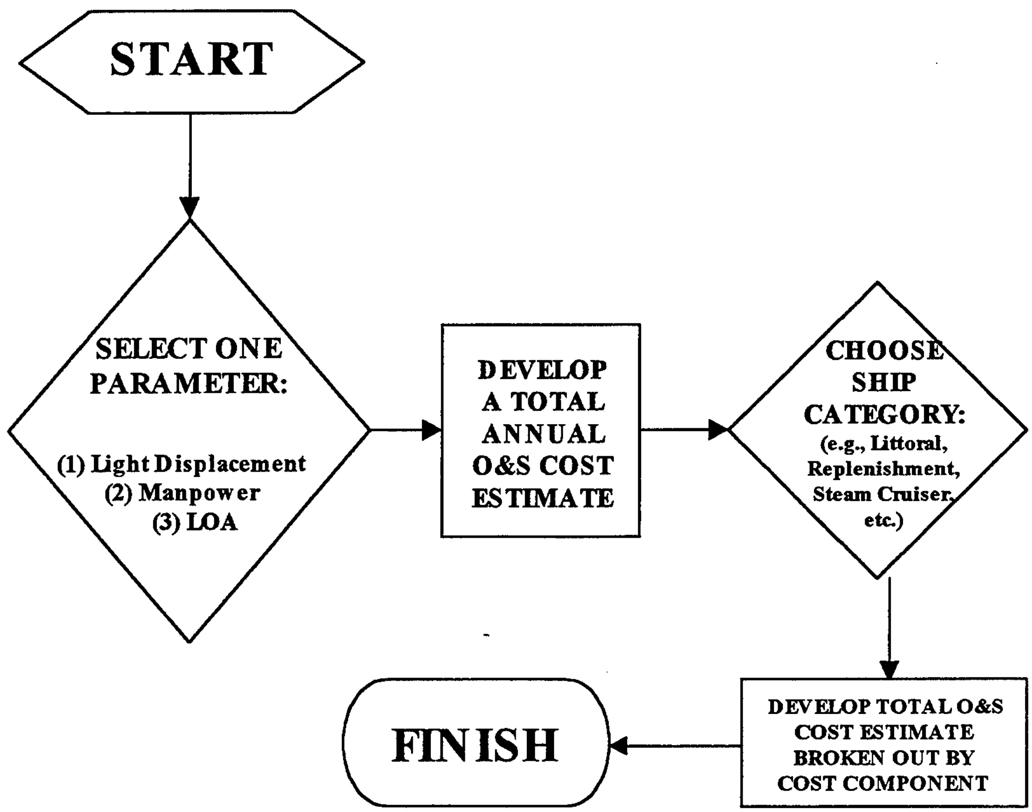

Figure 4. Flow Chart for the Total Annual O&S Cost Model Methodology.

An efficient application of the parametric model methodology requires independent variable values that are both realistic and known with a reasonable degree of confidence. Sometimes functional experts are not sure what the real physical characteristics or performance requirements for a new program will be. In such cases, a most-likely range will provide values that reflect an assessment of the associated uncertainties or unknowns. A corresponding range of cost can then be calculated. (Scott, p. 26)

In summary, the proposed parametric cost model will provide NCCA and other decision-makers a tool for calculating a reliable and robust total annual O&S cost estimate, backed up by history, for any current ship or future ship design based on ship light displacement, ship length overall, or ship manpower. Moreover, the parametric cost model will be useful for early milestone reviews (decision points) within a new ship acquisition program, cost estimates for loosely defined ships, and general (non-specific) assessments or comparisons of surface vessels such as force structure cost models and AOAs.

It is important to note that in any situation, the estimating procedure to be used should be determined by the data available, the purpose of the estimate, and, to an extent, by such other factors as the time available to make an estimate. When properly applied, statistical procedures are varied and flexible enough to be useful in most situations that government cost analysts are likely to encounter. Although no specified set of procedures can guarantee accuracy, decisions must be made; it is essential that they be based on the best possible answers, given the best information that is available. (USALMC, p. 1-13)

IV. TOTAL O&S COST DATA ANALYSIS

In this chapter, the development of the parametric O&S cost model begins with the collection, normalization, and evaluation of actual data. This step is critical and time-consuming since it is necessary to know what trends—if any—exist among the observations and to validate the specific assumptions postulated for the sample of U.S. Navy surface ships collected. Since it is generally the case that more data is better than less, the proposed cost model is perhaps limited by the extent of the historic cost data available. Nonetheless, a successful evaluation of the data's reliability is crucial for the level of cost realism desired for the model's cost estimating capacity.

A. DATA COLLECTION AND NORMALIZATION

Navy VAMOSC ship data was provided by NCCA on a spreadsheet from the Navy's VAMOSC Program Manager, Information Spectrum, Incorporated (ISI). The database contains total annual O&S costs for 417 individual ships distributed among 77 ship classes (see Appendix B for a sample of the raw data received and Appendix C for a brief description of each of the ship classes). The data reflects annual O&S costs from fiscal years 1984 through 1996. The cost data was normalized to constant 1998 dollars (CY98$) by the ISI Program Manager in order to remove the effects of inflation.

For each observation (or ship), the total annual O&S cost is broken down into its 122 component cost elements in accordance with the VAMOSC-defined Cost Element Structure (CES) (recall Appendix A). At the top-level of the CES, the total O&S cost for each ship is a sum of four major cost components, each of which is a further aggregation of multiple sub-elements (as first presented and discussed in Chapter II):

- direct unit cost (personnel and material)
- direct intermediate maintenance cost (material and labor expended by a tender, repair ship, or afloat IMA)
- direct depot cost (depot level maintenance performed by public or private shipyards—includes fleet modernization)
- indirect O&S cost (non-investment services and items essential for daily operations)

These component cost elements are used to breakout the total annual O&S cost estimate calculated from the parametric cost model developed in this study.

The standard categories of U.S. Navy ships analyzed for the development of the cost model include non-nuclear Aircraft Carriers, Cruisers/Destroyers (CRUDES[21]), Amphibious Warfare forces, Auxiliaries, Mine Warfare forces, and Patrol forces.[22] Each ship category has unique missions and operating cycles different from other ship categories. Hence, in the end it will be necessary to account for these factors in order to increase the usefulness of the calculated O&S cost estimate (see Chapter V).

For the purpose of data evaluation, individual ships are analyzed in the context of their classes. Ships within each class are assumed to be similar with respect to daily peacetime operations regardless of the age of the ship. The goal is to justify the determination of CERs (in Chapter V) by looking at averaged representations of ships

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21 A nominal label which describes such surface combatants as guided missile cruisers (CG), destroyers (DD), guided missile destroyers (DDG), frigates (FF), and guided missile frigates (FFG).

22 These category names are used by *Jane's Fighting Ships* (see List of References).

within each class (this becomes the basis of the analytical assumptions discussed in the next section).

Despite a few observed exceptions and a specific "system shock" (i.e., an unexpected, external influence on the observations), the assumptions stated above seem reasonable. The impact on total annual O&S costs by the Persian Gulf War in years 1990 and 1991 (the explainable "system shock") is small among most ships and does not appear to significantly detract from the cost trend analysis performed on the ship classes. Likewise, the evident external influence does not negatively affect the development of the parametric CERs. It does, however, provide a possible explanation for higher than average O&S costs during these years. It is reasonable to expect that similar system shocks will occur in the future given the nature of the political threats that the U.S. Navy currently faces.

Battleships are excluded from the cost model formulation due to their dissimilar hull construction compared with all other U.S. Navy surface ships. The most heavily armored U.S. warships ever constructed, battleships were designed to survive ship-to-ship combat with enemy ships armed with 18-inch guns (*Jane's*, p. 716). Battleships are no longer in active service, and since military strategy has shifted from the "capital ship" scenario to the vital role of the aircraft carrier, a future ship design to replace the battleships is not expected.

In the same spirit of achieving database parity of content, nuclear-powered vessels (both aircraft carriers and guided missile cruisers) are also excluded from the analysis. It is credible that there should be a difference in maintenance (both direct and indirect) and fuel costs compared with conventional (i.e., steam, diesel, and gas turbine propulsion) ships.

To recap, then, the following eight ship classes were removed from the collected Navy VAMOSC ship database:

- the Iowa-class (BB-61) battleships
- the Long Beach-class (CGN-9), Bainbridge-class (CGN-25), Truxton-class (CGN-35), California-class (CGN-36), and Virginia-class (CGN-38) nuclear guided missile cruisers
- the Enterprise-class (CVN-65) and Nimitz-class (CVN-68) nuclear aircraft carriers

Accordingly, the proposed parametric cost model is not expected to calculate reliable annual O&S cost estimates for these surface ship classes.

Small sample size presented yet another concern for effective statistical analysis. Ting's study excluded ship classes from his research that contained five or fewer ships in the class or fewer than fifty total observations (Ting, footnote 3). For this study, additional ship classes were removed if the observations covered a three-year or shorter period. Thus, a ship class was retained if its total number of observations was greater than three. The reason for this decision is merely subjective in nature, and is supported by the opinion that at least four data points within a ship class will yield a satisfactory analysis for the desired purpose of this study.[23] Table II lists the eleven U.S. Navy surface ship classes that were removed from the data collected.

[23] The decision was made after consultation with two statisticians from the Operations Research department of the Naval Postgraduate School.

In summary, of the original 77 ship classes contained in the VAMOSC ship database, only 57 classes[24] were retained for further evaluation and validation of the analytical assumptions discussed in the next section (see Appendix D).

VAMOSC-ISR for FY1996

SHIP CLASS	PERIOD OF DATA (19__)	SHIP HULL NUMBERS IN CLASS
AGDS-2	84-86	2
AGSS-555	96	555
AOE-6	95-96	6, 7, 8
ARL-1	86-88	24
ARS-6	88	8
ATF-148	89-91	159, 160
AVM-1	84-86	1
AVT-59	92	59
LSD-49	96	49, 50
MHC-51	94-96	51
PC-1	96	1 - 12

Table II. Eleven U.S. Navy Surface Ship Classes Removed from the Navy VAMOSC-ISR for FY96 Due To Small Sample Size.

Though the VAMOSC ship database encompasses a thirteen-year period of observations, closer inspection revealed a lack of continuity across the entire period for several ship classes. This is due primarily to decommissioning of older vessels and commissioning of newer ones. In other instances, data seemed to be missing or not reported. Nonetheless, the database is assumed to be correct and complete and to

[24]Note that a total of 20 ship classes were removed: eight classes of battleships and nuclear-powered ships; the 11 ship classes from Table II; and the Glover-class of frigates (FF-1098), which was excluded simply due to the fact that its parametric data was unavailable at the time of this analysis. USS Glover (FF-1098), the single ship within the class, was built to test a new hull design and propulsion system, and has since been decommissioned.

accurately reflect the actual historic annual O&S expenditures of U.S. Navy surface ships.[25] As will be noted again in Chapter VII, however, continual update of the formulated cost model is strongly recommended as more ship O&S cost data becomes available and the database is cleansed of any accounting or clerical errors.

B. DATA ASSUMPTIONS

Since the development of the predictive cost model is based on ship class averages, the first step of the data analysis is to validate two assumptions. Specifically, for a given ship class

- that annual O&S costs for any ship within the class do not change from year-to-year (recall that the effects of inflation were removed from the data); and
- that the collected observations represent a sample of actual total annual O&S costs that are likened to a random sample drawn from a theoretical population of such ships for a given class.

In consideration of the first assumption, we might logically think that as a ship grows older, maintenance and upkeep costs should increase, which is one possible indication of autoregressive (time-dependent) behavior (although costs can be increasing without autocorrelation). Though this would seem to be a reasonable presumption, further analysis will reveal convincing evidence to the contrary. Also, much as it is the case that the VAMOSC ship database reflects (for the most part) the entire population of Navy surface ship classes and the ships consolidated therein (less those whose observations are missing or unreported), the collected database is viewed as a sample of ships taken from the entire population of possible past, present, and future ships for purposes of this analysis. Thus,

[25] The direct responsibility for VAMOSC database integrity rests in fact with the ISI Program Manager.

the second assumption allows for a more robust approach to the comparison of individual ships within each class without compromising (the valid application of) statistical theory.

Effectively, the objective in the initial stage of the cost model development is to validate the assumptions that there exists a constant expenditure of O&S costs across time and that ships within a particular class are indistinguishable from the other ships in the class.

C. VALIDATING THE ASSUMPTIONS

In order to validate these assumptions, ordinary least squares (OLS) regression was employed on ship class scatterplots of total annual O&S cost data against time. The data analysis proceeded, then, with the additional OLS assumptions that the linear model is correct with normal, independent, and identically distributed—or Normal iid—errors (these assumptions are evaluated for credibility in the discussion on "Regression Diagnostics" in sub-section 5).

This section describes the graphical analysis and linear regression techniques on the VAMOSC ship database. In order to develop the cost model, we must be convinced that an increase in cost with age is negligible and that the costs of ships within a class are indistinguishable from one another. The following representative ship classes selected from each of the six standard U.S. Navy ship type categories listed in section A will be looked at in detail in the sub-sections that follow (refer to Appendices E, F, and G for the scatterplots, summary of predictive measures, and linear regression results, respectively, for the remainder of the ship classes):

- the Kittyhawk-class (CV-63) aircraft carriers
- the Leahy-class (CG-16) guided missile cruisers
- the Anchorage-class (LSD-36) dock landing ships

- the Sacramento-class (AOE-1) fast combat support ships
- the Aggressive-class (MSO-422) ocean minesweepers
- the Pegasus-class (PHM-1) missile patrol combatants (hydrofoil)

1. Graphical Analysis

Let the dependent variable Y_{ij} represent the total annual O&S cost for some ship-year *j* measured in 1998 constant dollars (CY98$) for ship *i*. The index *i* is assigned the numeric hull numbers of individual ships, which vary depending upon the ship class. Let the index *j* be assigned the alpha-numeric notations for ship classes. Individual ship composition varies from class to class.[26] Let the independent variable X_j represent a particular *ship-year* for class *j*. The term ship-year broadly describes the operating and support cycle of a ship during a 12-month period. It directly corresponds to a fiscal year (1 October through 30 September), ranging from 1984 to 1996, inclusive. As an example of the use of the notation, the total O&S cost during ship-year 1990 for USS Fort Fisher (LSD-40), an Anchorage-class (LSD-36) amphibious dock landing ship, would be denoted as follows:

$$Y_{40,LSD-36} = 26.6 \quad \text{(CY98\$M)} \quad \text{for } X_{LSD-36} = 1990 \qquad (1)$$

For every ship class, scatterplots of Y_{ij} versus X_j were constructed using the software program S-PLUS®4.[27] Figure 5 illustrates the scatterplots for the six representative ship classes. These prove useful for spotting any cost trends over time that may exist among the

[26] There are five classes for which annual O&S cost data is reported for only one ship: AGF-3, AGF-11, AS-19, AVT-16, and CV-67.

[27] S-PLU.S. for Windows Version 4.0, Copyright 1988-1997 © MathSoft, Inc.

data. (Note that individual ship hull numbers vice solid points are displayed in the graphs in order to give the reader a better feel of how each ship behaves within its class.)

A quick inspection of the graphs (both in Figure 5 and Appendix E) reveals that for most ship classes the data points seem to be fairly well scattered across the time period covered. A closer look, however, shows that some trends do persist, and a few definite outliers for each class are indeed noticeable. Moreover, the extreme observations tend to represent the same ship(s) within the particular ship class, and these ships, in most cases, are the "newer" (or more recently commissioned) ones of the class. This could possibly indicate that "newer" ships are more expensive to operate (perhaps due to higher optempo or state of readiness) or that the "older" ships spend more time pierside for maintenance requirements, overhauls, or even decommissioning preparations.

The real answer (not investigated herein) may serve to alleviate the concern of non-constant O&S costs, which is induced by the fact that several of the scatterplots give mild indication of a possible relationship between cost and ship-year. One should realize, though, that where an apparent trend may exist, in most cases it seems to be a negative relationship—something we would not expect.

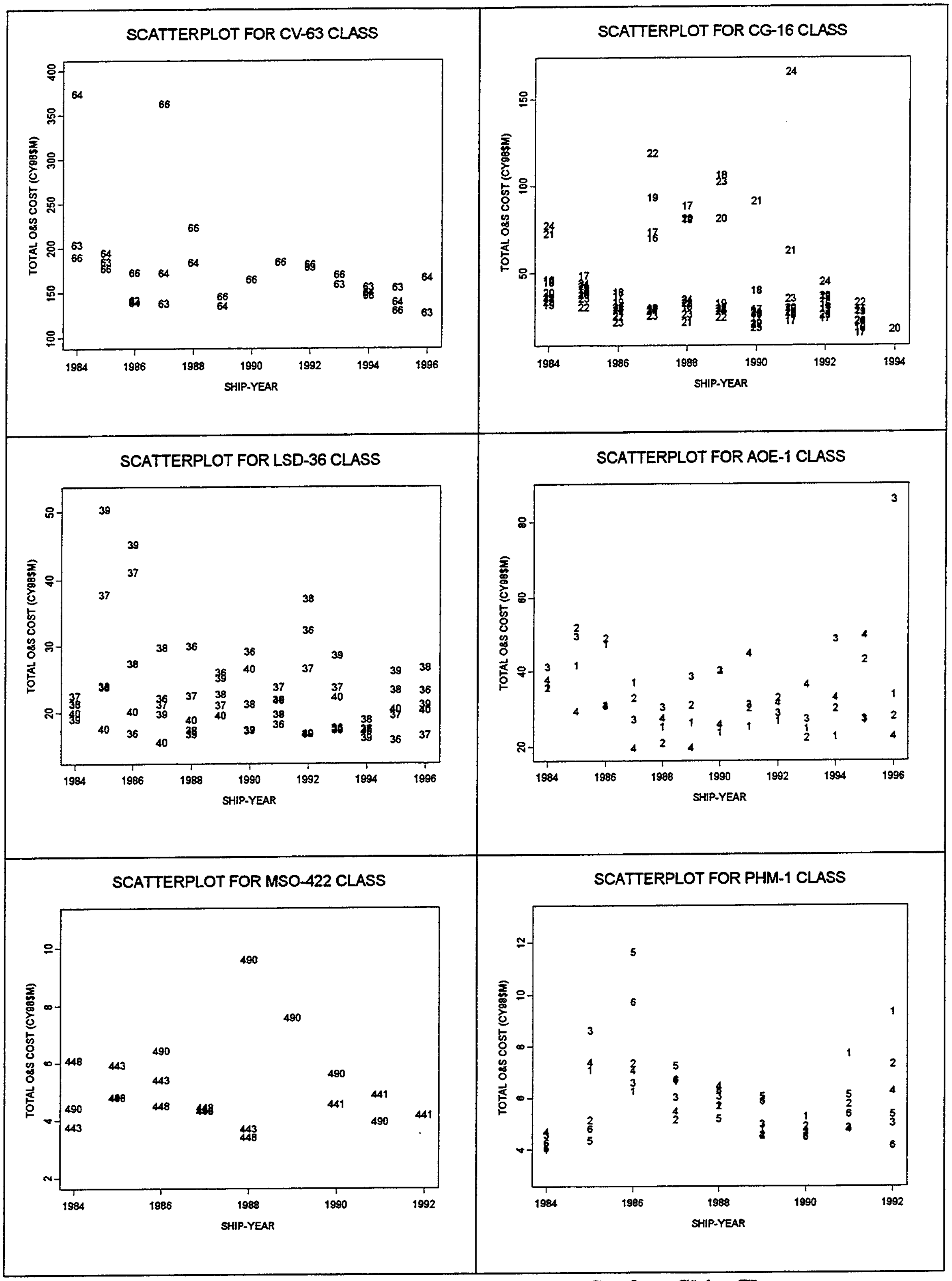

Figure 5. Scatterplots for Six U.S. Navy Surface Ship Classes.

Although a line of slope zero through the data points is assumed, the use of a function in S-PLUS®4 called *lowess* might prove useful for spotting any possible underlying trends. The lowess function fits a weighted smooth curve through the scatterplot data. Figure 6 shows a lowess curve fitted for each of the six ship classes. As suspected from the scatterplots illustrated below and in Appendix E, there appears to be indication of some sort of cost trend as ships age for about one-third of the ship classes. Of these, the lowess curves suggest decreasing trends for most of them.

Figure 7 illustrates three of the few cases with lowess curves that indicate increasing trends. Despite these apparent trends, however, it would be premature at this point in the analysis to accept the conclusion that there exists a definite relationship between cost and ship-year. Further statistical analysis would be required to shed some light on the matter. For now, regression analysis is pursued in order to evaluate a linear relationship (if any) between cost and time.

2. Regression Analysis

With the required variables defined and initial graphical analysis complete, the data analysis step proceeds by asking, "For a given ship i in some class j, can we predict the total annual O&S cost Y_{ij} for a desired ship-year X_j?" In other words, continuing with the previous sub-section example, for a specific ship-year, can we predict USS Fort Fisher's total annual O&S cost? This question is answered by applying OLS regression on the scatterplots constructed in sub-section 1 (recall Figure 5 and Appendix E). Again, S-PLUS®4 is used to graph the "best fit" line to each scatterplot.

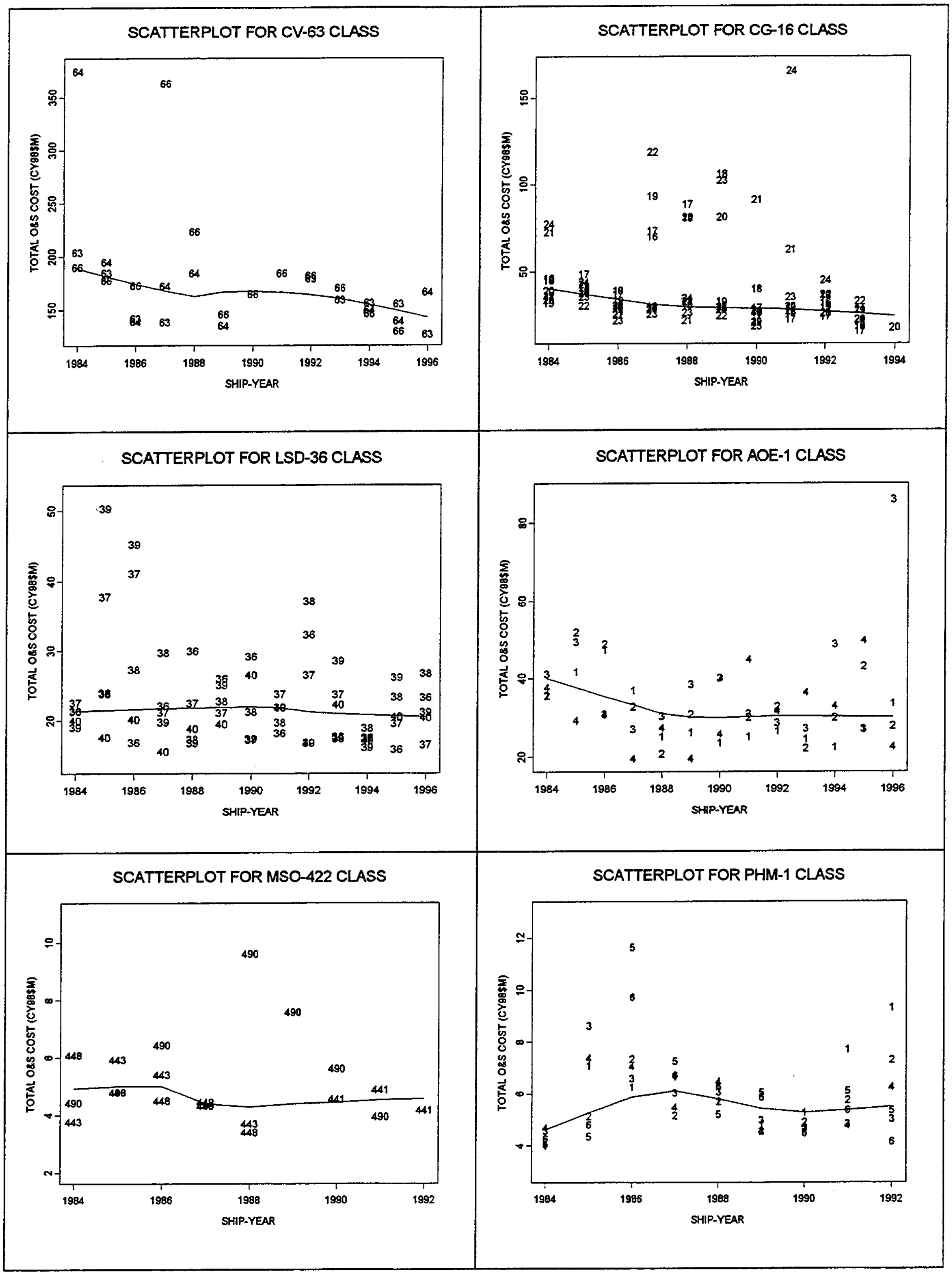

Figure 6. Lowess Smooth Curves for Six U.S. Navy Surface Ship Classes.

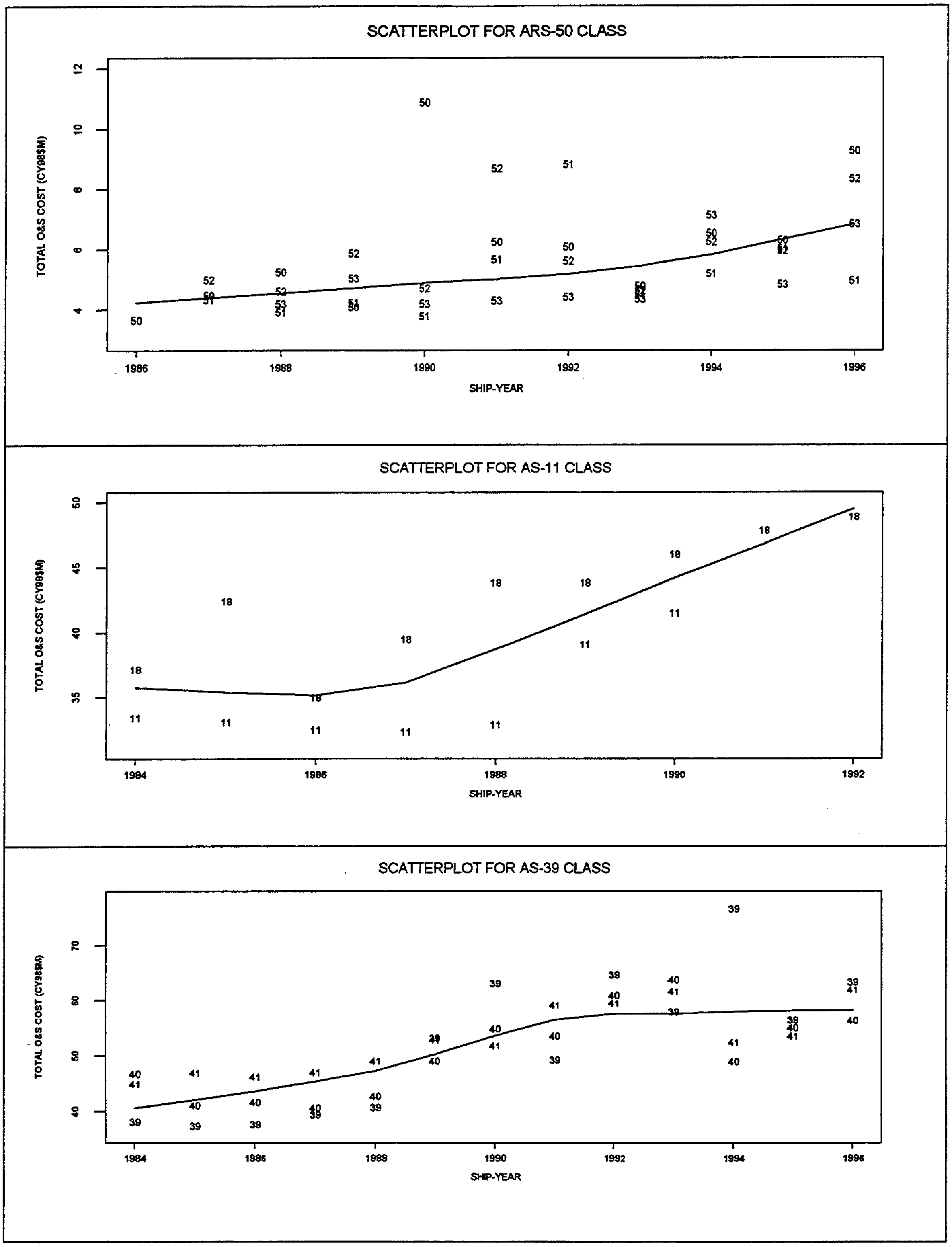

Figure 7. Lowess Smooth Curves Indicating Increasing Cost Trends for Three U.S. Navy Surface Ship Classes.

The regression (or prediction) line has the form

$$\hat{Y}_{ij} = b_{0j} + b_{1j} X_j \qquad (2)$$

where $\hat{Y}_{ij}$ denotes the predicted total O&S cost for some ship i in class j during ship-year X_j. (Note that the parameters b_{0j} and b_{1j} represent the intercept and slope of this line, respectively, for ship class j.)

Figure 8 shows the OLS "best-fit" regression line for the six ship category representatives (refer to Appendix E for all other ship classes). Where a zero slope (or something close to zero) is anticipated, three of these graphs show a slope value close to zero while the other three show decreasing slope values. It is important to note that OLS is greatly influenced by outliers, so their evident existence may provide some explanation for any trend that might be visible even where there were no real relationship between O&S cost and ship-year.

The regression lines drawn for each ship class represent the O&S costs we would have predicted given a specific ship-year (the "best" estimates in the sense that these regression lines are indeed the "best-fit" lines). We might now ask, "How good are the prediction lines?" The answer to this question is found by evaluating certain predictive measures, namely the standard error (SE), the coefficient of variation (CV), the coefficient of determination (R^2), and the coefficient of correlation (r). Table III provides a summary of these predictive measures for the six ship class representatives (refer to Appendix F for all other ship classes).

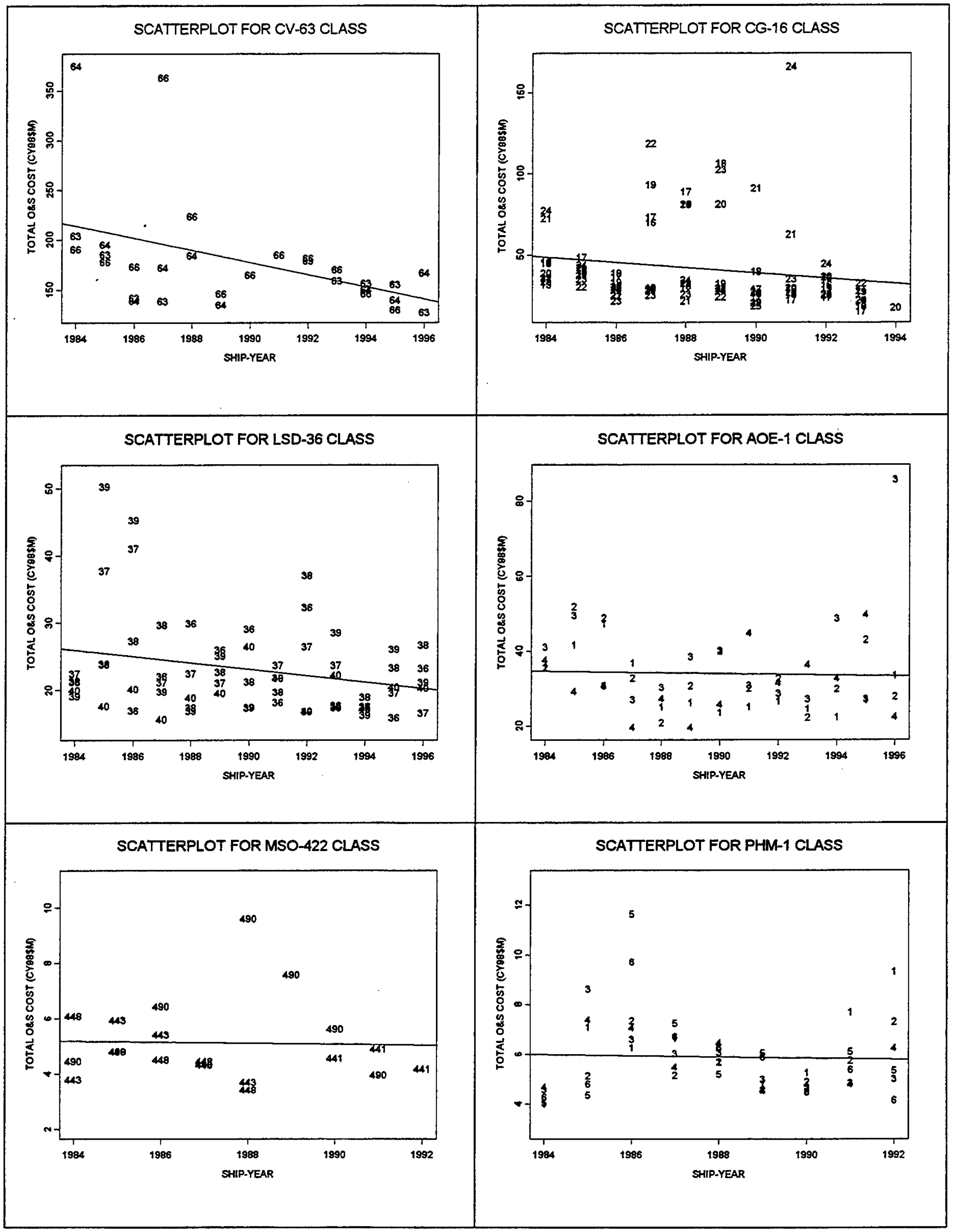

Figure 8. OLS Regression "Best Fit" Lines for Six U.S. Navy Surface Ship Classes.

VAMOSC-ISR for FY1996						Scope of Data: 1984-1996
SHIP CLASS	SAMPLE MEAN (CY98$)	SE (CY98$M)	CV	R^2	R^2 (adj)	r
AOE-1	34,091,121	11.370	33.35%	0.13%	-1.87%	-0.036
CG-16	41,555,425	25.630	61.68%	3.32%	2.23%	-0.149
CV-63	179,371,432	51.820	28.89%	19.24%	16.36%	-0.404
LSD-36	23,225,261	6.799	29.27%	6.52%	5.03%	-0.224
MSO-422	5,122,278	1.485	28.99%	0.10%	-5.16%	-0.032
PHM-1	5,895,284	1.547	26.24%	0.15%	-1.77%	-0.039

Table III. Summary of Predictive Measures for Six U.S. Navy Surface Ship Classes.

Since the SE measures the uncertainty in the estimation of the regression line, the smaller the error, the better the fit. CV (the ratio of SE to the sample mean) is a measure of the percentage by which—on average—the cost prediction will be off from the actual value (for $X_j = \overline{X}$); thus, a smaller CV implies a better fit.[28] Where R^2 gives a percentage of the total variation explained by the regression model, *r* measures both the strength and direction of the relationship between X_j and Y_{ij} (hence, the negative values of *r* indicate that total O&S is negatively related to ship year). For both indicators, the closer in magnitude that the value is to 100 percent, the better is the fit of the prediction line. (The adjusted R^2 value accounts for small sample sizes. The negative values of adjusted R^2 in the table are

[28] In the cost estimating community, a CV value less than or equal to 20% is considered to be acceptable for a good fit.

not significant but rather consequences of their calculation since their respective R^2 values are so close to zero.[29])

Now that these predictive measures are explained and understood, the results displayed in Table III and Appendix F indicate that for a significant majority of the ship classes, the regression line does not adequately explain the relationship between total annual O&S cost and ship-year. With the hypothesis that the prediction line for every ship class is in fact not the "best" fit, the focus is shifted to statistical inference and hypothesis testing.

3. Statistical Inference and Hypothesis Testing

Consider the collected cost data for each class as a sample drawn from the entire population of ship total annual O&S costs at large. What can be inferred? The answer lies in an extension of the regression analysis performed in the preceding section and a simple test of hypotheses.

Given that the collected ship data is a random sample, the regression model for the entire population has the linear form

$$Y_{ij} = \beta_{0j} + \beta_{1j} X_j + \varepsilon_{ij} \qquad (3)$$

where Y_{ij} denotes the actual total annual O&S cost for ship i in class j, and is equal to the cost we would predict (i.e., $[\beta_{0j} + \beta_{1j}X_j]$; recall Equation 2) plus some random error ε_{ij}. As defined earlier, X_j represents a specific ship-year for class j. Similar to Equation 2, β_{0j} and

---

[29] The adjusted coefficient of determination takes into account the complexity of the regression model relative to the complexity of the data. (Hamilton, p.42) It combines a measure of fit (R^2) with a measure of the difference in complexity between data (n, sample size) and model (K, number of parameters):

$R^2(\text{adj}) = R^2 - [(K-1)/(n-1)]*(1-R^2)$. (Hamilton, p. 72)

β_{1j} are the actual—but unknown—intercept and slope parameters, respectively, for each ship class population. These must be estimated with the random samples of VAMOSC ship O&S cost data collected.

Certain assumptions are made about the random error; specifically, that each is independent of the ship-year and the other ε_{ij}'s, and identically distributed (or iid). Further, these errors are assumed to be distributed Normally. It is generally unknown whether these assumptions are true. Sub-section 5 seeks to uncover any potential problems through some regression diagnostics.

Suggesting that no relationship exists between total annual O&S cost and ship-year is tantamount to stating that the population slope parameter is zero (i.e., $\beta_{1j} = 0$ for all j). Consequently, the null hypothesis, H_o, is written

$$H_o\colon \beta_{1j} = 0 \qquad \forall j \qquad (4)$$

The alternate hypothesis, H_a, states that there indeed exists a linear relationship between Y_{ij} and X_j:

$$H_a\colon \beta_{1j} \neq 0 \qquad \forall j \qquad (5)$$

The test of the null hypothesis is based on the Student's t-distribution. Running the regression model in S-PLUS®4 amounts to comparing a calculated t-statistic based on the sample data with the critical value derived from a t-distribution with the same number of degrees of freedom as the sample. The decision rule governing whether or not to reject H_o states that if the probability that H_o is rejected when the null hypothesis is true (essentially the p-value[30]) is less than some level of significance *alpha* (α), then we reject the null hypothesis. In statistical notation,

$$\text{if } P\{\text{reject } H_o \text{ when } H_o \text{ is true}\} < \alpha, \text{ then reject } H_o \qquad (6)$$

A failure to reject the null hypothesis—alternatively, to refute the claim that the slope population parameter is equal to zero—implies that the relationship between Y_{ij} and X_j is similar to the sort of thing we would see by chance if Y_{ij} and X_j were uncorrelated.

Armed with this information, the hypothesis testing was carried out for all 57 ship classes at a five percent significance level (i.e., $\alpha = 0.05$). Table IV and Appendix G list the t-test results for each ship class, and reveal that there would appear to be a significant relationship between total annual O&S cost and ship-year for 22 ship classes. This is considerably greater than the 1-out-of-20 tests that one would expect to show significance at an α-level of five percent if the null hypotheses were true. Of the 22 ship classes, five demonstrate a positive relationship, leaving the burden of explaining decreasing cost over time for the other 17.

Applying the Bonferroni correction[31] to these 57 independent t-tests, however, yields substantially different results (refer to the remarks in Table IV and Appendix G). Now, only eight ship classes test significantly, and of these only one show a positive cost-

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30 The *p-value* equals the estimated probability of obtaining these sample results, or results more favorable to H_a, if the sample were drawn randomly from a population where H_o is true. (Hamilton, p.44)

31 If one considers the set of 57 statistical tests as being performed simultaneously, then the Bonferroni correction sets the alpha-level for the entire set of 57 comparisons to be no bigger than α by making a revised alpha-level for *each* comparison equal to $\alpha/57$. (More information on this subject can be found on-line at <http:\\www.astro.virginia.edu\~eww6n\math\BonferroniCorrection.html>.)

VAMOSC-ISR for FY1996 *alpha* = 0.05; w/Bonferroni correction: *alpha'* = 0.05/57 = 8.77E-04

SHIP CLASS	OLS REGRESSION (COST~YEAR) p-value (F-test)	SIGNIFICANT (slope different from 0)?	REMARKS
AOE-1	0.802	NO	
CG-16	0.084	NO	
CV-63	0.015	NO	significant w/o Bonferroni
LSD-36	0.040	NO	significant w/o Bonferroni
MSO-422	0.891	NO	
PHM-1	0.780	NO	

Table IV. Regression *t*-test Results for Six U.S. Navy Surface Ship Classes.

versus-time trend (the AS-39 class—see Appendix G). The others reveal decreasing trends, which are difficult to explain. Such a negative relationship might be induced by several factors, not the least of which could be a gradual decrease in Defense department dollars spent per ship-year due to budget decreases, the net effect of which is a shrinking quantity of fleet assets and resources. Still, even with the Bonferroni correction, there does not appear to be strong or overwhelming indication that total annual ship O&S costs may not be constant over time.

4. Regression Diagnostics

OLS is just one of many techniques for regression analysis, although it is by far the most often used. Its theoretical advantages depend on conditions rarely found in practice. The farther we depart from these conditions, the less we can trust OLS. (Hamilton, p.34) As stated in the previous section, OLS assumes that the errors are Normal iid random variables. The estimate of the error term is called a residual, which is defined as the difference between the actual value and predicted estimate. Specifically,

$$\varepsilon_{ij} = Y_{ij} - \hat{Y}_{ij} \qquad \forall j \qquad (7)$$

OLS is most powerful when the assumptions regarding these residuals are met since the technique is not resistant to the presence of outliers.

Often, there are outliers, and this seems to be the case with the collected VAMOSC ship data as evidenced by the Y_{ij} *vs.* X_j scatterplots. Scatterplots of the residuals versus the predictions provide some useful diagnostic information. Figure 9 illustrates these graphs with the class (residual) mean—which we would expect to be zero—and median lines included for the six ship class representatives (see Appendix H for the associated graphs of the remaining ship classes). It is interesting to note that most median lines are less than zero—explained by outliers that are in the "high" direction.

For the most part, the graphs show a random spread of residuals, but there are some where a pattern is suspected. Heteroscedasticity (or non-constant variance) may provide an explanation. Though there appears to be mild evidence that the errors are non-Normally distributed for some ship classes, for the purpose of this data analysis the violations are viewed as not significant.

5. Analysis of Variance

What about the individual ship means within each ship class—specifically, are they the same (or close to it)? To assess the spread of the data for the individual ships in a given class, boxplots—like those depicted in Figure 10—were constructed. These indeed show considerable spread of costs for some ships in addition to significant outliers, which lie

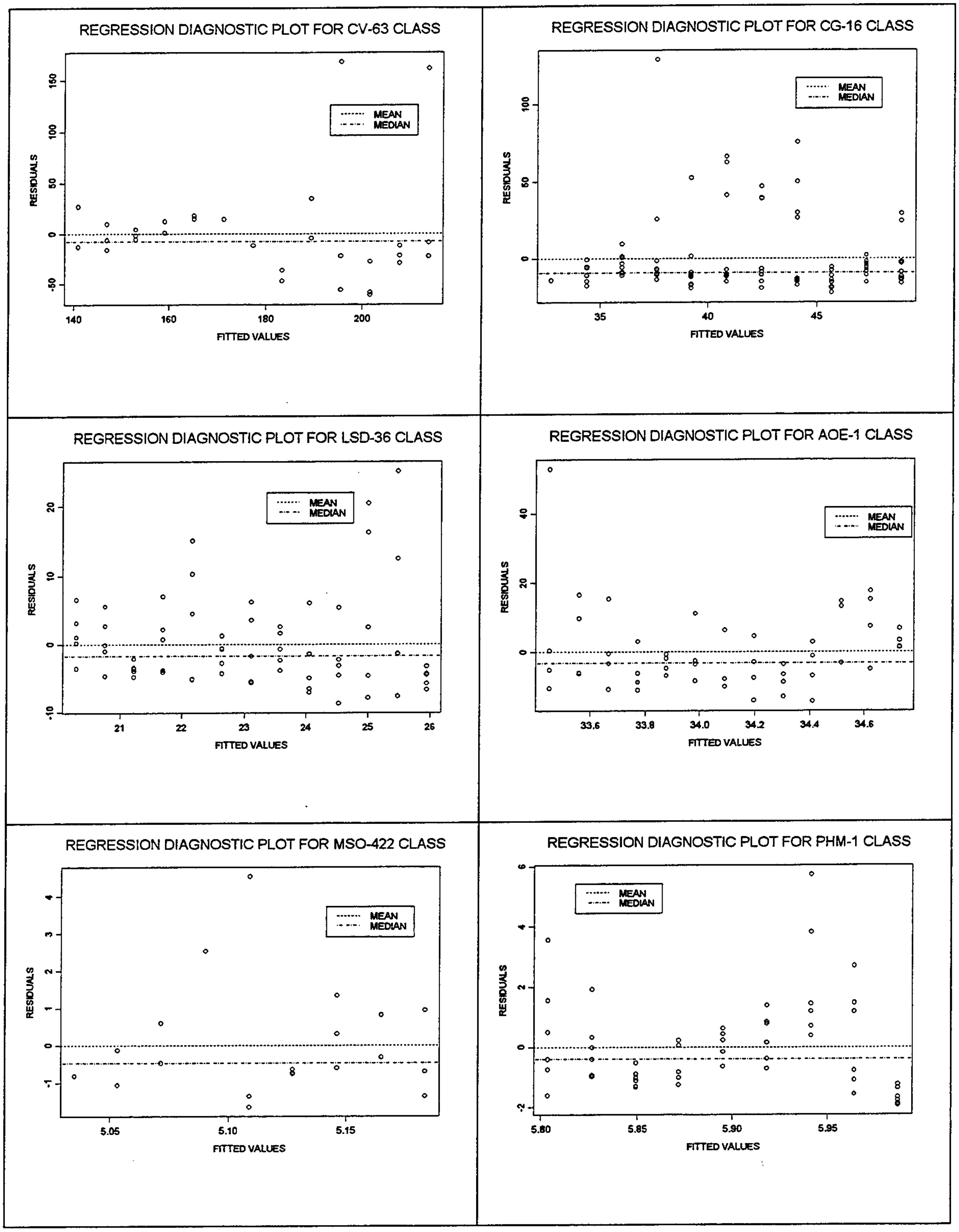

Figure 9. Residuals vs. Predicted Values for Six U.S. Navy Surface Ship Classes.

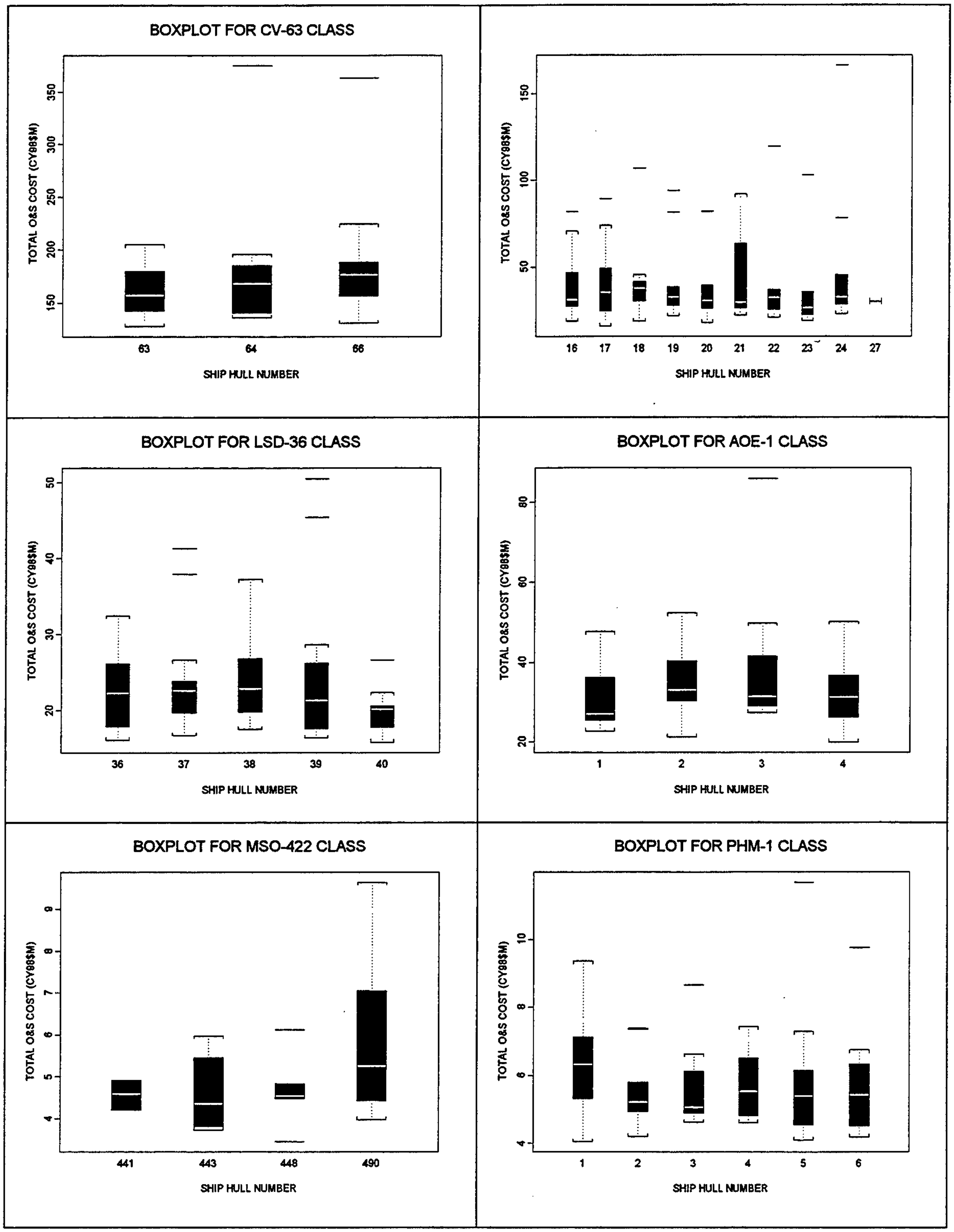

Figure 10. Boxplots for Six U.S. Navy Surface Ship Classes.

beyond one-and-a-half times the interquartile range (the "box"). Indicated by the horizontal line in each box, the individual ship class medians for annual total O&S costs for the time period covered are "roughly" the same. Thus, these comparably close distributions would seem to satisfactorily support (at least not completely remove the possibility of) constant ship class mean and variance.

There are two notable exceptions, however, and these ship classes are illustrated in Figure 11. Their existence, though mildly disturbing, do not by themselves defeat the broad assumption that ship means within a particular class are relatively constant and equal—we would expect a certain degree of random error to occur.[32]

A one-way analysis of variance (ANOVA) was used to test the significance of relationships between total annual O&S cost (Y_{kj}; now indexed by ship-year k vice individual ship i for every class j) and individual ships within each ship class (denoted Z_j). The F-test was used on the following null hypothesis:

$$H_o : \beta_{1j} = 0 \qquad \forall j, \tag{8}$$

where each β_{1j} are the coefficients corresponding to total annual O&S cost (Y_{kj}) modeled by individual ships within a class (Z_j):

$$Y_{kj} = \beta_{0j} + \beta_{1j} Z_j + \varepsilon_{kj} \qquad \forall j, \tag{9}$$

Results from the ANOVA tests are shown in Table V and Appendix I. Where there appears to be a significant relationship for two of the 57 ship classes (specifically, AS-11 and ASR-21; see Appendix I), after the Bonferroni correction was applied no ship class showed

[32] Investigation beyond the scope of this study would be required to explain the reason for disparities between the ship means for ships within the same class.

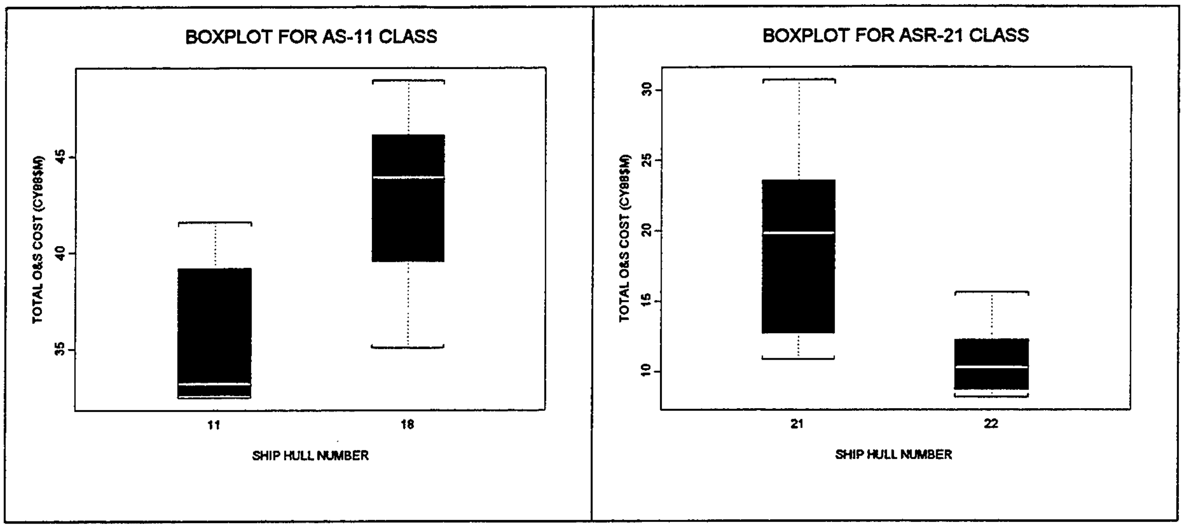

Figure 11. Boxplots Indicating Non-Constant Mean and Variance for Two U.S. Navy Surface Ship Classes.

significance. Since the linear regression analysis conducted previously indicated mild evidence of non-constant O&S costs over time, however, the overall variance might be artificially high—so that the overall ANOVA effects would seem non-significant. The consequence is that the ANOVA method may not be a very powerful tool for validation of the assumption that a ship is indistinguishable from the other ships within its class.

VAMOSC-ISR for FY1996

alpha = 0.05; w/Bonferroni correction: *alpha'* = 0.05/57 = 8.77E-04

SHIP CLASS	ANOVA (COST~SHIP) p-value (*F*-TEST)	SIGNIFICANT ? (non-constant variance w/in class; changing ship means)
AOE-1	0.220	NO
CG-16	0.979	NO
CV-63	0.543	NO
LSD-36	0.394	NO
MSO-422	0.326	NO
PHM-1	0.925	NO

Table V. ANOVA *F*-test Results for Six U.S. Navy Ship Classes.

D. DATA ANALYSIS CONCLUSIONS

First, the original assumption that total annual ship O&S costs are constant over time is not unreasonable despite mild evidence of a significant relationship between cost and time and the possibility of non-Normally distributed errors for some ship classes. It should be noted that where there appears to be a trend, the cost-time relationship is a negative one—a circumstance not as easily explained as an increasing trend. Figure 12 shows a direct comparison of three lines for the six U.S. Navy surface ship classes analyzed directly in this chapter: the ship class total O&S cost mean, the OLS regression "best fit" line, and the lowess smooth curve. Given that the assumption of constant total annual O&S costs for each ship class is true (and in the absence of non-random error), these three lines would be (theoretically) equal. That they are in fact not equal is understood as a consequence of random error and other unknown/unexplainable factors (as mentioned previously).

Second, basing a parametric cost model on ship class-averaged data should not compromise the model's reliability despite the indication that the variance between ships within some ship classes appears to be artificially high. Though the ANOVA tests performed on the ship classes showed no evidence against the claim of constant ship means within a class, the ANOVA test itself is probably not a very powerful tool for this analysis--it may possibly be tainted by the apparent existence of cost-versus-time trends as revealed by the regression analysis.

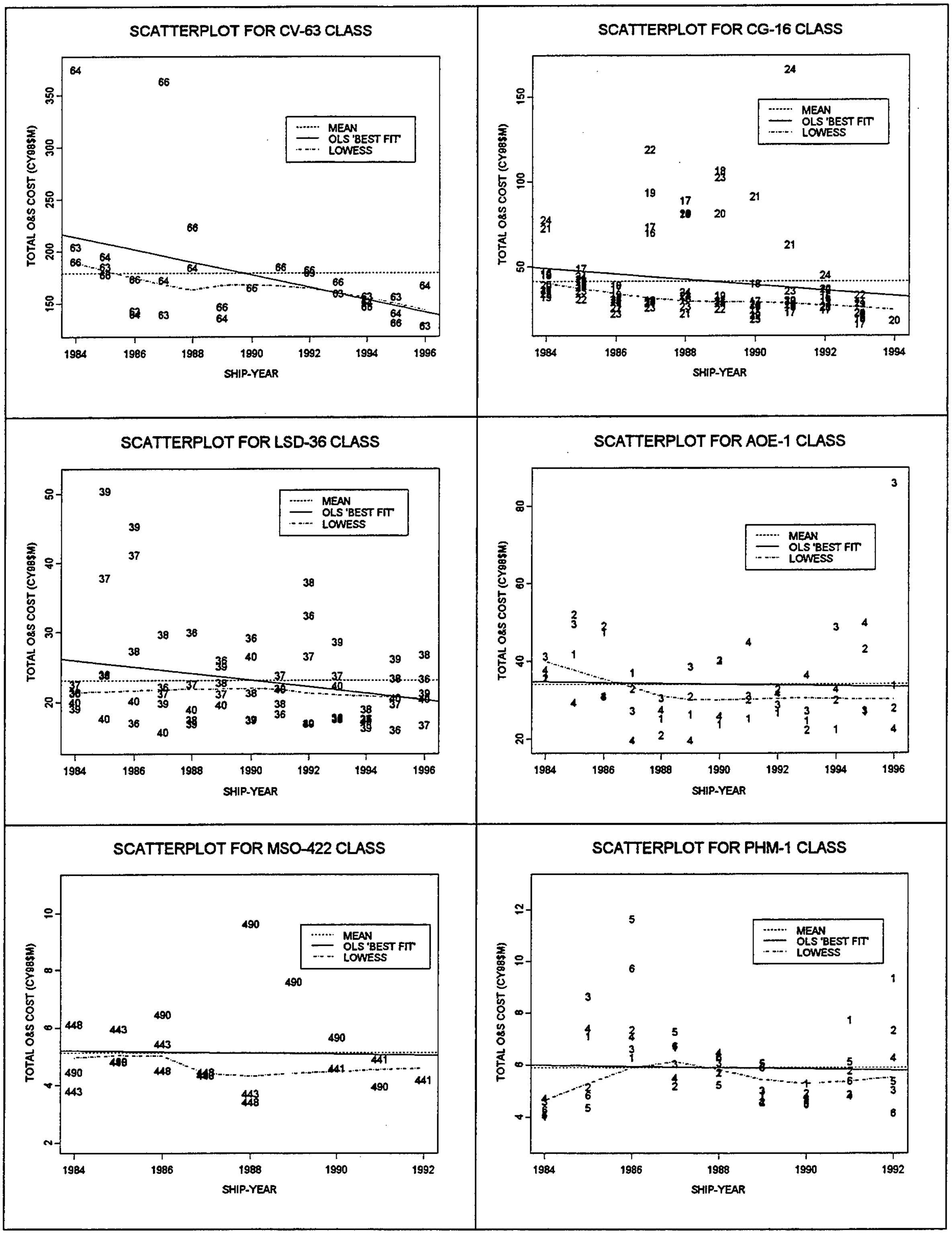

Figure 12. Scatterplots Showing the OLS Regression "Best Fit" Line, the Lowess Smooth Curve, and the Ship Class Mean for Six U.S. Navy Ship Classes.

In conclusion, given that the assumption of constant expenditure of total O&S dollars across time is not invalid (especially considering the small sample size and limited scope of data available), development of the cost model proceeds with ship class-averaged data. It is perhaps important to mention here that the results of this extensive data analysis, though somewhat disappointing, do not by themselves preclude the development of a cost model which meets the criteria set forth in Chapter I and Chapter III, Section B.

V. FORMULATION OF THE COST MODEL

As the previous chapter indicates, significant effort was expended toward analyzing and adjusting the raw Navy VAMOSC ship O&S cost data collected from NCCA and ISI. This initial step was necessary in order to ensure a reasonably consistent and comparable database that would be free of serious deficiencies and irregularities. While there appears to be mild evidence of non-constant total annual O&S costs over time and non-Normally distributed errors, use of the VAMOSC ship database is determined to be sufficient for the derivation of cost estimating relationships (CERs). The statistical development of the CERs and selection of cost model-specific surface ship categories for total O&S cost breakout calculations complete the modeling activity of this study.

A. DEVELOPING THE COST ESTIMATING RELATIONSHIPS

Recall that the definition of a CER is: "a mathematical expression relating cost as the dependent variable to one or more independent variables." (Scott and others, p.38) In this study, the dependent variable is the average total annual O&S cost calculated by ship class from FY84 to FY96. Three parameters related to the size of the ships—light displacement, length overall (LOA), and manpower—are designated as the independent variables due to their causal relationships with cost as demonstrated historically. Generally, the "bigger" the ship, the higher the total annual O&S expenditure. As major cost drivers, then, the parameters were selected because of their evident relevancy to historical cost, in addition to the fact that the data is easy to assemble and its realized effect on O&S cost can be modeled with little difficulty and high validity.

For each of the 57 ship classes, ship light displacement (measured in tons), ship LOA (measured in feet), and ship manpower (the sum total of all enlisted personnel and officers permanently assigned to the ship) data was collected (see Appendix J). A logical assumption regarding the cause-and-effect relationships between these three size characteristics and average total annual O&S cost is that as any one of the independent variables increases in magnitude, average total annual O&S cost will increase as well. Thus, this assumption becomes the working hypothesis for determining the CERs between average total annual O&S cost and light displacement, LOA, and manpower. OLS regression is employed as the statistical tool to test this hypothesis and to derive the CERs using an α-level of significance equal to 20 percent (a standard level used by analysts in the DoD cost community).

It should be noted here that a multivariate cost model would likely be problematic as an estimator of average total annual O&S cost due to suspected statistical correlations that exist between the independent variables. For instance, a ship of a known length would certainly tell us something about its manning level and displacement. Likewise, knowing the displacement of a ship would provide a reasonable indication of its associated length and manning level. For example, an aircraft carrier is physically larger than a frigate, so we would expect the aircraft carrier to be heavier and longer than the frigate with a higher level of manpower. Hence, a multivariate cost model based on collinear independent variables could only obtain a good prediction if the multicollinear relationship between the independent variables was maintained by the desired ship(s) to be estimated.

Before further discussion on this matter, let us first take a closer look at the suspected multicollinearity. To do this, a correlation matrix was calculated for the independent variables (see Table VI). It is commonly accepted by the DoD cost-estimating community that multicollinearity is present for a coefficient of correlation value greater than or equal to 70 percent (i.e., $r \geq 0.7$) (OSD CAIG). Since light displacement, LOA, and manpower parameters are statistically dependent given that their respective r-values exceed 80 percent, no consideration of a model other than a univariate one is made.

	COEFFICIENTS OF CORRELATION		
SHIP PARAMETERS	LIGHT DISPLACEMENT	LOA	MANPOWER
LIGHT DISPLACEMENT	1.000	0.880	0.926
LOA	0.880	1.000	0.827
MANPOWER	0.926	0.827	1.000

Table VI. Matrix of *r*-Values for Three Parameters of Ship Size.

Now (returning to the discussion on the preferred choice of the model), it would be a tedious task to quantify the physical relationship between these three parameters so as to apply it to a potential candidate to be estimated under a multivariate model. Given that a reliable *yet quick* cost estimate is desired, a less complex cost model based on one of the three parameters will provide the desired level of versatility and utility. Therefore, this thesis proceeds with the formulation of a univariate parametric cost model. It is anticipated that such a model will serve sufficiently as a powerful and reliable predictor of total annual O&S cost. Further, due to the nature of the data used for the model development, it is assumed that the historic cost relationships among ships will continue to old true for future ships and ship designs (a possible exception would be a U.S. Navy "Smart Ship").[33]

Graphical analysis by ship class of average total annual O&S cost versus each ship size parameter independently reveals indications of close functional relationships (see the scatterplots in Figure 13). The following sections examine the CER derivations for each of the three parameters separately. The last section visits the topic of regression diagnostics for the fitted models in order to lend validity to the standard OLS assumptions (as discussed in Chapter IV).

Lastly, the four leading predictive measures—standard error (SE), coefficient of variation (CV), coefficient of determination adjusted for small sample size (adj R^2), and coefficient of correlation (r)—will be evaluated in the derivation of each CER. Additionally, the Student's t-statistic and F-statistic will provide further assessment of each model's strength, and enable direct comparison among the functional models of the other cost drivers.

[33] The U.S. Navy "Smart Ship" program creates reduced manning level requirements for a few specified U.S. Navy combatants, thereby off-setting traditional manpower level relationships with respect to overall length and light displacement.

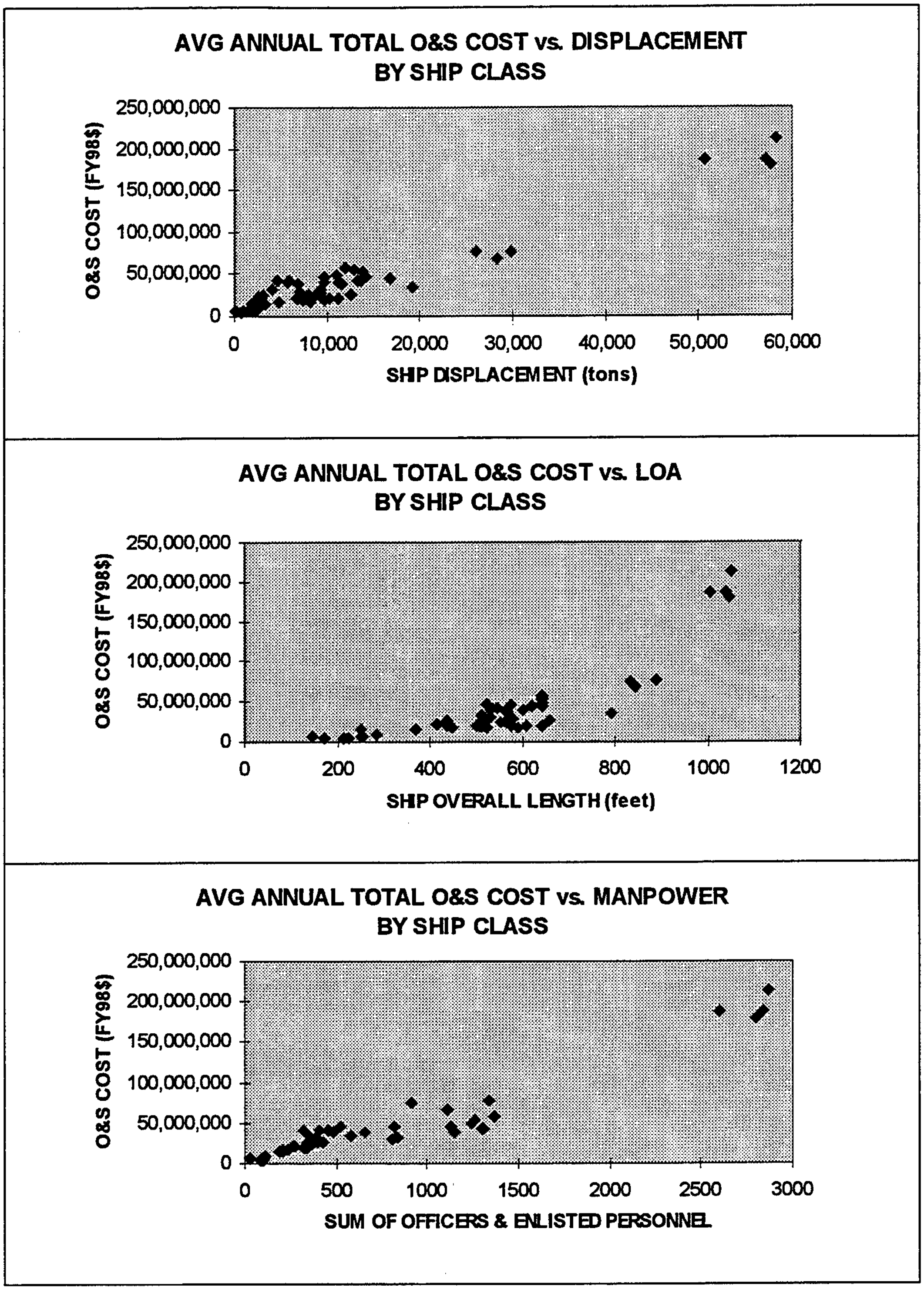

Figure 13. Scatterplots of Ship Class Average Annual Total O&S Cost Modeled by Displacement, LOA, and Manpower.

The Student's t-statistic tests the strength of the relationship between the independent and dependent variables by examining the slope coefficient β_1 for the model given by:

$$Y = \beta_{0k} + \beta_{1k} X_k + \varepsilon_k \qquad \forall \text{ k}, \tag{10}$$

where the index k corresponds to one of the three ship size parameters. The t-statistic, then, tests the hypotheses given by Equations 4 and 5 in Chapter IV with the index j replaced by k.

The F-statistic, in contrast, offers a broader evaluation of the CER. It tests the strength of the relationship between the assumed model and the dependent variable, enabling us to decide whether we prefer the predicted estimate given by the model, or the mean value of the sample. In the case of univariate models, however, the t-statistic and F-statistic will yield the same level of significance (so to reject a model based on a particular cost driver is to reject the model entirely and prefer the mean).

Hence, for evaluation of the strength of the univariate models, only the t-test is used on the hypotheses that

$$H_0 : \beta_{1k} = 0 \qquad \forall \text{ k} \tag{11}$$

versus

$$H_a : \beta_{1k} \neq 0 \qquad \forall \text{ k} \tag{12}$$

1. CER #1: Ship Light Displacement

Light displacement describes the weight of water in tons that a ship displaces under light load conditions (i.e., it does not account for a ship's full combat load capacity). The scatterplot of average annual total O&S cost versus light displacement in Figure 13 shows that the majority of the data points are collected near the bottom left side of the graph. The observations at the upper end are the aircraft carriers, while the few offset points just left of the "middle" represent the larger amphibious assault ship classes—LHDs and LHAs—and the training aircraft carrier (AVT-16). Figure 14 depicts the regression "best fit" line, and Table VII displays the summary results of OLS regression applied to this data.

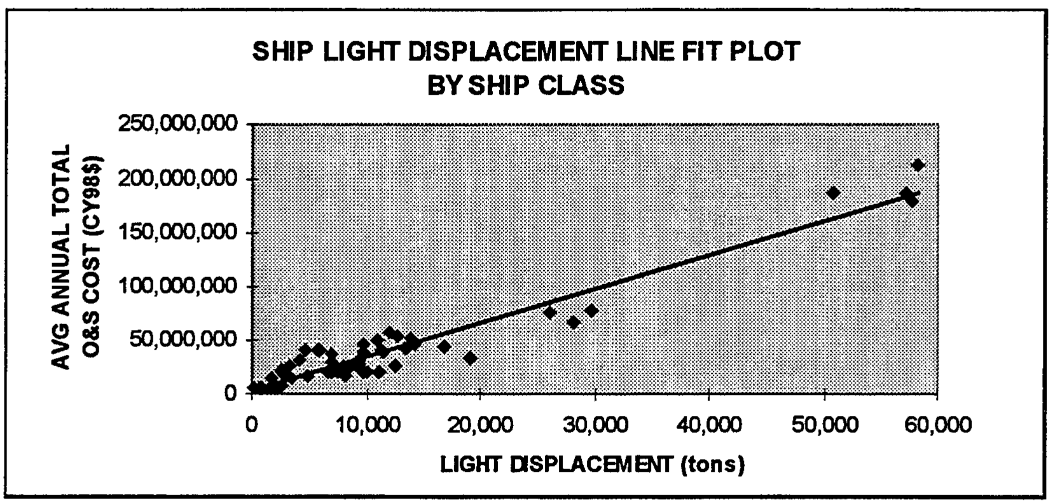

Figure 14. OLS Regression "Best Fit" Line for Average Annual Total O&S Cost versus Ship Light Displacement.

Regression Statistics	
r	0.964
R^2	0.930
Adjusted R^2	0.929
Standard Error	11970828.591
Coefficient of Variation	0.288
Observations	57

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 80.0%*	*Upper 80.0%*
Intercept	3294330.439	2122817.714	1.552	0.126	540749.314	6047911.565
LIGHT DISPLACEMENT	3162.712	116.790	27.080	1.759E-33	3011.219	3314.205

Table VII. Summary Output of OLS Regression on Ship Light Displacement CER.

All of the predictive measures indicate that light displacement is a reasonable predictor of total O&S cost, and we would prefer this model to the mean of the population. The standard error (SE) of the regression line, however, is assumed in this model to be constant regardless of the size of the dependent variable. Effectively, estimates calculated for a ship of relatively small displacement (where most of the ships are grouped) are assumed to have the same spread of error as those for ships of larger displacement. Rather than give this constant standard error for every calculated estimate, it is desired to provide a total O&S cost estimate bounded above and below by a percentage of the total (based on the standard error of regression). Hence, we consider a model of the general form $y = ax^b$, in which the magnitude of the error for a particular prediction depends on the value of the independent variable.

Moreover, a quick look at the residuals of the linear model (see Figure 15) leads one to suspect that they are not quite Normally distributed due possibly to a mild indication of heteroscedasticity and non-random pattern of errors. Consequently, a transformation of the data seems appropriate.

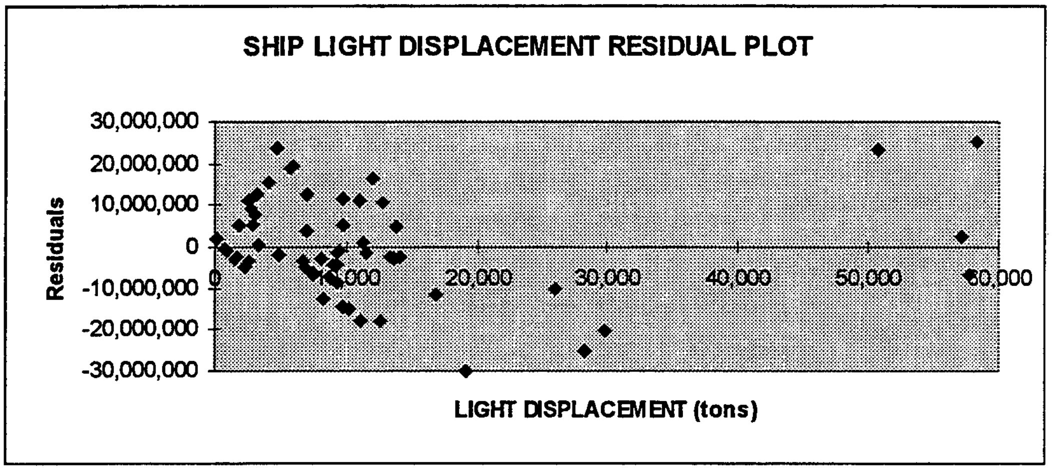

Figure 15. Scatterplot of Residuals for Ship Light Displacement.

By transforming both the displacement and cost data with natural logarithms, a multiplicative CER is considered. Such a model proposes that a change in the independent variable causes a similar change to the dependent variable by an amount proportional to the change in the independent variable. In mathematical terms, the equation is

$$\hat{Y} = AX^{\beta} \qquad (13)$$

where $\hat{Y}$ is the predicted average annual total O&S cost and X represents the light displacement for a given ship. The equation parameters A and β must be estimated, and their calculation is derived directly from log-linear regression.

In order to produce a multiplicative CER, OLS regression is performed on the natural logarithm of the dependent variable *Y* versus the natural logarithm of the independent variable *X*. Taking the natural logarithm of each side of Equation 13 results in an equation of the form

$$\hat{Y}' = b_0 + b_1 X' + \varepsilon \qquad (14)$$

where $\hat{Y}' = \ln(\hat{Y})$ and $X' = \ln(X)$. Equation 14 is then transformed into a unit space model by taking the exponential of both sides of the equation and solving for $\hat{Y}$:

$$e^{\hat{Y}'} = e^{b_0 + b_1 X' + \varepsilon} = e^{b_0} e^{b_1 X'} e^{\varepsilon}$$

$$\hat{Y} = e^{b_0} X^{b_1} \delta \qquad (15)$$

where δ is a multiplier since ε has constant standard deviation (additive).

In the model given by Equation 15, the coefficient e^{b_0} (recall that b_0 is the estimate for the y-intercept of Equation 14) becomes the estimate for the parameter *A* in Equation 13. Likewise, the exponent b_1 (the estimated slope parameter in Equation 14) becomes the estimate for β in Equation 13.

Applied to the transformed displacement and cost data, Figure 16 shows the regression "best fit" line, and Table VIII displays the results of OLS regression. Since this CER was derived in log space, the statistics of the transformed data can be misleading when compared with the strictly-linear model. On its own merit, though, the log-linear model shows strength with an approximate 80% coefficient of determination (R^2) and 90% coefficient of correlation (r). With significant results from the *t*-test, the null hypothesis is rejected, and a curvilinear model based on light displacement satisfactorily describes the effect on total O&S costs.

As indicated on the graph in Figure 16, the equation of the prediction line is

$$\hat{Y}' = 10.896 + 0.704X' \qquad (16)$$

where $\hat{Y}'$ and X' are as defined in Equation 14. When transformed from log space back into unit space (using the estimates derived in Equation 15), Equation 16 yields the multiplicative model

$$\hat{Y} = 53{,}892X^{0.704} \qquad \text{(CY98\$)} \qquad (17)$$

where X is ship light displacement (in tons).

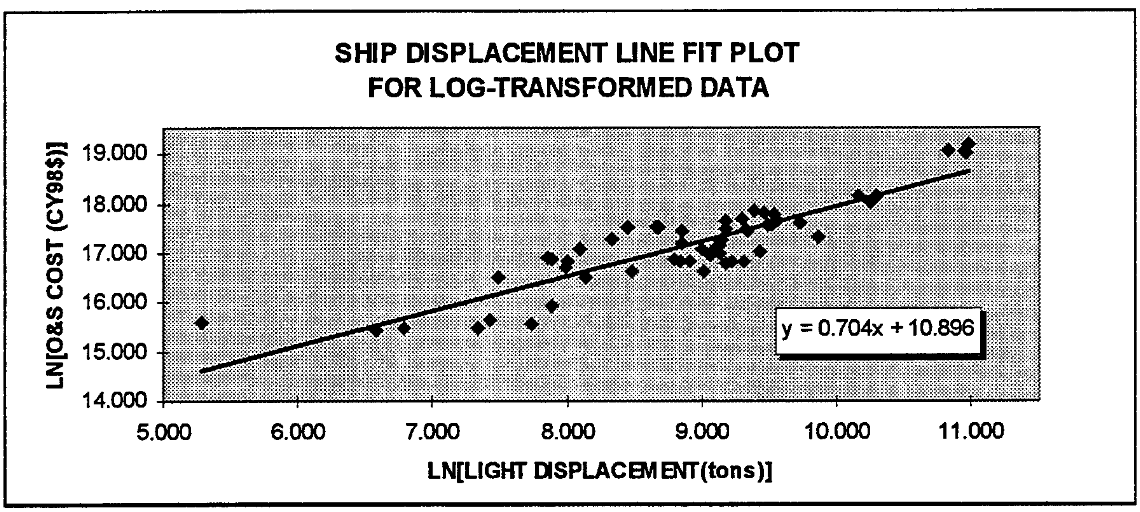

Figure 16. OLS Regression "Best Fit" Line for Ship Light Displacement CER Model Using Log-Transformed Data.

Regression Statistics	
r	0.887
R^2	0.787
Adjusted R^2	0.783
Standard Error	0.399
Coefficient of Variation	0.023
Observations	57

	Coefficients	Standard Error	t Stat	P-value	Lower 80.0%	Upper 80.0%
Intercept	10.896	0.443	24.592	2.368E-31	10.322	11.471
LN(Light Displacement)	0.704	0.049	14.255	4.080E-20	0.640	0.768

Table VIII. Summary Output of OLS Regression on the Log-Transformed Data of the Ship Light Displacement CER Model.

Figure 17 illustrates the unit space plot of this model for average annual total O&S cost modeled by light displacement and given by Equation 17. For the most part, the prediction line fits the data satisfactorily. There are, however, four significant outliers that are not well predicted by this univariate model. It is interesting to note that these outliers represent the four classes of (conventional-powered) aircraft carriers in the Navy VAMOSC-ISR database. Though their lack of good fit is disappointing, it is perhaps not too surprising given the extreme relative physical size difference between an aircraft carrier and all other surface ships. Clearly, the proportional relationships between physical parameters which exist somewhat consistently among the other surface ships differ radically from the aircraft carriers. Hence, a ship displacement CER model without the aircraft carrier classes is next considered.

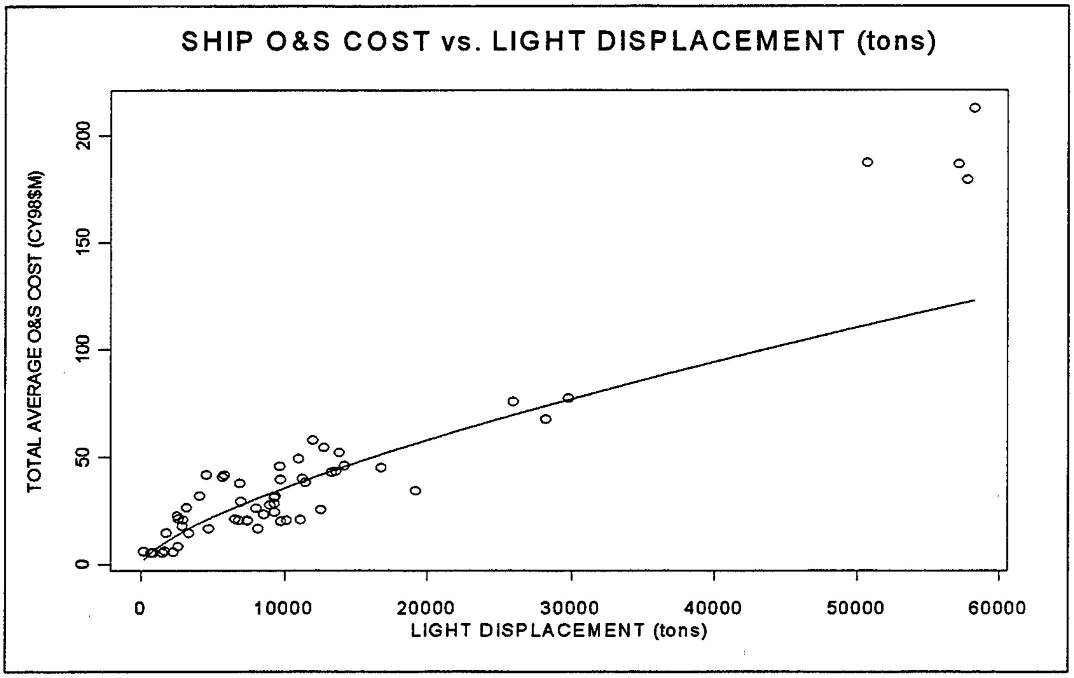

Figure 17. CER for Average Annual Total O&S Cost versus Light Displacement.

Since the model represented by Equation 17 will not produce reliable annual total O&S cost predictions (but rather gross under-estimates) for aircraft carriers, a ship light displacement CER model with the aircraft carrier class data removed is constructed (see Figure 18 and Table IX for the line fit plot and OLS regression results, respectively). Similar to Equation 16, the equation of the new prediction line is

$$\hat{Y}' = 11.620 + 0.618X' \quad (18)$$

and when transformed from log space to unit space, Equation 18 yields the multiplicative model

$$\boxed{\hat{Y} = 111{,}302X^{0.618} \qquad \text{(CY98\$)}} \quad (19)$$

where X is ship light displacement (in tons).

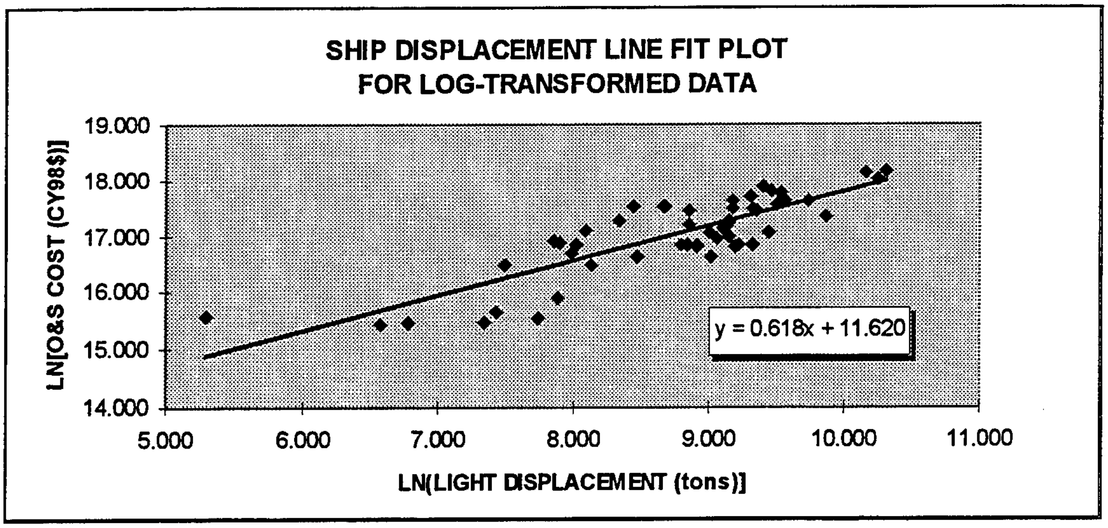

Figure 18. OLS Regression "Best Fit" Line for Ship Light Displacement CER Model Using Log-Transformed Data (With the Aircraft Carrier Classes Removed).

Regression Statistics	
r	0.842
R^2	0.709
Adjusted R^2	0.704
Standard Error	0.381
Coefficient of Variation	0.022
Observations	53

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 80.0%*	*Upper 80.0%*
Intercept	11.620	0.487	23.846	2.556E-29	10.987	12.252
LN(Light Displacement)	0.618	0.055	11.155	2.722E-15	0.546	0.690

Table IX. Summary Output of OLS Regression on the Log-Transformed Data of the Ship Light Displacement CER Model (With the Aircraft Carriers Classes Removed).

Figure 19 illustrates the unit space plot of this revised CER model given by Equation 19. The three observations in the upper right-hand corner represent the big deck amphibious assault ship classes (LHA-1 and LHD-1) and the training aircraft carrier class (AVT-16), which was retained since its hull characteristics are different from an operating aircraft carrier. Overall, this model seems to fit the data better than the one with the aircraft carrier classes retained.

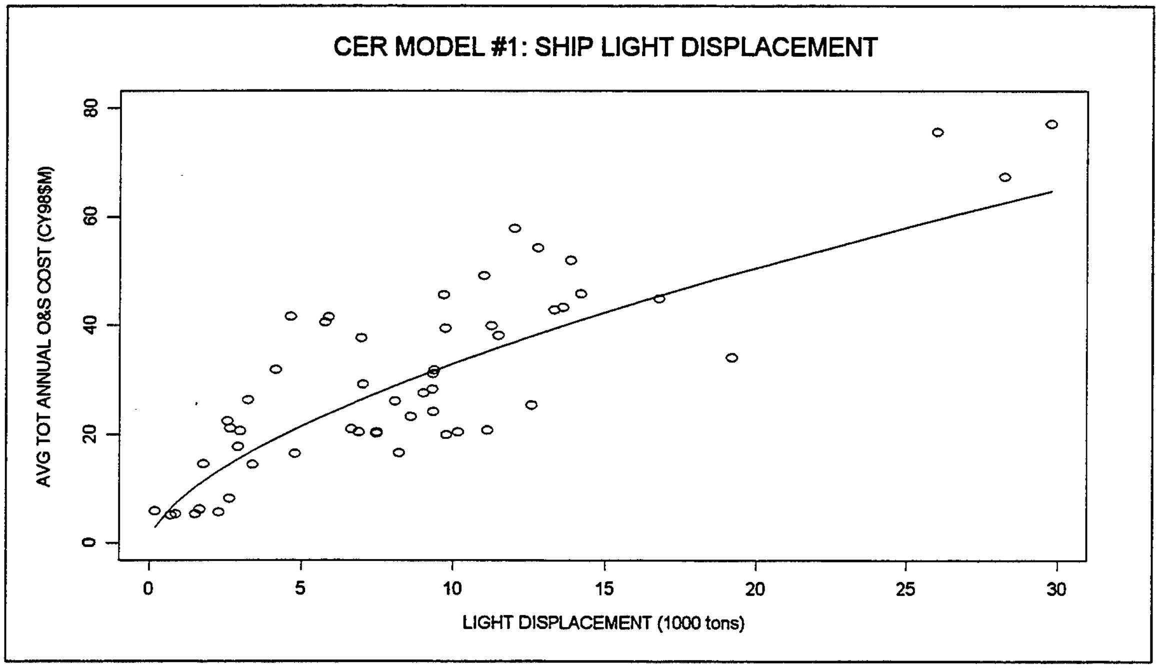

Figure 19. CER Model for Average Annual Total O&S Cost versus Ship Light Displacement By Ship Class (With the Aircraft Carrier Classes Removed).

2. CER #2: Ship Manpower

In the derivation of the CER for ship manpower, the method of approach and analytical results were quite similar to those for ship light displacement. Since manpower represents the shipboard manning level as the total number of all enlisted personnel and officers assigned to the ship, it does not include any personnel temporarily assigned or embarked for deployments or other miscellaneous ship operations. Like the displacement parameter, manpower appears to have a near-linear relationship with total O&S cost (refer back to the scatterplot in Figure 13). Again, the observations at the upper end are the four classes of aircraft carriers. The remainder of the observations towards the bottom left tend to be a bit more spread out in contrast to those for light displacement. Figure 20 displays the "best fit" line constructed by OLS regression of average total O&S cost on manpower.

Despite good predictive measures (see Table X), skepticism about the validity of assuming Normally distributed errors (see Figure 21) and the model's high SE as compared

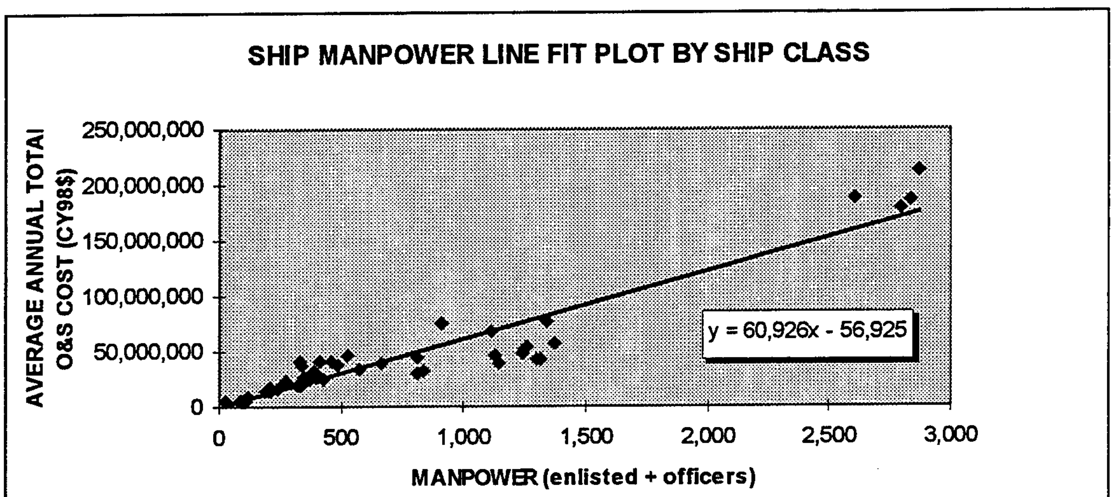

Figure 20. OLS Regression "Best Fit" Line for Average Annual Total O&S Cost versus Ship Light Displacement.

Regression Statistics	
r	0.945
R^2	0.894
Adjusted R^2	0.892
Standard Error	14761599
Coefficient of Variation	0.356
Observations	57

	Coefficients	Standard Error	t Stat	P-value	Lower 80.0%	Upper 80.0%
Intercept	-56925	2748192	-0.021	0.984	-3621701	3507851
MANPOWER	60926	2830	21.528	1.816E-28	57254	64596

Table X. Summary Output of OLS Regression on Ship Manpower.

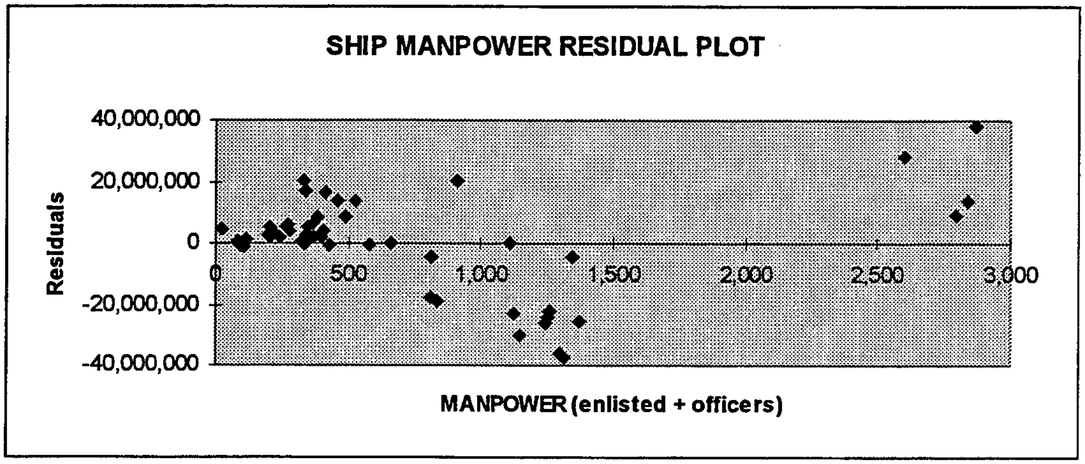

Figure 21. Scatterplot of Residuals for Manpower.

with the standard deviation of Y (average annual total cost) led to the hypothesis that a more robust multiplicative model might be appropriate. As in the model based on light displacement, manpower and O&S cost data were transformed using natural logarithms, and then OLS regression applied.

The log-linear CER model for manpower (see Figure 22 and Table XI) seems strong with an approximate 88% coefficient of determination (R^2) and 94% coefficient of correlation (r). With significant results from the t-test, the null hypothesis is rejected, and it may be concluded that a curvilinear model based on manpower satisfactorily describes the effect on total O&S costs.

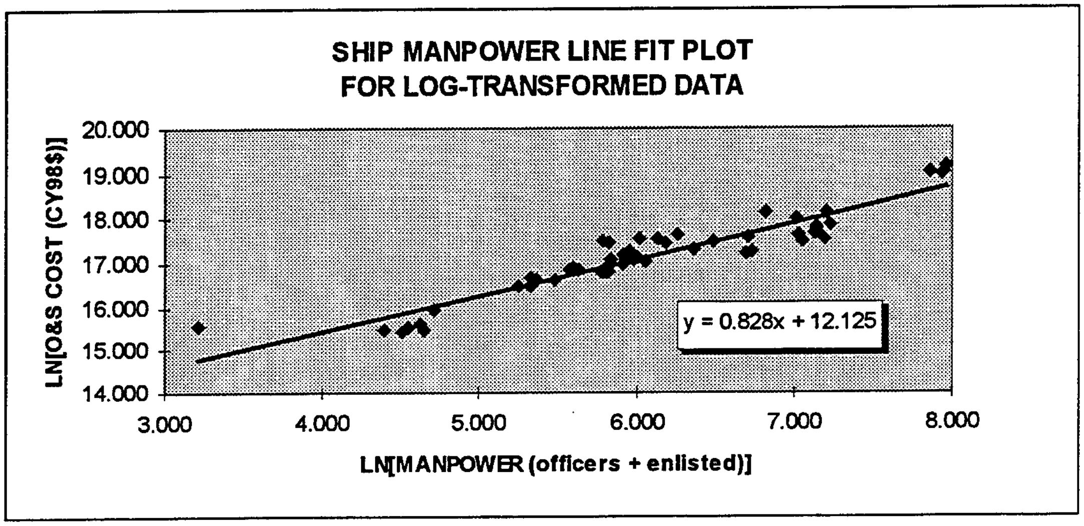

Figure 22. OLS Regression "Best Fit" Line for Ship Manpower CER Model Using Log-Transformed Data.

Regression Statistics	
r	0.939
R^2	0.882
Adjusted R^2	0.880
Standard Error	0.296
Coefficient of Variation	0.017
Observations	57

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 80.0%*	*Upper 80.0%*
Intercept	12.125	0.251	48.248	1.057E-46	11.799	12.451
LN(MANPOWER)	0.828	0.041	20.316	3.096E-27	0.775	0.881

Table XI. Summary Output of OLS Regression on the Log-Transformed Data of the Ship Manpower CER Model.

As indicated on the graph in Figure 22, the equation of the prediction line is

$$\hat{Y}' = 12.125 + 0.828X' \qquad (20)$$

which, when transformed from log space into unit space (again using the estimators from Equation 15), yields the multiplicative model

$$\hat{Y} = 184{,}370X^{0.828} \qquad \text{(CY98\$)} \qquad (21)$$

where X is manpower (as a total sum of all enlisted personnel and officers).

Figure 23 illustrates the unit space plot for average annual total O&S cost modeled by manpower and given by Equation 21. As was the case for the CER model for light displacement, the prediction line fits the data satisfactorily, although the same four significant outliers persist. Hence, as was done for the ship light displacement CER model given by Equation 17, this cost model for manpower is modified by removing carriers.

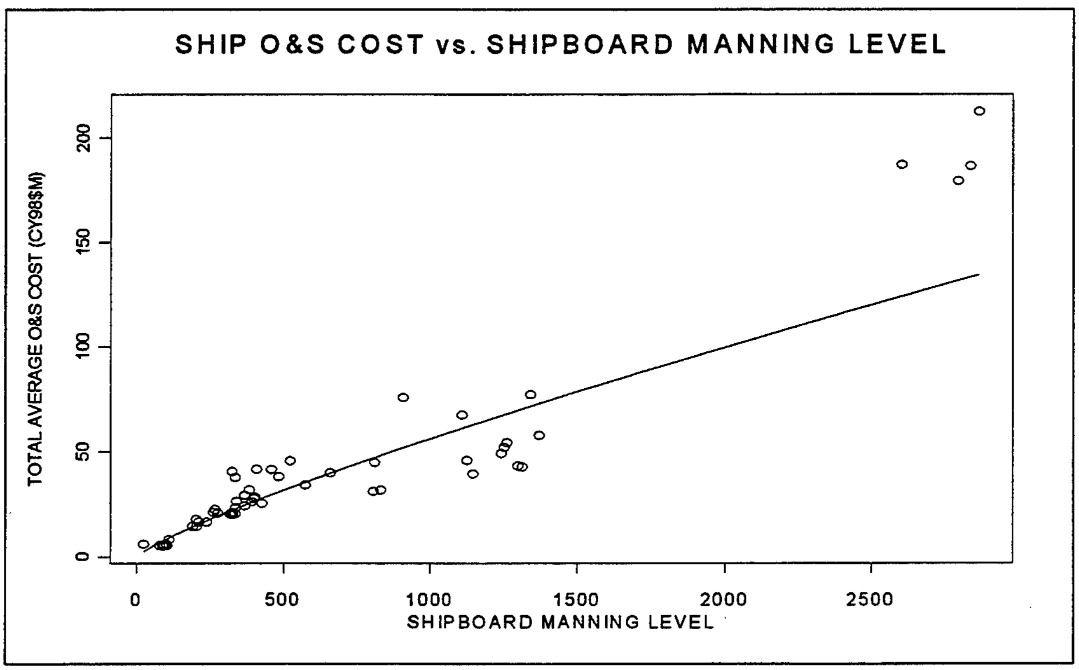

Figure 23. CER Model for Average Annual Total O&S Cost versus Ship Manpower by Ship Class.

Figure 24 and Table XII show the line fit plot and OLS regression results, respectively, for a ship manpower CER model with the aircraft carrier class data removed. Similar to Equation 20, the equation of this new prediction line is

$$\hat{Y}' = 12.561 + 0.750X' \quad (22)$$

and when transformed from log space to unit space, Equation 22 yields the multiplicative model

$$\boxed{\hat{Y} = 285{,}215X^{0.750} \qquad \text{(CY98\$)}} \quad (23)$$

where X is ship manpower (expressed as a sum of officers and enlisted personnel).

Figure 25 illustrates the unit space plot of this revised CER model given by Equation 23. Despite the larger spread of data on the upper end of the prediction line, this CER model better fits the ship class observations retained.

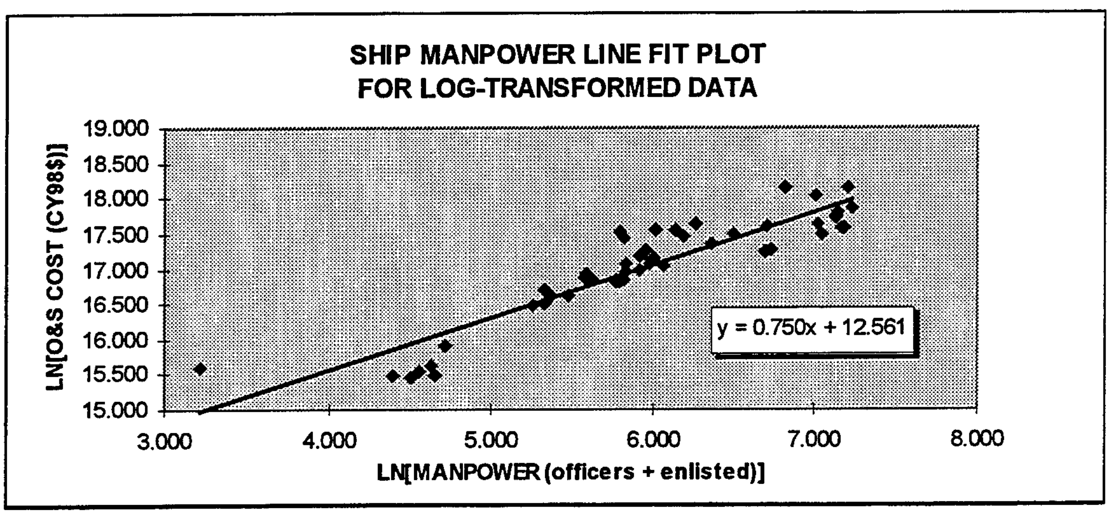

Figure 24. OLS Regression "Best Fit" Line for Ship Manpower CER Model Using Log-Transformed Data (With the Aircraft Carrier Classes Removed).

Regression Statistics	
r	0.919
R^2	0.845
Adjusted R^2	0.841
Standard Error	0.279
Coefficient of Variation	0.016
Observations	53

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 80.0%*	*Upper 80.0%*
Intercept	12.561	0.271	46.375	2.259E-43	12.209	12.913
LN(MANPOWER)	0.750	0.045	16.645	2.936E-22	0.691	0.808

Table XII. Summary Output of OLS Regression on the Log-Transformed Data of the Ship Manpower CER Model (With the Aircraft Carriers Classes Removed).

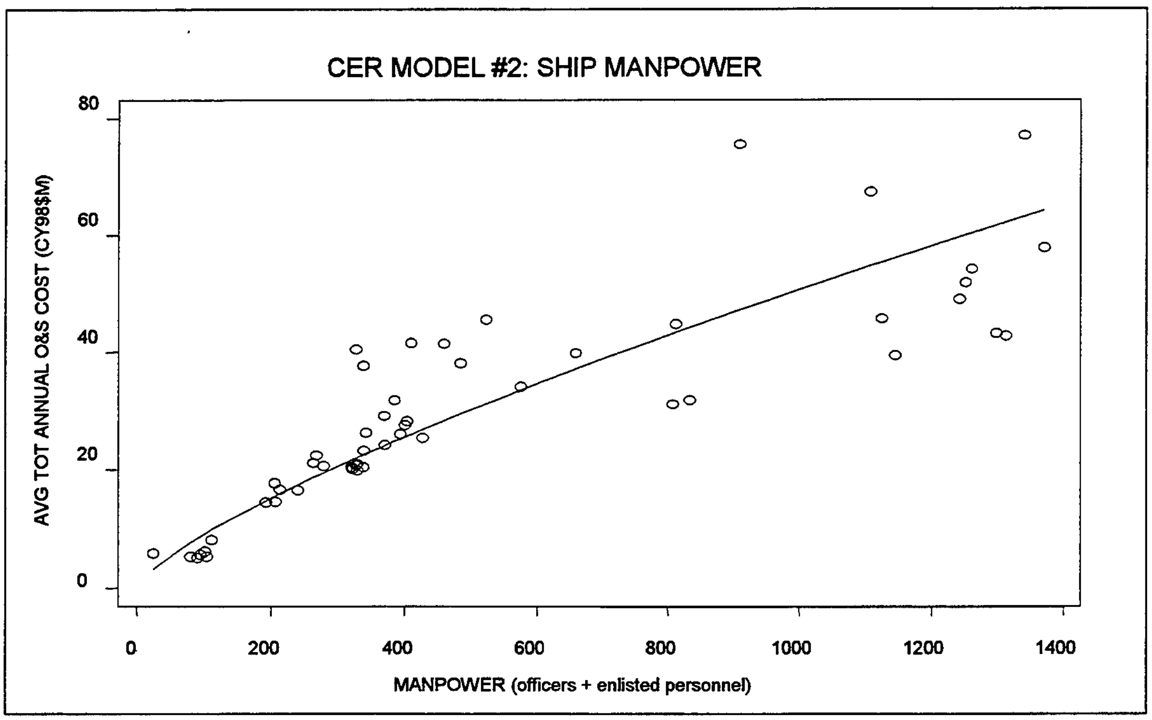

Figure 25. CER Model for Average Annual Total O&S Cost versus Ship Manpower By Ship Class (With the Aircraft Carrier Classes Removed).

3. CER #3: LOA

The CER derivation for surface ship length overall (LOA), a measurement in feet from the tip of the bow to the stern of a ship, proceeded without initial consideration of a linear model. Referring back to the scatterplot in Figure 13, there appears to be a definite non-linear relationship between LOA and average annual total O&S cost. Therefore, only a log-linear model was considered by transforming the LOA and average annual total O&S cost data with natural logarithms and applying OLS regression.

The log-linear CER model for LOA (see Figure 26 and Table XIII) shows an approximate 80 percent coefficient of determination (R^2) and 90 percent coefficient of correlation (r). With significant results from the t-test, the null hypothesis is rejected, and it may be conluded that a curvilinear model based on LOA satisfactorily describes the effect on average total O&S costs.

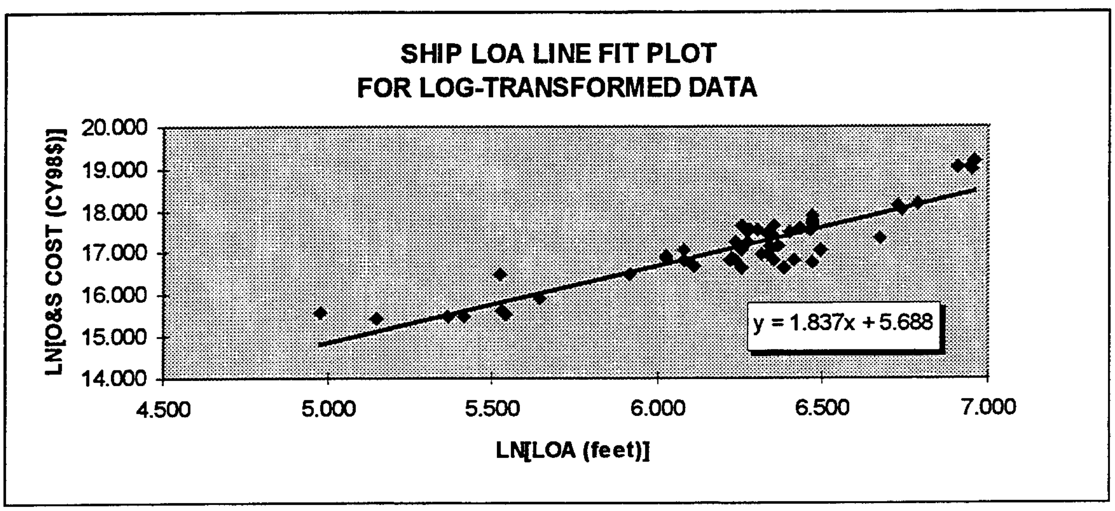

Figure 26. OLS Regression "Best Fit" Line for Log-Transformed Average Annual Total O&S Cost versus LOA Data.

Regression Statistics	
r	0.905
R^2	0.819
Adjusted R^2	0.815
Standard Error	0.368
Coefficient of Variation	0.021
Observations	57

	Coefficients	Standard Error	t Stat	P-value	Lower 80.0%	Upper 80.0%
Intercept	5.688	0.730	7.793	1.899E-10	4.741	6.635
LN(LOA)	1.837	0.117	15.763	4.706E-22	1.686	1.988

Table XIII. Summary Output of OLS Regression on the Log-Transformed LOA Model.

As indicated on the graph in Figure 26, the equation of the prediction line is

$$\hat{Y}' = 5.6878 + 1.8369\hat{X}' \qquad (24)$$

which, when transformed from log space into unit space (once again using the estimators derived by Equation 15), yields the multiplicative model

$$\hat{Y} = 295X^{1.8369} \qquad \text{(CY98\$)} \qquad (25)$$

where X is LOA (in feet).

Figure 27 illustrates the unit space plot for average total O&S cost modeled against LOA and given by Equation 25. The same four significant outliers persist as in the previous CERs, indicating once again that the prediction line grossly under-estimates the annual total O&S cost for aircraft carriers based on the LOA parameter. Hence, the model is modified by removing the aircraft carrier classes.

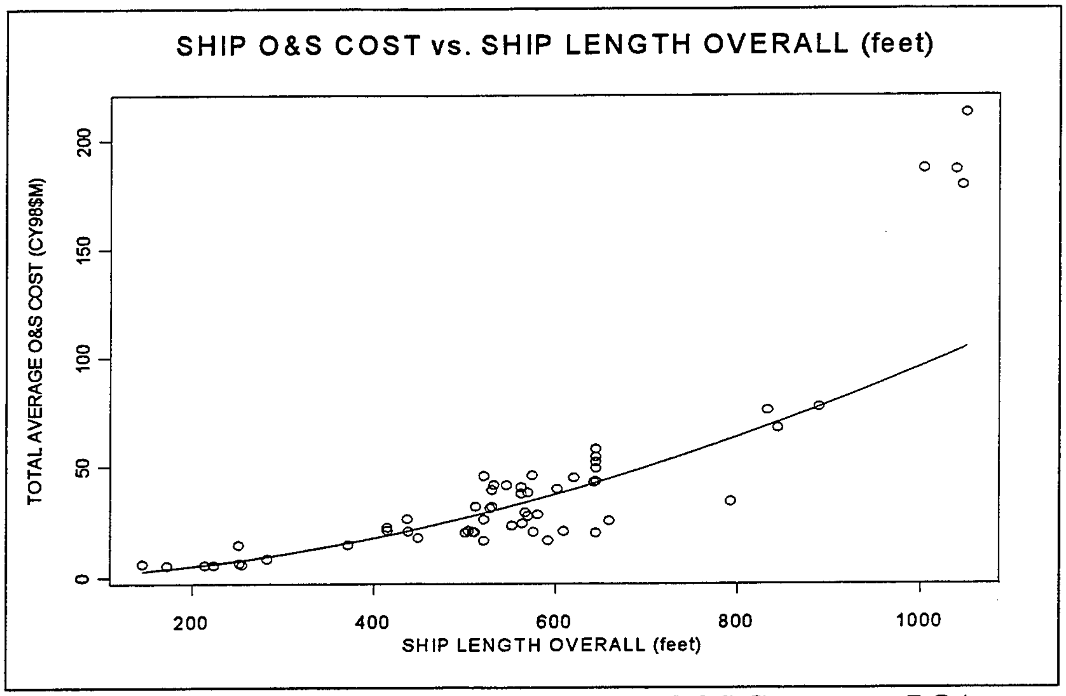

Figure 27. CER for Average Annual Total O&S Cost versus LOA.

Figure 28 and Table XIV show the line fit plot and OLS regression results, respectively, for a ship manpower CER model without the aircraft carrier class data. Similar to Equation 24, the equation of this new prediction line is

$$\hat{Y}' = 7.109 + 1.600X' \qquad (26)$$

and when transformed from log space to unit space, Equation 26 yields the multiplicative model

$$\boxed{\hat{Y} = 1{,}223X^{1.6} \qquad \text{(CY98\$)}} \qquad (27)$$

where X is ship overall length (LOA in feet).

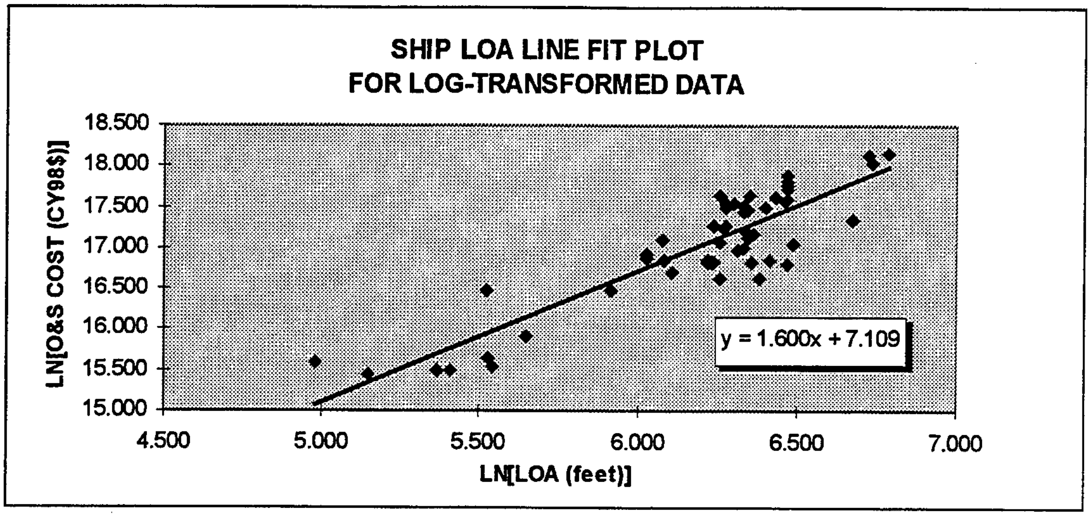

Figure 28. OLS Regression "Best Fit" Line for Ship LOA CER Model Using Log-Transformed Data (With the Aircraft Carrier Classes Removed).

Regression Statistics	
r	0.890
R^2	0.793
Adjusted R^2	0.789
Standard Error	0.322
Coefficient of Variation	0.019
Observations	53

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 80.0%*	*Upper 80.0%*
Intercept	7.109	0.711	9.997	1.301E-13	6.186	8.032
LN(LOA)	1.600	0.115	13.972	4.564E-19	1.451	1.749

Table XIV. Summary Output of OLS Regression on the Log-Transformed Data of the Ship LOA CER Model (With the Aircraft Carriers Classes Removed).

Figure 29 illustrates the unit space plot of this revised CER model given by Equation 27. As was the case with the CER model for ship light displacement, the three observations in the upper right-hand corner represent the big deck amphibious assault ship classes and the training aircraft carrier class. Though the data falling within the "middle" of the graph tend to have a wider spread, overall this model fits the data better than the one with the aircraft carrier classes retained.

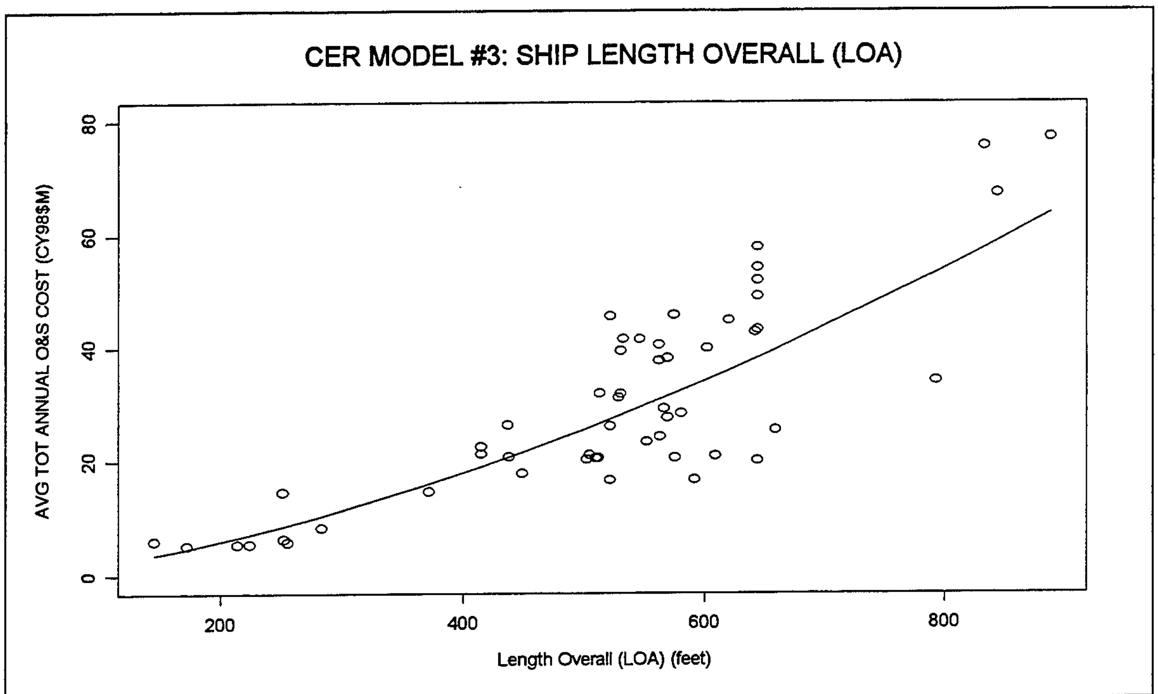

Figure 29. CER Model for Average Annual Total O&S Cost versus Ship LOA By Ship Class (With the Aircraft Carrier Classes Removed).

4. Regression Diagnostics and Standard Errors for CER Models

Since OLS is vulnerable to outliers, it is necessary to examine the residuals produced by each log-linear model. For the CER models, "significant" outliers are observations with a standardized residual (a residual divided by its standard deviation) value greater than ±2. Additionally, a useful empirical rule for data sets which are assumed to be Normally distributed says that approximately 95 percent of the data should fall within two standard deviations of the mean. We would expect, then, that five percent of the population will be significant outliers so that their presence should not create undue concern.

Scatterplots of the standardized residuals versus the predicted values serve to validate the traditional OLS assumption of normally distributed errors. Figure 30 illustrates the respective graphs for the ship light displacement, manpower, and LOA CER models. There is no overwhelming indication to refute the assumption of Normal errors for each CER model since there does not appear to be a clear pattern.

Standardized residuals calculated by OLS regression on each CER model were analyzed further to determine the presence of significant outliers. For the ship light displacement CER model, the one significant outlier is the averaged representation of the ARS-50 class of salvage and rescue ships. The three significant outliers for the ship manpower CER model are the averaged representations of the DD-963 class of destroyers, PHM-1 class of coastal patrol ships (which has the same residual value as DD-963 within 2 significant figures), and ARS-38 class of salvage and rescue ships. Lastly, the averaged representations of the AO-51 and AO-177 class of fleet oilers are the two significant

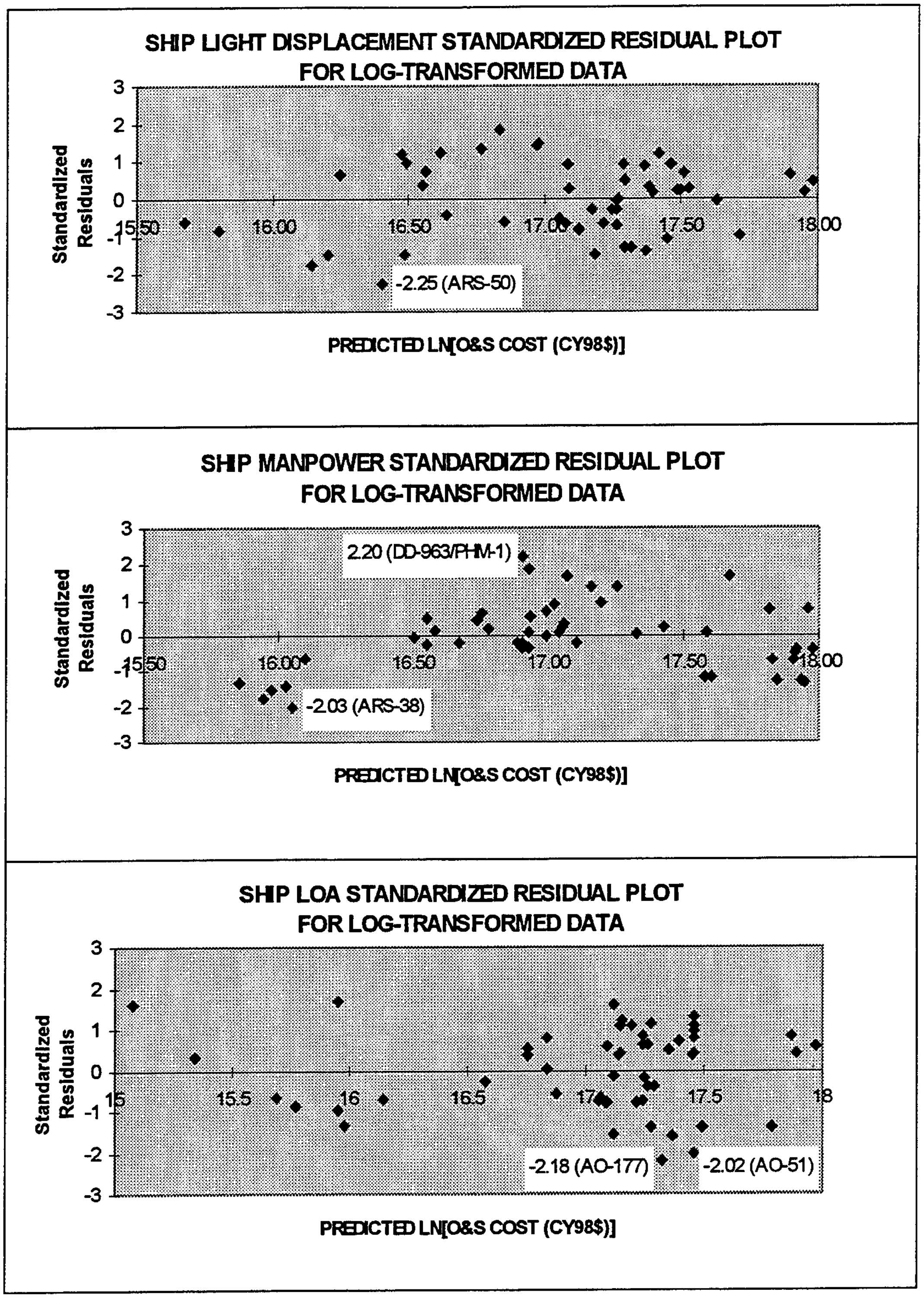

Figure 30. Standardized Residual Plots for the Ship Light Displacement, Manpower, and LOA CER Models Using Log-Transformed Data (With the Aircraft Carrier Classes Removed).

outliers for the CER model based on ship LOA. Since the occurrence of these outliers is what we would expect assuming a Normal data set (per the empirical rule), their existence should not significantly reduce the utility of the CERs given that each one of these observations indeed belongs to the total population of ship classes.

Lastly, in order to provide a total cost estimate that is bounded above and below based on the prediction error, the standard error of log-linear regression is used. For each of the three CER equations selected, an upper (U) and lower (L) error is determined as a percentage of the prediction ($\hat{Y}$). The derivation of these percentages follow:

For a model of the form $\hat{Y} = AX^{\beta}$, the standard error (SE) of $\ln(\hat{Y})$ is

$$SE = \pm\sqrt{(1/_{n-2})\sum(\ln \varepsilon_i)^2} \tag{28}$$

If we break apart Equation 28 into its upper and lower halves, then

$$SE^{+} = \ln(\hat{Y}^{+}) - \ln(\hat{Y}) \qquad \text{[upper residual]} \tag{29}$$

and

$$SE^{-} = \ln(\hat{Y}) - \ln(\hat{Y}^{-}) \qquad \text{[lower residual]} \tag{30}$$

for $\hat{Y}^{+}$ = upper bound estimate and $\hat{Y}^{-}$ = lower bound estimate of $\hat{Y}$. Through simple derivation, we find that

$$U = e^{SE} - 1 \tag{31}$$

and

$$L = e^{-SE} - 1 \tag{32}$$

where U and L are (effectively) error percentages used to calculate $\hat{Y}^{+}$ and $\hat{Y}^{-}$, respectively ($U \geq 0$, $L \leq 0$). More precisely,

$$\hat{Y}^{+} = (1+U)\hat{Y} \tag{33}$$

and

$$\hat{Y}^{-} = (1+L)\hat{Y} \tag{34}$$

B. SELECTION OF SURFACE SHIP CATEGORIES

A parametric cost model that simply calculates an estimate for total cost is not as useful as one that also provides a percentage break-down of the base estimate into its component cost elements. With this incentive, the VAMOSC-ISR O&S cost data is converted into proportions of total cost by cost element for each ship in accordance with the top-level of the VAMOSC CES (recall Appendix A). Subsequently, simple histogram-type analysis is used to compare the actual O&S cost element distributions in order to determine the aggregation of ships that makes the most sense. The objective here is to consolidate mission- and ship type-related ship classes into bigger groups until the most appropriate aggregation is reached. These final groupings will become the cost model-specific surface ship categories. Then, summary statistics are calculated to describe a typical total O&S cost breakdown for each category.

The goal is to look for mission- and type-related groupings in which the four primary O&S cost elements are distributed similarly. With dissimilar cost component distributions discovered within the traditional ship classes (as defined by *Jane's*), the focus turned to the development of surface ship categories in which the cost component distributions are fairly similar and the groupings themselves make sense. Specifically, these categories are defined based on the particular type of ship (i.e., auxiliary, cruiser, destroyer, etc.) and relevant mission and operating characteristics (for example, AEGIS-based platforms).

A stratification of the VAMOSC-ISR data by ship categories yields a population composed of several families of similar distributions (see Figure 31 for one particular example and Appendix K for the remaining eleven ship categories—note that "intermediate maintenance" is abbreviated as "IM"). Such a family grouping helps to clarify total O&S cost component trends that are believable. Indeed, there are one or two class-averaged representations in a few of the surface ship categories which appear different from the other observations within the category (most notably within the "Salvage and Rescue" category). These "outliers" further serve to exert influence on the summary statistics calculated for the particular grouping. However, the derived aggregations used for the cost model generally make sense and provide a useful tool for the component cost breakout of the total O&S cost base estimate.

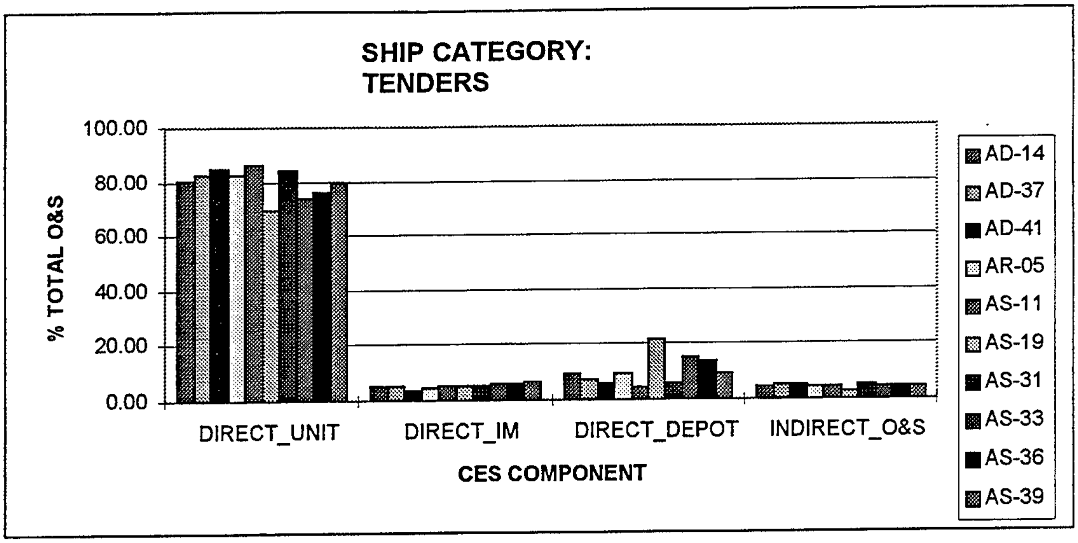

Figure 31. Illustration of Total O&S Cost Component Distribution for the Surface Ship Category of Tenders.

Finally, after the eleven surface ship categories were selected, the statistical means and standard deviations of the four primary cost element proportions for each grouping were calculated by ship class (but based on individual ships) and are reported in Appendix L. Table XV shows the descriptive statistics summary for the surface ship category of "Tenders."

Surface Ship Category: TENDERS

O&S COST ELEMENT	AD-14	AD-37	AD-41	AR-05	AS-11	AS-19	AS-31	AS-33	AS-36	AS-39	MEAN	STD DEV
DIRECT_UNIT	80.79	82.43	85.12	82.28	86.23	69.69	84.01	74.13	75.91	80.07	81.68	11.72
DIRECT_IM	5.30	5.24	3.86	4.19	5.20	5.43	5.43	5.65	5.99	6.19	5.17	5.23
DIRECT_DEPOT	9.74	7.08	5.85	9.36	4.31	21.65	5.51	15.52	13.94	9.11	8.69	10.38
INDIRECT_O&S	4.17	5.26	5.17	4.17	4.26	3.23	5.04	4.70	4.15	4.63	4.46	2.68
TOTAL	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	

Table XV. O&S Cost Element Distribution Percentages and Descriptive Statistics for the Surface Ship Category Tenders.

VI. RESULTS

With the analysis of the Navy VAMOSC-ISR O&S cost data and derivation of the CERs complete, formal documentation and validation of the parametric O&S cost model is required in order to enable it to be used. In the sections that follow, source documentation is discussed with validation of the cost model carried out on new data obtained from NCCA and ISI on non-nuclear surface ships (excluding aircraft carriers) active during FY1997. General use of the cost model is then explained and illustrated by a flow chart and user instructions. Lastly, an example is provided.

A. THE PARAMETRIC COST MODEL

1. Summary of Results

To review, formulation of the parametric O&S cost model began with identifying a reliable, accurate source of data—Navy VAMOSC—and collecting it in a spreadsheet format for ease of manipulation. The data was normalized to constant 1998 dollars and purged of ship classes that either had sample sizes too small for effective statistical analysis or lacked consistency with the other ship classes—in the latter case, nuclear-powered ships and battleships. Lastly, three ship size parameters—namely, light displacement, LOA, and manpower—were selected primarily due to historically-demonstrated causal relationships with cost. Also, each of these parameters are relatively easy to capture as independent variables.

Prior to derivation of the parametric CERs, the VAMOSC-ISR database was evaluated by ship class for validation of the two overriding assumptions that annual O&S

costs for each class were constant across time and that the observations represented a random sample drawn from a theorectical population of similar observations. Graphical analysis revealed that, though the observations are fairly well scattered across the reported ship-years, in some classes certain individual ships have consistently high annual O&S costs. Moreover, where a cost trend was perceived to exist, most of the cases showed indication of a negative (or decreasing) relationship. Regression analysis confirmed these perceptions, while graphical analysis revealed that a (non-zero) linear relationship does not adequately explain the dependence of total O&S cost on ship-year.

Assuming iid Normal errors, statistical inference and hypothesis testing (with the Bonferroni correction applied) confirmed that there was only mild indication of some sort of trend between total O&S cost and time. In most of the cases it was a decreasing one—something difficult to explain. Regression diagnostics further revealed that there are some ship classes with significant outliers, and others with non-random patterns of residuals, which may indicate non-Normality of errors. Still, as there was no strong indication to the contrary—and in keeping to the overriding goal to develop a standardized method for calculating a fairly reliable and robust cost estimate—it seemed safe to move ahead with the cost model formulation and accept the assumption of constant total O&S cost over time.

Using standard OLS regression, CERs were developed between three ship size parameters—light displacement, LOA, and manpower—and annual total O&S cost. Three univariate CER equations were derived. In each case, the historical data was modeled by log-linear regression in order to capture the variability at the extremes. These log-linear equations seem to provide a more reliable estimation of annual total O&S cost. It was during this stage in the model formulation that conventional aircraft carriers were discovered to be not well-estimated by any of the CERs. Since the CER equations thus derived would yield gross under-estimations for these large ships, it was concluded that they should not be used to estimate the annual total O&S costs for aircraft carriers. Therefore, modified CER models with the conventional aircraft carrier classes removed were considered and shown to be satisfactory.

In order to make a more robust estimate, probability distributions of top-level O&S cost component proportions were analyzed by ship class using simple histograms. Ship classes with similar cost distributions and physical and/or mission characteristics were thereby grouped into eleven surface ship categories. Based on individual ships, the mean and standard deviation were calculated for each of the four primary cost component elements within each surface ship category.

2. Documentation of the Cost Model

A detailed description and official documentation of the parametric O&S cost model developed by this study is provided in Appendix M.[34] It is useful as a stand-alone summary and procedures guide for the U.S. Navy (non-nuclear) surface ship average annual total O&S cost estimating model. It also will enable prospective cost analysts and other interested officials to determine its usefulness in calculating an average annual total O&S cost estimate for current and future design non-nuclear surface ships.

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[34] The formal documentation meets the requirements set forth in the Joint Government/Industry Parametric Cost Estimating Initiative Steering Committee's *Parametric Cost Estimating Handbook* (see List of References).

3. Validation of the Cost Model

Navy VAMOSC-ISR data for FY1997 (in constant 1998 dollars) was provided by the ISI Program Manager on a spreadsheet for the purpose of testing and validating the proposed parametric cost model (formerly presented in Appendix M). Like the original database used to derive the CERs, the FY1997 data was purged of all nuclear-powered ships and all classes of aircraft carriers. After verification that the test data was consistent with the original database used for the development of the model, the cost data for individual ships was averaged by ship class. This was done in order to compare the observed total costs with the predictions generated by the cost model using the same summary statistics as before.

For each ship class, three average annual total O&S cost base estimates were calculated by inputting the class-specific parametric values for ship light displacement, ship LOA, or ship manpower into the respective CER equations (see Appendix N for a sample spreadsheet of the cost model). Based on the standard error of regression derived for each equation, upper and lower error percentages were determined in order to provide each base estimate with an upper and lower bound (recall sub-section 4 of Chapter V). Further, the total O&S cost breakouts for each ship class were determined for each base estimate by using the appropriate surface ship category O&S cost component distributions.

Table XVI summarizes the results of the four predictive measures calculated for each parameter. Overall, these results indicate that the parametric cost model is a good predictor of average total annual O&S costs based on the VAMOSC-ISR data for FY1997.

VAMOSC-ISR FOR FY1997 (CY98$)	
Sample Mean	33,150,011
Sample Std Dev	21,571,437

CER#1: LIGHT DISPLACEMENT Regression Statistics	
% W/IN CER SE	61.90%
r	0.782
R^2	0.611
Adj *R2*	0.592
SE	4,399,217
CV	13.27%
Observations	21

CER #2: MANPOWER Regression Statistics	
% W/IN CER SE	76.19%
r	0.879
R^2	0.773
Adj *R2*	0.762
SE	3,360,963
CV	10.14%
Observations	21

CER #3: LENGTH OVERALL Regression Statistics	
% W/IN CER SE	52.38%
r	0.730
R^2	0.533
Adj *R2*	0.509
SE	4,823,410
CV	14.55%
Observations	21

Table XVI. Summary of Predictive Measures for Validation of Cost Model with FY1997 VAMOSC-ISR Data.

Specifically, the CVs for each equation are less than 20 percent, and the values for R^2 indicate that 53 to 77 percent of the variation in average annual total O&S cost can be explained by the parameters, which means that there exists a relatively low proportion of error with respect to the spread of the data (especially for the manpower parameter).

What is interesting to note, however, is that approximately 77 percent of the total O&S cost estimates based on the parametric values for manpower fell within the upper and lower prediction estimates (based on the SE of the CER); the CERs for the light displacement and LOA parameter did not deliver as favorable results, yielding 62 and 52 percent, respectively. Though not a standard statistical measurement, it does provide some insight into the model's capability to produce an acceptable O&S cost estimate.

Based on this validation, therefore, it would seem apparent that there is a higher level of confidence in the use of the ship manpower CER as a reliable and robust predictor of surface ship average annual total O&S costs than with either the light displacement or LOA parameters. In seeking out a cost estimate, then, it is recommended that ship manpower be the parameter of choice in seeking a cost estimate.

B. PRESENTATION OF THE COST MODEL

1. Flow Chart and User Instructions

Figure 32 (a reproduction of Figure 4 from Chapter III) illustrates a handy flow chart for the user of the parametric O&S cost model. It provides a visual reference of the methodology for estimating the total annual operating and support cost for a U.S. Navy (non-nuclear) surface ship. The following sequence of instructions (in conjunction with the formal documentation of the cost model—see Appendix M) further serves to detail the process of obtaining a total O&S cost estimate from the model:

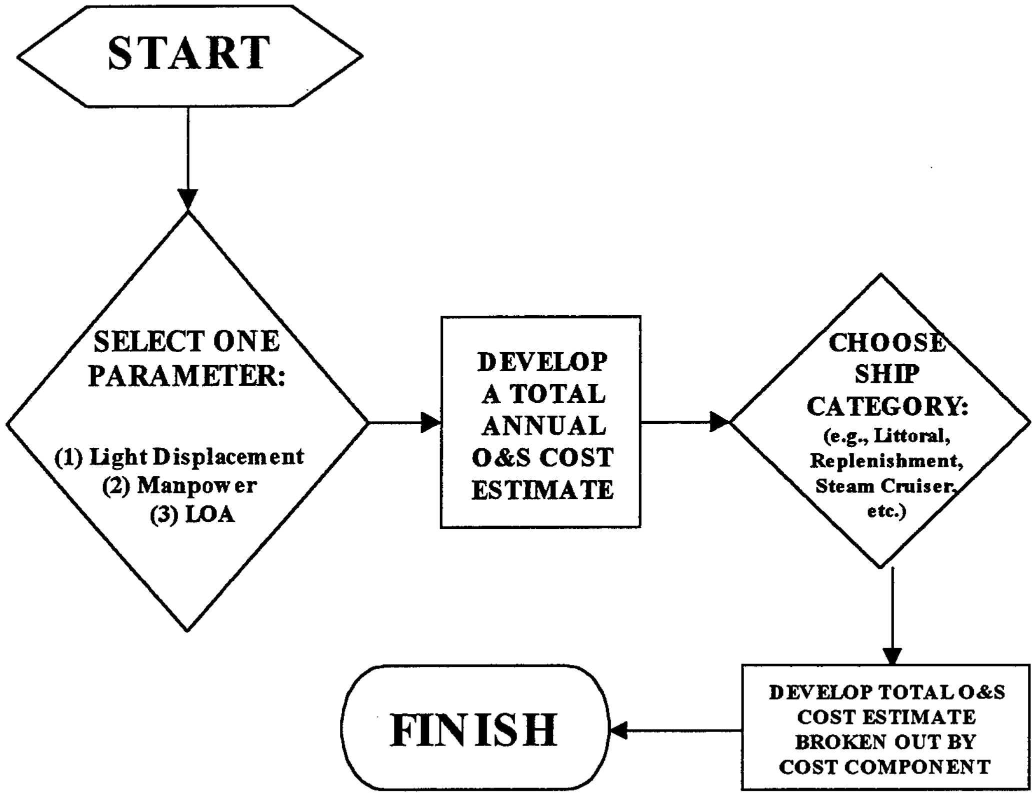

Figure 32. User Flow Chart for the Parametric O&S Cost Model.

- **STEP 1:** With a specific U.S. Navy surface ship or ship design (excluding aircraft carriers) for which a cost estimate is desired, choose the ship size parameter in which you have the most confidence.

- **STEP 2:** Calculate the total annual O&S cost estimate using the appropriate CER equation for the parameter selected. With this total estimate, calculate its upper and lower bounds using the SE percentages given for that CER.

- **STEP 3:** Report the average annual total O&S cost estimate in constant 1998 dollars with its upper and lower bounds. Proceed with STEP 4 if a cost component break-out of this base estimate is desired.

- **STEP 4:** Determine the surface ship category in which your ship or ship design would likely fall by matching it with the ship class examples given for each category.

- **STEP 5:** With the selected surface ship category and base estimate from STEP 3, use the mean percentages of the total estimate given for the four primary O&S cost components (direct unit, direct intermediate maintenance, direct depot, and indirect O&S) to calculate the break-out amounts based on the base estimate. Use each cost component's standard deviation percentage to calculate the upper and lower bounds (based on the cost component amount not the base estimate).

- **STEP 6:** Report the average annual total O&S cost estimate in constant CY98 dollars.

2. Illustrated Example

Now assume you are a cost analyst working for NCCA. You have been asked by the project manager of a new ship acquistion program to provide an average annual total O&S cost estimate of a new class of guided missile destroyers (gas turbine engines) currently in the concept phase. The project manager informs you that this new ship concept will have approximately 250 total personnel onboard (officer and enlisted personnel). Further, she would like to know how the total cost breaks out into its four component elements. The following sequence illustrates the calculation of the complete estimate (Appendix N illustrates the use of the cost model using a spreadsheet):

STEP 1: As requested, you choose the ship manpower parameter (equal to 250) in order to determine the total O&S cost base estimate.

STEP 2: For the manpower parameter, the applicable CER model is given by Equation 22 (refer to Chapter V). Using a manpower value equal to 250, the average annual total O&S cost estimate is:

$$\hat{Y} = 285{,}215 * (250)^{0.750} = 17{,}931{,}944 \quad \text{(CY98\$)}$$

Since the associated SE percentages for this CER are (-24.35%, +32.18%) (obtained from Appendix M), the upper and lower bounds this total cost estimate are:

([1-0.2435]*[$17,931,944], [1+0.3218]*[$17,931,944]) = ($13,566,251 , $23,702,609)

STEP 3: The average annual total O&S cost estimate for the new ship concept is:

$17,931,944 (-24.35%, +32.18%) (CY98$)

Since you were asked to break out the estimate, you proceed to STEP 4.

STEP 4: Since the new ship design concept is a guided missile destroyer (gas turbine propulsion plant), the only surface ship category applicable is the "Conventional (Gas Turbine) Destroyers" category.

STEP 5: The break-out percentages (obtained from Appendix M) are as follows:

CONVENTIONAL (GAS TURBINE) DESTROYERS (DD/DDG)	
1.0:	62.41% ± 25.38%
2.0:	1.01% ± 1.08%
3.0:	33.52% ± 26.53%
4.0:	3.05% ± 1.72%

The break-out amounts for each cost component are calculated by multiplying these factors by the base estimate from STEP 3. Therefore,

1.0: 0.6241*($17,931,944) = $11,191,342
2.0: 0.0101*($17,931,944) = $ 181,113
3.0: 0.3352*($17,931,944) = $ 6,010,796
4.0: 0.0305*($17,931,944) = $ 546,925

The standard deviations for these break-out amounts are calculated by multiplying the given factors by the respective values listed above:

1.0: +/- 0.2538*($11,191,342) = $ 2,840,363
2.0: +/- 0.0108*($ 181,113) = $ 1,956
3.0: +/- 0.2653*($ 6,010,796) = $ 1,594,664
4.0: +/- 0.0172*($ 546,925) = $ 9,407

STEP 6: You now report the complete O&S cost estimate in in the format of Table I (see Chapter III). Based on a ship manpower of 250, the average annual total O&S cost estimate for the new ship design is:

ANNUAL TOTAL O&S COST (CY98$)	**$17.9M (+24%, −32%)**
DIRECT UNIT COST (62.4%)	$11.2M ± $2.8M
DIRECT INTERMEDIATE MAINTENANCE COST (1.0%)	$ 181K ± $2K
DIRECT DEPOT MAINT COST (33.5%)	$ 6.0M ± $1.6M
INDIRECT O&S COST (3.1%)	$ 547K ± $9K

Table XVII. Parametric O&S Cost Model Output for Illustrated Example.

VII. CONCLUSIONS AND RECOMMENDATIONS

With satisfactory results (especially with the ship manpower parameter CER), and in the absence of a more effective decision-making tool, the parametric O&S cost model developed in this thesis provides a capable and standardized method for calculating average annual total O&S cost estimates of U.S. Navy (non-nuclear) surface ships. These reliable and robust estimates are grounded in history and can be useful to cost analysts and other decision-makers for assessing the affordability of current ships and future ship designs based on three standard ship size parameters.

This parametric cost model does have its limitations, however. It should only be used for non-nuclear-powered ships with battleships and aircraft carriers excluded. The significant effort exhausted in the analysis of the Navy VAMOSC database for surface ships revealed a particular concern—namely that the assumption of constant O&S cost over time may not be completely valid. Further analysis into the causes of any real cost trends—particularly for *decreasing* trends—is recommended in this regard.

Additionally, due to the limited scope of ship data available, it is recommended that this cost model be updated periodically as the VAMOSC database grows in order to increase its reliability, effectiveness, and utility. Moreover, other cost drivers may need to be considered as well as the development of a more versatile model so that an estimate may be calculated for any U.S. Navy ship (including submarines).

Cost analysis provides a quick and confident assessment to the critical issues of affordability. Operating and support costs will continue to be a point of major concern, especially amidst DoD's focus on modernization of U.S. military forces in a fiscal environment of budget cutbacks. A standardized method for estimating these costs is invaluable for economic prudence and overall effective manageability. As Secretary of Defense William S. Cohen indicated in his personal message for the *Report of the Quadrennial Defense Review* (May 1997), "For the past several years our defense program has suffered from unrealized expectations with regard to modernization. Failure to address these fiscal problems would undermine our ability to execute the [National Military] strategy. For a variety of reasons described in [the QDR], projected increases in funding for modernization have continually been delayed as modernization funds migrated to operations and support accounts to pay current bills. While contingency operations have contributed to the problem, they have not been the chief cause. Failure to address these fiscal problems would undermine our ability to execute the [National Military] strategy."

APPENDIX A. VAMOSC-ISR CES

LEVELS
1 2 3 4 5 6

1.0 DIRECT UNIT COSTS

- PERSONNEL
  - MANPOWER
    - OFFICER
    - ENLISTED
    - REPORTED MAINTENANCE LABOR HOURS
  - TAD
- MATERIAL
  - POL
    - FUEL (FOSSIL)
    - OTHER POL
  - REPAIR PARTS
  - SUPPLIES
    - EQUIPMENT/EQUIPAGE
    - CONSUMMABLES
  - TRAINING EXPENDABLE STORES
    - AMMUNITION
    - OTHER EXPENDABLES
- PURCHASED SERVICES
  - PRINTING AND REPRODUCTION
  - ADP RENTAL AND CONTRACT SERVICES
  - RENT AND UTILITIES
  - COMMUNICATIONS

2.0 DIRECT INTERMEDIATE MAINTENANCE COSTS

- AFLOAT MAINTENANCE LABOR
  - AFLOAT LABOR MANHOURS
- ASHORE MAINTENANCE LABOR
  - ASHORE MAINTENANCE LABOR HOURS
- MATERIAL
  - AFLOAT REPAIR PARTS
  - ASHORE REPAIR PARTS
- COMMERCIAL INDUSTRIAL SERVICES

LEVELS

1	2	3	4	5	6
3.0 DIRECT DEPOT MAINTENANCE COSTS					
	SCHEDULED SHIP OVERHAUL				
		RESTRICTED OVERHAUL (ROH)			
			PUBLIC SHIPYARDS		
				OVERHEAD	
				LABOR	
					MANDAYS
				MATERIAL	
			PRIVATE SHIPYARDS		
			SHIP REPAIR FACILITIES		
				OVERHEAD	
				LABOR	
					MANDAYS
				MATERIAL	
		SELECTED RESTRICTED AVAILABILITY (SRA)			
			PUBLIC SHIPYARDS		
				OVERHEAD	
				LABOR	
					MANDAYS
				MATERIAL	
			PRIVATE SHIPYARDS		
			SHIP REPAIR FACILITIES		
				OVERHEAD	
				LABOR	
					MANDAYS
				MATERIAL	
	NON-SCHEDULED SHIP REPAIR				
		R-AVAILABILITY			
			PUBLIC SHIPYARDS		
				OVERHEAD	
				LABOR	
					MANDAYS
				MATERIAL	
			PRIVATE SHIPYARDS		
			SHIP REPAIR FACILITIES		
				OVERHEAD	
				LABOR	
					MANDAYS
				MATERIAL	

LEVELS

1	2	3	4	5	6
3.0 DIRECT DEPOT MAINTENANCE COSTS (CONT.)					
		TECHNICAL AVAILABILITY			
			PUBLIC SHIPYARDS		
				OVERHEAD	
				LABOR	
					MANDAYS
				MATERIAL	
			PRIVATE SHIPYARDS		
			SHIP REPAIR FACILITIES		
				OVERHEAD	
				LABOR	
					MANDAYS
				MATERIAL	
	FLEET MODERNIZATION				
		PUBLIC SHIPYARDS			
			OVERHEAD		
			LABOR		
			MATERIAL		
		PRIVATE SHIPYARDS			
		SHIP REPAIR FACILITIES			
			OVERHEAD		
			LABOR		
			MATERIAL		
		CENTRALLY PROVIDED MATERIAL			
		OTHER			
		OUTFIT AND SPARES			
	OTHER DEPOT				
		NAVAL AVIATION DEPOT			
			OVERHEAD		
			LABOR		
			MATERIAL		
		FIELD CHANGE INSTALLATION			
		REWORK			
			ORDNANCE REWORK		
			HM&E REWORK		
			ELECTRONIC REWORK		

LEVELS

1 2 3 4 5 6

3.0 DIRECT DEPOT MAINTENANCE COSTS (CONT.)

DESIGN SERVICES
PERA SUBMEPP
PERA SUBMEPP PLANNING
PERA SUBMEPP PROCUREMENT

4.0 INDIRECT OPERATING AND SUPPORT

TRAINING
PUBLICATIONS
ENGINEERING AND TECHNICAL SERVICES
AMMUNITION HANDLING

APPENDIX B. SAMPLE OF RAW VAMOSC-ISR DATA FOR FY95

NAVY VAMOSC
OPERATING AND SUPPORT COSTS BY SHIP FY-1995

	UIC	20591	20598	20599	20600	20601	20602	20603	20604	20611
	NAME	DAVID R	OLDENDO	JOHN YO	COMTE D	O'BRIEN.	MERRILL	BRISCOE	STUMP	CONOLLY
	FLEET	PAC	PAC	PAC	LANT	PAC	PAC	LANT	LANT	LANT
	SHIP TYPE AND HULL NO	DD 0971	DD 0972	DD 0973	DD 0974	DD 0975	DD 0976	DD 0977	DD 0978	DD 0979
	NUMBER OFFICER PERSONNEL-NAVY	21	24	24	20	24	24	23	22	23
	NUMBER ENLISTED PERSONNEL-NAVY	303	307	313	302	313	313	311	321	310
	STEAMING HOURS UNDERWAY	4154	1930	1423	2399	3665	4512	521	1842	1711
	STEAMING HOURS NOT UNDERWAY	1908	988	516	1812	2170	1920	984	1157	2825
	BBLS FUEL PER STEAM HOUR UNDERWAY	29	28	31	24	24	26	26	30	29
ELEMENT NUMBER	ELEMENT DESCRIPTION	(DOLLARS IN THOUSANDS--OTHER DATA IN UNITS)								
1.0	DIRECT UNIT COSTS	15533	15089	13725	14548	18303	16695	12352	13120	13731
1.1	* PERSONNEL	8676	8522	8905	8656	11866	9478	9236	8897	8545
1.1.1	MANPOWER	8595	8510	8887	8615	11829	9425	9155	8851	8499
1.1.1.1	REPORTED MAINT LABOR MANHRS	(56155)	(41619)	(88474)	(62890)	(75320)	(73445)	(172410)	(70766)	(115297)
1.1.1.2	OFFICER MANPOWER	1172	1098	1124	979	1667	1298	1017	1062	1016
1.1.1.3	ENLISTED MANPOWER	7423	7412	7763	7636	10162	8127	8138	7789	7483
1.1.2	TAD	81	12	18	42	37	52	81	46	46
1.2	* MATERIAL	6448	5892	4338	5110	5759	6633	2709	3604	4517
1.2.1	SHIP POL	3699	1917	1536	1777	2804	3493	487	1615	1662
1.2.1.1	FUEL (FOSSIL)	3688	1905	1535	1768	2780	3492	471	1588	1647
1.2.1.1.1	UNDERWAY	3393	1752	1381	1502	2474	3282	311	1413	1268
1.2.1.1.2	NOT UNDERWAY	295	152	153	265	306	210	160	175	379
1.2.1.2	OTHER POL	11	12	2	9	24	1	16	27	15
1.2.1.3	BARRELS OF FUEL CONSUMED	(132637)	(59357)	(48493)	(67426)	(99228)	(123662)	(20026)	(61849)	(63488)
1.2.1.3.1	UNDERWAY	(121788)	(54499)	(43718)	(57062)	(88346)	(116620)	(13315)	(55298)	(48800)
1.2.1.3.2	NOT UNDERWAY	(10849)	(4858)	(4775)	(10364)	(10882)	(7042)	(6711)	(6551)	(14688)
1.2.2	REPAIR PARTS	1676	1911	1688	1093	1543	1932	1675	1378	1940
1.2.3	SUPPLIES	429	484	381	449	368	526	486	381	391
1.2.3.1	EQUIPMENT/EQUIPAGE	38	82	31	41	62	103	106	34	67
1.2.3.2	CONSUMABLES	391	402	350	408	306	423	380	347	324

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NAVY VAMOSC
OPERATING AND SUPPORT COSTS BY SHIP FY-1995

	UIC	20591	20598	20599	20600	20601	20602	20603	20604	20611
	NAME	DAVID R	OLDENDO	JOHN YO	COMTE P	PIEN	MERRILL	BRISCOE	STUMP	CONOLLY
	FLEET	PAC	PAC	PAC	LANT		PAC	LANT	LANT	LANT
	SHIP TYPE AND HULL NO	DD 0971	DD 0972	DD 0973	DD 0974	DD 0975	DD 0976	DD 0977	DD 0978	DD 0979
ELEMENT NUMBER	ELEMENT DESCRIPTION	(DOLLARS IN THOUSANDS--OTHER DATA IN UNITS)								
1.2.4	TRAINING EXPENDABLE STORES	644	1581	733	1790	1044	682	61	229	525
1.2.4.1	AMMUNITION	447	1575	733	1769	1004	682	59	226	525
1.2.4.2	OTHER EXPENDABLES	197	6	0	21	40	0	2	3	0
1.2.5	REPAIRABLES	312	886	1126	361	955	975	302	699	871
1.2.5.1	ORGANIZATIONAL EXCHANGES	227	705	828	294	750	757	169	491	675
1.2.5.2	ORGANIZATIONAL ISSUES	85	181	297	67	206	219	133	207	195
1.3	* PURCHASED SERVICES	409	674	482	782	678	584	407	619	669
1.3.1	PRINTING AND REPRODUCTION	3	5	1	8	6	2	3	2	0
1.3.2	ADP RENTAL & CONTRACT SERVICES	184	110	94	144	326	188	31	212	95
1.3.3	RENT AND UTILITIES	160	540	356	588	304	353	362	397	549
1.3.4	COMMUNICATIONS	62	19	31	41	43	41	11	8	25
2.0	DIRECT INTERMED MAINTENANCE	125	369	424	375	76	199	442	1114	505
2.1	* AFLOAT MAINTENANCE LABOR	16	2	95	154	74	0	13	28	70
2.1.1	AFLOAT MAINT LABOR MANHRS	(914)	(107)	(5610)	(9102)	(4344)	(9)	(759)	(1657)	(4151)
2.2	* ASHORE MAINTENANCE LABOR	89	353	247	61	1	199	209	253	228
2.2.1	ASHORE MAINT LABOR MANHRS	(5238)	(20809)	(14580)	(3587)	(86)	(11717)	(12323)	(14925)	(13441)
2.3	* MATERIAL	16	0	56	107	1	0	204	818	175
2.3.1	AFLOAT REPAIR PARTS	16	0	56	54	1	0	24	46	27
2.3.2	ASHORE REPAIR PARTS	0	0	0	52	0	0	181	772	148
2.4	* COMMERCIAL INDUSTRIAL SERVICES	5	14	26	53	0	0	16	15	31

NAVY VAMOSC
OPERATING AND SUPPORT COSTS BY SHIP FY-1995

ELEMENT NUMBER	ELEMENT DESCRIPTION	20591 DAVID R PAC DD 0971	20598 OLDENDO PAC DD 0972	20599 JOHN YO PAC DD 0973	20600 COMTE D LANT DD 0974	20601 O'BRIEN PAC DD 0975	20602 MERRILL PAC DD 0976	20603 BRISCOE LANT DD 0977	20604 STUMP LANT DD 0978	20611 CONOLLY LANT DD 0979
UIC / NAME / FLEET / SHIP TYPE AND HULL NO	(DOLLARS IN THOUSANDS--OTHER DATA IN UNITS)									
3.0	DIRECT DEPOT MAINTENANCE	2519	6508	7884	3441	2931	6663	19870	4858	3080
3.1	* SCHEDULED SHIP OVERHAUL	460	0	1656	1813	686	9	11885	0	1901
3.1.1	REGULAR OVERHAUL	460	0	0	0	0	0	0	0	0
3.1.1.1	PUBLIC SHIPYARD	460	0	0	0	0	0	0	0	0
3.1.1.1.1	OVERHEAD	186	0	0	0	0	0	0	0	0
3.1.1.1.2	LABOR	246	0	0	0	0	0	0	0	0
3.1.1.1.2.1	MANDAYS	(833)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
3.1.1.1.3	MATERIAL	28	0	0	0	0	0	0	0	0
3.1.1.2	PRIVATE SHIPYARD	0	0	0	0	0	0	0	0	0
3.1.1.3	SHIP REPAIR FACILITY	0	0	0	0	0	0	0	0	0
3.1.1.3.1	OVERHEAD	0	0	0	0	0	0	0	0	0
3.1.1.3.2	LABOR	0	0	0	0	0	0	0	0	0
3.1.1.3.3	MATERIAL	0	0	0	0	0	0	0	0	0
3.1.2	SELECTED RESTRICTED AVAIL	0	0	1656	1813	686	9	11885	0	1901
3.1.2.1	PUBLIC SHIPYARD	0	0	0	0	0	0	0	0	0
3.1.2.1.1	OVERHEAD	0	0	0	0	0	0	0	0	0
3.1.2.1.2	LABOR	0	0	0	0	0	0	0	0	0
3.1.2.1.2.1	MANDAYS	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
3.1.2.1.3	MATERIAL	0	0	0	0	0	0	0	0	0
3.1.2.2	PRIVATE SHIPYARD	0	0	1656	1813	0	9	11885	0	1901

ELEMENT NUMBER	ELEMENT DESCRIPTION	UIC 20591 NAME DAVID R FLEET PAC DD 0971	20598 OLDENDO PAC DD 0972	20599 JOHN YO PAC DD 0973	20600 COMTE D LANT DD 0974	20601 O'BRIEN PAC DD 0975	20602 MERRILL PAC DD 0976	20603 BRISCOE LANT DD 0977	20604 STUMP LANT DD 0978	20611 CONOLLY LANT DD 0979
		(DOLLARS IN THOUSANDS--OTHER DATA IN UNITS)								
3.1.2.3	SHIP REPAIR FACILITY	0	0	0	0	686	0	0	0	0
3.1.2.3.1	OVERHEAD	0	0	0	0	0	0	0	0	0
3.1.2.3.2	LABOR	0	0	0	0	74	0	0	0	0
3.1.2.3.3	MATERIAL	0	0	0	0	612	0	0	0	0
3.2	* NON-SCHEDULED SHIP REPAIR	334	7	19	695	349	0	195	760	321
3.2.1	RESTRICTED AVAILABILITY	121	7	19	4	349	0	0	78	0
3.2.1.1	PUBLIC SHIPYARD	56	0	0	0	0	0	0	0	0
3.2.1.1.1	OVERHEAD	1	0	0	0	0	0	0	0	0
3.2.1.1.2	LABOR	0	0	0	0	0	0	0	0	0
3.2.1.1.2.1	MANDAYS	(2)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
3.2.1.1.3	MATERIAL	55	0	0	0	0	0	0	0	0
3.2.1.2	PRIVATE SHIPYARD	23	7	19	4	0	0	0	78	0
3.2.1.3	SHIP REPAIR FACILITY	42	0	0	0	349	0	0	0	0
3.2.1.3.1	OVERHEAD	0	0	0	0	0	0	0	0	0
3.2.1.3.2	LABOR	5	0	0	0	108	0	0	0	0
3.2.1.3.3	MATERIAL	37	0	0	0	240	0	0	0	0
3.2.2	TECHNICAL AVAILABILITY	213	0	0	690	0	0	195	682	321
3.2.2.1	PUBLIC SHIPYARD	213	0	0	27	0	0	4	166	62
3.2.2.1.1	OVERHEAD	119	0	0	14	0	0	2	101	1
3.2.2.1.2	LABOR	76	0	0	8	0	0	2	60	1
3.2.2.1.2.1	MANDAYS	(347)	(0)	(0)	(47)	(0)	(0)	(10)	(307)	(3)
3.2.2.1.3	MATERIAL	18	0	0	5	0	0	0	5	60
3.2.2.2	PRIVATE SHIPYARD	0	0	0	663	0	0	191	517	259

NAVY VAMOSC
OPERATING AND SUPPORT COSTS BY SHIP FY-1995

(DOLLARS IN THOUSANDS--OTHER DATA IN UNITS)

ELEMENT NUMBER	ELEMENT DESCRIPTION	UIC 20591 NAME DAVID R FLEET PAC DD 0971	20598 OLDENDO PAC DD 0972	20599 JOHN YO PAC DD 0973	20600 COMTE D LANT DD 0974	20601 O'BRIEN PAC DD 0975	20602 MERRILL PAC DD 0976	20603 BRISCOE LANT DD 0977	20604 STUMP LANT DD 0978	20611 CONOLLY LANT DD 0979
3.2.2.3	SHIP REPAIR FACILITY	0	0	0	0	0	0	0	0	0
3.2.2.3.1	OVERHEAD	0	0	0	0	0	0	0	0	0
3.2.2.3.2	LABOR	0	0	0	0	0	0	0	0	0
3.2.2.3.3	MATERIAL	0	0	0	0	0	0	0	0	0
3.3	* FLEET MODERNIZATION	1139	5922	5278	226	1117	6067	7610	3737	297
3.3.1	PUBLIC SHIPYARD	190	0	0	0	0	0	0	0	0
3.3.1.1	OVERHEAD	8	0	0	0	0	0	0	0	0
3.3.1.2	LABOR	6	0	0	0	0	0	0	0	0
3.3.1.2.1	MANDAYS	(25)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
3.3.1.3	MATERIAL	176	0	0	0	0	0	0	0	0
3.3.2	PRIVATE SHIPYARD	0	2	547	0	0	0	0	0	0
3.3.3	SHIP REPAIR FACILITY	0	0	0	0	0	0	0	0	0
3.3.3.1	OVERHEAD	0	0	0	0	0	0	0	0	0
3.3.3.2	LABOR	0	0	0	0	0	0	0	0	0
3.3.3.3	MATERIAL	0	0	0	0	0	0	0	0	0
3.3.4	CENTRALLY PROVIDED MATERIAL	153	21	141	80	402	28	6223	1628	96
3.3.5	OTHER	138	718	667	27	162	735	948	1909	36
3.3.6	OUTFITTING AND SPARES	658	5181	3923	118	552	5304	439	199	165
3.4	* OTHER DEPOT	587	580	932	708	780	587	180	362	560
3.4.1	NAVAL AVIATION DEPOT	551	541	896	551	24	551	24	196	24
3.4.1.1	OVERHEAD	80	148	163	80	24	80	24	65	24
3.4.1.2	LABOR	96	75	146	96	0	96	0	25	0
3.4.1.3	MATERIAL	375	317	587	375	0	375	0	106	0

NAVY VAMOSC
OPERATING AND SUPPORT COSTS BY SHIP FY-1995

ELEMENT NUMBER	ELEMENT DESCRIPTION	20591 DAVID R PAC DD 0971	20598 OLDENDO PAC DD 0972	20599 JOHN YO PAC DD 0973	20600 COMTE D LANT DD 0974	20601 O'BRIEN PAC DD 0975	20602 MERRILL PAC DD 0976	20603 BRISCOE LANT DD 0977	20604 STUMP LANT DD 0978	20611 CONOLLY LANT DD 0979
	UIC / NAME / FLEET / SHIP TYPE AND HULL NO — (DOLLARS IN THOUSANDS--OTHER DATA IN UNITS)									
3.4.2	FIELD CHANGE INSTALLATION	0	3	0	1	0	0	0	10	20
3.4.3	REWORK	36	36	36	156	756	36	156	156	516
3.4.3.1	ORDNANCE REWORK	0	0	0	0	0	0	0	0	0
3.4.3.2	HM&E REWORK	36	36	36	156	756	36	156	156	516
3.4.3.3	ELECTRONIC REWORK	0	0	0	0	0	0	0	0	0
3.4.4	DESIGN SERVICES ALLOCATION	0	0	0	0	0	0	0	0	0
3.4.5	PERA, SUBMEPP	0	0	0	0	0	0	0	0	0
3.4.5.1	PLANNING	0	0	0	0	0	0	0	0	0
3.4.5.2	PROCUREMENT	0	0	0	0	0	0	0	0	0
4.0	INDIRECT OPERATING & SUPPORT	1346	1560	1366	1223	1267	1408	1276	1162	1260
4.1	* TRAINING	649	671	682	643	682	682	673	687	672
4.2	* PUBLICATIONS	330	391	210	373	442	324	338	299	359
4.3	* ENGINEERING & TECH SERVICES	308	479	443	102	144	338	114	130	130
4.4	* AMMUNITION HANDLING	59	18	32	105	0	64	151	46	99
	** TOTALS	19524	23526	23400	19587	22578	24965	33940	20254	18575

* THE SUM OF THESE ELEMENTS PROVIDES COST FOR ELEMENTS 1.0, 2.0, 3.0, 4.0 RESPECTIVELY. OTHER ELEMENTS ARE SUBSETS.

** TOTAL COST IS THE SUM OF ELEMENTS 1.0, 2.0, 3.0, 4.0.

APPENDIX C. DESCRIPTION OF U.S. NAVY SHIP CLASSES

HULL NUMBER	CLASS NAME	TYPE DESCRIPTION	COMMISSIONING DATES
AD-14	DIXIE	DESTROYER TENDERS	1940-44
AD-37	SAMUEL GOMPERS	DESTROYER TENDERS	1967-68
AD-41	YELLOWSTONE	DESTROYER TENDERS	1980-83
AE-21	SURIBACHI	AMMUNITION SHIPS	1956-57
AE-23	NITRO	AMMUNITION SHIPS	1959
AE-26	KILAUEA	AMMUNITION SHIPS	1968-72
AFS-1	MARS	COMBAT STORE SHIPS	1963-70
AGF-3	CONVERTED RALEIGH CLASS (LPD-3)	(COMMANDER, 6TH FLEET, GAETA, ITALY)	1964
AGF-11	CONVERTED AUSTIN CLASS (LPD-11)	(COMMANDER, 3RD FLEET, SAN DIEGO, CA)	1970
AGDS-2	POINT BARROW	AUXILIARY DEEP SUBMERGENCE SUPPORT SHIPS	1958, 1975
AGSS-555	DOLPHIN	DEEP DIVING OPERATIONS SHIPS	1968
AO-177	NEW CIMARRON	OILERS	1981-83
AO-51	JUMBOISED OLD CIMARRON	OILERS	1943-45
AOE-1	SACRAMENTO	FAST COMBAT SUPPORT SHIPS	1964
AOE-6	SUPPLY	FAST COMBAT SUPPORT SHIPS	1994-98
AOR-1	WICHITA	REPLENISHMENT OILER	1969-76
AR-5	AJAX	REPAIR SHIPS	1941
ARL-1	ACHELOUS	REPAIR SHIPS (SMALL) FOR LANDING CRAFT (CONVERTED LST)	1944
ARS-6	DIVER	SALVAGE SHIPS	1944
ARS-38	BOLSTER	SALVAGE SHIPS	1945
ARS-50	SAFEGUARD	SALVAGE SHIPS	1985-86
AS-11	FULTON	SUBMARINE TENDERS	1941-43
AS-19	PROTEUS	SUBMARINE TENDERS	1944
AS-31	HUNLEY	SUBMARINE TENDERS	1962-63
AS-33	SIMON LAKE	SUBMARINE TENDERS	1964-65
AS-36	L. Y. SPEAR	SUBMARINE TENDERS	1970-71
AS-39	EMORY S. LAND	SUBMARINE TENDERS	1979-81
ASR-7	CHANTICLEER	SUBMARINE RESCUE SHIPS	1943-47
ASR-21	PIGEON	SUBMARINE RESCUE SHIPS	1973
ATF-148	ABNAKI	FLEET TUGS	1944-45
ATS-1	EDENTON	SALVAGE & RESCUE SHIPS	1971-72
AVT-16	HANCOCK	TRAINING AIRCRAFT CARRIER	1943
AVT-59	FORRESTAL	TRAINING AIRCRAFT CARRIER	1955

HULL NUMBER	CLASS NAME	TYPE DESCRIPTION	COMMISSIONING DATES
BB-61	IOWA	BATTLESHIPS	1943-44
CG-16	LEAHY	GUIDED MISSILE CRUISERS	1962-64
CG-26	BELKNAP	GUIDED MISSILE CRUISERS	1964-67
CG-47	TICONDEROGA	GUIDED MISSILE CRUISERS (AEGIS)	1983-94
CV-41	MIDWAY	MULTI-PURPOSE AIRCRAFT CARRIERS	1945-47
CV-59	FORRESTAL	MULTI-PURPOSE AIRCRAFT CARRIERS	1955-59
CV-63	KITTYHAWK	MULTI-PURPOSE AIRCRAFT CARRIERS	1961-65
CV-67	JOHN F. KENNEDY	MULTI-PURPOSE AIRCRAFT CARRIERS	1968
DD-963	SPRUANCE	DESTROYERS	1975-83
DDG-2	CHARLES F. ADAMS	GUIDED MISSILE DESTROYERS	1960-64
DDG-37	COONTZ	GUIDED MISSILE DESTROYERS	1959-61
DDG-51	ARLEIGH BURKE	GUIDED MISSILE DESTROYERS	1991-PRESENT
DDG-993	KIDD	GUIDED MISSILE DESTROYERS	1981-82
FF-1037	BRONSTEIN	FRIGATES	1963
FF-1040	GARCIA	FRIGATES	1964-68
FF-1052	KNOX	FRIGATES	1969-74
FFG-1	BROOKE	GUIDED MISSILE FRIGATE	1966-68
FFG-7	OLIVER HAZARD PERRY	GUIDED MISSILE FRIGATE	1977-88
LCC-19	BLUE RIDGE	AMPHIBIOUS COMMAND SHIPS	1970-71
LHA-1	TARAWA	AMPHIBIOUS ASSAULT SHIPS (MULTI-PURPOSE)	1976-80
LHD-1	WASP	AMPHIBIOUS ASSAULT SHIPS (MULTI-PURPOSE)	1989-PRESENT
LKA-113	CHARLESTON	AMPHIBIOUS CARGO SHIPS	1968-70
LPD-1	RALEIGH	AMPHIBIOUS TRANSPORT DOCK SHIPS	1962-63
LPD-4	AUSTIN	AMPHIBIOUS TRANSPORT DOCK SHIPS	1965-71
LPH-2	IWO JIMA	AMPHIBIOUS ASSAULT SHIPS	1961-70
LSD-28	THOMASTON	DOCK LANDING SHIPS	1954-57
LSD-36	ANCHORAGE	DOCK LANDING SHIPS	1969-72
LSD-41	WHIDBEY ISLAND	DOCK LANDING SHIPS	1985-92
LSD-49	HARPER'S FERRY	DOCK LANDING SHIPS	1995-PRESENT
LST-1179	NEWPORT	TANK LANDING SHIPS	1969-72
MCM-1	AVENGER	MCM SHIPS	1987-94
MHC-51	OSPREY	COASTAL MINEHUNTERS	1993-PRESENT
MSO-422	AGGRESSIVE	OCEAN MINESWEEPERS	1954-56
PHM-1	PEGASUS	PATROL COMBATANT MISSILE (HYDROFOIL)	1977-82
PC-1	CYCLONE	COASTAL DEFENSE SHIPS	1993-96

APPENDIX D. DESCRIPTION OF VAMOSC-ISR DATA

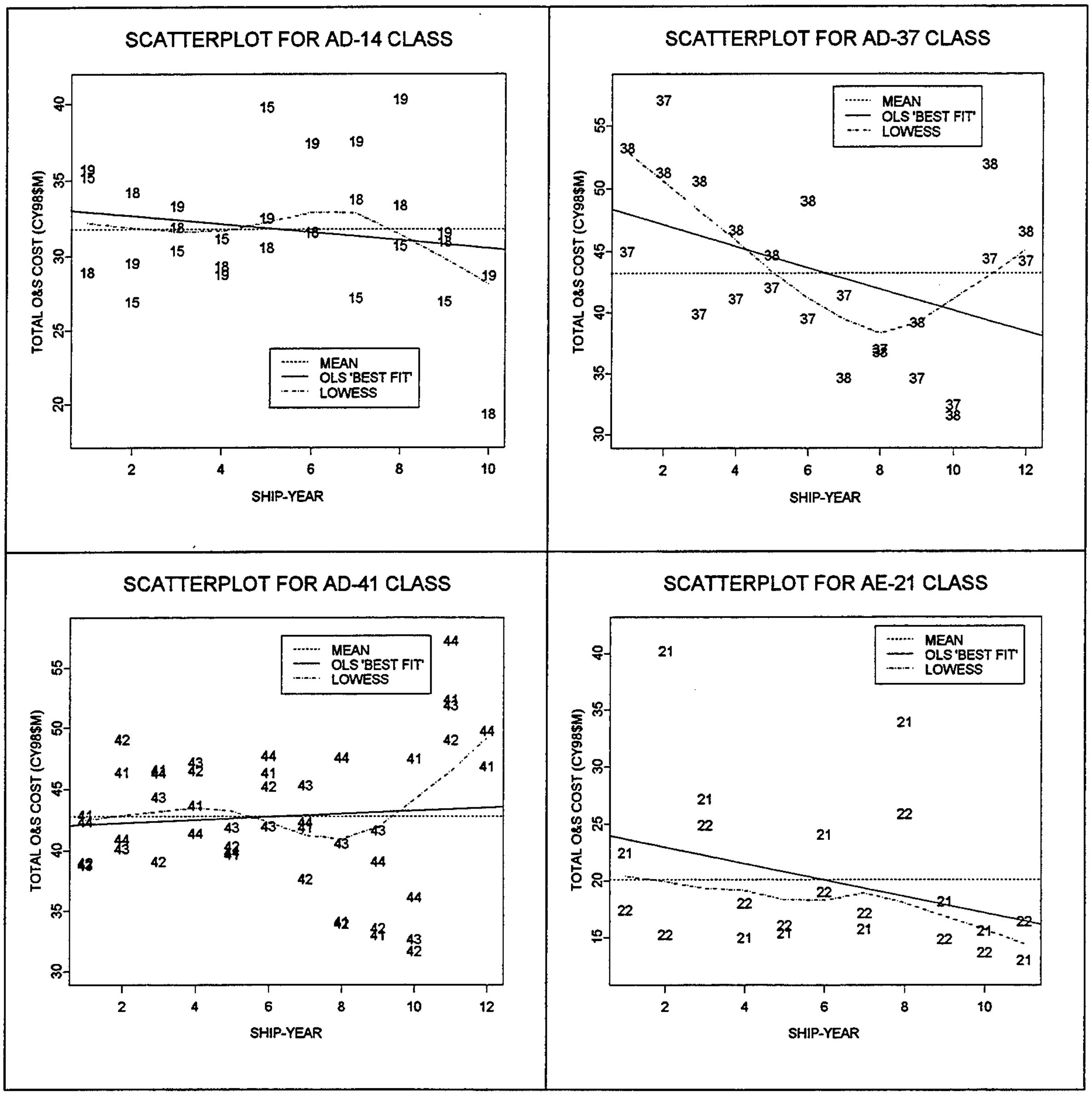
VAMOSC-ISR for FY96 — Period of Coverage: 1984-1996

SHIP CLASS	PERIOD OF DATA	# OF OBSERVATIONS	SHIP HULL NUMBERS IN CLASS
AD-14	84-93	29	15, 18, 19
AD-37	84-95	24	37, 38
AD-41	84-95	46	41, 42, 43, 44
AE-21	84-94	22	21, 22
AE-23	84-93	31	23, 24, 25
AE-26	84-96	87	27, 28, 29, 32, 33, 34, 35
AFS-1	84-93	61	1, 2, 3, 4, 5, 6, 7
AGF-3	84-96	13	3
AGF-11	84-96	13	11
AO-51	84-89	12	98, 99
AO-177	84-96	65	177, 178, 179, 180, 186
AOE-1	84-96	52	1, 2, 3, 4
AOR-1	84-95	75	1, 2, 3, 4, 5, 6, 7
AR-5	84-94	24	5, 6, 7, 8
ARS-38	85-93	33	39, 40, 41, 42, 43
ARS-50	86-96	40	50, 51, 52, 53
AS-11	84-92	16	11, 18
AS-19	84-91	8	19
AS-31	84-95	22	31, 32
AS-33	84-96	24	33, 34
AS-36	84-95	24	36, 37
AS-39	84-96	39	39, 40, 41
ASR-7	84-93	34	9, 13, 14, 15
ASR-21	84-94	19	21, 22
ATS-1	84-95	36	1, 2, 3
AVT-16	84-91	8	16
CG-16	84-94	91	16, 17, 18, 19, 20, 21, 22, 23, 24
CG-26	84-93	91	26, 27, 28, 29, 30, 31, 32, 33, 34
CG-47	84-96	182	47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73
CV-41	84-91	14	41, 43
CV-59	84-96	35	60, 61, 62
CV-63	84-96	30	63, 64, 66
CV-67	84-94	11	67
DD-963	84-96	403	963-992, 997
DDG-2	84-92	162	2-24
DDG-37	84-92	73	37-46
DDG-51	92-96	21	51-61
DDG-993	84-96	52	993-996

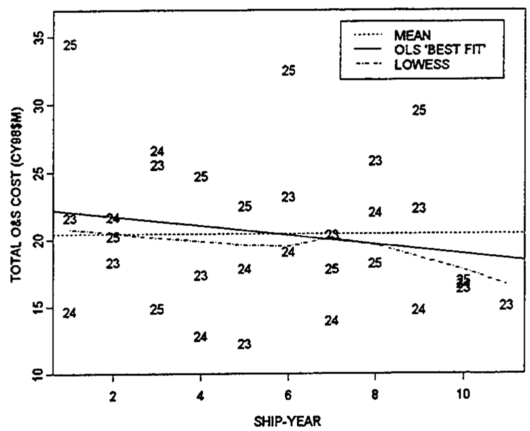
VAMOSC-ISR for FY96 Period of Coverage: 1984-1996

SHIP CLASS	PERIOD OF DATA	# OF OBSERVATIONS	SHIP HULL NUMBERS IN CLASS
FF-1037	84-90	14	1037-1038
FF-1040	84-88	47	1040, 1041, 1043, 1044, 1045, 1047, 1048, 1049, 1050, 1051
FF-1052	84-92	302	1052, 1053, 1055-1059, 1062-1071, 1073-1090, 1092-1095, 1097
FFG-1	84-88	25	1, 2, 3, 4, 5, 6
FFG-7	84-96	446	8, 11-15, 19-34, 36-43, 45-61
LCC-19	84-96	26	19, 20
LHA-1	84-96	65	1, 2, 3, 4, 5
LHD-1	90-96	14	1, 2, 3, 4
LKA-113	84-93	47	113, 114, 115, 116, 117
LPD-1	84-91	16	1, 2
LPD-4	84-96	143	4-9, 10, 12-15
LPH-2	84-96	75	2-3, 7, 9, 10-12
LSD-28	84-89	20	32, 33, 34, 35
LSD-36	84-96	65	36, 37, 38, 39, 40
LSD-41	86-96	57	41, 42, 43, 44, 45, 46, 47, 48
LST-1179	84-94	175	1179-1189, 1192-1198
MCM-1	88-96	58	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14
MSO-422	84-92	21	441, 443, 448, 490
PHM-1	84-92	54	1, 2, 3, 4, 5, 6

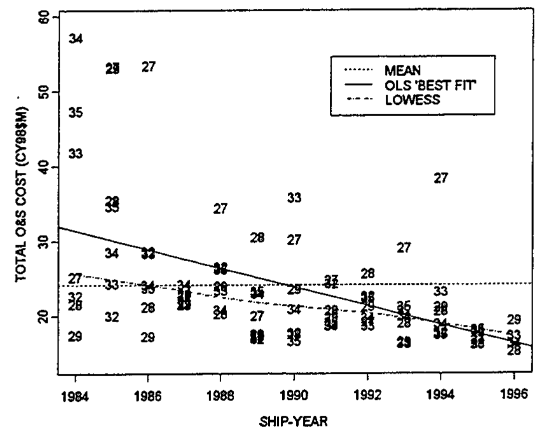
APPENDIX E. U.S. NAVY SHIP CLASS SCATTERPLOTS



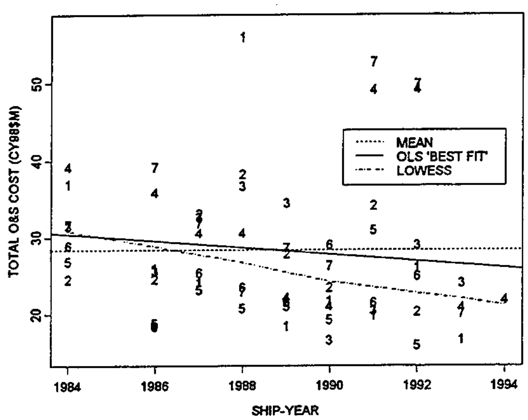
SCATTERPLOT FOR AE-23 CLASS



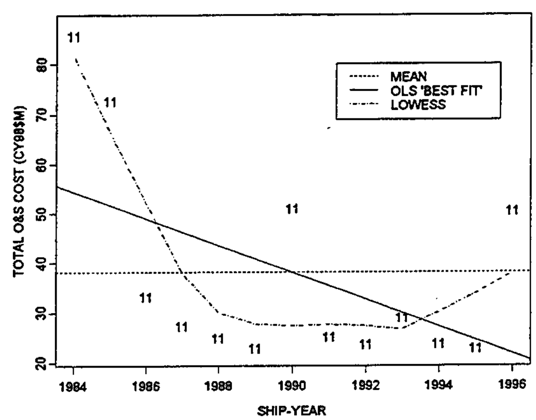
SCATTERPLOT FOR AE-26 CLASS



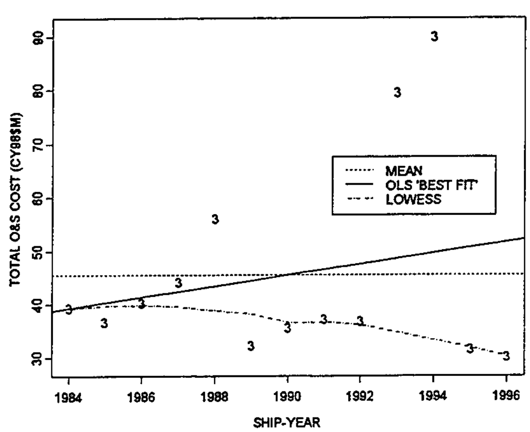
SCATTERPLOT FOR AFS-1 CLASS



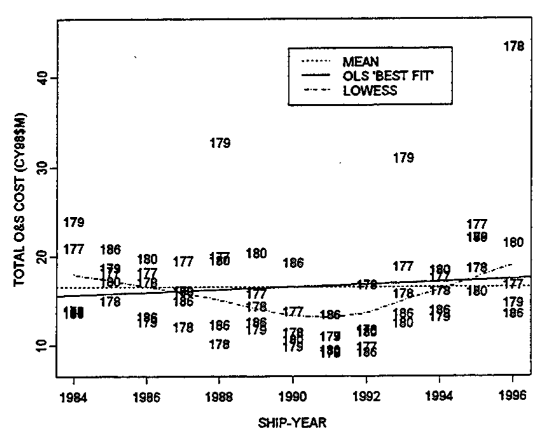
SCATTERPLOT FOR AGF-11 CLASS



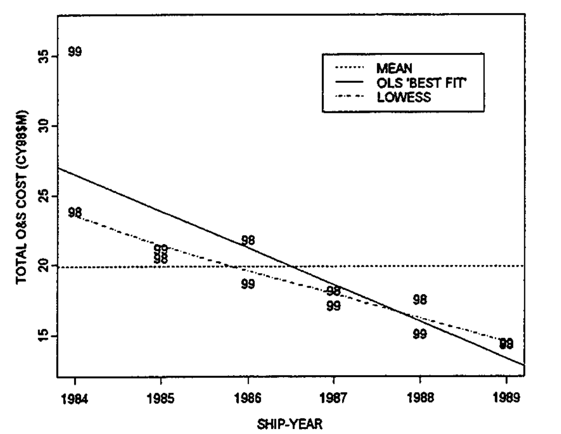
SCATTERPLOT FOR AGF-3 CLASS



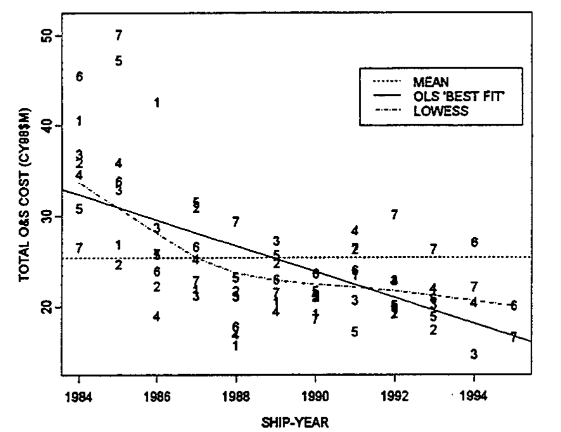
SCATTERPLOT FOR AO-177 CLASS



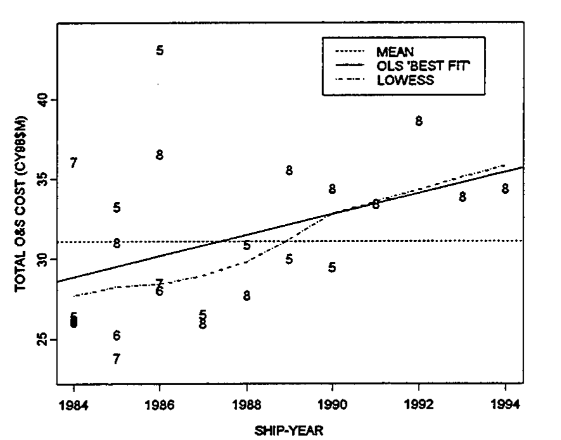
SCATTERPLOT FOR AO-51 CLASS



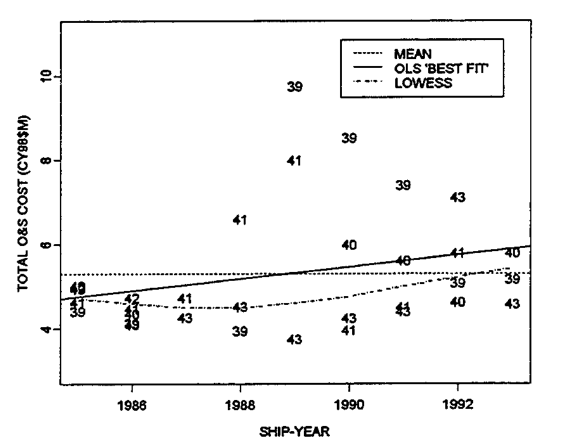
SCATTERPLOT FOR AOR-1 CLASS



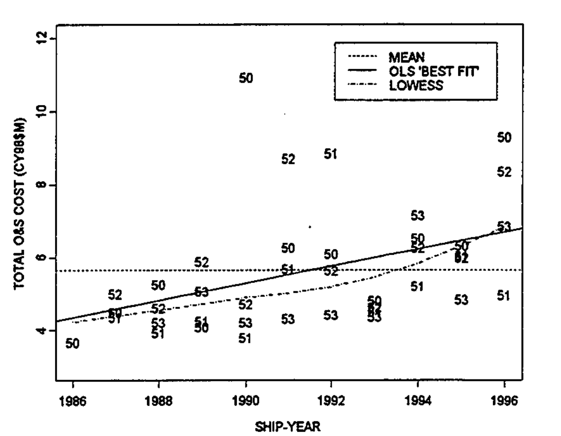
SCATTERPLOT FOR AR-5 CLASS



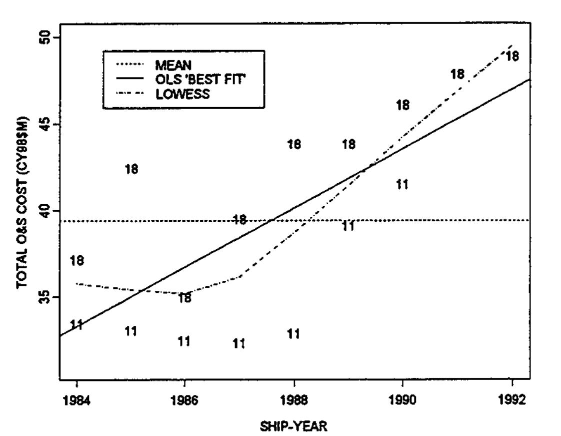
SCATTERPLOT FOR ARS-38 CLASS



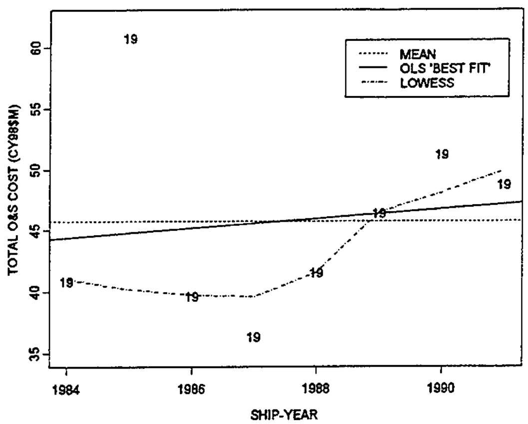
SCATTERPLOT FOR ARS-50 CLASS



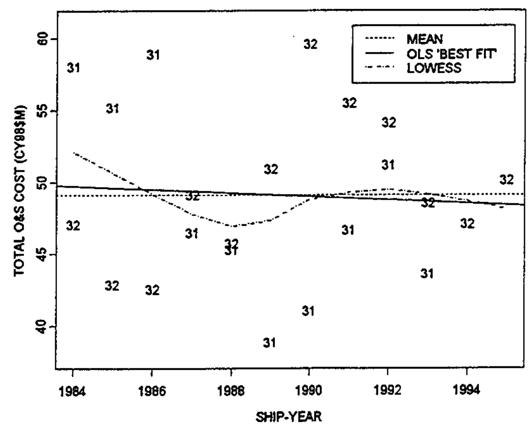
SCATTERPLOT FOR AS-11 CLASS



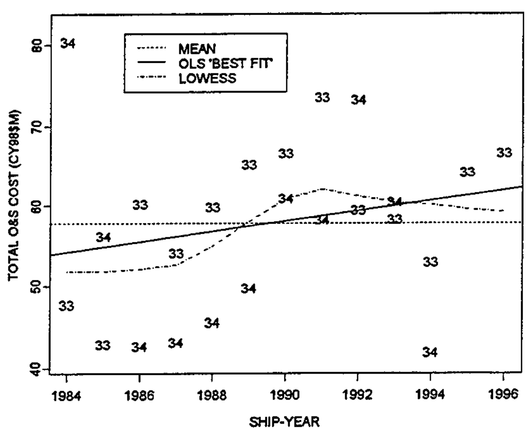
SCATTERPLOT FOR AS-19 CLASS



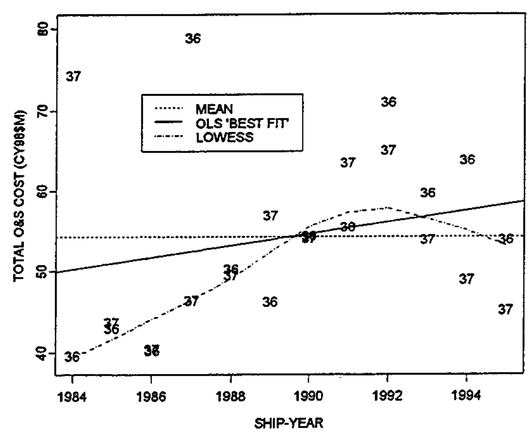
SCATTERPLOT FOR AS-31 CLASS



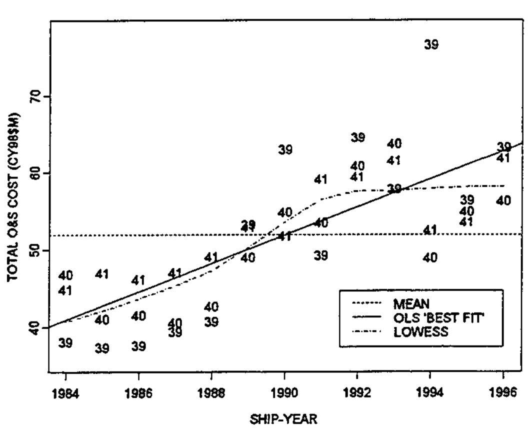
SCATTERPLOT FOR AS-33 CLASS



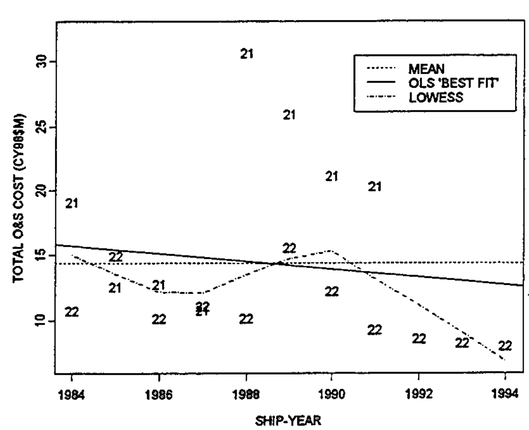
SCATTERPLOT FOR AS-36 CLASS

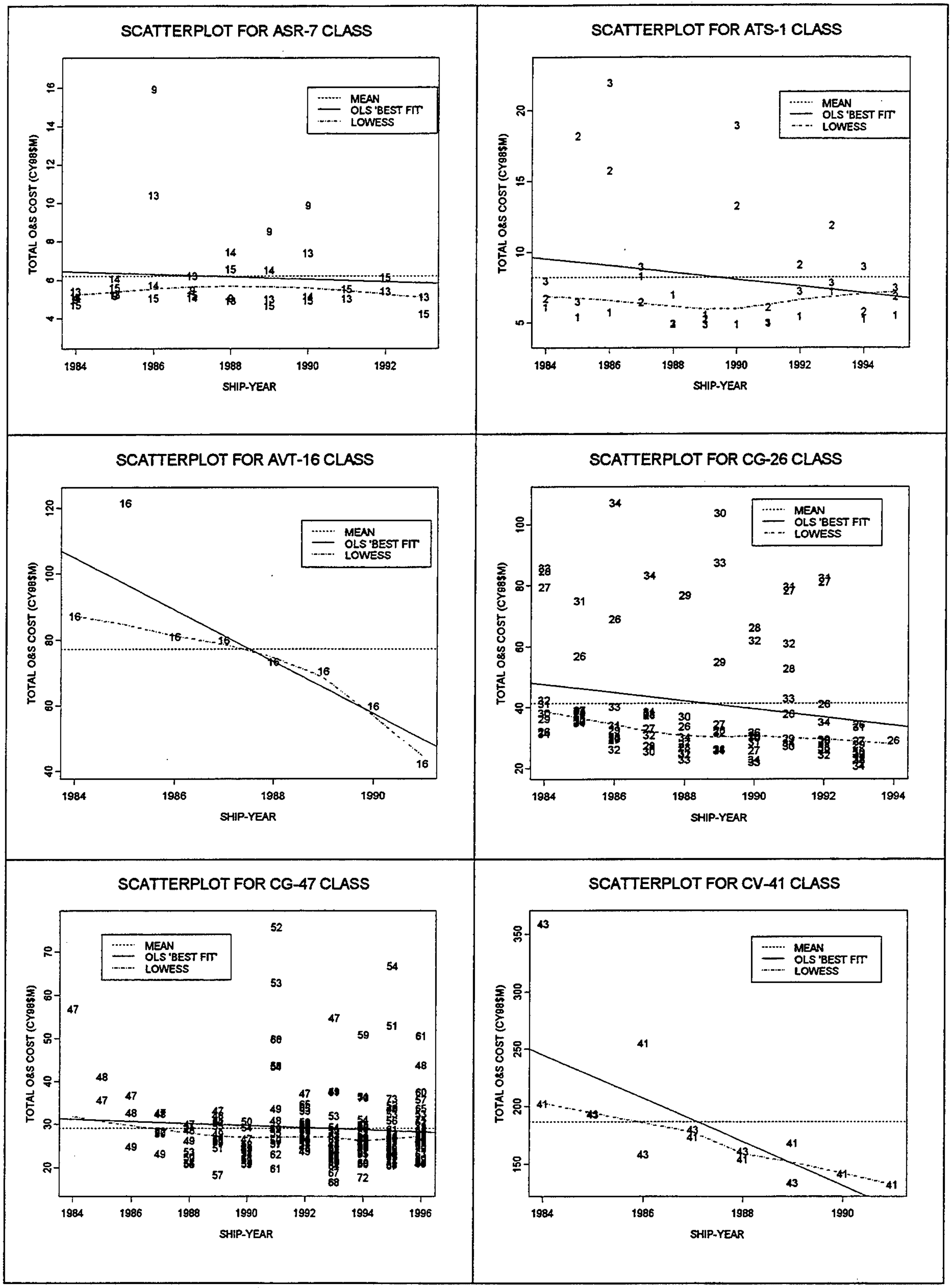


SCATTERPLOT FOR AS-39 CLASS

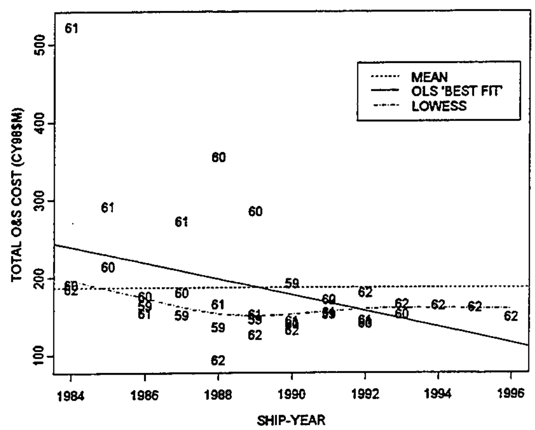


SCATTERPLOT FOR ASR-21 CLASS

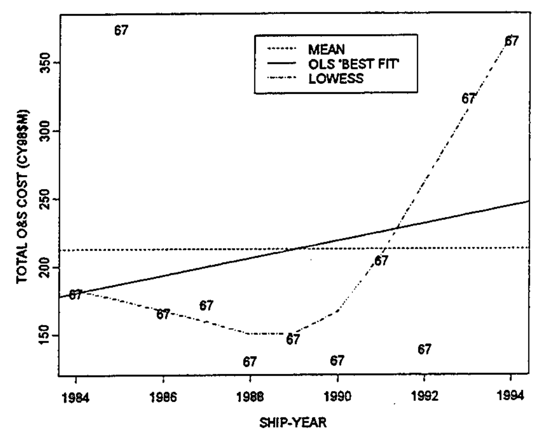



SCATTERPLOT FOR ASR-7 CLASS
MEAN
OLS 'BEST FIT'
LOWESS
TOTAL O&S COST (CY98$M)
SHIP-YEAR
SCATTERPLOT FOR ATS-1 CLASS
MEAN
OLS 'BEST FIT'
LOWESS
TOTAL O&S COST (CY98$M)
SHIP-YEAR
SCATTERPLOT FOR AVT-16 CLASS
MEAN
OLS 'BEST FIT'
LOWESS
TOTAL O&S COST (CY98$M)
SHIP-YEAR
SCATTERPLOT FOR CG-26 CLASS
MEAN
OLS 'BEST FIT'
LOWESS
TOTAL O&S COST (CY98$M)
SHIP-YEAR
SCATTERPLOT FOR CG-47 CLASS
MEAN
OLS 'BEST FIT'
LOWESS
TOTAL O&S COST (CY98$M)
SHIP-YEAR
SCATTERPLOT FOR CV-41 CLASS
MEAN
OLS 'BEST FIT'
LOWESS
TOTAL O&S COST (CY98$M)
SHIP-YEAR

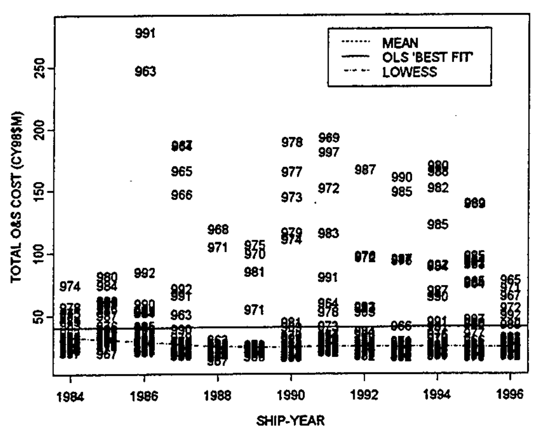
SCATTERPLOT FOR CV-59 CLASS



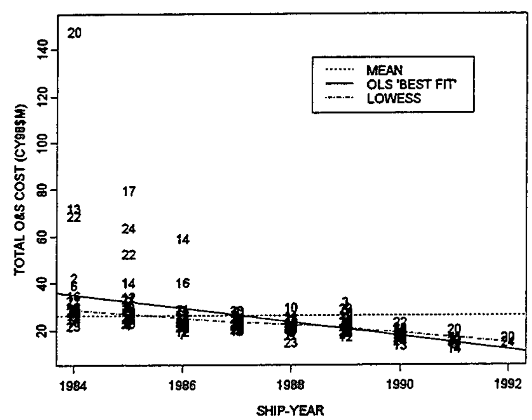
SCATTERPLOT FOR CV-67 CLASS



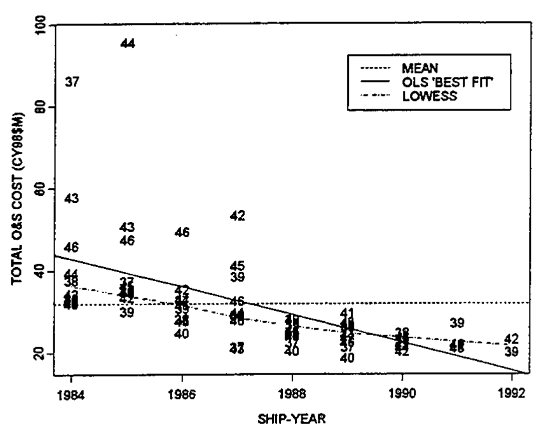
SCATTERPLOT FOR DD-963 CLASS



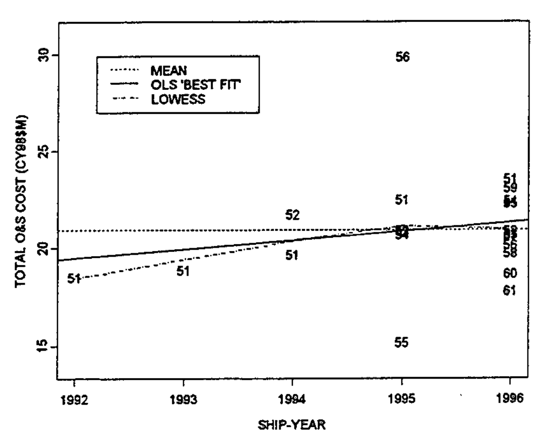
SCATTERPLOT FOR DDG-2 CLASS

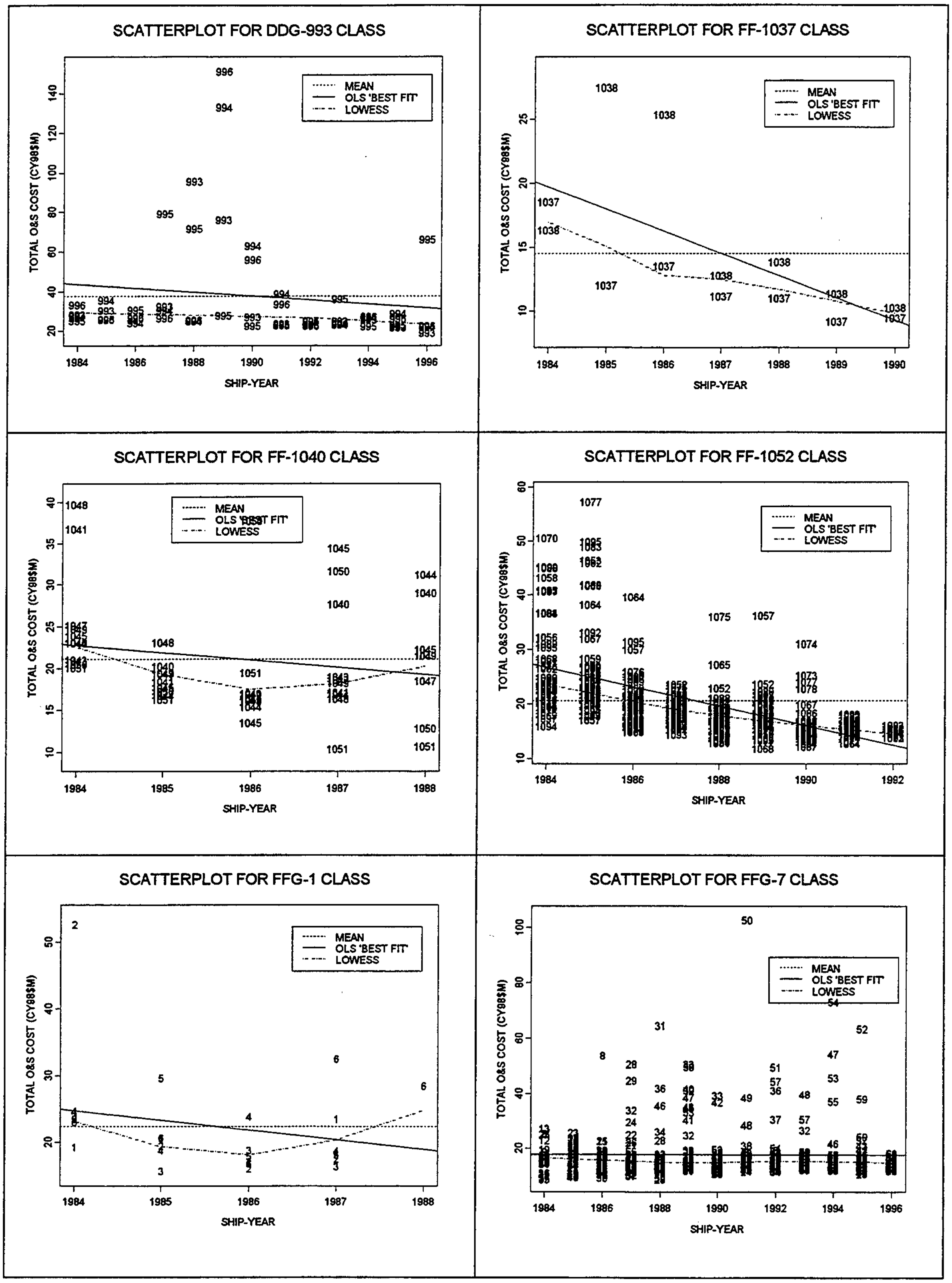


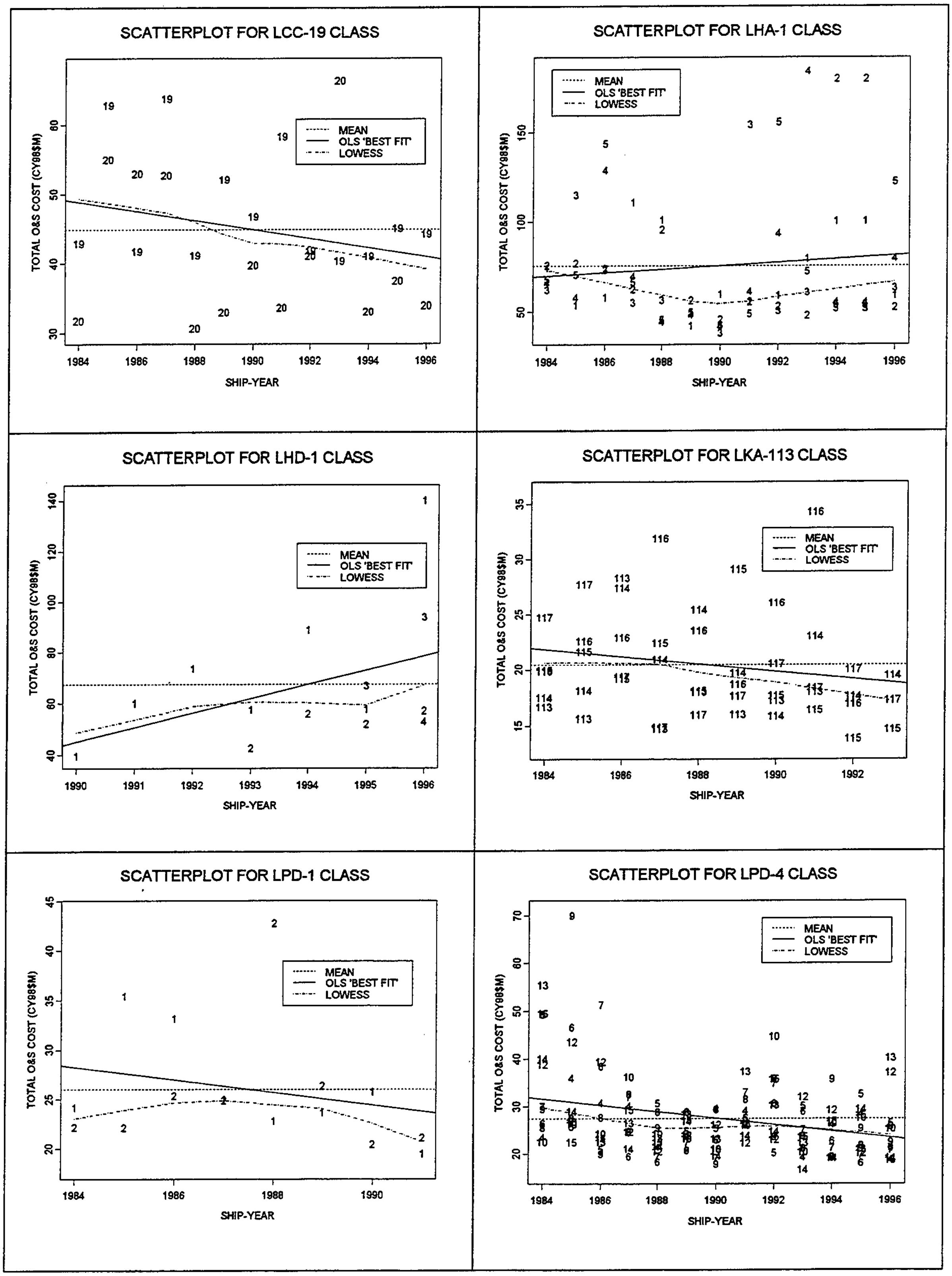
SCATTERPLOT FOR DDG-37 CLASS

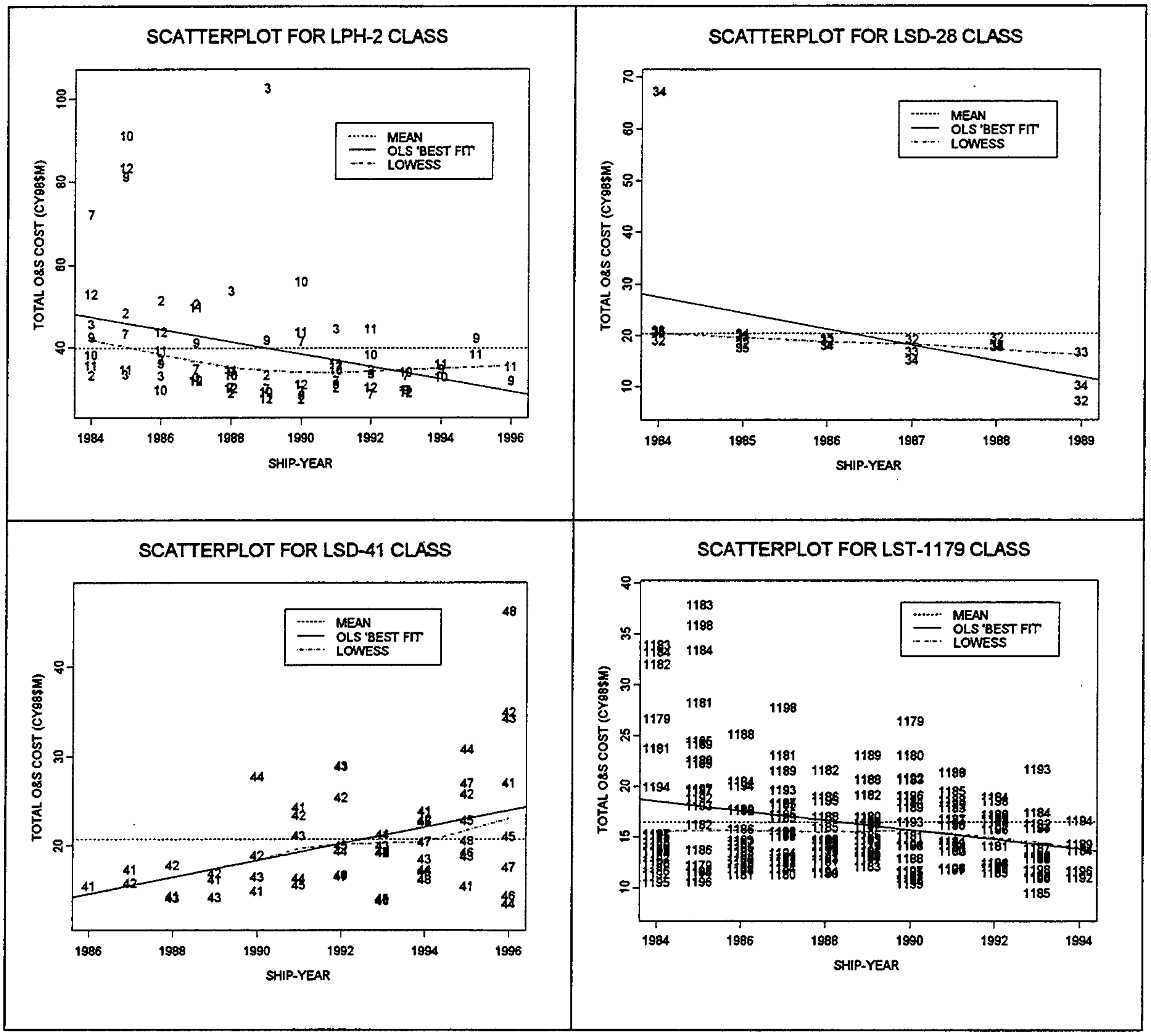


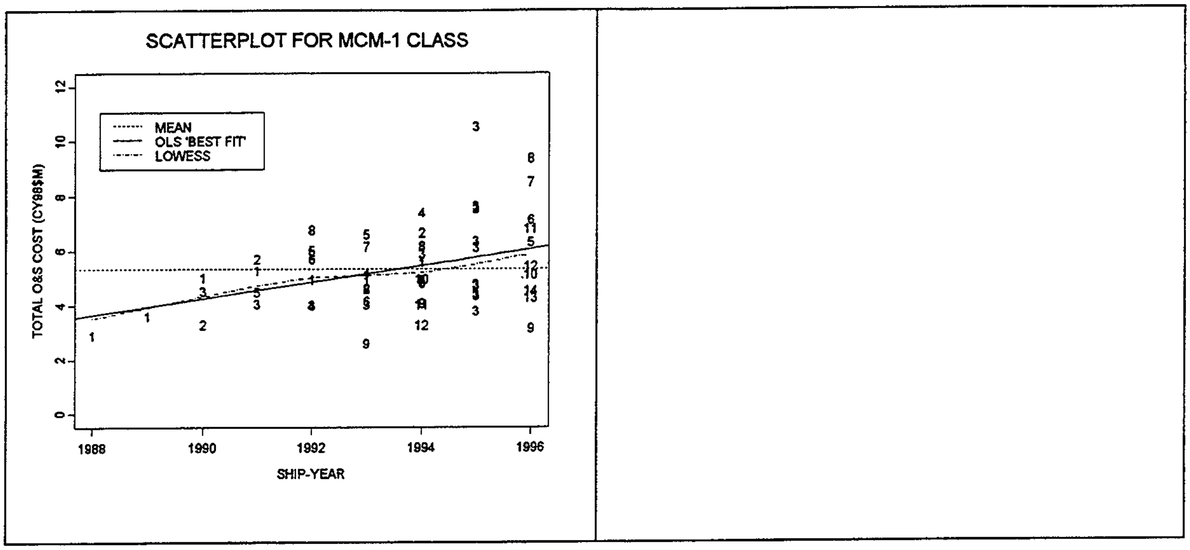
SCATTERPLOT FOR DDG-51 CLASS




SCATTERPLOT FOR DDG-993 CLASS
MEAN
OLS 'BEST FIT'
LOWESS
TOTAL O&S COST (CY98$M)
SHIP-YEAR
SCATTERPLOT FOR FF-1037 CLASS
MEAN
OLS 'BEST FIT'
LOWESS
TOTAL O&S COST (CY98$M)
SHIP-YEAR
SCATTERPLOT FOR FF-1040 CLASS
MEAN
OLS 'BEST FIT'
LOWESS
TOTAL O&S COST (CY98$M)
SHIP-YEAR
SCATTERPLOT FOR FF-1052 CLASS
MEAN
OLS 'BEST FIT'
LOWESS
TOTAL O&S COST (CY98$M)
SHIP-YEAR
SCATTERPLOT FOR FFG-1 CLASS
MEAN
OLS 'BEST FIT'
LOWESS
TOTAL O&S COST (CY98$M)
SHIP-YEAR
SCATTERPLOT FOR FFG-7 CLASS
MEAN
OLS 'BEST FIT'
LOWESS
TOTAL O&S COST (CY98$M)
SHIP-YEAR


SCATTERPLOT FOR LCC-19 CLASS
SCATTERPLOT FOR LHA-1 CLASS
SCATTERPLOT FOR LHD-1 CLASS
SCATTERPLOT FOR LKA-113 CLASS
SCATTERPLOT FOR LPD-1 CLASS
SCATTERPLOT FOR LPD-4 CLASS
MEAN
OLS 'BEST FIT'
LOWESS
TOTAL O&S COST (CY98$M)
SHIP-YEAR


SCATTERPLOT FOR LPH-2 CLASS
MEAN
OLS 'BEST FIT'
LOWESS
TOTAL O&S COST (CY98$M)
SHIP-YEAR
SCATTERPLOT FOR LSD-28 CLASS
MEAN
OLS 'BEST FIT'
LOWESS
TOTAL O&S COST (CY98$M)
SHIP-YEAR
SCATTERPLOT FOR LSD-41 CLASS
MEAN
OLS 'BEST FIT'
LOWESS
TOTAL O&S COST (CY98$M)
SHIP-YEAR
SCATTERPLOT FOR LST-1179 CLASS
MEAN
OLS 'BEST FIT'
LOWESS
TOTAL O&S COST (CY98$M)
SHIP-YEAR


SCATTERPLOT FOR MCM-1 CLASS
MEAN
OLS 'BEST FIT'
LOWESS
TOTAL O&S COST (CY98$M)
SHIP-YEAR
0
2
4
6
8
10
12
1988
1990
1992
1994
1996

APPENDIX F. U.S. NAVY SHIP CLASS SUMMARY OF PREDICTIVE MEASURES

VAMOSC-ISR for FY96 — Period of Coverage: 1984-1996

SHIP CLASS	SAMPLE MEAN (CY98$)	SE	CV	R^2	R^2 (adj)	r
AD-14	31,766,994	4,269,000	13.44%	3.15%	-0.43%	-0.1775
AD-37	43,210,754	6,272,000	14.51%	20.00%	16.36%	-0.4045
AD-41	42,772,231	5,676,000	13.27%	0.56%	-1.70%	0.0748
AE-21	20,109,464	6,676,000	33.20%	11.42%	6.99%	-0.2644
AE-23	20,412,638	5,553,000	27.20%	3.60%	0.27%	-0.0521
AE-26	24,149,862	7,728,000	32.00%	26.12%	25.25%	-0.5025
AFS-1	28,279,133	9,222,000	32.61%	1.73%	0.06%	-0.0244
AGF-3	45,575,840	19,170,000	42.06%	4.62%	-4.05%	0.2150
AGF-11	38,088,453	18,770,000	49.28%	25.66%	18.90%	-0.4348
AO-51	19,896,370	3,459,000	17.39%	67.15%	63.87%	-0.7992
AO-177	16,557,329	5,838,000	35.26%	1.01%	-0.56%	0.1007
AOE-1	34,091,121	11,370,000	33.35%	0.13%	-1.87%	-0.0356
AOR-1	25,372,722	5,821,000	22.94%	38.12%	37.27%	-0.6105
AR-5	31,107,062	4,598,000	14.78%	15.97%	12.15%	0.3486
ARS-38	5,305,629	1,403,000	26.44%	7.32%	4.33%	0.2080
ARS-50	5,636,843	1,528,000	27.11%	17.67%	15.50%	0.3937
AS-11	39,398,528	4,057,000	10.30%	53.70%	50.39%	0.7099
AS-19	45,759,172	8,433,000	18.43%	1.49%	-14.93%	0.1221
AS-31	49,093,235	6,022,000	12.27%	0.44%	-4.54%	-0.0664
AS-33	57,801,422	10,500,000	18.17%	4.96%	0.64%	0.0801
AS-36	54,233,463	10,850,000	20.01%	5.54%	1.24%	0.1115
AS-39	51,926,510	6,006,000	11.57%	57.75%	56.61%	0.7524
ASR-7	6,187,768	2,251,000	36.38%	0.60%	-2.51%	-0.0772
ASR-21	14,414,867	6,446,000	44.72%	2.04%	-3.72%	-0.1428
ATS-1	8,180,746	4,281,000	52.33%	3.89%	1.07%	-0.1033
AVT-16	77,136,165	13,300,000	17.24%	70.98%	66.14%	-0.8133
CG-16	41,555,425	25,630,000	61.68%	3.32%	2.23%	-0.1494
CG-26	41,468,161	20,340,000	49.05%	3.68%	2.59%	-0.1610
CG-47	29,146,933	8,546,000	29.32%	0.69%	0.14%	-0.0368
CV-41	187,099,489	43,900,000	23.46%	48.93%	44.67%	-0.6684
CV-59	186,528,677	72,360,000	38.79%	17.14%	14.63%	-0.3825
CV-63	179,371,432	51,820,000	28.89%	19.24%	16.36%	-0.4044
CV-67	212,520,084	97,290,000	45.78%	4.97%	-5.59%	0.2230
DD-963	40,476,669	37,190,000	91.88%	0.01%	-0.24%	0.0099
DDG-2	26,283,606	12,190,000	46.38%	20.42%	19.92%	-0.4463
DDG-37	31,830,390	10,670,000	33.52%	33.85%	32.92%	-0.5737
DDG-51	20,944,863	2,854,000	13.63%	3.31%	-1.78%	0.1819
DDG-993	37,625,643	27,090,000	72.00%	1.91%	-0.06%	-0.1380

VAMOSC-ISR for FY96 Period of Coverage: 1984-1996

SHIP CLASS	SAMPLE MEAN (CY98$)	SE	CV	R^2	R^2 (adj)	r
FF-1037	14,510,777	4,567,000	31.47%	40.13%	35.14%	-0.5928
FF-1040	21,123,679	6,711,000	31.77%	3.17%	1.02%	-0.1009
FF-1052	20,604,292	6,072,000	29.47%	32.25%	32.02%	-0.5659
FFG-1	22,414,705	7,660,000	34.17%	5.29%	1.18%	-0.1084
FFG-7	17,711,906	9,196,000	51.92%	0.01%	-0.22%	-0.0087
LCC-19	44,845,018	10,240,000	22.83%	5.87%	1.94%	-0.1394
LHA-1	75,593,560	35,880,000	47.46%	1.05%	-0.52%	0.1023
LHD-1	67,398,986	24,550,000	36.42%	17.65%	10.79%	0.3284
LKA-113	20,413,038	4,668,000	22.87%	3.76%	1.62%	-0.1274
LPD-1	26,028,440	6,167,000	23.69%	5.98%	-0.74%	-0.2445
LPD-4	27,533,787	7,640,000	27.75%	9.90%	9.26%	-0.3044
LPH-2	39,868,127	13,720,000	34.41%	11.81%	10.60%	-0.3256
LSD-28	20,365,300	10,470,000	51.41%	22.79%	18.50%	-0.4301
LSD-36	23,225,261	6,799,000	29.27%	6.52%	5.03%	-0.2243
LSD-41	20,749,858	5,690,000	27.42%	16.96%	15.45%	0.3931
LST-1179	16,467,656	4,929,000	29.93%	7.40%	6.86%	-0.2620
MCM-1	5,330,771	1,438,000	26.98%	14.93%	13.41%	0.3662
MSO-422	5,122,278	1,485,000	28.99%	0.10%	-5.16%	-0.0317
PHM-1	5,895,284	1,547,000	26.24%	0.15%	-1.77%	-0.0390

APPENDIX G. U.S. NAVY SHIP CLASS OLS REGRESSION RESULTS

VAMOSC-ISR for FY96 (alpha = 0.05; revised alpha (w/Bonferroni correction): 0.05/57 = 0.0008772)

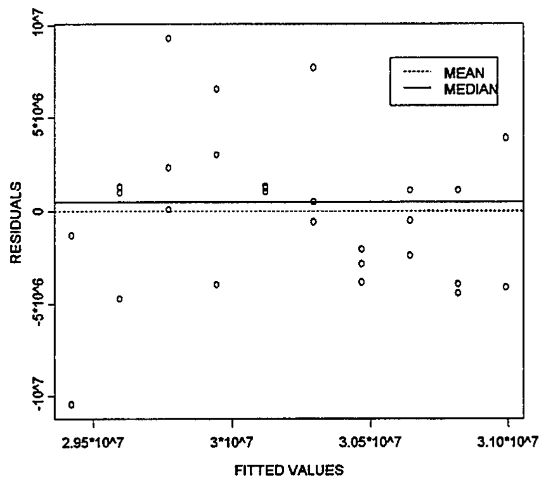
SHIP CLASS	OLS REGRESSION (COST~YEAR) p-value (*t*-test)	SIGNIFICANT ? (slope different from 0)	NOTE
AD-14	0.3569	NO	
AD-37	0.02845	NO	significant w/o Bonferroni correction
AD-41	0.6214	NO	
AE-21	0.1239	NO	
AE-23	0.3069	NO	
AE-26	4.24E-07	YES	indication of **decreasing** trend
AFS-1	0.313	NO	
AGF-3	0.4805	NO	
AGF-11	0.07729	NO	
AO-177	0.4248	NO	
AO-51	0.001106	NO	significant w/o Bonferroni correction
AOE-1	0.8021	NO	
AOR-1	3.64E-09	YES	indication of **decreasing** trend
AR-5	0.05301	NO	
ARS-38	0.1279	NO	
ARS-50	0.006925	NO	significant w/o Bonferroni correction
AS-11	0.001243	NO	significant w/o Bonferroni correction
AS-19	0.7734	NO	
AS-31	0.7689	NO	
AS-33	0.2954	NO	
AS-36	0.2683	NO	
AS-39	2.02E-08	YES	indication of **decreasing** trend
ASR-7	0.6644	NO	
ASR-21	0.5598	NO	
ATS-1	0.2487	NO	
AVT-16	0.008648	NO	significant w/o Bonferroni correction
CG-16	0.08398	NO	
CG-26	0.06865	NO	
CG-47	0.266	NO	
CV-41	0.005358	NO	significant w/o Bonferroni correction
CV-59	0.01342	NO	significant w/o Bonferroni correction
CV-63	0.01532	NO	significant w/o Bonferroni correction
CV-67	0.5099	NO	

VAMOSC-ISR for FY96 (alpha = 0.05; revised alpha (w/Bonferroni correction): 0.05/57 = 0.0008772)

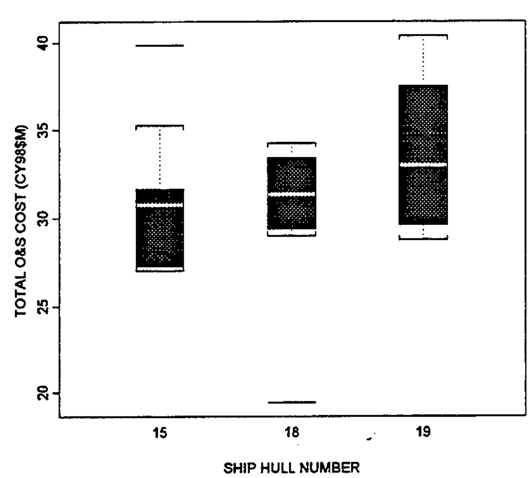
SHIP CLASS	OLS REGRESSION (COST~YEAR) p-value (*t*-test)	SIGNIFICANT ? (slope different from 0)	NOTE
DDG-2	1.57E-09	YES	indication of **decreasing** trend
DDG-37	6.73E-08	YES	indication of **decreasing** trend
DDG-51	0.4299	NO	
DDG-993	0.3292	NO	
FF-1037	0.015	NO	significant w/o Bonferroni correction
FF-1040	0.2312	NO	
FF-1052	0	YES	indication of **decreasing** trend
FFG-1	0.2686	NO	
FFG-7	0.8554	NO	
LCC-19	0.2333	NO	
LHA-1	0.4172	NO	
LHD-1	0.1347	NO	
LKA-113	0.1915	NO	
LPD-1	0.3614	NO	
LPD-4	0.0001293	YES	indication of **decreasing** trend
LPH-2	0.002537	NO	significant w/o Bonferroni correction
LSD-28	0.0333	NO	significant w/o Bonferroni correction
LSD-36	0.04014	NO	significant w/o Bonferroni correction
LSD-41	0.001458	NO	significant w/o Bonferroni correction
LST-1179	0.0002715	YES	indication of **decreasing** trend
MCM-1	0.002739	NO	significant w/o Bonferroni correction
MSO-422	0.8914	NO	
PHM-1	0.7797	NO	

APPENDIX H. U.S. NAVY SHIP CLASS REGRESION DIAGNOSTIC PLOTS

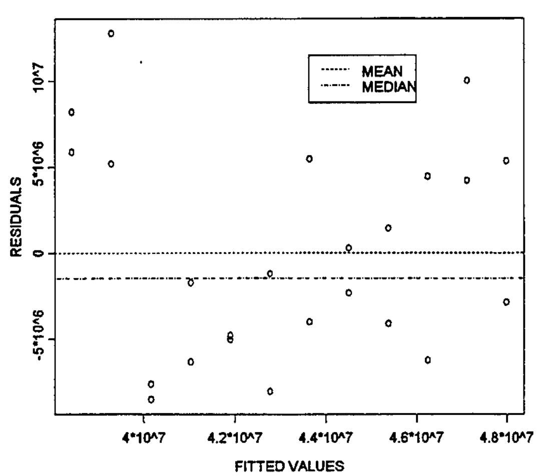
REGRESSION DIAGNOSTIC PLOT FOR AD-14 CLASS



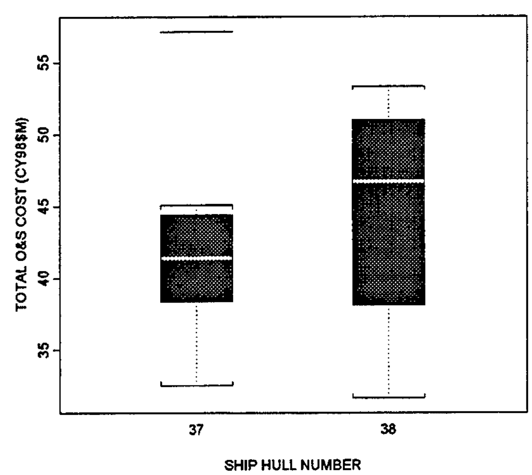
BOXPLOT FOR AD-14 CLASS



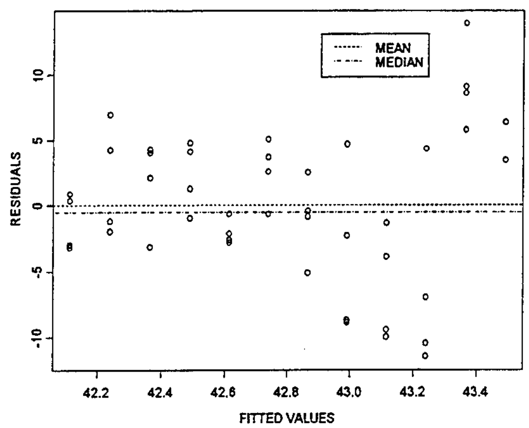
REGRESSION DIAGNOSTIC PLOT FOR AD-37 CLASS



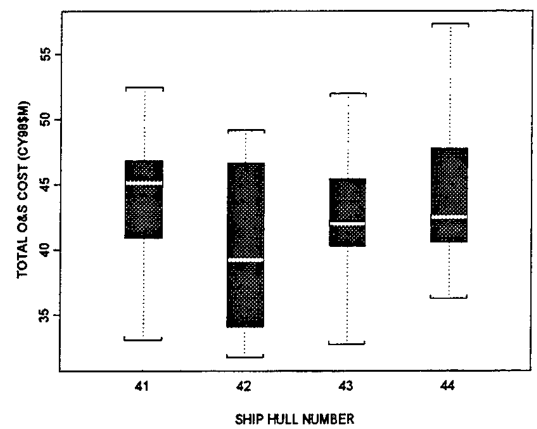
BOXPLOT FOR AD-37 CLASS



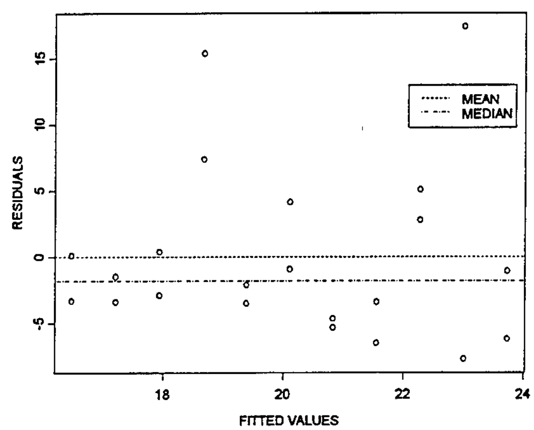
REGRESSION DIAGNOSTIC PLOT FOR AD-41 CLASS



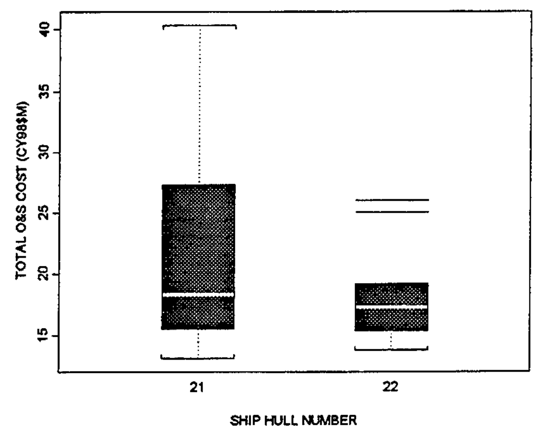
BOXPLOT FOR AD-41 CLASS



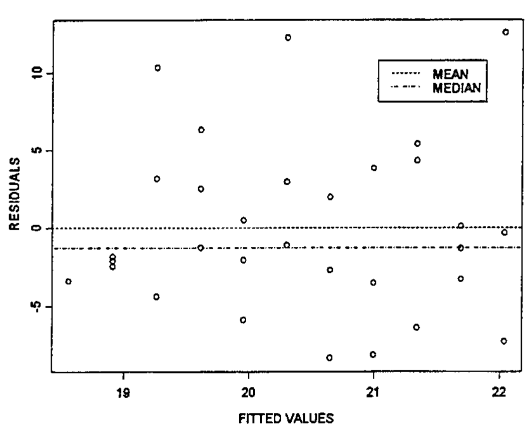
REGRESSION DIAGNOSTIC PLOT FOR AE-21 CLASS



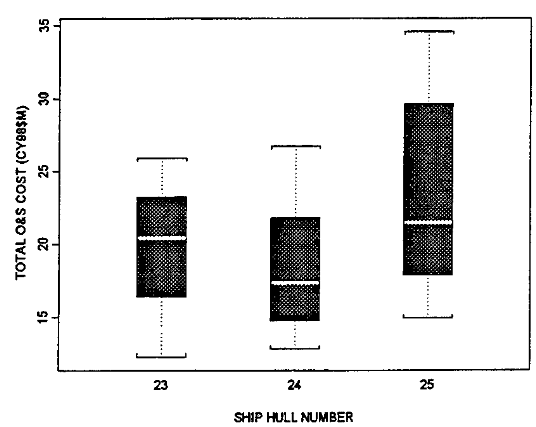
BOXPLOT FOR AE-21 CLASS



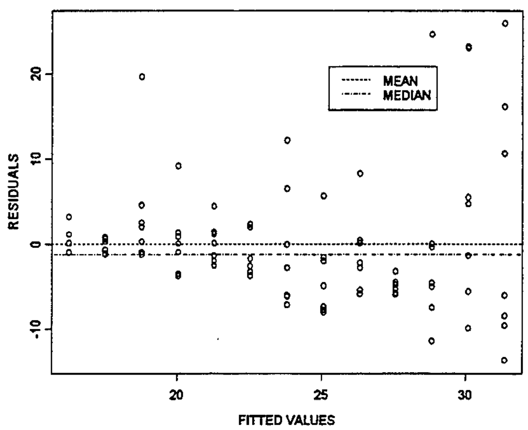
REGRESSION DIAGNOSTIC PLOT FOR AE-23 CLASS



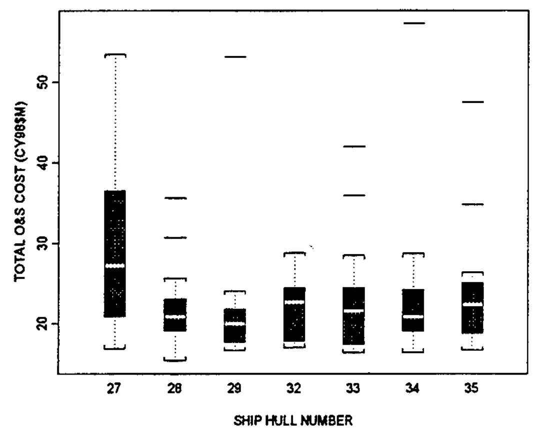
BOXPLOT FOR AE-23 CLASS



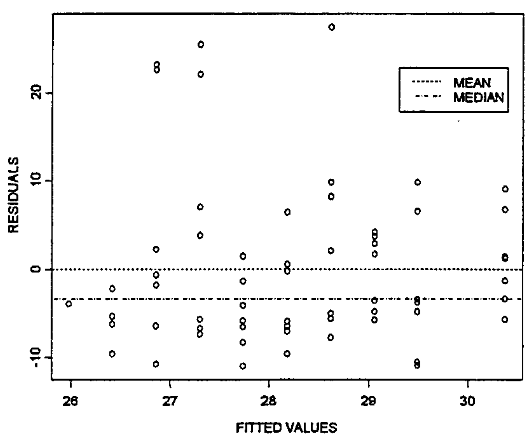
REGRESSION DIAGNOSTIC PLOT FOR AE-26 CLASS



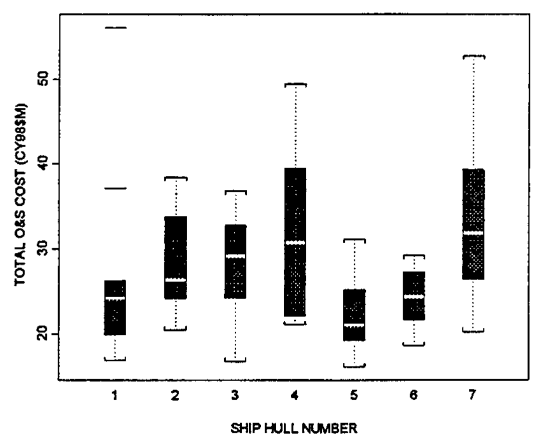
BOXPLOT FOR AE-26 CLASS



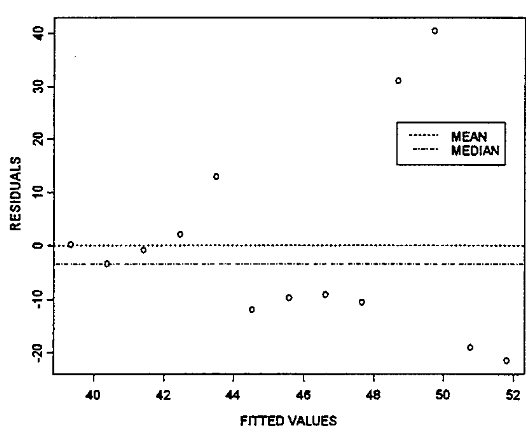
REGRESSION DIAGNOSTIC PLOT FOR AFS-1 CLASS



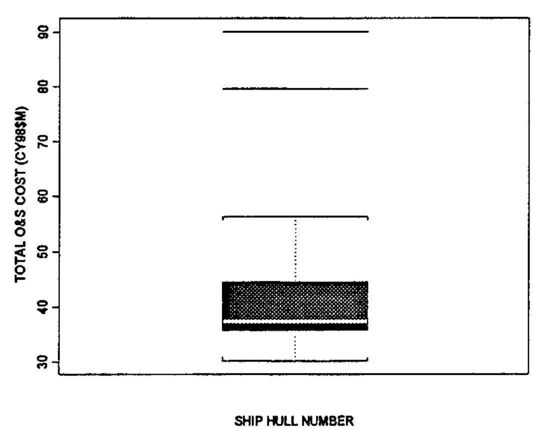
BOXPLOT FOR AFS-1 CLASS



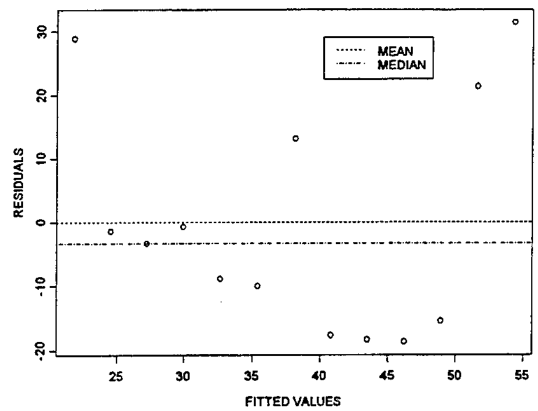
REGRESSION DIAGNOSTIC PLOT FOR AGF-3 CLASS



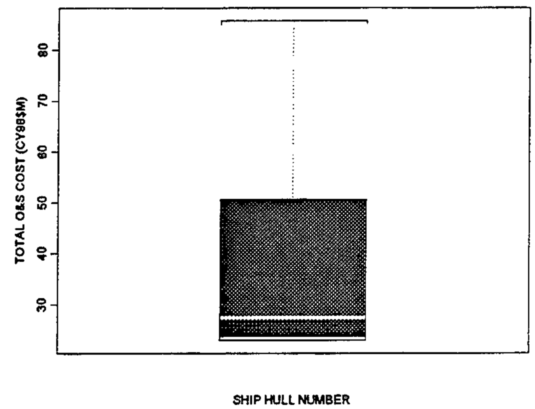
BOXPLOT FOR AGF-3 CLASS



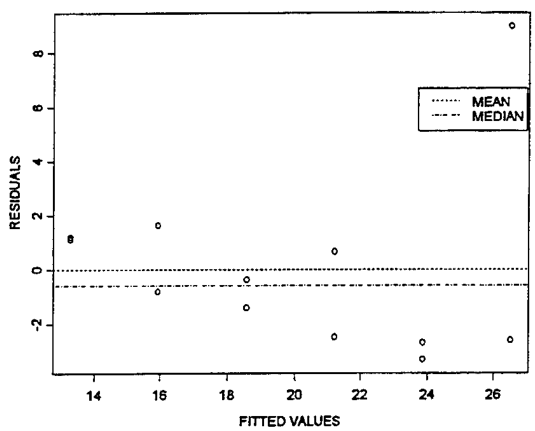
REGRESSION DIAGNOSTIC PLOT FOR AGF-11 CLASS



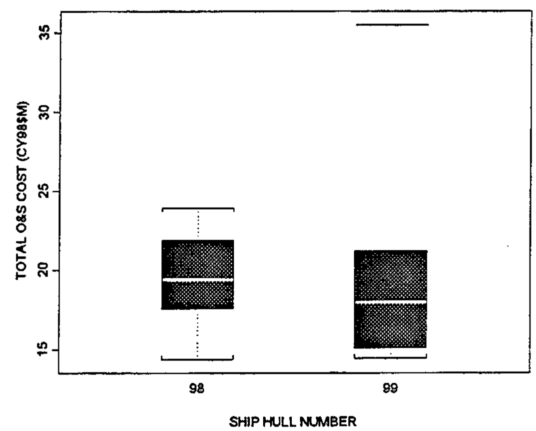
BOXPLOT FOR AGF-11 CLASS



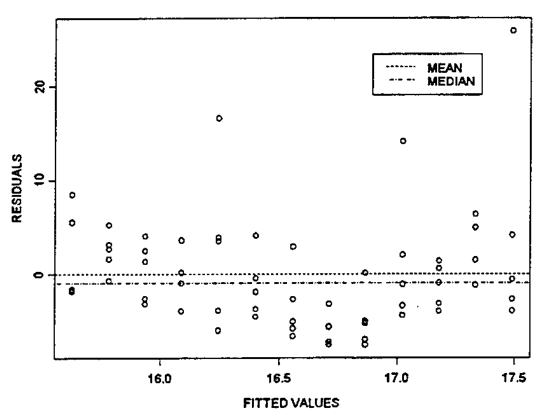
REGRESSION DIAGNOSTIC PLOT FOR AO-51 CLASS



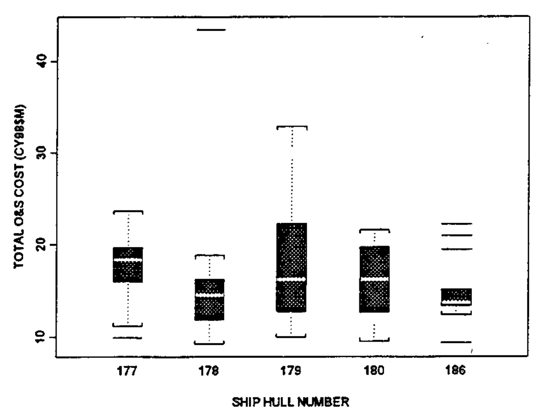
BOXPLOT FOR AO-51 CLASS



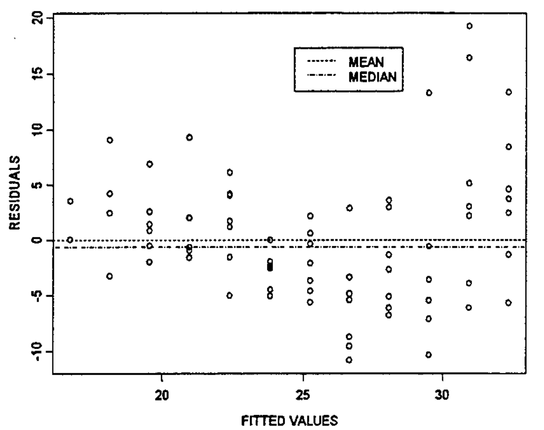
REGRESSION DIAGNOSTIC PLOT FOR AO-177 CLASS



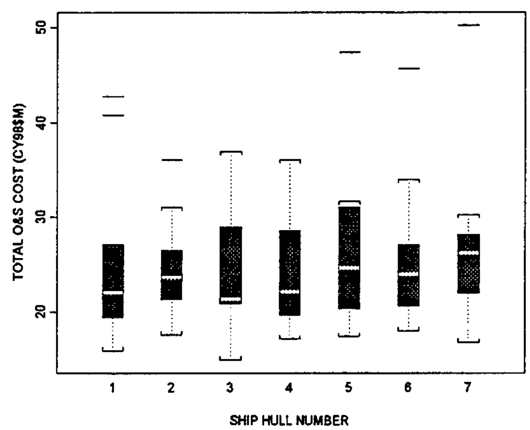
BOXPLOT FOR AO-177 CLASS



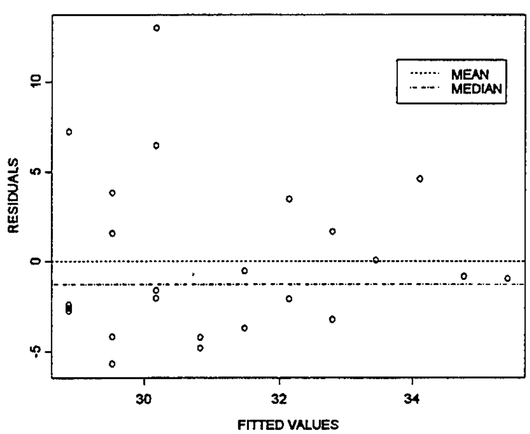
REGRESSION DIAGNOSTIC PLOT FOR AOR-1 CLASS



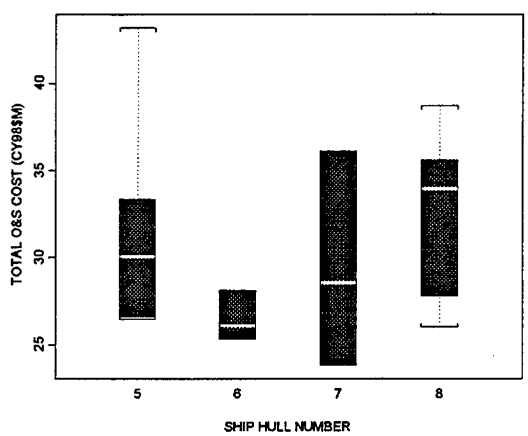
BOXPLOT FOR AOR-1 CLASS



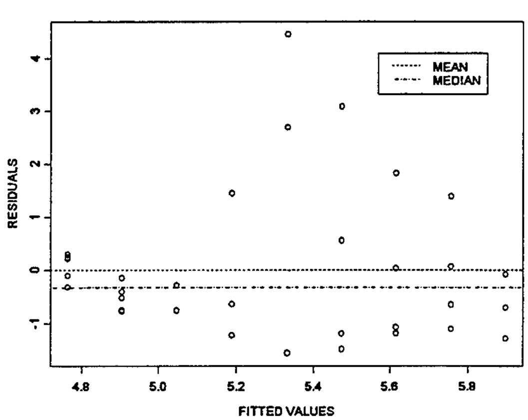
REGRESSION DIAGNOSTIC PLOT FOR AR-5 CLASS



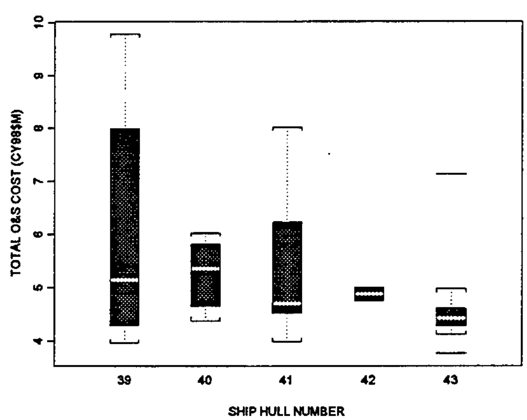
BOXPLOT FOR AR-5 CLASS



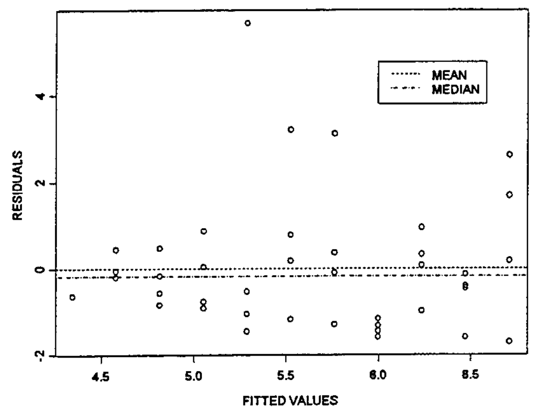
REGRESSION DIAGNOSTIC PLOT FOR ARS-38 CLASS



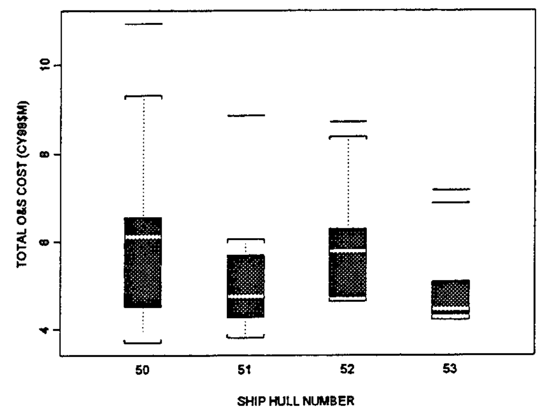
BOXPLOT FOR ARS-38 CLASS



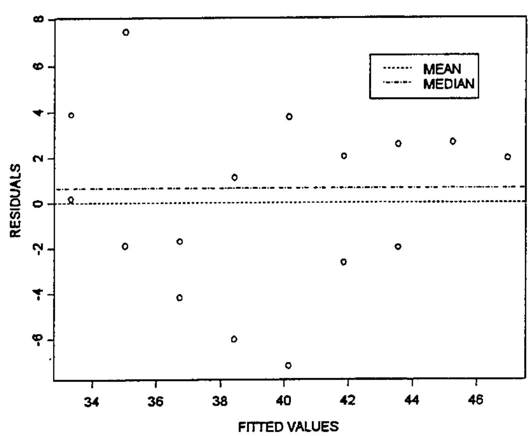
REGRESSION DIAGNOSTIC PLOT FOR ARS-50 CLASS



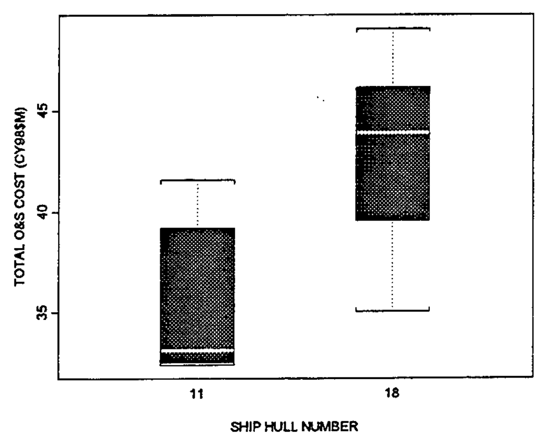
BOXPLOT FOR ARS-50 CLASS



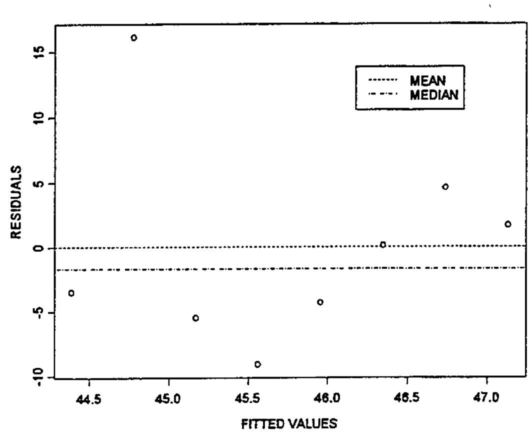
REGRESSION DIAGNOSTIC PLOT FOR AS-11 CLASS



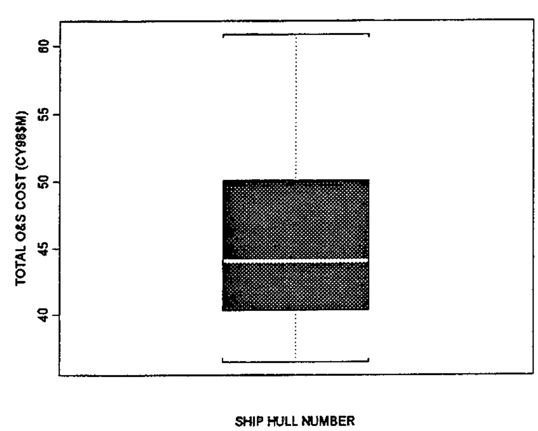
BOXPLOT FOR AS-11 CLASS



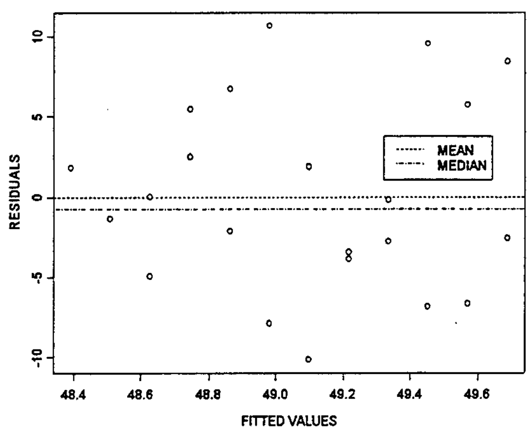
REGRESSION DIAGNOSTIC PLOT FOR AS-19 CLASS



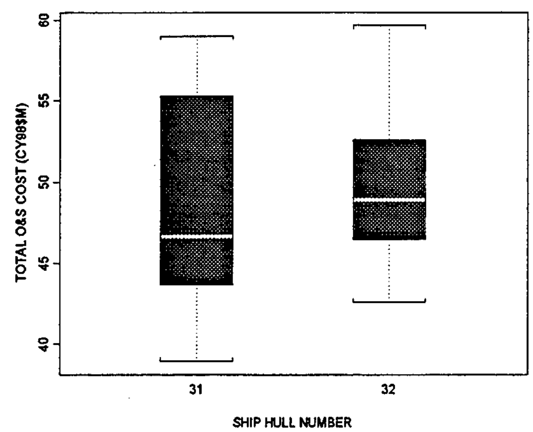
BOXPLOT FOR AS-19 CLASS



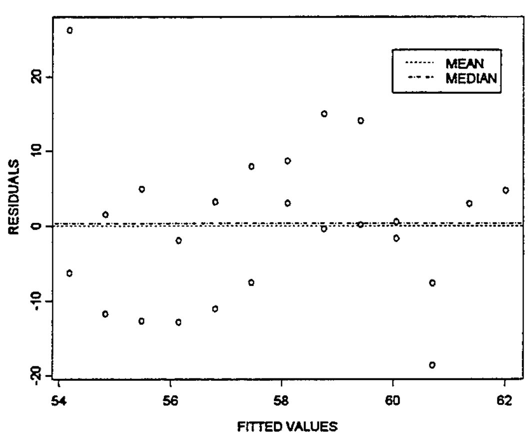
REGRESSION DIAGNOSTIC PLOT FOR AS-31 CLASS



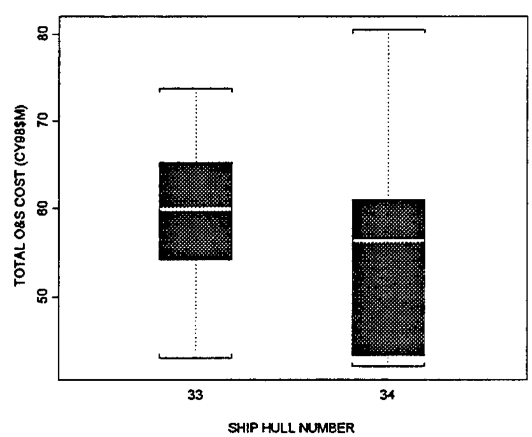
BOXPLOT FOR AS-31 CLASS



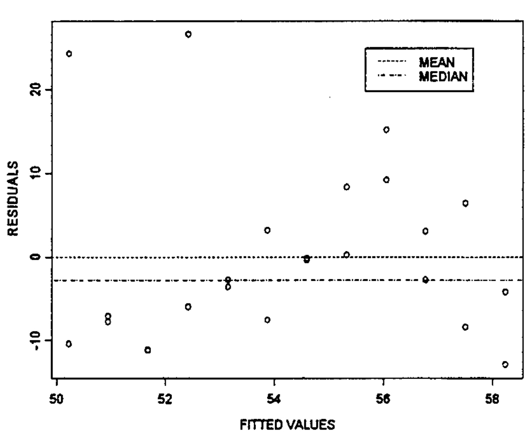
REGRESSION DIAGNOSTIC PLOT FOR AS-33 CLASS



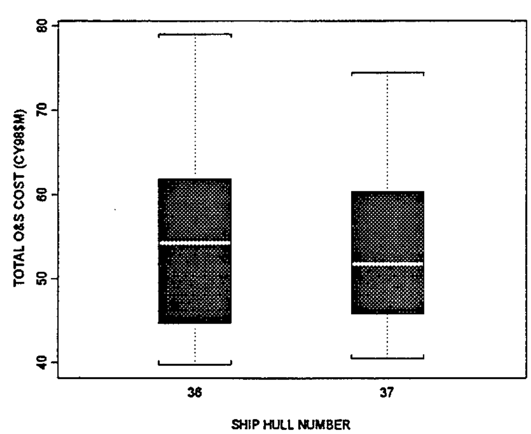
BOXPLOT FOR AS-33 CLASS



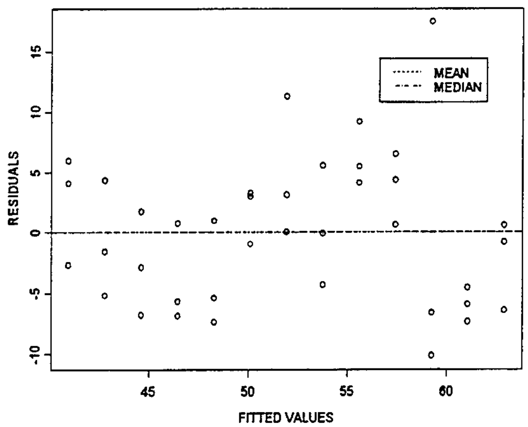
REGRESSION DIAGNOSTIC PLOT FOR AS-36 CLASS



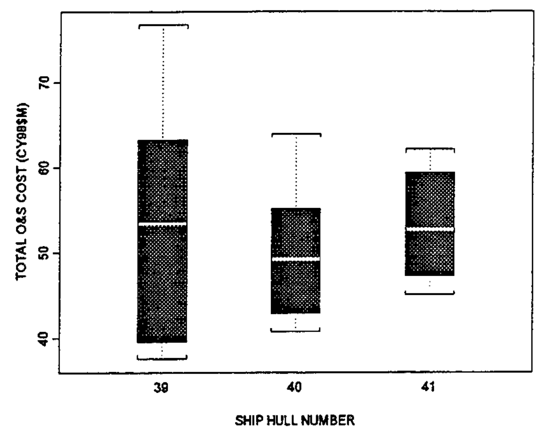
BOXPLOT FOR AS-36 CLASS



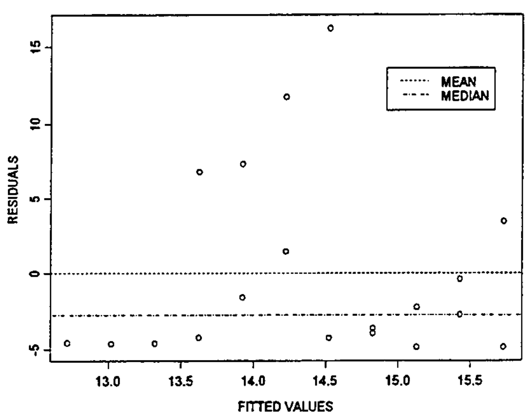
REGRESSION DIAGNOSTIC PLOT FOR AS-39 CLASS



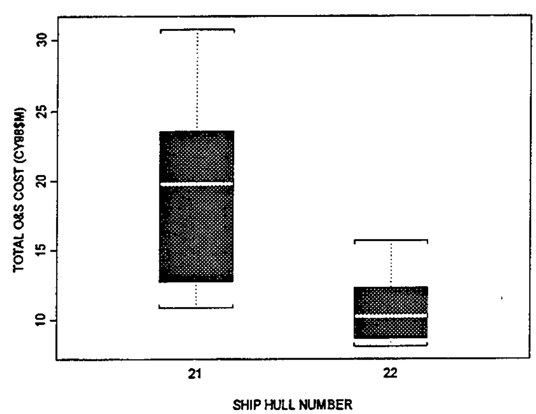
BOXPLOT FOR AS-39 CLASS



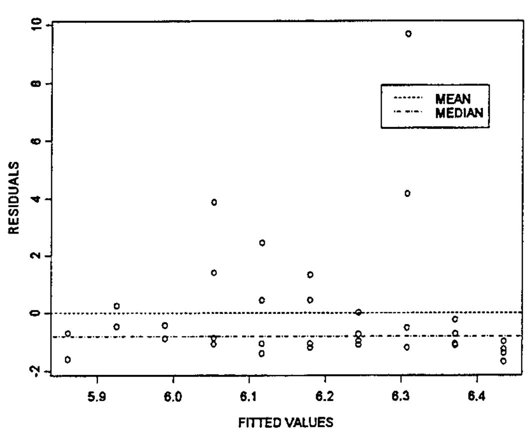
REGRESSION DIAGNOSTIC PLOT FOR ASR-21 CLASS



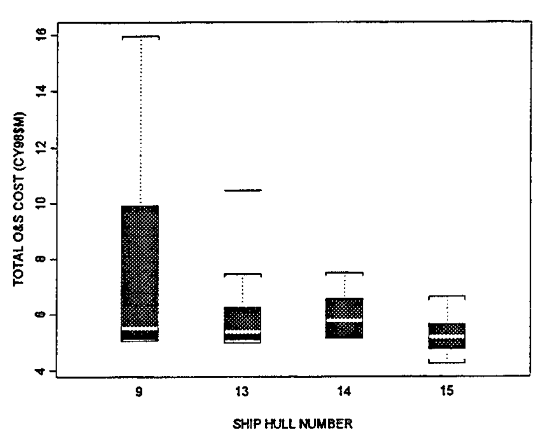
BOXPLOT FOR ASR-21 CLASS



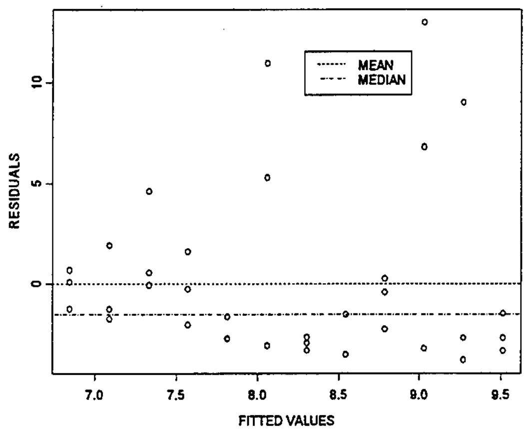
REGRESSION DIAGNOSTIC PLOT FOR ASR-7 CLASS



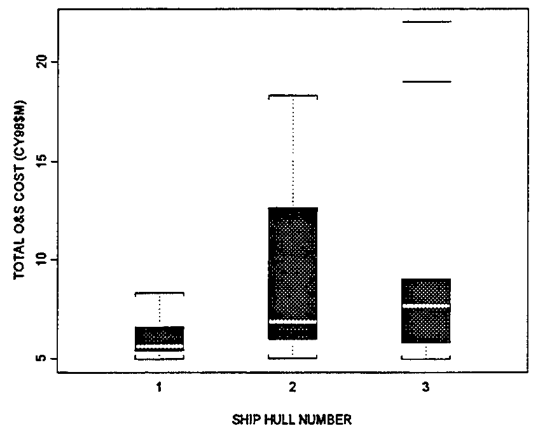
BOXPLOT FOR ASR-7 CLASS



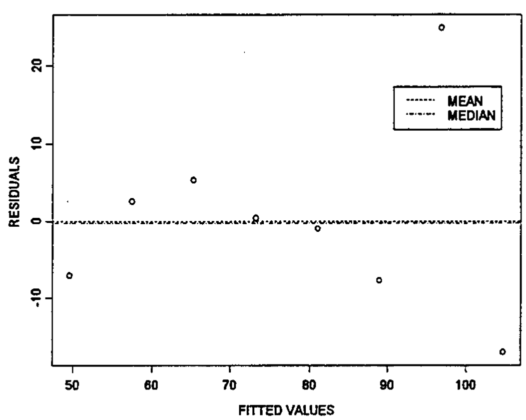
REGRESSION DIAGNOSTIC PLOT FOR ATS-1 CLASS



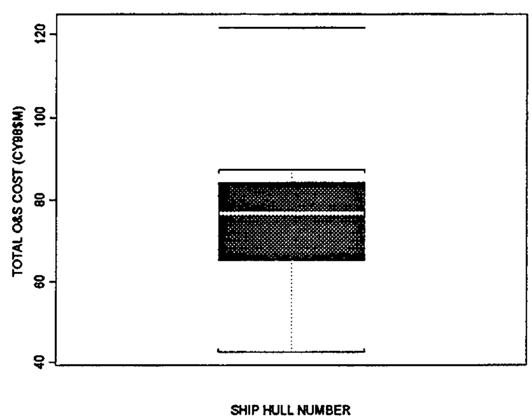
BOXPLOT FOR ATS-1 CLASS



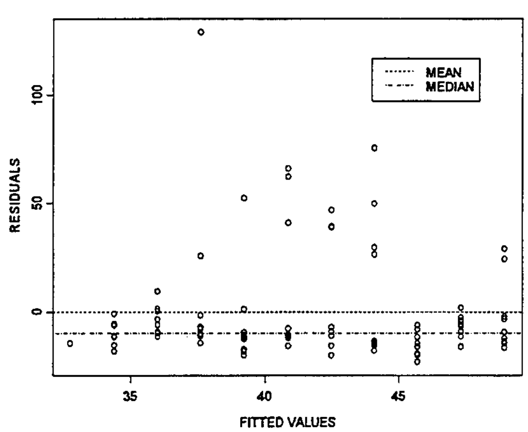
REGRESSION DIAGNOSTIC PLOT FOR AVT-16 CLASS

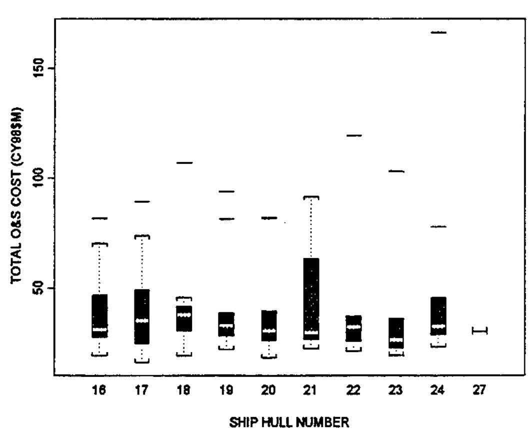


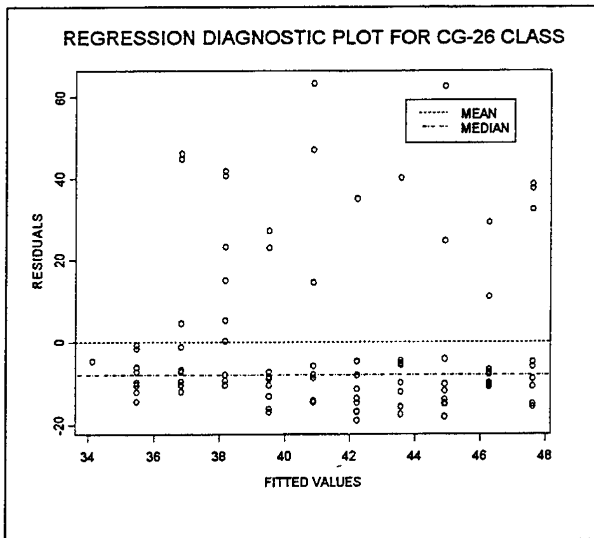
BOXPLOT FOR AVT-16 CLASS

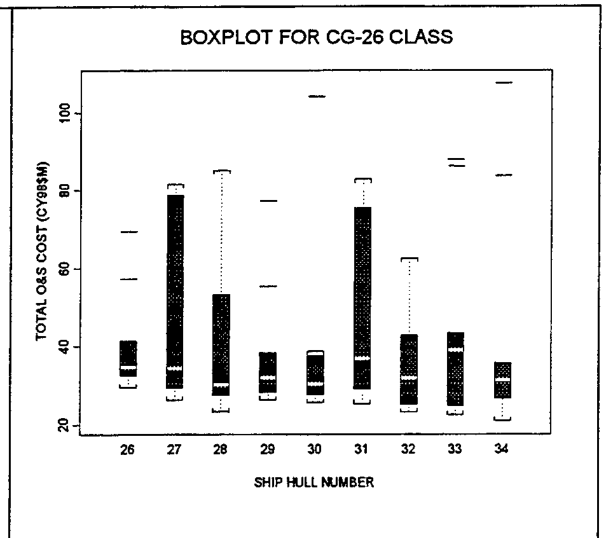


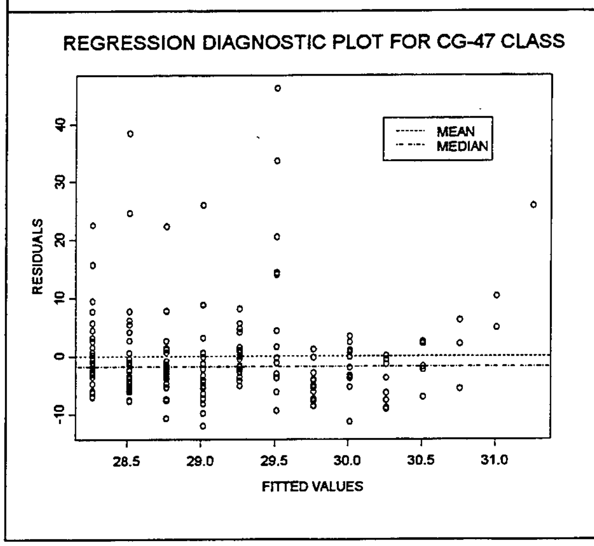
REGRESSION DIAGNOSTIC PLOT FOR CG-16 CLASS

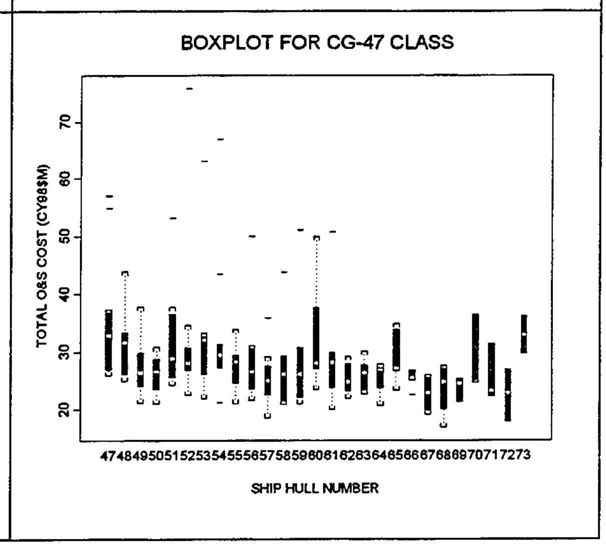




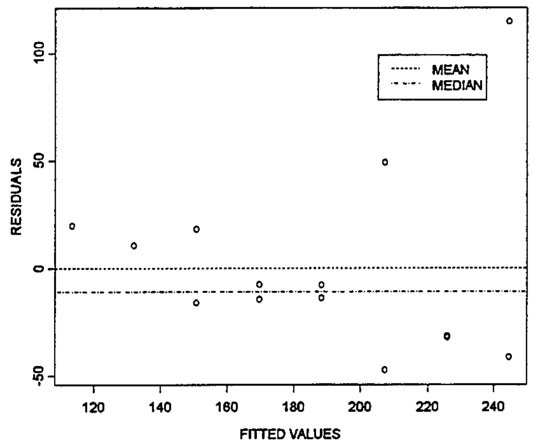

REGRESSION DIAGNOSTIC PLOT FOR CG-26 CLASS
MEAN
MEDIAN
RESIDUALS
FITTED VALUES
-20
0
20
40
60
34
36
38
40
42
44
46
48


BOXPLOT FOR CG-26 CLASS
TOTAL O&S COST (CY98$M)
SHIP HULL NUMBER
20
40
60
80
100
26
27
28
29
30
31
32
33
34

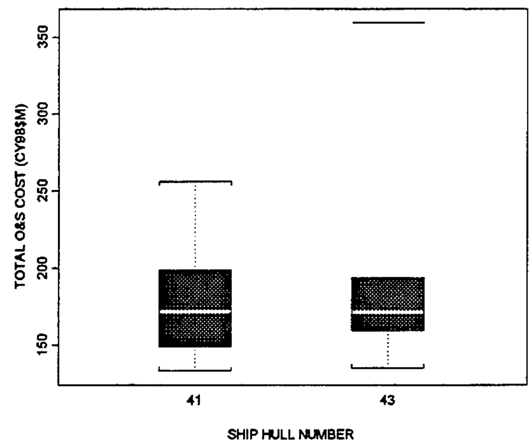

REGRESSION DIAGNOSTIC PLOT FOR CG-47 CLASS
MEAN
MEDIAN
RESIDUALS
FITTED VALUES
-10
0
10
20
30
40
28.5
29.0
29.5
30.0
30.5
31.0


BOXPLOT FOR CG-47 CLASS
TOTAL O&S COST (CY98$M)
SHIP HULL NUMBER
20
30
40
50
60
70
474849505152535455565758596061626364656667686970717273

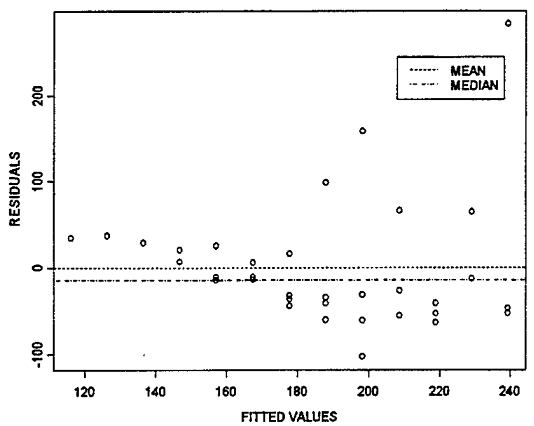
REGRESSION DIAGNOSTIC PLOT FOR CV-41 CLASS



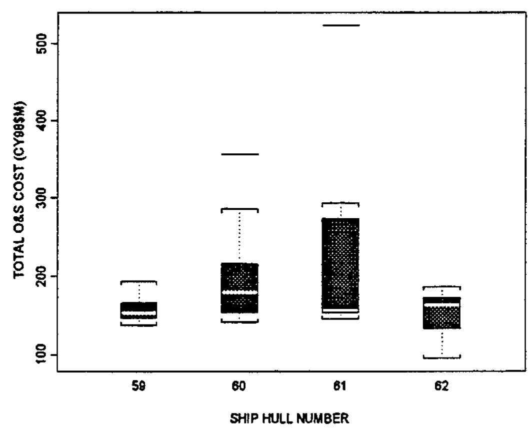
BOXPLOT FOR CV-41 CLASS



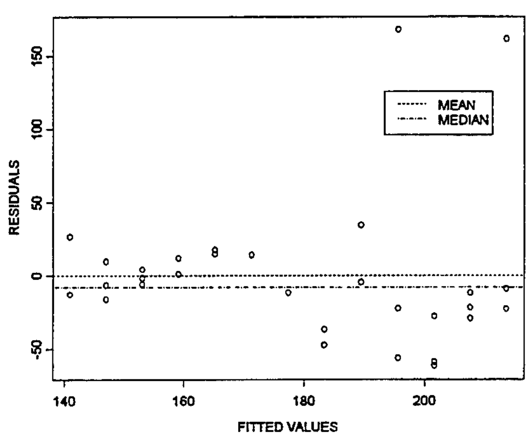
REGRESSION DIAGNOSTIC PLOT FOR CV-59 CLASS



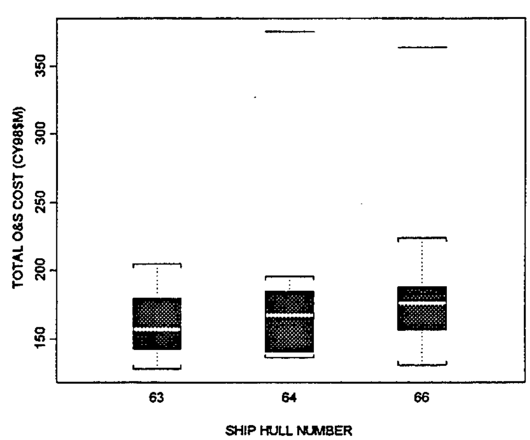
BOXPLOT FOR CV-59 CLASS



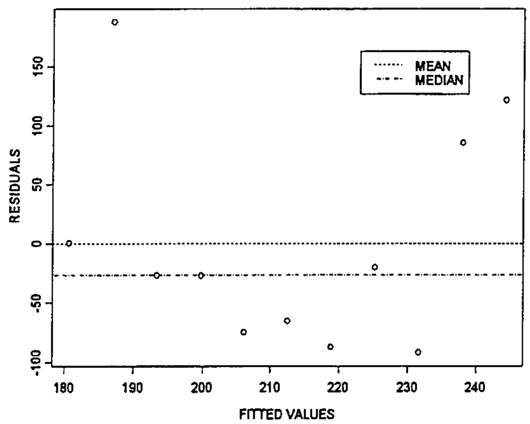
REGRESSION DIAGNOSTIC PLOT FOR CV-63 CLASS



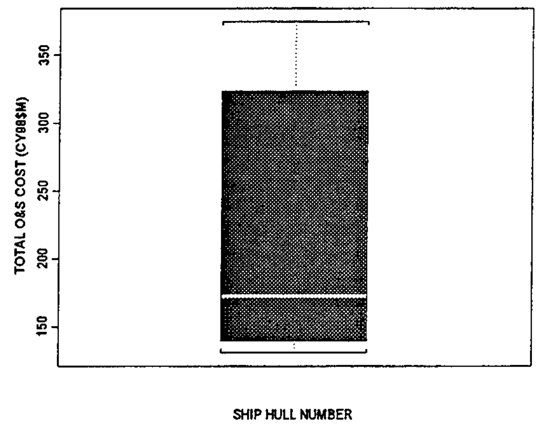
BOXPLOT FOR CV-63 CLASS



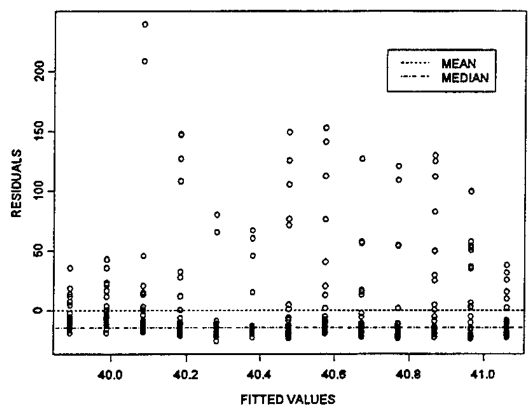
REGRESSION DIAGNOSTIC PLOT FOR CV-67 CLASS



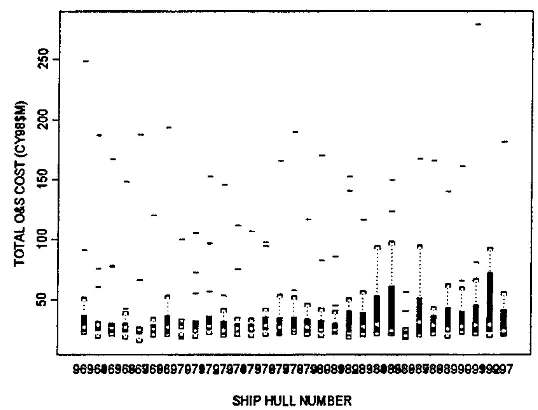
BOXPLOT FOR CV-67 CLASS



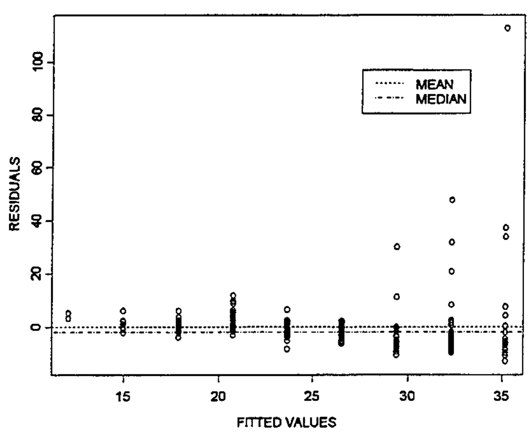
REGRESSION DIAGNOSTIC PLOT FOR DD-963 CLASS



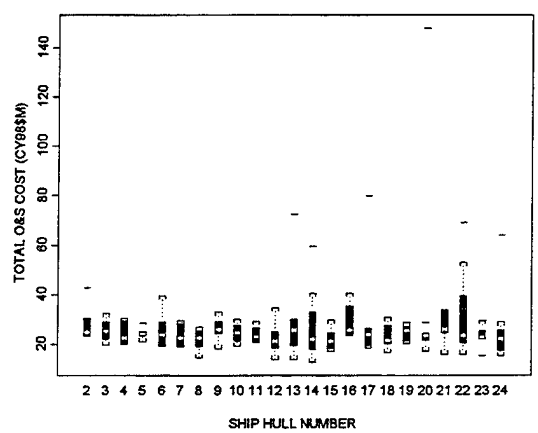
BOXPLOT FOR DD-963 CLASS



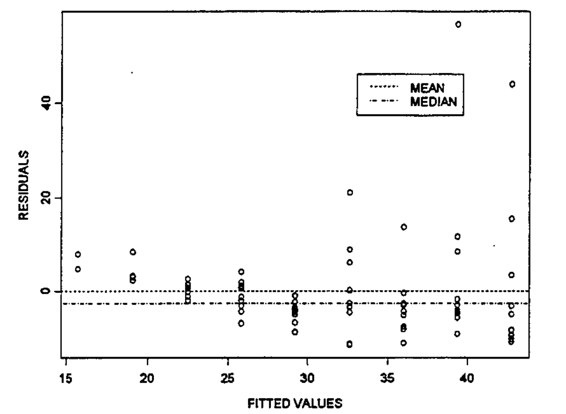
REGRESSION DIAGNOSTIC PLOT FOR DDG-2 CLASS



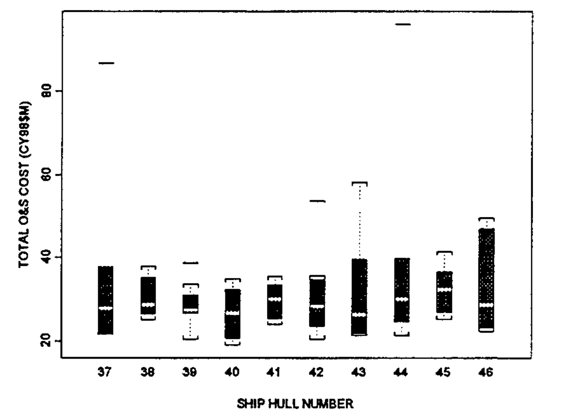
BOXPLOT FOR DDG-2 CLASS



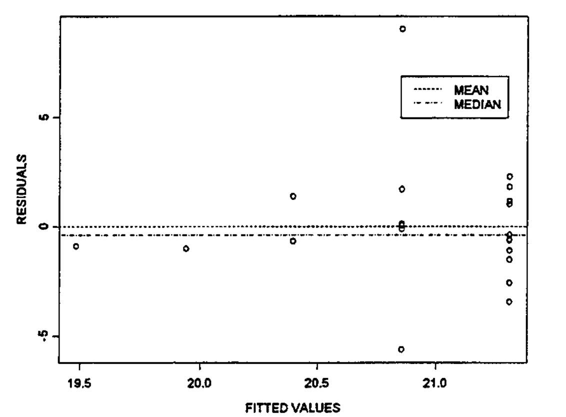
REGRESSION DIAGNOSTIC PLOT FOR DDG-37 CLASS



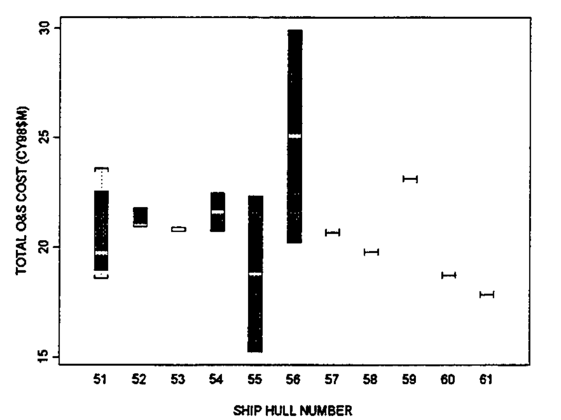
BOXPLOT FOR DDG-37 CLASS



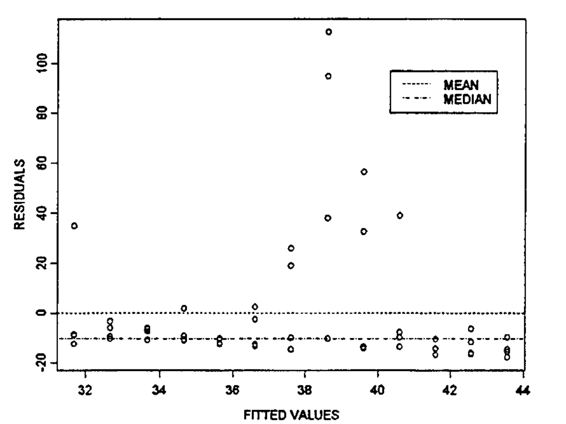
REGRESSION DIAGNOSTIC PLOT FOR DDG-51 CLASS



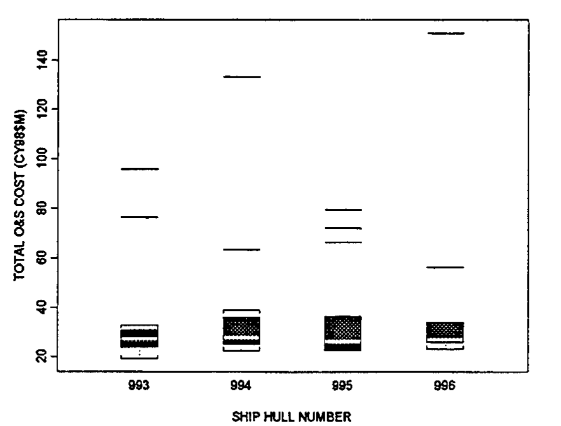
BOXPLOT FOR DDG-51 CLASS



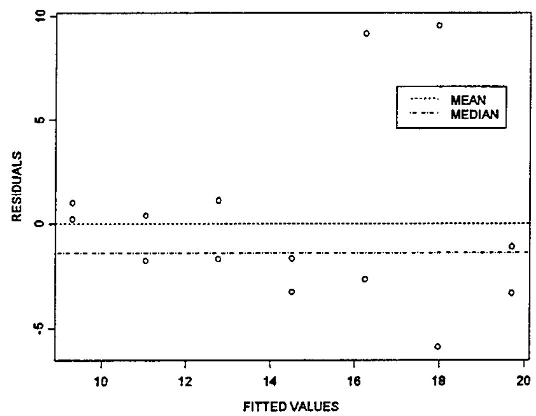
REGRESSION DIAGNOSTIC PLOT FOR DDG-993 CLASS



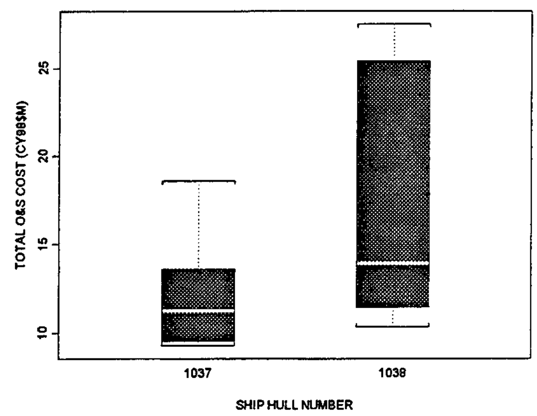
BOXPLOT FOR DDG-993 CLASS



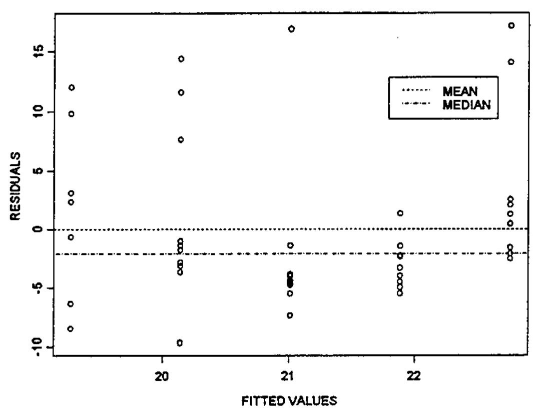
REGRESSION DIAGNOSTIC PLOT FOR FF-1037 CLASS



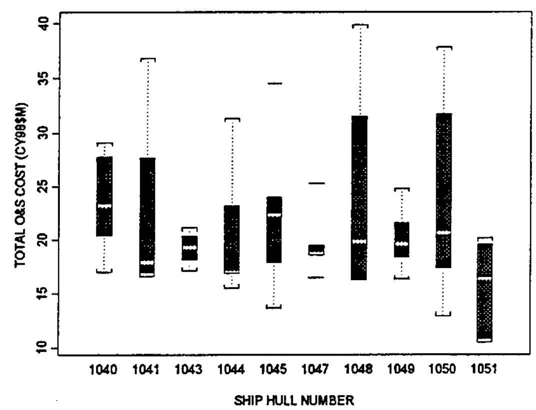
BOXPLOT FOR FF-1037 CLASS



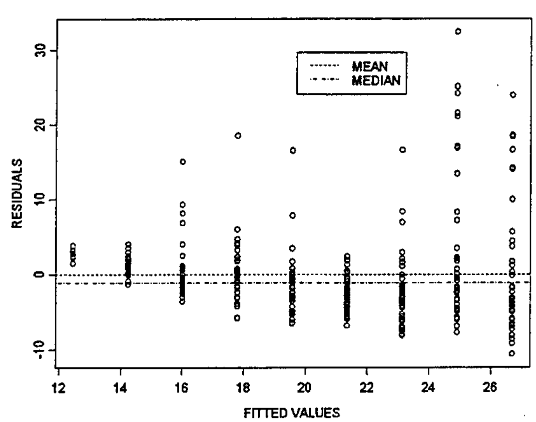
REGRESSION DIAGNOSTIC PLOT FOR FF-1040 CLASS



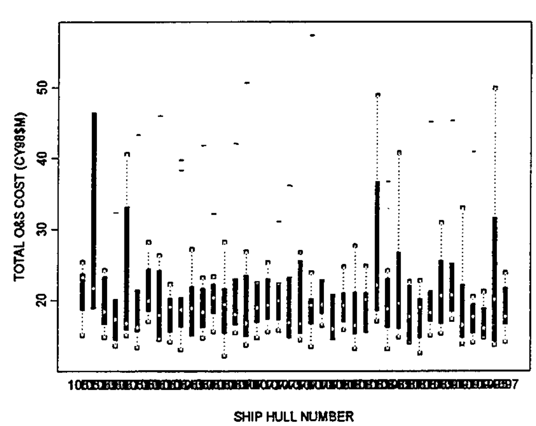
BOXPLOT FOR FF-1040 CLASS



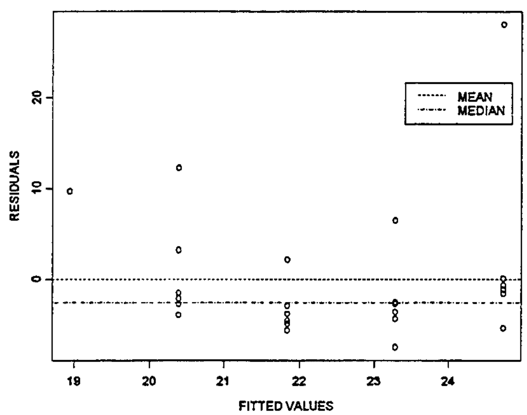
REGRESSION DIAGNOSTIC PLOT FOR FF-1052 CLASS



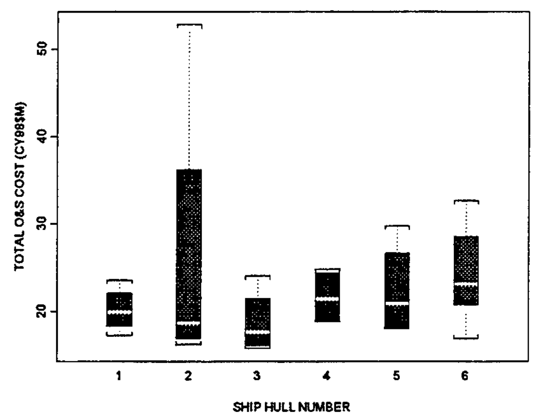
BOXPLOT FOR FF-1052 CLASS



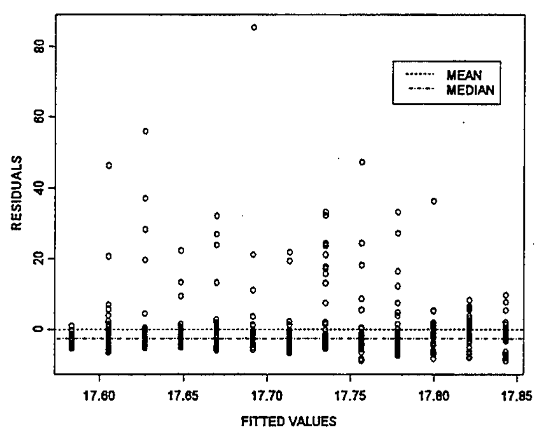
REGRESSION DIAGNOSTIC PLOT FOR FFG-1 CLASS



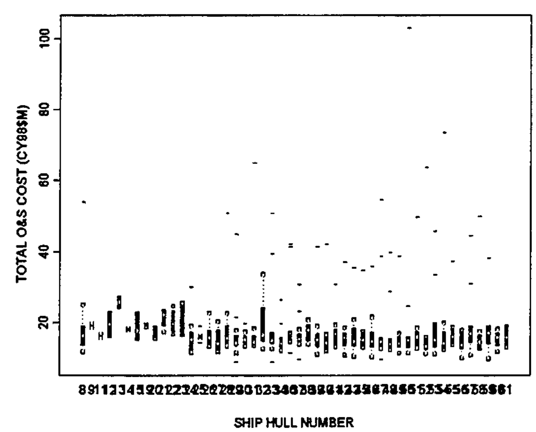
BOXPLOT FOR FFG-1 CLASS



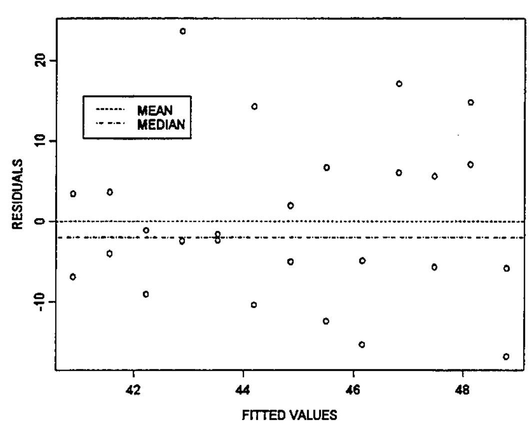
REGRESSION DIAGNOSTIC PLOT FOR FFG-7 CLASS



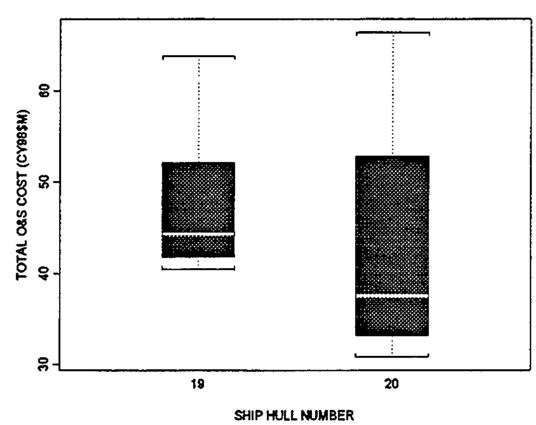
BOXPLOT FOR FFG-7 CLASS



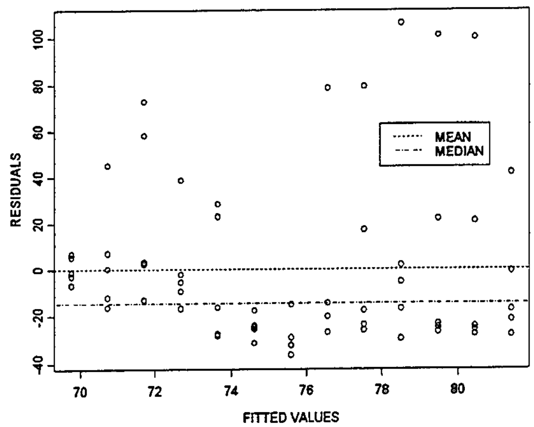
REGRESSION DIAGNOSTIC PLOT FOR LCC-19 CLASS



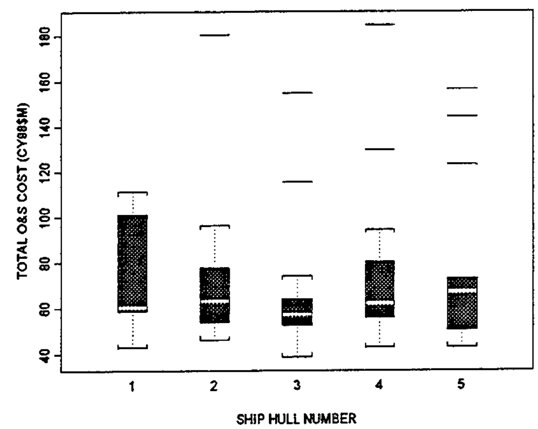
BOXPLOT FOR LCC-19 CLASS



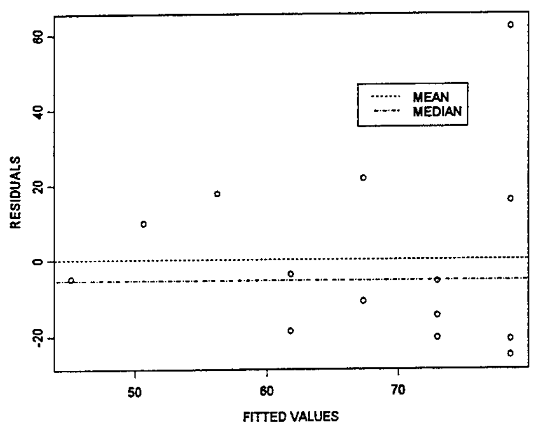
REGRESSION DIAGNOSTIC PLOT FOR LHA-1 CLASS



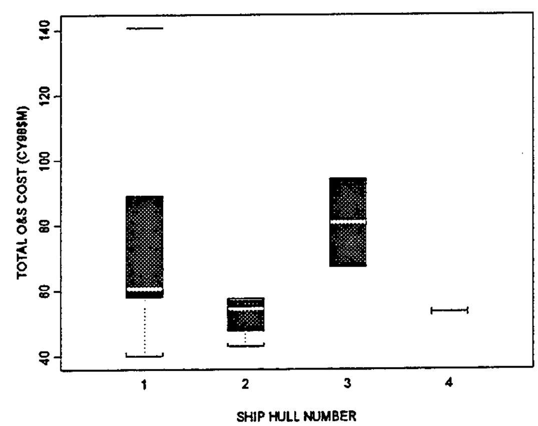
BOXPLOT FOR LHA-1 CLASS



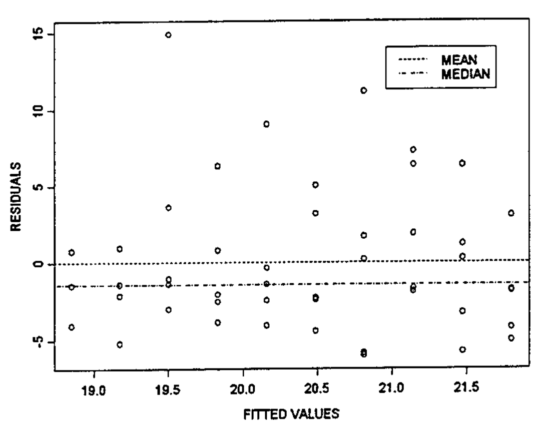
REGRESSION DIAGNOSTIC PLOT FOR LHD-1 CLASS



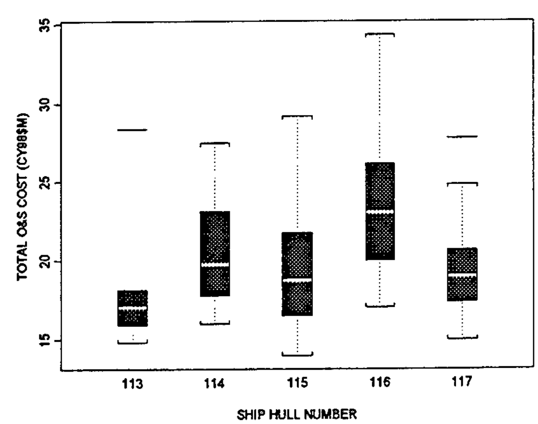
BOXPLOT FOR LHD-1 CLASS



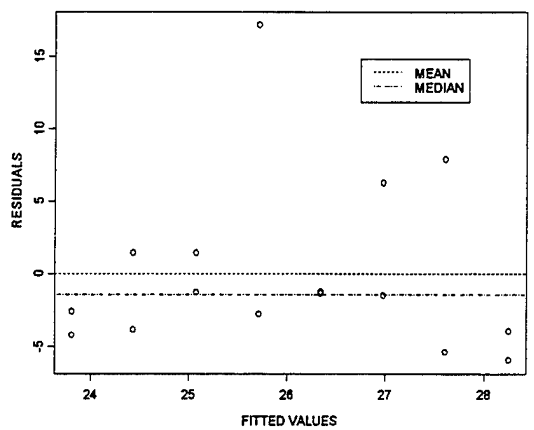
REGRESSION DIAGNOSTIC PLOT FOR LKA-113 CLASS



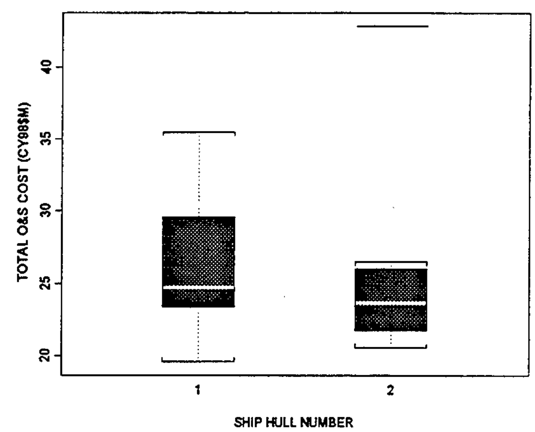
BOXPLOT FOR LKA-113 CLASS



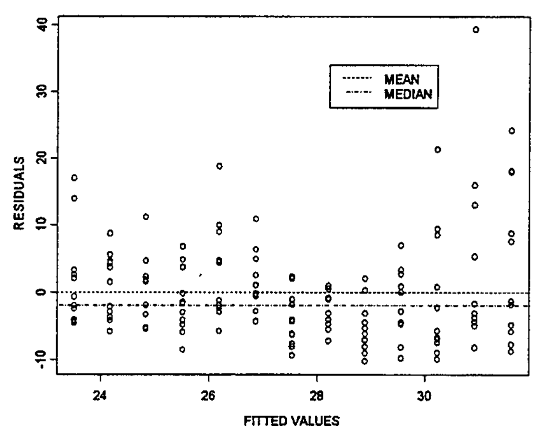
REGRESSION DIAGNOSTIC PLOT FOR LPD-1 CLASS



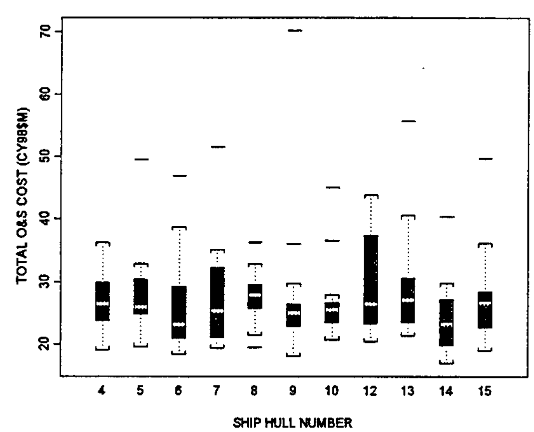
BOXPLOT FOR LPD-1 CLASS



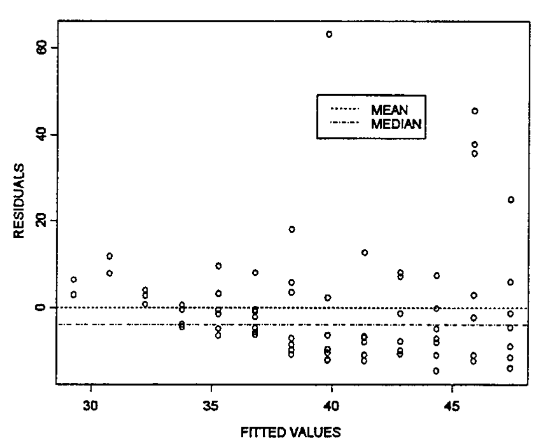
REGRESSION DIAGNOSTIC PLOT FOR LPD-4 CLASS



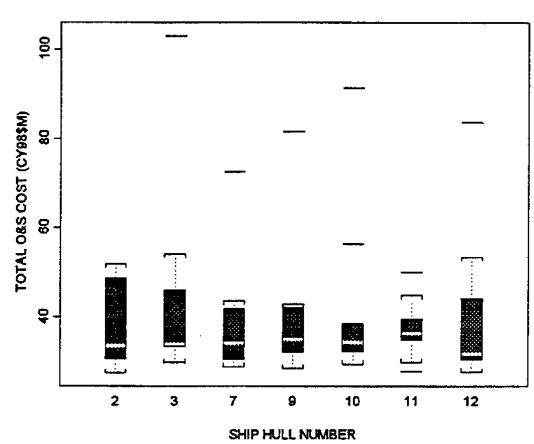
BOXPLOT FOR LPD-4 CLASS



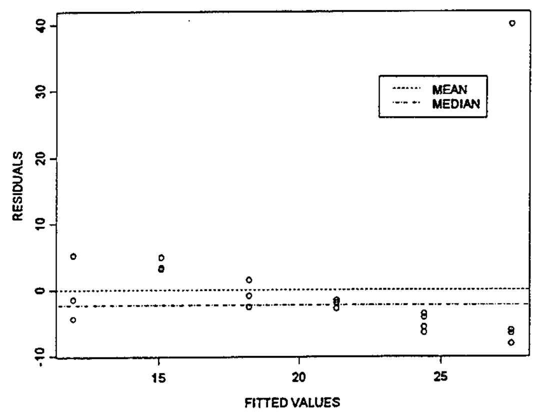
REGRESSION DIAGNOSTIC PLOT FOR LPH-2 CLASS



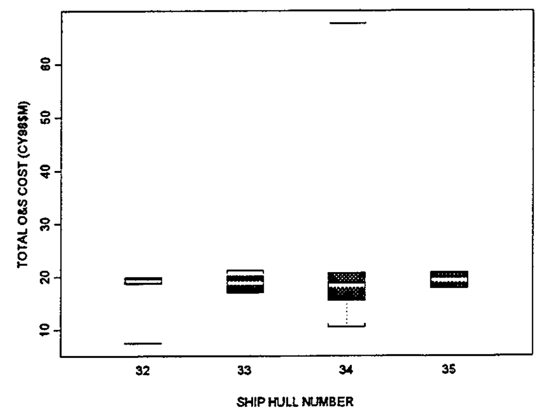
BOXPLOT FOR LPH-2 CLASS



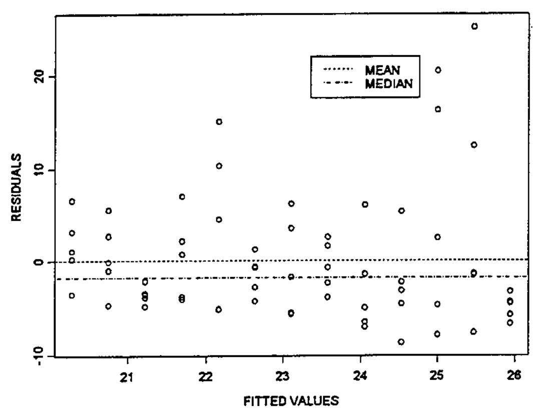
REGRESSION DIAGNOSTIC PLOT FOR LSD-28 CLASS



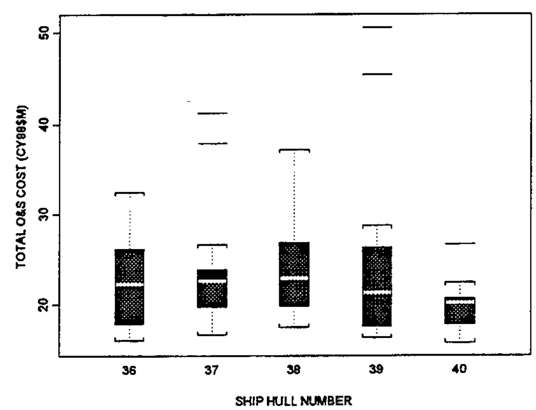
BOXPLOT FOR LSD-28 CLASS



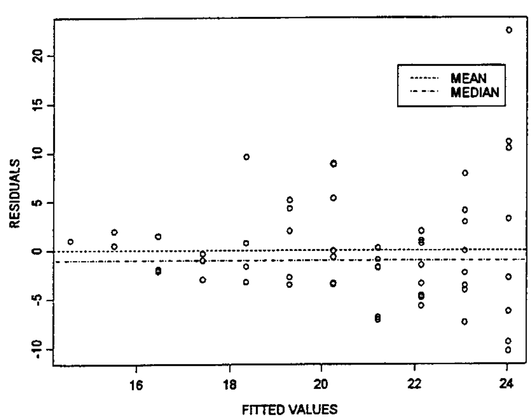
REGRESSION DIAGNOSTIC PLOT FOR LSD-36 CLASS



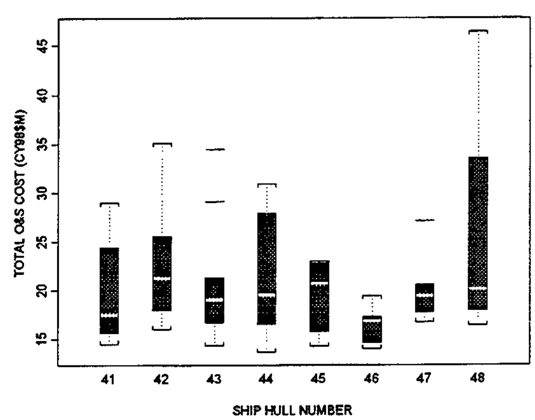
BOXPLOT FOR LSD-36 CLASS



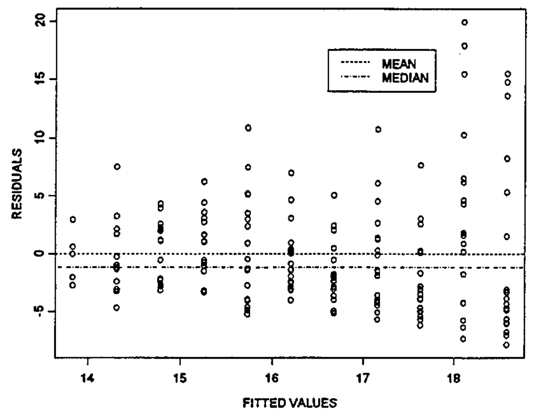
REGRESSION DIAGNOSTIC PLOT FOR LSD-41 CLASS



BOXPLOT FOR LSD-41 CLASS



REGRESSION DIAGNOSTIC PLOT FOR LST-1179 CLASS



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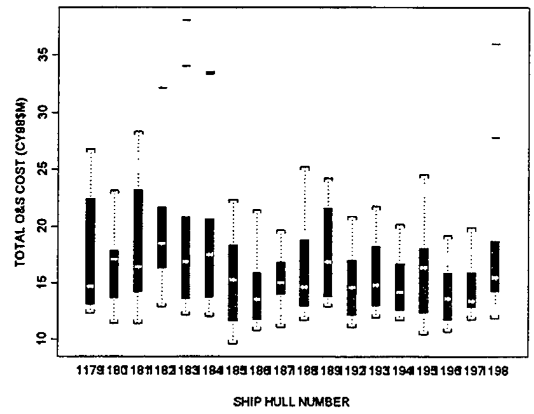
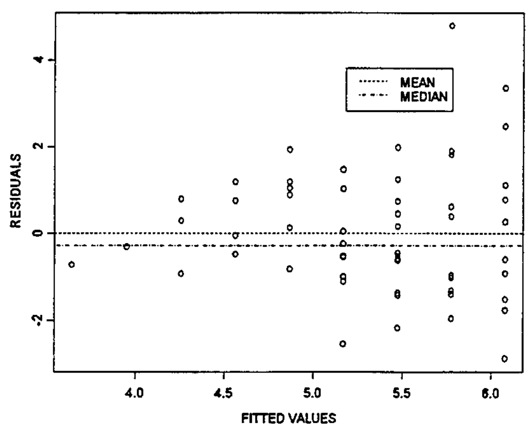
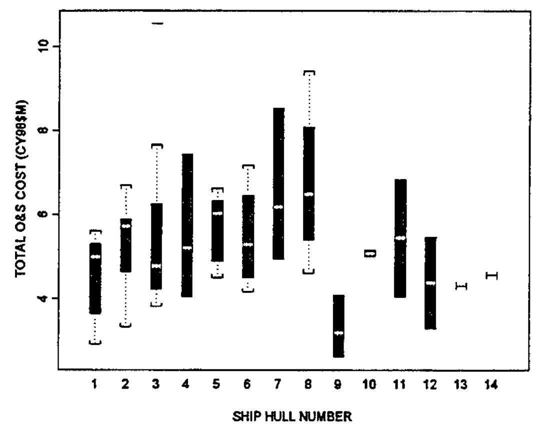


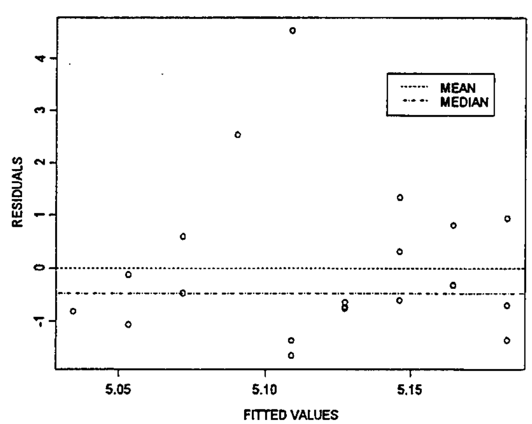
REGRESSION DIAGNOSTIC PLOT FOR MCM-1 CLASS



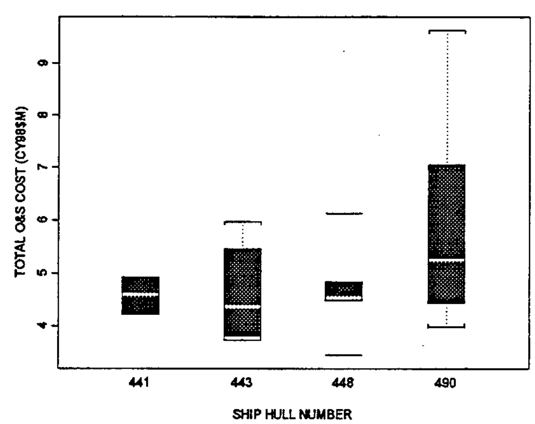
BOXPLOT FOR MCM-1 CLASS

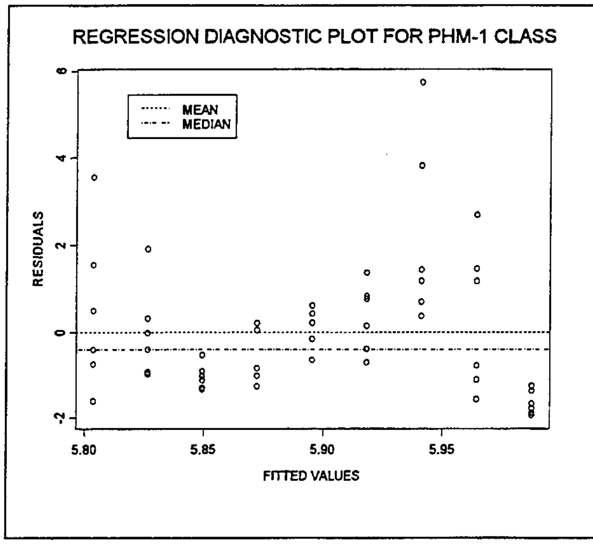


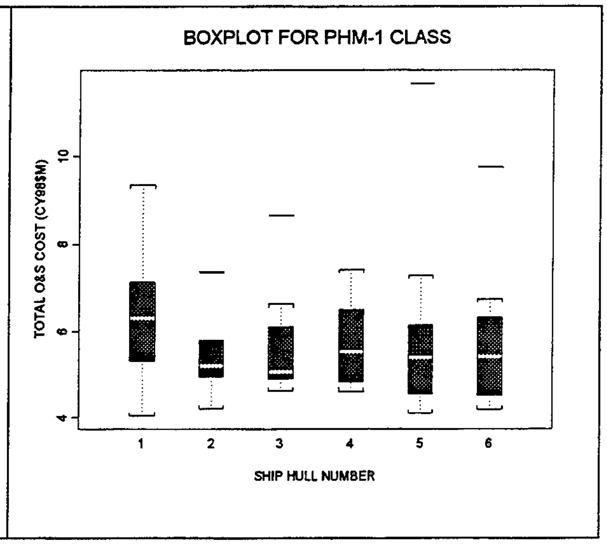
REGRESSION DIAGNOSTIC PLOT FOR MSO-422 CLASS



BOXPLOT FOR MSO-422 CLASS




REGRESSION DIAGNOSTIC PLOT FOR PHM-1 CLASS
MEAN
MEDIAN
RESIDUALS
FITTED VALUES
5.80
5.85
5.90
5.95


BOXPLOT FOR PHM-1 CLASS
TOTAL O&S COST (CY98$M)
SHIP HULL NUMBER
1
2
3
4
5
6

APPENDIX I. U.S. NAVY SHIP CLASS ANOVA TEST RESULTS

VAMOSC-ISR for FY96 (alpha = 0.05; revised alpha (w/Bonferroni correction): 0.05/57 = 0.0008772)

SHIP CLASS	ANOVA (COST~SHIP) p-value (F-TEST)	SIGNIFICANT ? (non-constant variance w/in class; changing ship	NOTE
AD-14	0.2325883	NO	
AD-37	0.2759485	NO	
AD-41	0.4284085	NO	
AE-21	0.2031179	NO	
AE-23	0.105724	NO	
AE-26	0.227843	NO	
AFS-1	0.1101615	NO	
AGF-3	NA	NA	one ship in class
AGF-11	NA	NA	one ship in class
AO-177	0.6718426	NO	
AO-51	0.7914067	NO	
AOE-1	0.2196715	NO	
AOR-1	0.987577	NO	
AR-5	0.2725438	NO	
ARS-38	0.3973306	NO	
ARS-50	0.3355186	NO	
AS-11	0.003231622	NO	
AS-19	NA	NA	one ship in class
AS-31	0.731305	NO	
AS-33	0.4075234	NO	
AS-36	0.7898003	NO	
AS-39	0.7865386	NO	
ASR-7	0.1122755	NO	
ASR-21	0.001822061	NO	
ATS-1	0.09847759	NO	
AVT-16	NA	NA	one ship in class
CG-16	0.978592	NO	
CG-26	0.9734161	NO	
CG-47	0.2662949	NO	
CV-41	0.5548676	NO	
CV-59	0.1795094	NO	
CV-63	0.5434735	NO	
CV-67	NA	NA	one ship in class

VAMOSC-ISR for FY96 (alpha =0.05; revised alpha (w/Bonferroni correction): 0.05/57 =0.0008772)

SHIP CLASS	ANOVA (COST~SHIP) p-value (F-TEST)	SIGNIFICANT ? (non-constant variance w/in class; changing ship	NOTE
DDG-2	0.9646534	NO	
DDG-37	0.8568229	NO	
DDG-51	0.7160076	NO	
DDG-993	0.9849391	NO	
FF-1037	0.1318233	NO	
FF-1040	0.6979833	NO	
FF-1052	0.9301515	NO	
FFG-1	0.779295	NO	
FFG-7	0.9999691	NO	
LCC-19	0.13021	NO	
LHA-1	0.9208202	NO	
LHD-1	0.4940631	NO	
LKA-113	0.07554985	NO	
LPD-1	0.8736371	NO	
LPD-4	0.9328952	NO	
LPH-2	0.9148725	NO	
LSD-28	0.7084551	NO	
LSD-36	0.3941557	NO	
LSD-41	0.5503663	NO	
LST-1179	0.1624303	NO	
MCM-1	0.1148312	NO	
MSO-422	0.3257504	NO	
PHM-1	0.9245267	NO	

APPENDIX J. PARAMETRIC AND TOTAL O&S COST DATA BY SHIP CLASS

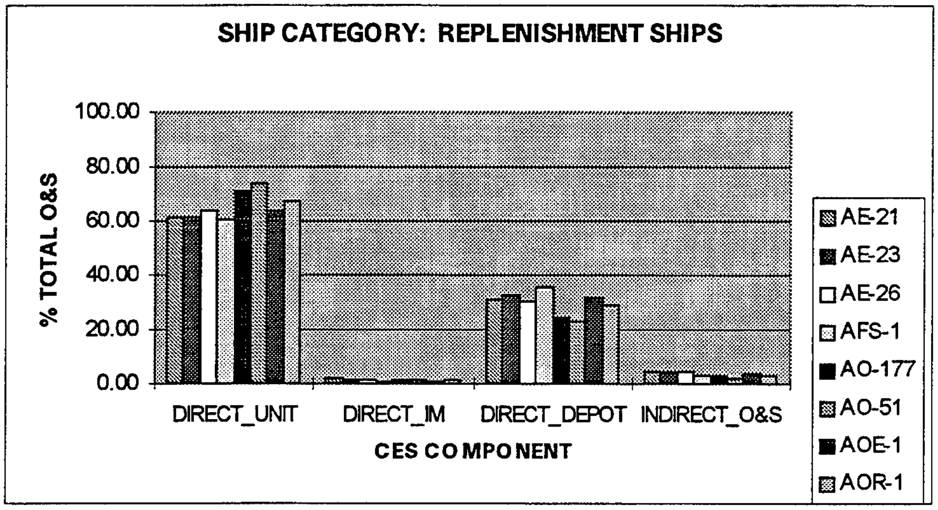
VAMOSC-ISR for FY96 — Period of Coverage: 1984-1996

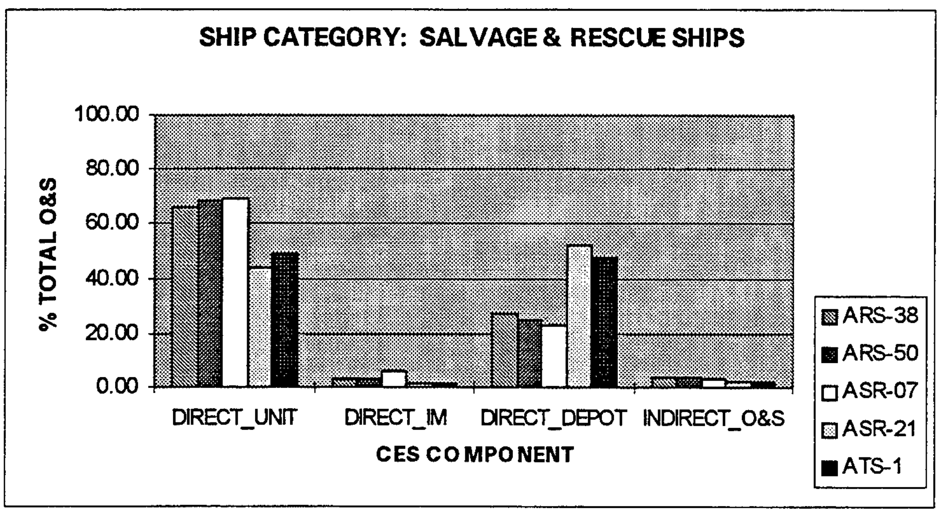
SHIP CLASS	LIGHT DISPLACEMENT (tons)	LOA (feet)	MANPOWER (enlisted + officers)	AVERAGE TOTAL O&S (CY98$)	LN(DISPL)	LN(LOA)	LN(MANPWR)	LN(O&S)
AD-14	9368	531	833	31,766,994	9.14505	6.27382	6.72503	17.27394
AD-37	13600	644	1298	43,210,754	9.51783	6.46770	7.16858	17.58160
AD-41	13318	642	1313	42,772,231	9.49687	6.46428	7.18007	17.57140
AE-21	7470	502	322	20,109,464	8.91865	6.21860	5.77455	16.81670
AE-23	7470	512	320	20,412,638	8.91865	6.23832	5.76832	16.83166
AE-26	9338	564	370	24,149,862	9.14185	6.33505	5.91350	16.99979
AFS-1	9314	581	404	28,279,133	9.13927	6.36475	6.00141	17.15763
AGF-3	9670	522	523	45,575,840	9.17678	6.25728	6.25958	17.63489
AGF-11	11482	570	485	38,088,453	9.34854	6.34564	6.18415	17.45542
AO-51	9769	644	329	19,896,370	9.18697	6.46770	5.79606	16.80605
AO-177	8210	592	213	16,557,329	9.01311	6.38351	5.36129	16.62234
AOE-1	19200	793	575	34,091,121	9.86267	6.67582	6.35437	17.34455
AOR-1	12571	659	428	25,372,722	9.43915	6.49072	6.05912	17.04919
AR-5	9325	529	807	31,107,062	9.14045	6.27156	6.69332	17.25295
ARS-38	1530	214	105	5,305,629	7.33302	5.36364	4.65396	15.48428
ARS-50	2300	255	95	5,636,843	7.74066	5.54126	4.55388	15.54483
AS-11	9734	531	1145	39,398,528	9.18338	6.27382	7.04316	17.48924
AS-19	14195	575	1125	45,759,172	9.56065	6.35350	7.02554	17.63890
AS-31	11000	644	1242	49,093,235	9.30565	6.46770	7.12448	17.70923
AS-33	12000	644	1371	57,801,422	9.39266	6.46770	7.22330	17.87252
AS-36	12770	644	1261	54,233,463	9.45485	6.46770	7.13966	17.80881
AS-39	13842	644	1251	51,926,510	9.53546	6.46739	7.13170	17.76534
ASR-7	1670	252	102	6,187,768	7.42058	5.52744	4.62497	15.63808
ASR-21	3411	251	192	14,414,867	8.13476	5.52545	5.25750	16.48377
ATS-1	2650	283	112	8,180,746	7.88231	5.64403	4.71850	15.91729
AVT-16	29783	889	1341	77,136,165	10.30169	6.79010	7.20117	18.16108
CG-16	4650	533	410	41,555,425	8.44462	6.27852	6.01616	17.54254
CG-26	5878	547	460	41,468,161	8.67897	6.30445	6.13123	17.54044
CG-47	7015	567	369	29,146,933	8.85581	6.34036	5.91080	17.18786
CV-41	50700	1004	2604	187,099,489	10.83368	6.91175	7.86480	19.04715
CV-59	57149	1039	2839	186,528,677	10.95342	6.94601	7.95121	19.04410
CV-63	57760	1046	2796	179,371,432	10.96405	6.95273	7.93595	19.00497
CV-67	58268	1050	2869	212,520,084	10.97281	6.95655	7.96172	19.17455

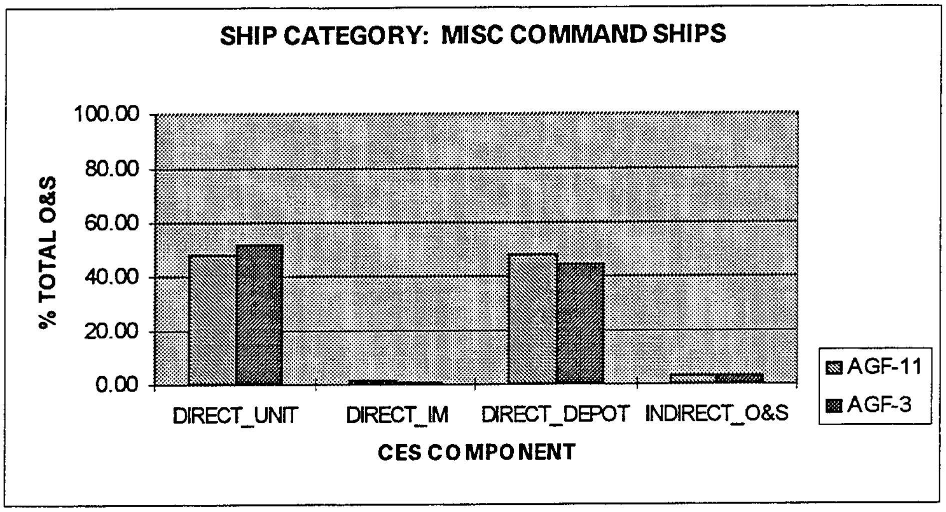
VAMOSC-ISR for FY96 Period of Coverage: 1984-1996

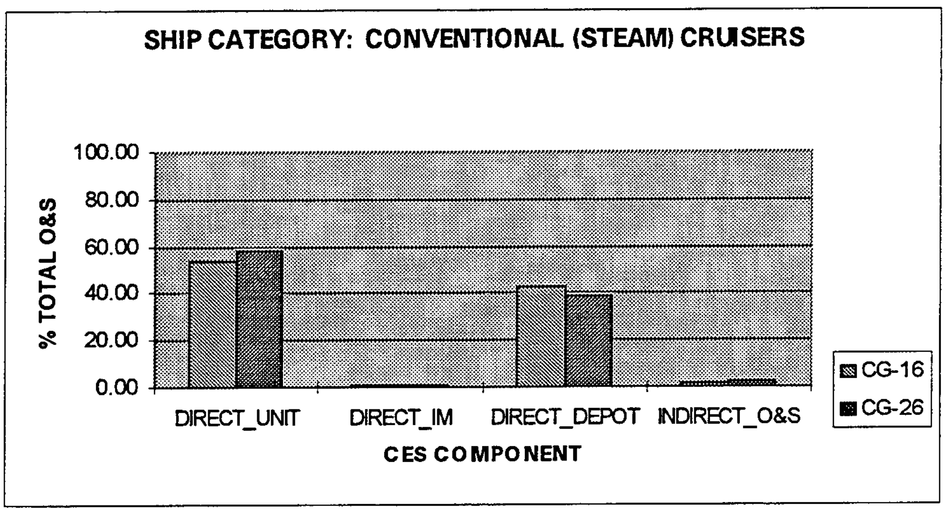
SHIP CLASS	LIGHT DISPLACEMENT (tons)	LOA (feet)	MANPOWER (enlisted + officers)	AVERAGE TOTAL O&S (CY98$)	LN(DISPL)	LN(LOA)	LN(MANPWR)	LN(O&S)
DDG-2	3258	437	342	26,283,606	8.08887	6.07993	5.83481	17.08446
DDG-37	4167	513	385	31,830,390	8.33495	6.23930	5.95324	17.27593
DDG-51	6625	505	329	20,944,863	8.79861	6.22357	5.79606	16.85740
DDG-993	6950	563	338	37,625,643	8.84650	6.33381	5.82305	17.44320
FF-1037	1792	372	206	14,510,777	7.49109	5.91755	5.32788	16.49040
FF-1040	2673	415	263	21,123,679	7.89096	6.02707	5.57215	16.86591
FF-1052	3004	438	278	20,604,292	8.00770	6.08222	5.62762	16.84101
FFG-1	2585	415	268	22,414,705	7.85748	6.02707	5.59099	16.92523
FFG-7	2934	449	205	17,711,906	7.98412	6.10725	5.32301	16.68975
LCC-19	16790	620	812	44,845,018	9.72854	6.42972	6.69950	17.61872
LHA-1	26001	833	909	75,593,560	10.16589	6.72503	6.81235	18.14088
LHD-1	28233	844	1108	67,398,986	10.24825	6.73815	7.01031	18.02614
LKA-113	10157	576	338	20,413,038	9.22592	6.35524	5.82305	16.83168
LPD-1	8074	522	394	26,028,440	8.99640	6.25728	5.97635	17.07470
LPD-4	9014	570	401	27,533,787	9.10653	6.34564	5.99396	17.13092
LPH-2	11255	602	659	39,868,127	9.32857	6.40076	6.49072	17.50109
LSD-28	6880	510	321	20,365,300	8.83637	6.23441	5.77144	16.82934
LSD-36	8600	553	339	23,225,261	9.05952	6.31590	5.82600	16.96075
LSD-41	11125	609	328	20,749,858	9.31695	6.41182	5.79301	16.84805
LST-1179	4793	522	240	16,467,656	8.47491	6.25824	5.48064	16.61691
MCM-1	880	224	81	5,330,771	6.77992	5.41165	4.39445	15.48901
MSO-422	716	172	91	5,122,278	6.57368	5.14749	4.51086	15.44911
PHM-1	198	145	25	5,895,284	5.28827	4.97880	3.21888	15.58966

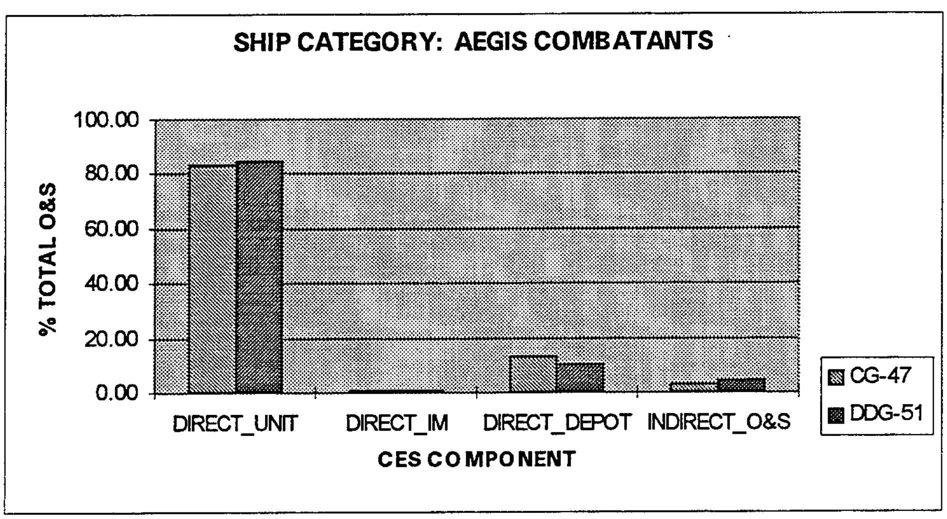
APPENDIX K. U.S. NAVY SURFACE SHIP CATEGORIES

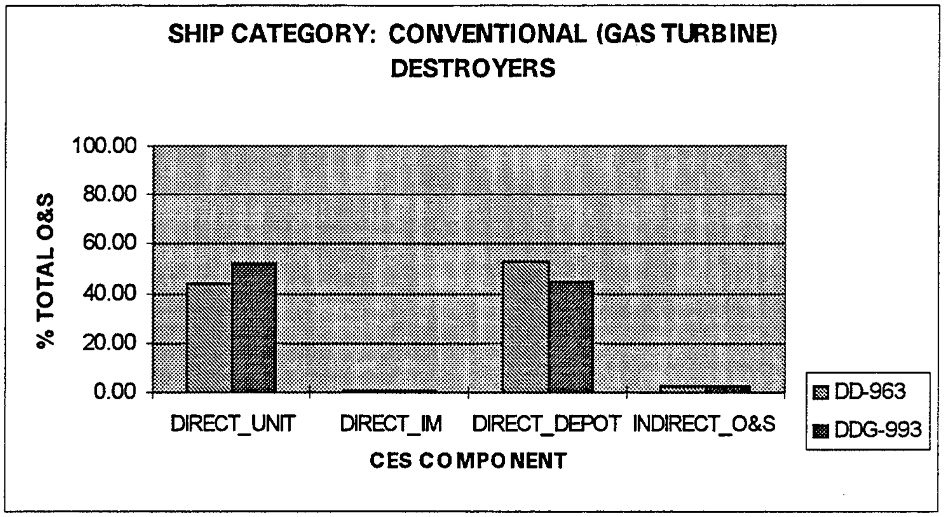


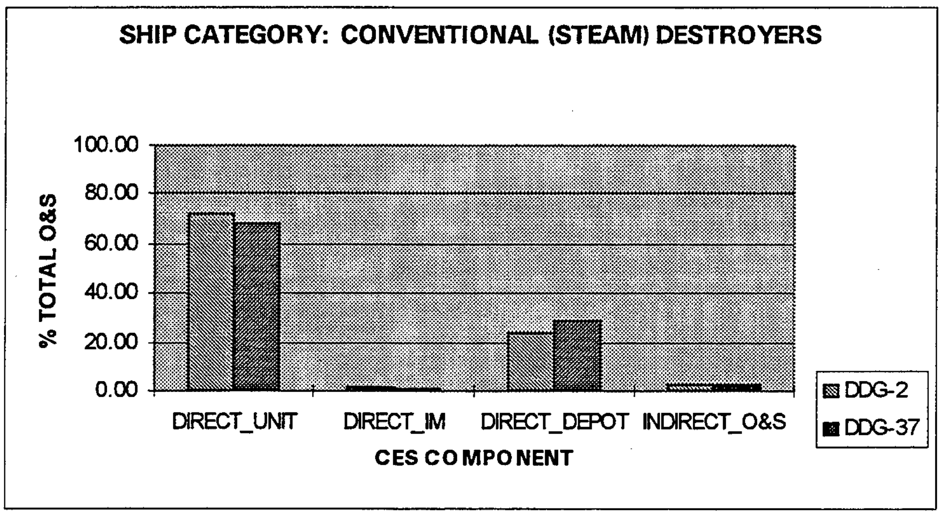


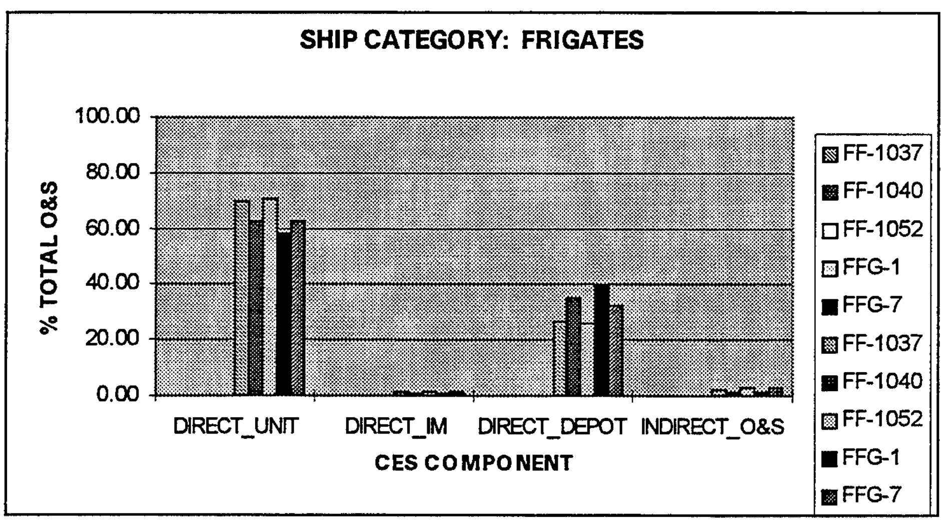

SHIP CATEGORY: MISC COMMAND SHIPS
100.00
80.00
60.00
40.00
20.00
0.00
% TOTAL O&S
DIRECT_UNIT
DIRECT_IM
DIRECT_DEPOT
INDIRECT_O&S
CES COMPONENT
AGF-11
AGF-3

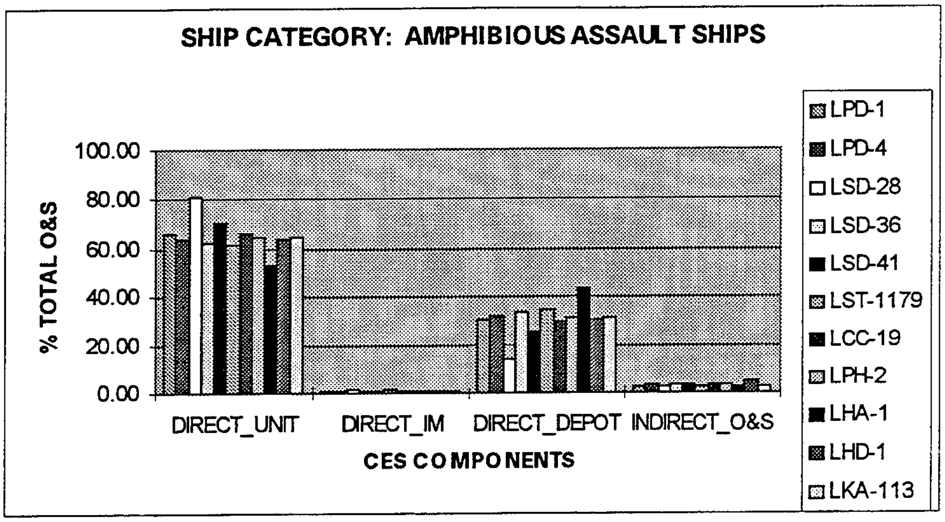

SHIP CATEGORY: CONVENTIONAL (STEAM) CRUISERS
100.00
80.00
60.00
40.00
20.00
0.00
% TOTAL O&S
DIRECT_UNIT
DIRECT_IM
DIRECT_DEPOT
INDIRECT_O&S
CES COMPONENT
CG-16
CG-26

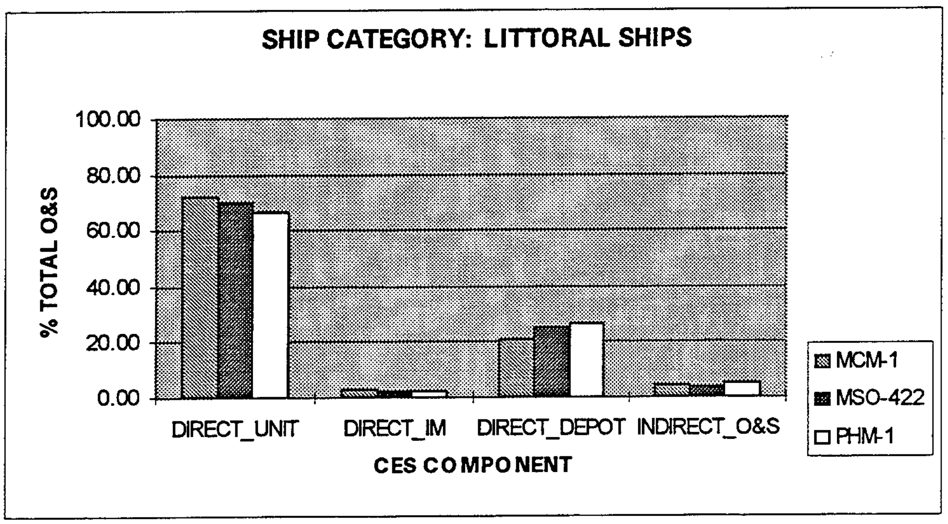

SHIP CATEGORY: AEGIS COMBATANTS
100.00
80.00
60.00
40.00
20.00
0.00
% TOTAL O&S
DIRECT_UNIT
DIRECT_IM
DIRECT_DEPOT
INDIRECT_O&S
CES COMPONENT
CG-47
DDG-51


SHIP CATEGORY: CONVENTIONAL (GAS TURBINE) DESTROYERS
100.00
80.00
60.00
40.00
20.00
0.00
% TOTAL O&S
DIRECT_UNIT
DIRECT_IM
DIRECT_DEPOT
INDIRECT_O&S
CES COMPONENT
DD-963
DDG-993


SHIP CATEGORY: CONVENTIONAL (STEAM) DESTROYERS
100.00
80.00
60.00
40.00
20.00
0.00
% TOTAL O&S
DIRECT_UNIT
DIRECT_IM
DIRECT_DEPOT
INDIRECT_O&S
CES COMPONENT
DDG-2
DDG-37


SHIP CATEGORY: FRIGATES
100.00
80.00
60.00
40.00
20.00
0.00
% TOTAL O&S
DIRECT_UNIT
DIRECT_IM
DIRECT_DEPOT
INDIRECT_O&S
CES COMPONENT
FF-1037
FF-1040
FF-1052
FFG-1
FFG-7
FF-1037
FF-1040
FF-1052
FFG-1
FFG-7


SHIP CATEGORY: AMPHIBIOUS ASSAULT SHIPS
% TOTAL O&S
100.00
80.00
60.00
40.00
20.00
0.00
DIRECT_UNIT
DIRECT_IM
DIRECT_DEPOT
INDIRECT_O&S
CES COMPONENTS
LPD-1
LPD-4
LSD-28
LSD-36
LSD-41
LST-1179
LCC-19
LPH-2
LHA-1
LHD-1
LKA-113


SHIP CATEGORY: LITTORAL SHIPS
% TOTAL O&S
100.00
80.00
60.00
40.00
20.00
0.00
DIRECT_UNIT
DIRECT_IM
DIRECT_DEPOT
INDIRECT_O&S
CES COMPONENT
MCM-1
MSO-422
PHM-1

APPENDIX L. CES PROBABILITY DISTRIBUTIONS FOR MODEL-SPECIFIC SURFACE SHIP CATEGORIES

Ship Category: REPLENISHMENT SHIPS

O&S COST ELEMENT	AE-21	AE-23	AE-26	AFS-1	AO-177	AO-51	AOE-1	AOR-1	MEAN	STD DEV
DIRECT_UNIT	61.85	61.52	63.44	61.04	70.82	73.82	63.84	67.17	69.04	17.61
DIRECT_IM	1.95	1.46	1.71	0.74	1.56	1.23	0.84	1.14	1.46	1.18
DIRECT_DEPOT	31.40	32.46	30.41	35.60	24.65	22.95	31.78	28.59	25.65	18.64
INDIRECT_O&S	4.79	4.55	4.44	2.61	2.98	2.00	3.55	3.09	3.85	2.52
TOTAL	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	

Ship Category: SALVAGE & RESCUE SHIPS

O&S COST ELEMENT	ARS-38	ARS-50	ASR-07	ASR-21	ATS-1	MEAN	STD DEV
DIRECT_UNIT	66.37	68.66	68.98	43.80	48.96	66.14	19.05
DIRECT_IM	2.93	2.86	5.75	1.71	1.20	3.12	2.79
DIRECT_DEPOT	27.17	24.64	22.43	52.39	47.43	27.55	20.96
INDIRECT_O&S	3.54	3.84	2.83	2.08	2.41	3.20	1.77
TOTAL	100.00	100.00	100.00	100.00	100.00	100.00	

Ship Category: MISCELLANEOUS COMMAND SHIPS

O&S COST ELEMENT	AGF-11	AGF-3	MEAN	STD DEV
DIRECT_UNIT	48.28	52.20	59.24	21.45
DIRECT_IM	1.21	0.60	1.13	1.08
DIRECT_DEPOT	47.86	44.20	36.27	22.97
INDIRECT_O&S	2.63	2.99	3.37	1.67
TOTAL	100.00	100.00	100.00	

Ship Category: CONVENTIONAL (STEAM) CRUISERS

O&S COST ELEMENT	CG-16	CG-26	MEAN	STD DEV
DIRECT_UNIT	54.12	58.17	66.32	23.31
DIRECT_IM	0.94	1.08	1.20	1.06
DIRECT_DEPOT	42.88	38.38	29.89	24.46
INDIRECT_O&S	2.05	2.37	2.59	1.60
TOTAL	100.00	100.00	100.00	

Ship Category: AEGIS COMBATANTS

O&S COST ELEMENT	CG-47	DDG-51	MEAN	STD DEV
DIRECT_UNIT	83.12	84.84	78.26	15.12
DIRECT_IM	0.70	0.64	1.02	0.73
DIRECT_DEPOT	13.37	9.93	16.65	15.24
INDIRECT_O&S	2.82	4.58	4.06	1.27
TOTAL	100.00	100.00	100.00	

Ship Category: CONVENTIONAL (GAS TURBINE) DESTROYE

O&S COST ELEMENT	DD-963	DDG-993	MEAN	STD DEV
DIRECT_UNIT	44.09	52.17	62.41	25.38
DIRECT_IM	0.71	0.75	1.01	1.08
DIRECT_DEPOT	53.04	44.72	33.52	26.53
INDIRECT_O&S	2.15	2.35	3.05	1.72
TOTAL	100.00	100.00	100.00	

Ship Category: CONVENTIONAL (STEAM) DESTROYERS

O&S COST ELEMENT	DDG-2	DDG-37	MEAN	STD DEV
DIRECT_UNIT	72.04	67.84	74.77	16.87
DIRECT_IM	1.32	1.17	1.23	0.88
DIRECT_DEPOT	24.08	28.56	21.57	17.73
INDIRECT_O&S	2.59	2.41	2.43	1.18
TOTAL	100.00	100.00	100.00	

Ship Category: FRIGATES

O&S COST ELEMENT	FF-1037	FF-1040	FF-1052	FFG-1	FFG-7	MEAN	STD DEV
DIRECT_UNIT	69.43	62.26	70.24	58.25	62.47	71.33	18.65
DIRECT_IM	1.39	0.85	1.40	0.78	1.75	1.65	1.38
DIRECT_DEPOT	26.87	35.32	25.83	39.36	32.65	24.03	19.46
INDIRECT_O&S	2.29	1.55	2.52	1.61	3.13	2.98	1.58
TOTAL	100.00	100.00	100.00	100.00	100.00	100.00	

Ship Category: AMPHIBIOUS ASSAULT SHIPS

O&S COST ELEMENT	LPD-1	LPD-4	LSD-28	LSD-36	LSD-41	LST-1179	LCC-19	LPH-2	LHA-1	LHD-1	LKA-113	MEAN	STD DEV
DIRECT_UNIT	66.14	63.71	81.29	62.09	70.25	61.66	66.36	64.66	53.35	64.14	65.06	67.89	17.53
DIRECT_IM	1.09	1.22	1.97	1.19	0.93	1.24	0.52	1.08	0.53	0.63	0.85	1.16	0.88
DIRECT_DEPOT	30.58	31.68	14.29	33.70	25.46	34.26	29.63	30.79	43.38	30.67	31.30	27.55	18.40
INDIRECT_O&S	2.18	3.37	2.45	3.02	3.35	2.84	3.50	3.48	2.75	4.56	2.80	3.40	1.95
TOTAL	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	

Ship Category: LITTORAL SHIPS

O&S COST ELEMENT	MCM-1	MSO-422	PHM-1	MEAN	STD DEV
DIRECT_UNIT	72.08	70.10	66.85	69.77	14.61
DIRECT_IM	2.73	2.01	1.89	2.65	3.68
DIRECT_DEPOT	20.88	24.54	26.22	23.20	15.10
INDIRECT_O&S	4.31	3.35	5.03	4.38	2.60
TOTAL	100.00	100.00	100.00	100.00	

APPENDIX M. DOCUMENTATION OF THE PARAMETRIC COST MODEL

Title: **Top-Level U.S. Navy Surface Ship (Non-nuclear) Parametric O&S Cost Model**

Purpose: To estimate average annual total operating and support (O&S) costs of U.S. Navy non-nuclear surface ships based on one of three physical parameters: ship light displacement, ship length overall (LOA), or ship manpower.

Applicability: This top-level ship O&S cost model is a parametric cost-estimating tool which will provide NCCA analysts and other decision-makers with a standardized method for calculating reliable and robust O&S cost estimates, backed up by history, for U.S. Navy surface ships (excluding any nuclear-powered ship or aircraft carrier). Moreover, the cost model can be useful for early milestone reviews within a new ship acquisition program, cost estimates for loosely defined ships, and general (non-specific) assessments or comparisons of surface vessels such as force structure cost models and analysis of alternatives.

Model Description: This top-level ship O&S cost model consists of three univariate cost estimating relationship (CER) equations. The first equation predicts average annual total O&S cost based on ship light displacement (in tons). The second equation predicts average annual total O&S cost based on ship LOA (in feet). The third equation predicts average annual total O&S cost based on ship manpower (inputed as a total sum of all enlisted and officer personnel permanently assigned to the ship). All three equations are fitted to a historical cost database spanning 13 years, which includes former and current classes of auxiliaries, cruisers, destroyers, frigates, amphibious assault ships, mine sweepers, and patrol craft. By selecting one of 11 model-specific surface ship categories, the calculated average annual total O&S cost base estimate can be further broken down into its four primary component cost elements: direct unit, direct intermediate maintenance, direct depot, and indirect O&S. The breakout percentages of the base estimate and associated standard deviations are based on derived probability distributions of the component cost elements within each model-specific surface ship category.

Status/Availability: This top-level ship O&S cost model is complete with periodic updates strongly recommended. The original release date of the cost model is tentatively scheduled for the third quarter of FY1999. The model can be adapted to spreadsheet format for quick calculation and presentation of estimates.

Input Variables:

- Ship Light Displacement (in tons)
- Ship Length Overall (in feet)
- Ship Manpower (sum of enlisted and officer personnel)

Output: (1) Average annual total O&S costs in constant year 1998 dollars bounded above and below by the standard error of log-linear regression; and
(2) Component cost breakout percentages of the base estimate bounded above and below by the standard deviation of the derived probability distribution of component costs within a model-specific surface ship category.

Data Source: Navy VAMOSC Individual Ship Report (ISR) O&S cost database for FY1984 through FY1996 containing O&S cost data for 417 ships aggregated over 125 component cost elements.

Point of Contact: LCDR Tim Anderson, USN
Department of Operations Research
Naval Postgraduate School, Monterey, CA

User Community: NCCA and DoD Cost Analysts and Project Managers

Principal Ground Rules/Assumptions/Limitations: Nuclear-powered ships, battleships, and submarines were removed from the VAMOSC-ISR raw database in order to achieve parity of data for more robust estimates. Additionally, ship classes which reported observations for three years or less were also removed. The raw data was adjusted to constant 1998 dollars. The derivation of the three CERs are based on ship class averages, and assume constant (non-increasing) total O&S cost across time. Log-linear regression revealed that the cost model would grossly under-estimate conventional-powered aircraft carriers, so these observations were removed from the database prior to final formulation of the model.

Software: The CER equations and model-specific surface ship category probability distributions can be easily programmed in any language or spreadsheet.

CER Equations:

$\hat{Y} = 111{,}302 * (D)^{0.618}$ (CY98\$), SE = (-31.68%, +46.37%)

$\hat{Y} = 1{,}223 * (L)^{1.6}$ (CY98\$), SE = (-27.53%, +37.99%)

$\hat{Y} = 285{,}215 * (M)^{0.750}$ (CY98\$), SE = (-24.35%, +32.18%)

$\hat{Y}$ ≡ total annual O&S cost estimate (CY98$)
D ≡ light displacement (in tons)
L ≡ length overall (in feet)
M ≡ manpower (total number of enlisted + officer personnel)

Surface Ship Categories: The following tables list (by category) the breakout percentages of the total annual O&S cost (base) estimate bounded by a standard deviation interval. The four primary cost component element numbers per the VAMOSC-ISR cost element structure correspond to:

1.0: Direct Unit Costs
2.0: Direct Intermediate Maintenance Costs
3.0: Direct Depot Costs
4.0: Indirect O&S Costs

<u>TENDERS (AD/AR/AS)</u>

1.0:	81.68% ± 11.72%
2.0:	5.17% ± 5.23%
3.0:	8.69% ± 10.38%
4.0:	4.46% ± 2.68%

<u>REPLENISHMENT SHIPS (AE/AFS/AO/AOE/AOR)</u>

1.0:	69.04% ± 17.61%
2.0:	1.46% ± 1.18%
3.0:	25.65% ± 18.64%
4.0:	3.85% ± 2.52%

SALVAGE & RESCUE SHIPS (ARS/ASR/ATS)

1.0:	66.14% ± 19.05%
2.0:	3.12% ± 2.79%
3.0:	27.55% ± 20.96%
4.0:	3.20% ± 1.77%

MISCELLANEOUS COMMAND SHIPS (AGF)

1.0:	59.24% ± 21.45%
2.0:	1.13% ± 1.08%
3.0:	36.27% ± 22.97%
4.0:	3.37% ± 1.67%

CONVENTIONAL (STEAM) CRUISERS (CG)

1.0:	66.32% ± 23.31%
2.0:	1.20% ± 1.06%
3.0:	29.89% ± 24.46%
4.0:	2.59% ± 1.60%

AEGIS COMBATANTS (CG/DDG)

1.0:	78.26% ± 15.12%
2.0:	1.02% ± 0.73%
3.0:	16.65% ± 15.24%
4.0:	4.06% ± 1.27%

CONVENTIONAL (GAS TURBINE) DESTROYERS (DD/DDG)

1.0:	62.41% ± 25.38%
2.0:	1.01% ± 1.08%
3.0:	33.52% ± 26.53%
4.0:	3.05% ± 1.72%

CONVENTIONAL (STEAM) DESTROYERS (DDG)

1.0:	74.77% ± 16.87%
2.0:	1.23% ± 0.88%
3.0:	21.57% ± 17.73%
4.0:	2.43% ± 1.18%

FRIGATES (FF/FFG)

1.0:	71.33% ± 18.65%
2.0:	1.65% ± 1.38%
3.0:	24.03% ± 19.46%
4.0:	2.98% ± 1.58%

AMPHIBIOUS ASSAULT SHIPS
(LPD/LSD/LST/LCC/LPH/LHA/LHD/LKA)

1.0: 67.89% ± 17.53%
2.0: 1.16% ± 0.88%
3.0: 27.55% ± 18.40%
4.0: 3.40% ± 1.95%

LITTORAL SHIPS (MCM/MSO/PHM)

1.0: 69.77% ± 14.61%
2.0: 2.65% ± 3.68%
3.0: 23.20% ± 15.10%
4.0: 4.38% ± 2.60%

Test Results/ Validation: This top-level ship O&S cost model was validated against VAMOSC-ISR data for FY1997. Results for all parameters were satisfactory with CVs between 10 and 15 percent. Most notably, manpower is the parameter of choice for the cost model: with a CV of 10 percent, approximately 76 percent of the total O&S cost estimates fell within the CER equation's SE. The least favorable parameter is LOA with slightly less than 50 percent of the estimates falling within the CER equation's SE and a CV of 15 percent.

APPENDIX N. A SPREADSHEET ILLUSTRATION OF THE PARAMETRIC COST MODEL

Choose the ship size parameter you have most confidence in:

Light Displacement	
Length Overall (LOA)	
Manpower (Officers + Enlisted)	250

Choose the ship type category that closely matches the ship you are estimating:

Tenders	
Replenishment Ships	
Salvage & Rescue Ships	
Miscellaneous Command Ships	
Cruisers (Conventional)	
Aegis Combatants (Cruisers/Destroyers)	
Destroyers (Gas Turbine)	X
Destroyers (Steam)	
Frigates	
Amphibious Assault Ships	
Littoral Ships	

The estimated average annual total O&S cost for your ships is:

	TOT ANNUAL O&S COST	UPPER LIM	LOWER LIM	
DISP	0	0	0	(CY98$)
LOA	0	0	0	(CY98$)
MPWR	17,931,970	23,702,609	13,566,251	(CY98$)

And the total cost estimate breaks out as follows:

CER: DISPLACEMENT

DIRECT UNIT	0	+/-	0
DIRECT INTERMEDIATE MAINT	0	+/-	0
DIRECT DEPOT	0	+/-	0
INDIRECT O&S	0	+/-	0
TOTAL =	0		

CER: LOA

DIRECT UNIT	0	+/-	0
DIRECT INTERMEDIATE MAINT	0	+/-	0
DIRECT DEPOT	0	+/-	0
INDIRECT O&S	0	+/-	0
TOTAL =	0		

CER: MANPOWER

DIRECT UNIT	11,191,342	+/-	2,840,363
DIRECT INTERMEDIATE MAINT	181,113	+/-	1,956
DIRECT DEPOT	6,010,796	+/-	1,594,664
INDIRECT O&S	546,925	+/-	9,407
TOTAL =	17,930,176		

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