# NAVAL POSTGRADUATE SCHOOL
# Monterey, California

# THESIS

**MAINTENANCE TREND ANALYSIS OF AIR CONDITIONING SYSTEMS FOR SHIP OPERATIONS IN THE ARABIAN GULF**

by

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December 2001


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In December 2000, Program Budget Decision (PBD) 096 changed the way the Department of the Navy (DoN) budgets for Arabian Gulf operations. The cost of operations is now required to be submitted as part of the annual budget vice funded as contingency operations. In order to justify increased funding of incremental costs for operations in the Gulf, a method to justify such budget requests must be developed. This research developed a regression model targeted at the intermediate and depot level maintenance cost trends for Air Conditioning (A/C) systems based upon the assumption that the severe weather factors of the Gulf would impact the maintenance of A/C equipment. The model used ship age, deployed operational tempo (OPTEMPO), and temperature factors as explanatory variables in the model. The results of the regression analysis indicate the model does not provide evidence of increased maintenance costs of A/C systems for operations in the Gulf. Based on the inconsistencies in the maintenance data and the limitations of the explanatory variables, it is recommended that this approach be excluded from further research to justify increased budget requests for operations in the Gulf.

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# MAINTENANCE TREND ANALYSIS OF AIR CONDITIONING SYSTEMS FOR SHIP OPERATIONS IN THE ARABIAN GULF

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In December 2000, Program Budget Decision (PBD) 096 changed the way the Department of the Navy (DoN) budgets for Arabian Gulf operations. The cost of operations is now required to be submitted as part of the annual budget vice funded as contingency operations. In order to justify increased funding of incremental costs for operations in the Gulf, a method to justify such budget requests must be developed. This research developed a regression model targeted at the intermediate and depot level maintenance cost trends for Air Conditioning (A/C) systems based upon the assumption that the severe weather factors of the Gulf would impact the maintenance of A/C equipment. The model used ship age, deployed operational tempo (OPTEMPO), and temperature factors as explanatory variables in the model. The results of the regression analysis indicate the model does not provide evidence of increased maintenance costs of A/C systems for operations in the Gulf. Based on the inconsistencies in the maintenance data and the limitations of the explanatory variables, it is recommended that this approach be excluded from further research to justify increased budget requests for operations in the Gulf.

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# I. BACKGROUND/INTRODUCTION

## A. ARABIAN GULF OPERATIONS

Since the end of the Gulf War in 1991, the United States has conducted ongoing operations in the Arabian Gulf to enforce United Nations (U.N.) sanctions against Iraq, ensure stability in the Middle East, and protect the free flow of oil exports worldwide. The total reported incremental costs for Southwest Asia operations were $7.44 billion as of March 2000 with Operations and Maintenance (O&M) funds representing the bulk of the contingency costs. Until recently, the increased costs associated with these ongoing operations have not been included in the Department of Defense (DOD) annual budget approved by Congress. They have been paid for by reprogramming and transfers, supplemental appropriations, or specific contingency operations accounts such as the Overseas Contingency Operations Transfer Fund (OCOTF). Program Budget Decision (PBD) 096 dated 19 December 2000 has changed the way DOD budgets for operations in the Arabian Gulf.

Arabian Gulf operations have continued for more than a decade and are no longer considered contingency operations by DOD. PBD 096 requires costs of operations in the Gulf to be submitted in the regular budget cycle. Several factors led to this decision. In the past, DOD has had to reprogram or transfer money from other programs into the O&M account to pay for operations hoping for additional funding from Congress later in the year. Additionally, the Budget Enforcement Act of 1990 placed budgetary caps on spending which has resulted in rescissions to partially fund the supplemental appropriations provided by Congress. Typically, the DOD has paid for the rescissions with procurement and modernization funds or has cancelled end of the year training and maintenance. The result of these actions has been a degradation of readiness, modernization, and the budget process. Including the cost of operations in the Gulf in our regular budget will help the Department of the Navy (DoN) plan and execute the budget more efficiently. The key will be to identify and capture the incremental costs associated with Arabian Gulf operations.

## B. INCREMENTAL COSTS/RECONSTITUTION

The DOD's regulations prior to 2001 did not standardize the process for identifying incremental costs, and the General Accounting Office (GAO) Report B-285260 dated June 2000 summarizes their concerns regarding this lack of uniformity. The most obvious example was the flying hour program in which the Air Force and the Navy's Atlantic and Pacific fleets all had different approaches to calculate their costs for support of contingency operations. [Ref. 1, p.2] The DOD Financial Management Regulation (DODFMR) Volume 12, Chapter 23 dated February 2001 has standardized the guidelines for identifying and requesting funding for Contingency Operations, but not the process for calculating the costs. By regulation, the DOD is limited to claiming only the incremental costs of the operation, which are above the normal baseline for training, operations, and personnel costs. [Ref. 9, p.23-6] Baseline costs are defined as those costs that would have incurred regardless of the contingency operation, i.e., normal budgeted operations.

There are many factors that can be included to justify incremental cost estimates. They include: Number of troops, Duration, Terrain/Weather, Operational Tempo (OPTEMPO), Reconstitution, Training, Host Nation Support, etc. The assumptions and facts that apply to the cost estimates must be noted in the justification statements. There are four major cost categories to justify claims: Personnel, Personnel Support, Operating Support, and Transportation. This thesis will concentrate on the category of operating support.

Air conditioning (A/C) maintenance has been singled out for research because of the severe environment of the Arabian Gulf. The basic laws of physics state that the more work it takes to cool air or water the hotter it is. The Arabian Gulf has significantly hotter air and water temperatures than our other major deployment areas such as the Mediterranean Sea. Therefore, its impact on A/C maintenance warrants close examination.

Operating support is broken down into seven subcategories: Training, Operation OPTEMPO, Other Supplies and Equipment, Facilities/Base Support, Reconstitution, Command Control Communications Computers and Intelligence (C4I), and Other

Services and Miscellaneous Contracts. The two subcategories that apply to A/C system maintenance are operation OPTEMPO and reconstitution. Operation OPTEMPO includes the incremental costs to operate including repair parts, maintenance support, and the equipment maintenance required to prepare for deployment and maintain equipment during the operation. For maintenance of equipment, we must identify that portion of equipment overhaul and maintenance costs, computed on a fractional use basis, when the additive cost attributable to the contingency can be identified. [Ref. 9, p.23-18] Simply stated, a baseline cost estimate must be established so that incremental costs of operations can be identified.

Reconstitution includes the cost to clean, inspect, maintain, replace, and restore equipment to the required condition at the conclusion of the contingency operation or unit deployment. It covers equipment organic to the participating unit and war reserve stocks prior to replacement into storage. It excludes the cost to transport equipment being repaired/restored. The DODFMR's guideline question for reconstitution states: What supplies must be replaced and equipment repaired when troops and/or equipment are redeployed or rotated? [Ref. 9, p. 23-13]

## C. BENEFITS OF THE STUDY

Documentation and justification of incremental costs present a difficult challenge for our budget personnel. Numerous GAO studies have highlighted the DOD's inability to standardize the process for identifying these additional costs. This breeds mistrust by Congress of the reliability of our cost estimates and makes it harder for agency personnel to justify additional funding.

The DODFMR Chapter 23 provides broad guidelines for justification of incremental costs, but not a method for calculation of these costs. The goal of this study is to present a justifiable incremental cost model for A/C system maintenance associated with Arabian Gulf operations. This will aid in providing better budget estimates and improving the credibility of requests for increased funding for our continued presence in the Gulf. Also, with the start of operations in support of Enduring Freedom, this model can provide a template for calculating incremental costs for reimbursement of contingency operations.

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# II. DATA COLLECTION AND REDUCTION

## A. AIR CONDITIONING SYSTEMS

### 1. Equipment Identification

Equipment onboard ship is categorized by Equipment Identification Code (EIC). The first number identifies the system and the first and second numbers together identify the equipment subsystem. EIC T4 represents the equipment and supporting infrastructure for A/C systems including the A/C plants, fan coil units (FCU), and all ventilation and piping associated with the system. [Ref. 7, p. A-23]

### 2. Organizational Level Maintenance

Organizational level maintenance is the lowest echelon of maintenance and is conducted by ship's force personnel. The ship's auxiliaries and electrical divisions are responsible for all ship's force level maintenance on the A/C system. Typical maintenance actions include cleaning, preservation, routine maintenance and inspection, and preventative maintenance actions all of which occur on a continuous basis in accordance with the Preventative Maintenance System (PMS). All maintenance actions are documented in the Current Ship's Maintenance Project (CSMP) by regulation and the ship is required to keep the CSMP up to date and accurate.

### 3. Intermediate Level Maintenance

Intermediate level maintenance is for maintenance actions that are above and beyond the capability of ship's force personnel. It is normally accomplished by Navy Intermediate Maintenance Activities (NIMA) on repair ships and aircraft carriers or at Shore Intermediate Maintenance Activities (SIMA). IMA's perform maintenance, repair, overhaul, calibration, and testing functions that are beyond the capability or capacity of the customer. Since the aircraft carriers are designated as NIMAs, the maintenance at the intermediate level will be shared by both ship's force personnel and by personnel at the SIMA. Intermediate maintenance is conducted on a continuous basis and nearly every in port period for aircraft carriers is designated as an Intermediate Maintenance Availability (IMAV). The maintenance actions are tracked by number of man-hours to complete each job.

### 4. Depot Level Maintenance

Depot level maintenance is required for maintenance actions that are beyond the capability or capacity of organizational and intermediate maintenance levels, and is performed by naval shipyards, private shipyards, and item specific depot activities. Depot level maintenance for aircraft carriers is normally scheduled during Chief of Naval Operations (CNO) availabilities that vary in complexity and length according to the operational schedule and maintenance plan for each ship. The Type Commander (TYCOM) is responsible for the training, material readiness, and equipping of forces for the fleet commanders and conducts the screening for jobs to be accomplished by depot level activities. The maintenance actions are tracked by number of man-days to complete each job. Although there are cost data associated with these jobs, man-days are a more appropriate predictor since there are different man-day rates for each shipyard which complicates normalization of the cost data. Therefore, maintenance man-days will be studied.

## B. SOURCES OF INFORMATION

### 1. Technical/Operational Sources

Aircraft carriers were chosen as the platform for study because of the availability of their detailed operational schedules and the relatively small number (twelve) of maintenance databases that would be analyzed. The TYCOMs play a major role in the maintenance execution for ships including the screening of jobs in the CSMP that are approved for accomplishment at the intermediate and depot level. Commander, Naval Air Forces Pacific Fleet (COMNAVAIRPAC) N434 has control of the maintenance database for A/C systems of aircraft carriers from which historical data were pulled. The database includes repair and replacement costs for the organizational and intermediate levels of maintenance. For depot level maintenance, the Supervisor of Shipbuilding (SUPSHIP) Carrier Planning Office organization provided the data. For operational data, Commander in Chief Atlantic Fleet (CINCLANTFLT) N3 and COMNAVAIRPAC N31 provided the underway deployed and non-deployed data for the carriers and the days spent in each operating area.

### 2. Budgetary Sources

The DoN Office of Budget (FMB) coordinates and reviews the Navy's requests for contingency operations funding before submittal to the Undersecretary of Defense (Comptroller). The requests have also been studied and reviewed by the GAO and Congressional Research Service analysts. The various publications put out by FMB and GAO were reviewed to ensure the proper justification for incremental costs requests.

### 3. Environmental Sources

The environmental differences between the Arabian Gulf and the Mediterranean Sea are key to the justification of incremental costs of operations. The Naval Oceanographic Office (NAVOCEANO) provided the database for differences in water temperatures. Various Internet weather sites provided the geographic temperature differences with information being drawn from the U.S. Climatic Data Center in Asheville, North Carolina and International Station Meteorological Climate Surveys.

## C. DATA COLLECTION METHODS

### 1. Review of Regulations and Reports

Various regulations and reports provide important insight to the difficulties in justifying incremental costs for operations. Several GAO reports provide an external view of DoN's past cost requests and budget methods for contingency operations. The DODFMR has been updated with a chapter specifically for contingency operations funding requests. Various DOD documents including PBD 096 address the strain that contingency operations have on our budget plan and execution.

Regarding ship operations and maintenance, OPNAVINST 4790.4 Ship's Maintenance and Material Management (3-M) Manual and CINCLANTFLT/CINCPACFLT 4790.3 Joint Fleet Maintenance Manual were reviewed to understand the maintenance procedures for ships and the level of oversight that is involved in scheduling and approving availabilities and overhauls. An overview was conducted of the various echelons of maintenance activities and their responsibilities in maintaining a ship's material readiness.

### 2. Databases

The TYCOM level database of historical maintenance actions for each aircraft carrier in service was a valuable information resource. It listed all organizational level maintenance and intermediate maintenance conducted for the life of the ship. The data can be pulled by specific EIC to target specific equipment or systems. The data are in both man-hours and cost figures.

For the ocean environmental data, NAVOCEANO provided access to the Master Oceanographic Observation Data Set (MOODS) database, which includes all water temperature history as far back as the early 1900's. The data were extracted by specific date ranges, latitude, longitude and depth.

### 3. Interviews

Actual interviews were key to understanding the maintenance and operational procedures for the personnel who actually operate the equipment. The maintenance managers at the TYCOM level also provided an important perspective for the entire carrier fleet. Lastly, the budgetary personnel who are responsible for tracking, controlling, or requesting O&M funding for ship's maintenance were a valuable resource for understanding the procedures for planning, justification and execution of this piece of the budget.

## D. VARIABLES AFFECTING MAINTENANCE AND REPAIR COSTS

### 1. Operational Variables

#### *a. Ship Age*

Increasing ship age can result in higher maintenance and repair actions. Although shipboard preservation is an ongoing process, older ships tend to have more preservation problems than newer ships. The performance of equipment operating in an increasingly aging environment will be affected and result in a higher occurrence of maintenance problems. The increase of repairs on older ships results in increased maintenance and repair costs. [Ref. 3, p. 2-6]

#### *b. Operating Area*

The environmental factors of different operating areas affects the usage and assumed level of usage of A/C systems. The Arabian Gulf has significantly higher water and air temperatures than the Mediterranean operating area. Figure 1 and Figure 2 show the difference in average monthly water and air temperatures respectively between the two regions. The resulting increase of space temperatures onboard ships causes more demand for A/C usage to keep the workspaces and other compartments at a reasonable temperature. There were also numerous ship alteration maintenance jobs requested to add cooling units in compartments that became too hot to comfortably work while conducting operations in the Arabian Gulf. The higher usage of the A/C system and increased requests for ship alterations specifically requested because of operations in the Arabian Gulf will equate to higher maintenance and repair costs.

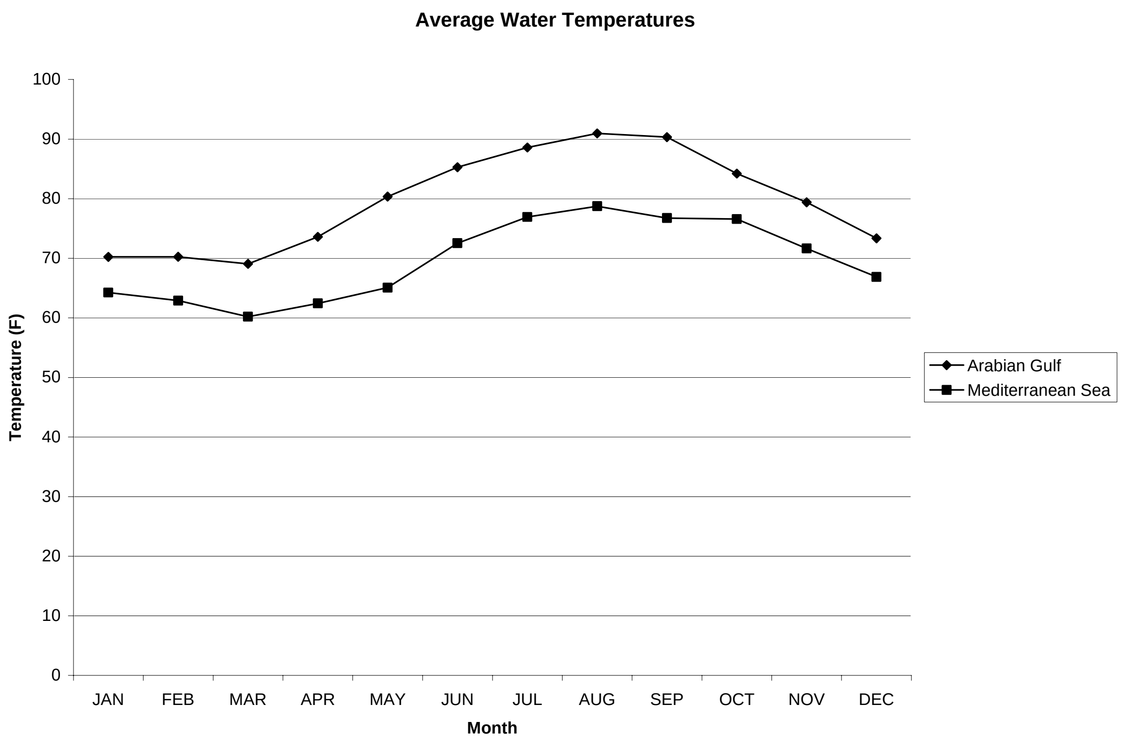


Figure 1. Arabian Gulf and Mediterranean Sea Average Water Temperature

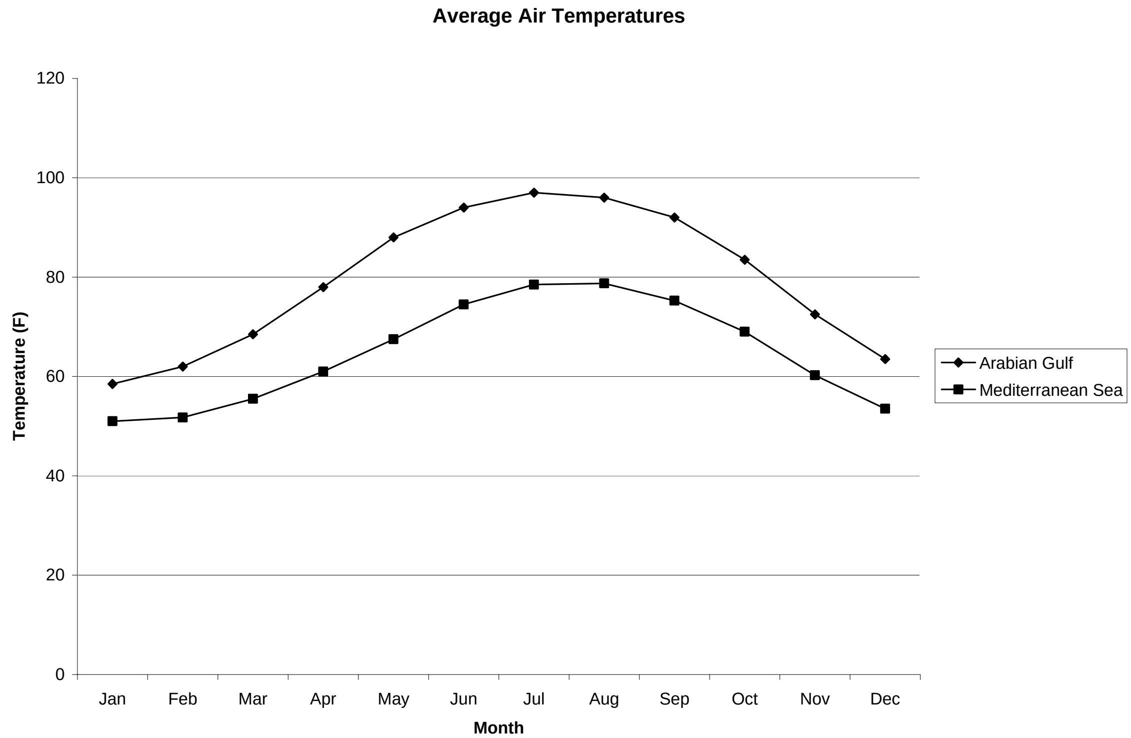


Figure 2. Arabian Gulf and Mediterranean Sea Average Air Temperature

#### *c. OPTEMPO*

The A/C usage during underway periods is greater than during inport periods. The greater demand on the A/C system is because of the amount of activity onboard such as flight operations and the fact that electronic and mechanical equipment are in operation twenty-four hours a day. The increased activity causes temperatures to be higher in compartments such as engine rooms, auxiliary machinery spaces, combat information center, etc. than during inport periods. Therefore an increase in OPTEMPO will likely increase the frequency of maintenance and repairs needed to keep the plant operating effectively.

## E. VARIABLE SEPARATION

### 1. Baseline OPTEMPO

Normal or baseline OPTEMPO is defined as the budgeted OPTEMPO goal of underway days per quarter. Presently, the Navy budget provides funds to execute an OPTEMPO goal of 50.5 underway days per quarter for deployed forces and 28 underway days per quarter for non-deployed forces. [Ref. 3, p.2-3] Any increase over the baseline OPTEMPO for deployed days should be considered an incremental cost of operations.

### 2. Environmental Factors

Environmental factors affecting A/C maintenance include seawater and air temperatures. The baseline used for comparison was the Mediterranean Sea operating area since this region represents a major area of ongoing deployed operations. The significant difference in environmental factors between the Mediterranean Sea and Arabian Gulf should result in different levels of usage and demand on the A/C systems onboard ships resulting in an increased level of maintenance and repair costs for operations in the Arabian Gulf.

### 3. Ship Age

With the decline in battle force ships to Quadrennial Defense Review (QDR) directed levels, the stress of maintaining current OPTEMPO on an aging fleet is evident in increased depot maintenance requirements. The Department's active ship depot maintenance budget finances 97.8% of the notional requirement in FY 2002. Depot maintenance availabilities are increasingly exceeding notional costs. [Ref 3, p. 2-6] The cost trends have proven that as fleet units age, their maintenance costs increase. The incremental costs of A/C maintenance should take into consideration the age of the ships.

## F. GOAL OF VARIABLE SEPARATION

The goal of defining and separating the variables affecting A/C maintenance and repair costs is to define the baseline cost of operations. Without a baseline of maintenance costs, arguments for justifying costs of operations in the Arabian Gulf are left to assumption or interpretation. Establishing an acceptable baseline of A/C maintenance in terms of a short list of variables will aid in justifying budget requests for operations in the Arabian Gulf.

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# III. DATA PRESENTATION AND ANALYSIS

## A. REGRESSION ANALYSIS

### 1. Theory

Regression analysis is a common technique for determining relationships between two or more variables. Regression is perhaps the most widely used quantitative technique in business and governmental organizations because of the many issues faced by managers involving the extent of one variable's relationship to another. [Ref. 18, p.1] In cost estimation, the dependent variable is often cost, and in the case of this thesis the dependent variable is maintenance hours on A/C systems. The other variables called independent variables or explanatory variables are the subject of the research.

Simple linear regression involves the analysis of a single explanatory variable's affect on the dependent variable. The major assumption for simplicity of the model is that the relationship is a straight line or linear. Each independent variable assumed to affect A/C maintenance was tested in a simple linear regression model for its statistical relevance in explaining maintenance hours.

Multiple regression involves two or more explanatory variables for predicting the behavior of the dependent variable. Although including more than one variable into the regression model can increase the accuracy of the regression model, the addition of multiple variables can increase the chance of violating the basic mathematical assumptions of regression. However, there are methods for detecting such violations and those tests have been incorporated into the analysis.

The statistical results from a regression analysis are expressed in terms of $R^2$, f-statistic, and t-statistic. $R^2$, the coefficient of determination, measures the percentage of variability in the dependent variable Y or maintenance hours that can be explained by the regression with a value of 1 being a perfect model. The f-statistic is used to check the statistical significance of $R^2$, with the lower the significance value the better. The f-statistic is a statistical check for the entire regression model. The t-statistic indicates whether the independent variables are important in explaining the value of the dependent variable. In a single variable model, the f-statistic and t-statistic are equal. Choosing acceptable values of each statistical predictor can be subjective, but the combination of analyzing all predictors together will determine whether the regression model is valid.

This thesis utilizes regression analysis to determine a model to explain A/C maintenance trends of ships operating in the Arabian Gulf. Chapter II described several variables that would reasonably impact A/C maintenance and these variables are considered the explanatory variables with maintenance man-hours as the dependent variable for intermediate maintenance and maintenance man-days as the dependent variable for depot level maintenance.

## B. INTERMEDIATE MAINTENANCE TREND ANALYSIS

### 1. Fiscal Year Analysis

The first analysis was conducted by looking at each fiscal year for trends. The years under research were from fiscal year (FY) 1996 through FY 2000. The reason for choosing this time period was that the maintenance database for intermediate maintenance covered the past ten fiscal years, but the operational underway databases began in FY 1996. Therefore, to study the impact of underway operations on maintenance hours, the study was limited to FY 1996 through FY 2000.

Since intermediate maintenance, in theory, is conducted on a continuous basis, a fiscal year analysis seemed a likely starting point. The single variable regression analysis looked at age, deployed OPTEMPO, and days in the Gulf. The explanatory variable for the Gulf was approached both as days in the Gulf and as a temperature factor. The weighted temperature factor was calculated by multiplying the number of days in each area of operations (AOR) and weighting the percentage of time in each region by the average temperature for the corresponding region. Tables 1 and 2 show the data used in the analysis.

**FY96 - FY00 IMA Data**

| Ship | Ship's Age (end of FY00) | IMA Man Hours Total |
|---|---|---|
| CV67 | 33 | 12772 |
| CVN68 | 26 | 958 |
| CVN69 | 24 | 5087 |
| CVN70 | 19 | 1048 |
| CVN71 | 15 | 5050 |
| CVN73 | 9 | 3463 |

Table 1. Regression Data Totals for Ship Age FY96 through FY00

**Fiscal Year Regression Data**

| Ship | FY | IMA Man Hours | Days in Gulf | Days in Med | Temp factor | OPTEMPO | Age |
|---|---|---|---|---|---|---|---|
| CV67 | FY97 | 54 | 0 | 144 | 69.57 | 71.5 | 30 |
| CV67 | FY98 | 354 | 0 | 10 | 69.57 | 21 | 31 |
| CV67 | FY00 | 124 | 82 | 30 | 77.62 | 63.5 | 33 |
| CVN69 | FY98 | 109 | 0 | 79 | 69.57 | 39.5 | 22 |
| CVN69 | FY99 | 260 | 20 | 24 | 73.8 | 62 | 23 |
| CVN69 | FY00 | 798 | 56 | 61 | 74.02 | 41.3 | 24 |
| CVN70 | FY98 | 180 | 12 | 0 | 78.87 | 52 | 17 |
| CVN70 | FY99 | 636 | 74 | 0 | 78.87 | 54.5 | 18 |
| CVN71 | FY97 | 1422 | 0 | 106 | 70.79 | 46 | 12 |
| CVN71 | FY99 | 1807 | 71 | 75 | 72.8 | 48.7 | 14 |

Table 2. Fiscal Year Regression Model Data

#### *a. Regression Results*

When analyzing the maintenance database for the regression analysis, several ships had to be removed from the analysis. The USS Kitty Hawk (CV63) was removed because she is forward deployed and her data for intermediate maintenance were considerably higher than any other aircraft carrier. This is to be expected. The majority of her maintenance must be accomplished at the intermediate level since she is restricted from depot level availabilities in her increased readiness posture. The other outliers were the USS Constellation (CV64), USS Enterprise (CVN65), USS Abraham Lincoln (CVN72), USS John C. Stennis (CVN74), and USS Harry S. Truman (CVN75). The reason for their removal was the lack of complete maintenance data at the intermediate level. Additionally CVN75 had not completed a deployment. The removal of the outliers left six carriers in the model, effectively reducing by half the number of data points available for the model. Table 3 shows the outliers removed from the regression analysis.

**FY96 - FY00 IMA Data**

| Ship | Ship's Age (end of FY00) | IMA Man Hours Total |
|---|---|---|
| CV63 | 40 | 21722 |
| CV64 | 40 | 399 |
| CVN65 | 40 | 235 |
| CVN72 | 12 | 118 |
| CVN74 | 6 | 257 |
| CVN75 | 3 | 1636 |

Table 3. Outlying Data Pulled from Regression Model

Every simple linear regression model using age, OPTEMPO, and number of days in the Gulf as explanatory variables resulted in statistically weak models (see

Figures 3 through 6). The data plot for each model showed a random pattern with no recognizable linear relationship. Further analysis showed that there appeared to be a time lag between deployment and the intermediate maintenance. The IMAV plot over time for USS Enterprise shows evidence of a time lag between the end of deployment and the maintenance occurring (see Figure 7). In theory, intermediate maintenance is a continuous process, but in actuality there is a lag between the end of a deployment and beginning of the IMAV.


Figure 3. IMA Man Hours vs. Ship Age

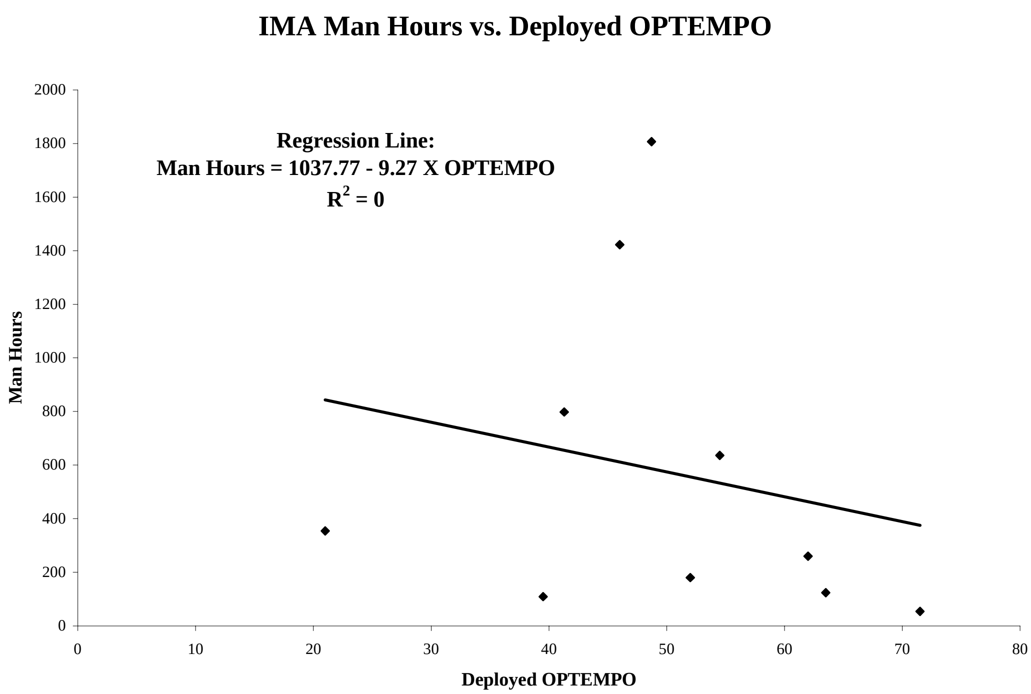


Figure 4. IMA Man Hours vs. Deployed OPTEMPO

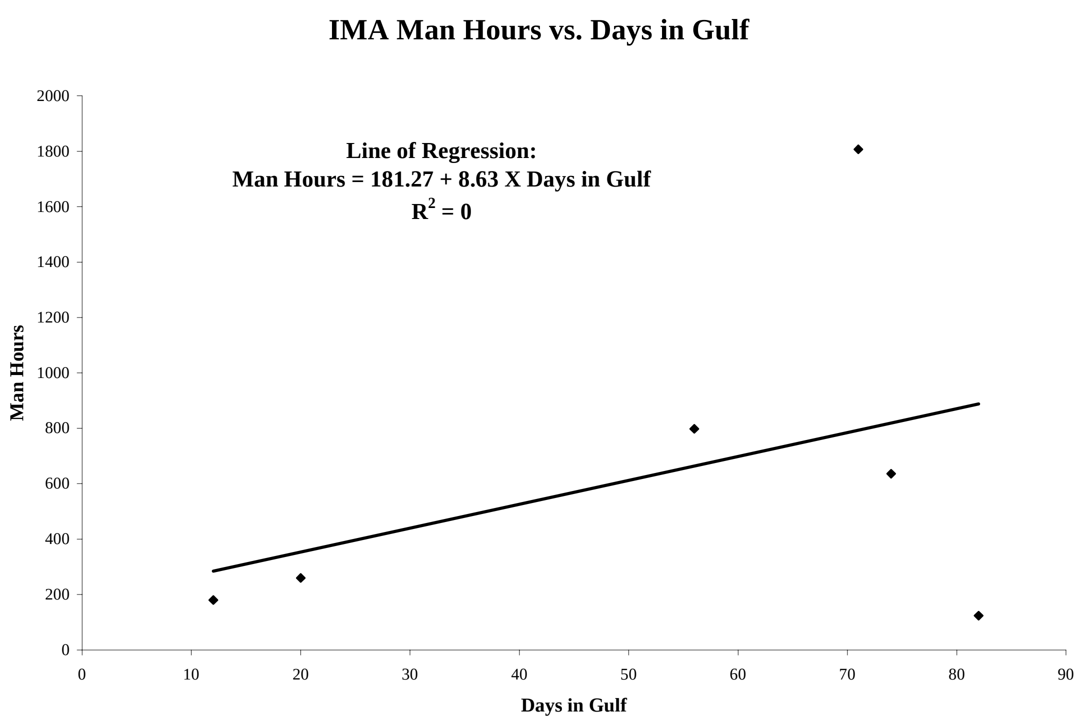


Figure 5. IMA Man Hours vs. Days in Arabian Gulf

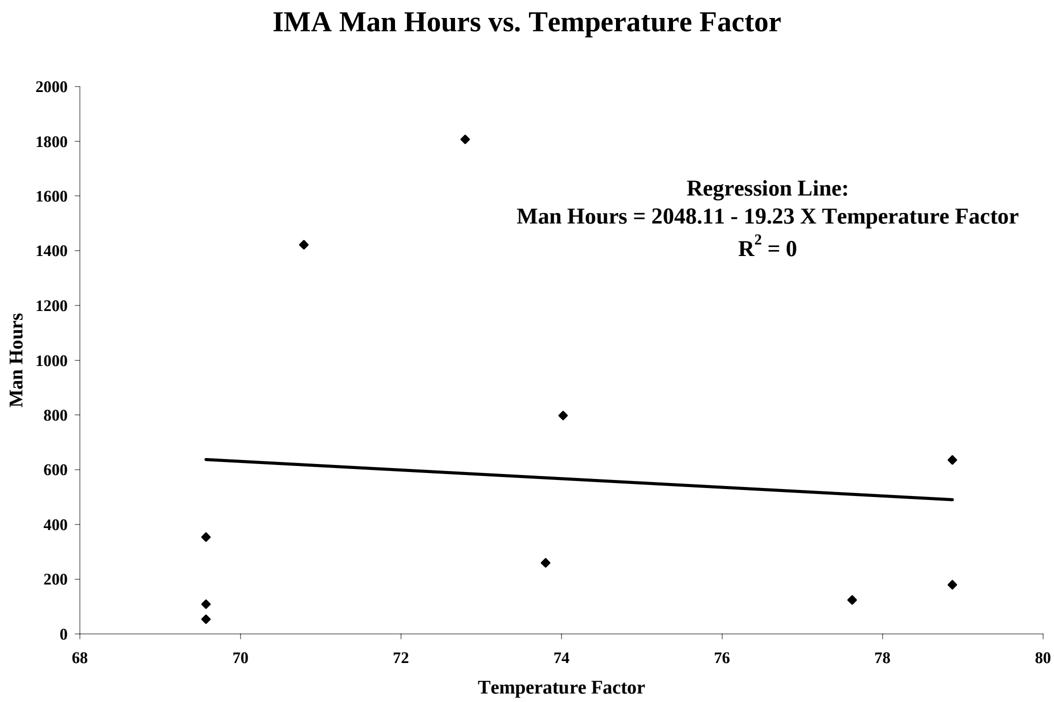


Figure 6. IMA Man Hours vs. Temperature Factor

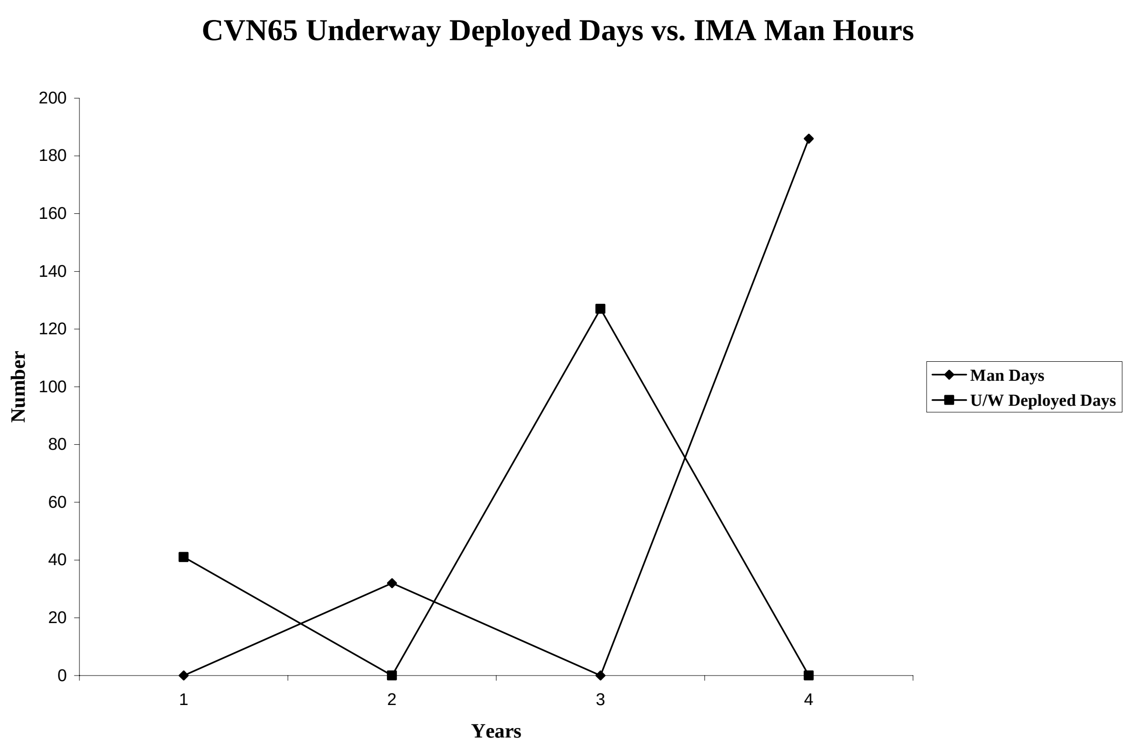


Figure 7. CVN 65 Deployment Timing vs. IMAV Timing

It is clear from a statistical point of view that a simple linear regression based upon fiscal year totals for underway data and A/C maintenance man-hours is not a good predictive model. Not only were the models poor statistically, but in the case of OPTEMPO and temperature factor, the model showed a negative relationship between these variables and forecasted maintenance. The next logical step in the analysis was to time-lag the maintenance data back to the respective deployed periods.

### 2. Lagged Regression Analysis

The second model required a more detailed study of ships' historical schedules and maintenance periods. In many cases, the deployments and maintenance periods crossed fiscal years, which created difficulty in selecting a time period to analyze. The time-lag chosen for each ship was based on individual schedules and unique circumstances, with the starting period for each time-lag period as the beginning date of a deployment. For example, if a ship entered a major overhaul period following deployment it was evident that the intermediate maintenance was deferred to the depot level vice the intermediate level. In such a case, the time period would have to be eliminated from the model.

In most cases, it was clear from the historical schedules when the IMAV would start with an average time delay of three to six months. These delays are normal and are caused by SIMA's lower prioritization of ships returning from deployment and the timing of fiscal year O&M funds which grow scarce in the fourth quarter. Table 4 shows the data used for the time lagged regression analysis.

**Lagged IMA Data**

| Ship | Fiscal Year | IMA Man Hours Lagged | Days In Gulf | Days in Med | Temp Factor | OPTEMPO | Age |
|---|---|---|---|---|---|---|---|
| CV67 | FY98 | 354 | 0 | 144 | 69.57 | 54.7 | 31 |
| CV67 | FY00 | 542 | 82 | 30 | 76.38 | 46.3 | 33 |
| CVN69 | FY98 | 736 | 20 | 103 | 71.08 | 47 | 22 |
| CVN69 | FY00 | 428 | 56 | 61 | 74.02 | 41.3 | 24 |
| CVN70 | FY97 | 339 | 79 | 0 | 78.87 | 50 | 16 |
| CVN70 | FY99 | 648 | 80 | 0 | 78.87 | 53.7 | 18 |
| CVN71 | FY98 | 1704 | 16 | 100 | 70.85 | 46 | 13 |
| CVN71 | FY00 | 3050 | 40 | 75 | 72.8 | 48.7 | 15 |

Table 4. Lagged IMA Data for Regression Analysis

### *a. Regression Results*

Age, OPTEMPO, days in the Gulf, and temperature factor were used as explanatory variables in single variable regression models. The regression models were limited to eight data points after removal of the outliers. As in the fiscal year regression approach, none of the new models result in any statistical significance. The regression results are shown in Figures 8 through 11.

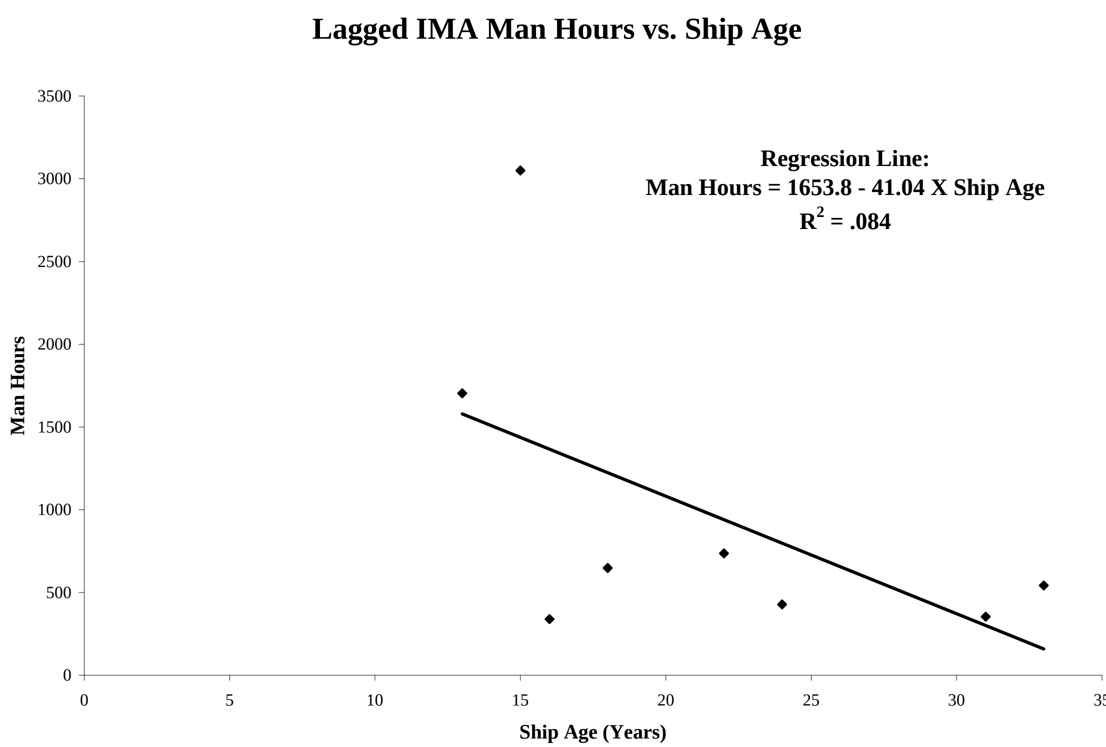


Figure 8. Lagged IMA Man Hours vs. Ship Age

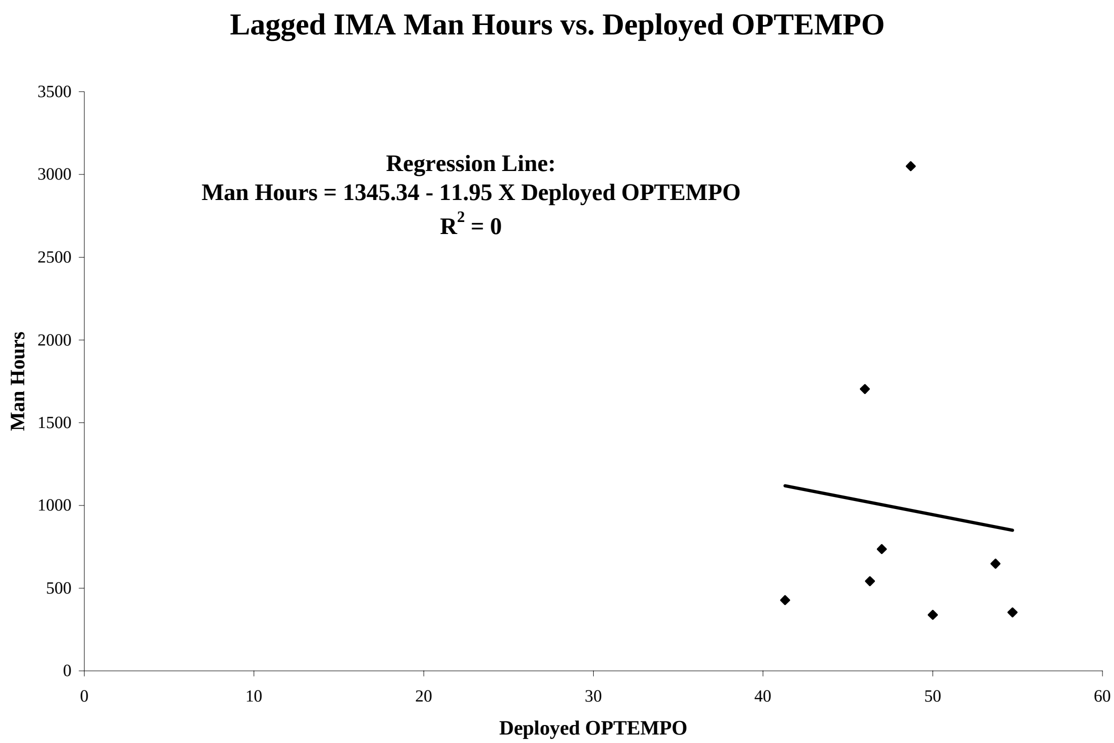


Figure 9. Lagged IMA Man Hours vs. Deployed OPTEMPO

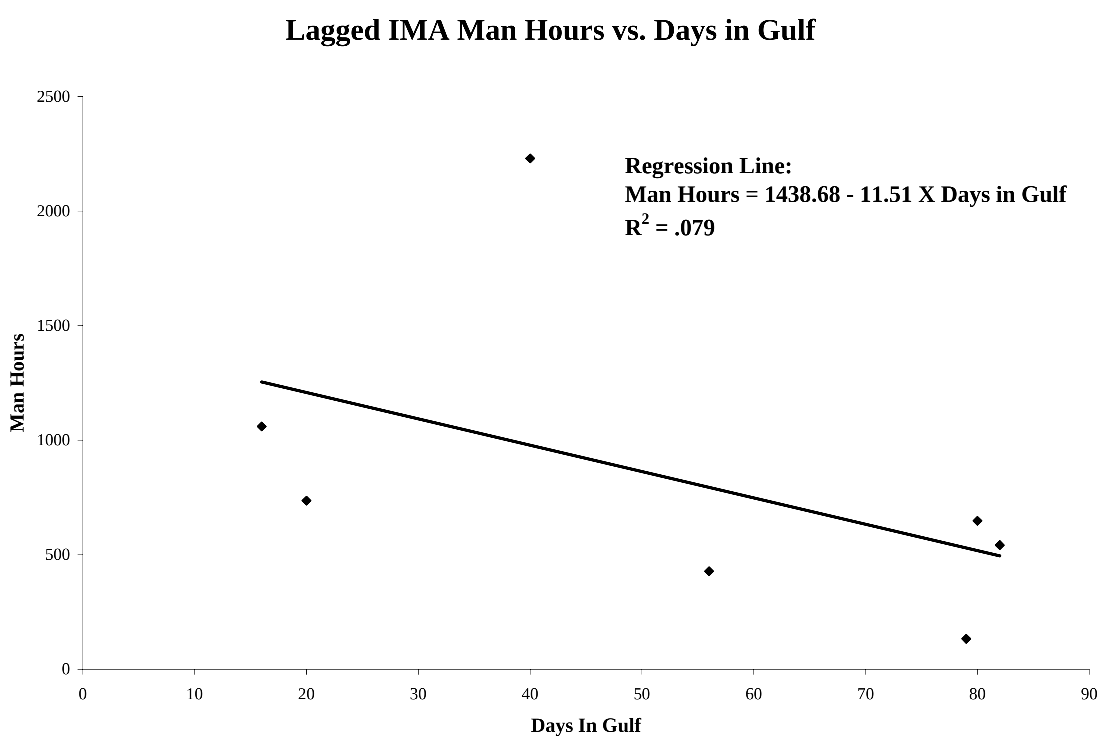


Figure 10. Lagged IMA Man Hours vs. Days In Gulf

**Lagged IMA Man Hours vs. Temperature Factor**

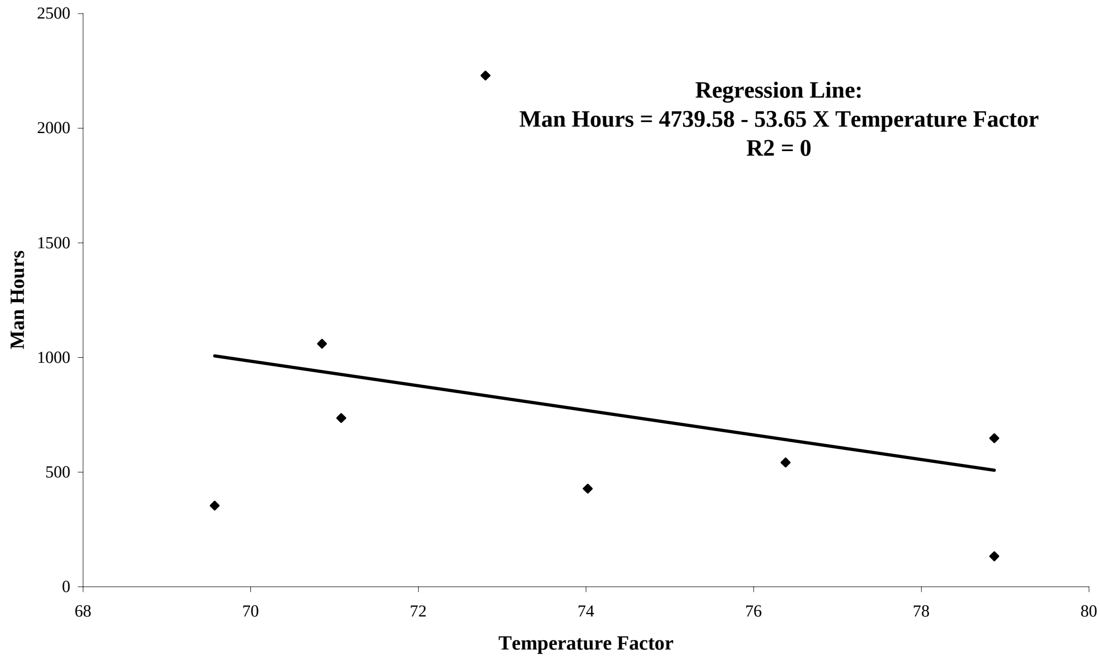


Figure 11. Lagged IMA Man Hours vs. Temperature Factor

Lagging the intermediate maintenance man hours back to the deployment periods did not result in any improvement in the results of the regression analysis. The above figures do not show any linear pattern to the data which appear to be randomly dispersed. The regression results for deployed OPTEMPO, the number of days in the Gulf and temperature factor analyses resulted in a negative trend line which is contrary to the assumptions of the research that the hotter climate of the Gulf causes increased maintenance on the A/C systems. The lack of an adequate number of data points in each model compounds the error in the analysis. It is clear from a statistical perspective that the four explanatory variables are not adequate predictors for intermediate maintenance forecasting.

## C. DEPOT LEVEL MAINTENANCE TREND ANALYSIS

### 1. Maintenance Timing and Deferral

The timing of depot level maintenance availabilities must be taken into consideration when analyzing the affect of operations on maintenance costs. In many cases, maintenance periods are deferred because of scheduling issues with ships and the shipyard availability. Another reason for maintenance deferment is to delay the funding until the next fiscal year because of a shortage in the O&M account. The deferment period will be tailored individually for each ship and must be identified in order to match operational periods to their corresponding maintenance availabilities. The depot maintenance time lag is clear, unlike the intermediate maintenance, since the availabilities are easily identified in a ship's historical schedule and the infrequent nature of overhauls. Figure 12 shows an example of the timing of depot maintenance for the USS Dwight D. Eisenhower (CVN69). Since the maintenance availability periods are spread out over different time intervals, a correlation must be established between the operations of the ship and the resulting maintenance.

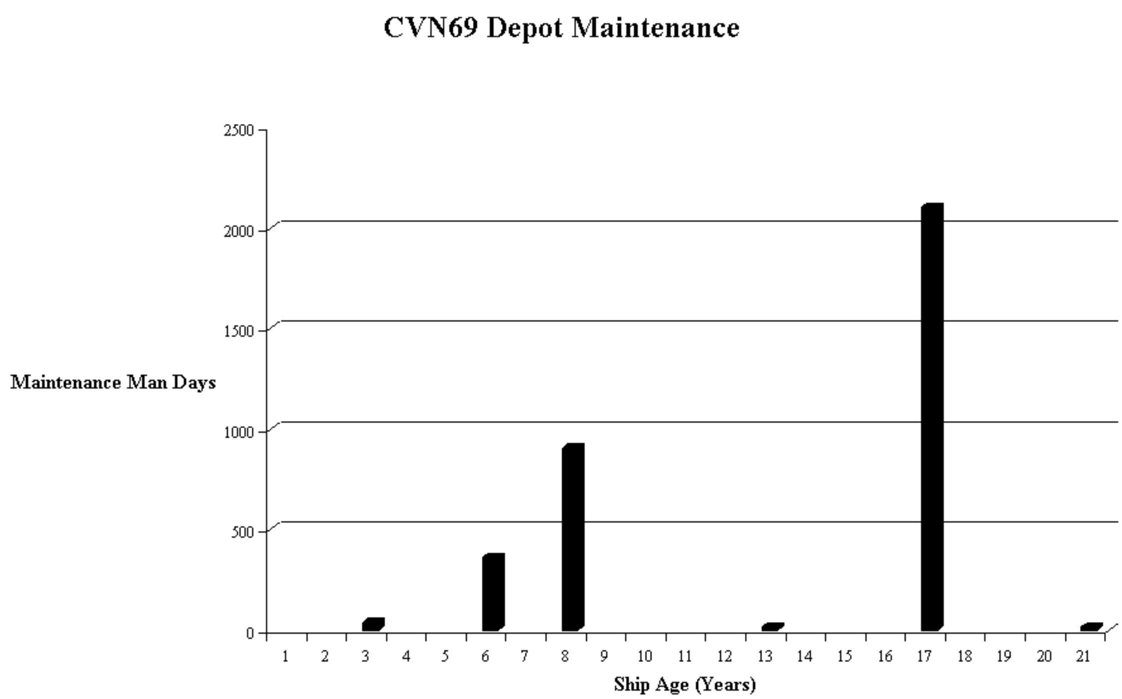


Figure 12. USS Dwight D. Eisenhower (CVN69) Historical Depot Maintenance

### 2. Regression Results

The explanatory variables used to predict maintenance man-days for depot level maintenance on A/C systems were ship age, deployed OPTEMPO, days in the Gulf, and temperature factor. The database for depot level maintenance included information for nine aircraft carriers spanning their entire service period. Because the database for historical underway data was limited to FY 1996 through FY 2000, the number of data points for depot level availabilities that matched with underway data available for study was reduced to six. The carriers included in the models were USS Enterprise (CVN65), USS Dwight D. Eisenhower (CVN69), USS Carl Vinson (CVN70), USS Abraham Lincoln (CVN72), and USS John C. Stennis (CVN74). As in the intermediate level analysis, the lack of data points will reduce the statistical relevance of each model. Table 5 shows the data used in the regression model.

**Depot Level Regression Data**

| Ship | Period | Depot Level Man Days | Days in Gulf | Temp Factor | OPTEMPO | Age |
|---|---|---|---|---|---|---|
| CVN65 | FY 96/97 | 96 | 60 | 73.93 | 45.3 | 37 |
| CVN69 | FY 98/99 | 120 | 20 | 71.08 | 47.0 | 22 |
| CVN70 | FY 96/97 | 6176 | 79 | 78.87 | 50.0 | 16 |
| CVN70 | FY 99/00 | 5304 | 80 | 78.87 | 53.7 | 18 |
| CVN72 | FY 95/96 | 1808 | 76 | 78.87 | 46.7 | 8 |
| CVN74 | FY 98/99 | 1440 | 107 | 78.53 | 49.7 | 4 |

Table 5. Depot Level Regression Data

The results of the four single variable regression models are shown in Figures 13 through 16. For the models predicting the effect of ship age, days in the Gulf and temperature factor variables, the results are statistically insignificant. In each case, the data dispersion was random and showed no linear relationship. For the deployed OPTEMPO independent variable, the model proved to be statistically significant. However, since the environmental variables of days in the Gulf and temperature factor were poor predictors of maintenance man-days, running a multi-variable model with deployed OPTEMPO and either environmental variable proved to be statistically insignificant. The poor results for the multi-variable model were expected since the single variable models with days in the Gulf and temperature factor were found to be poor explanatory variables.

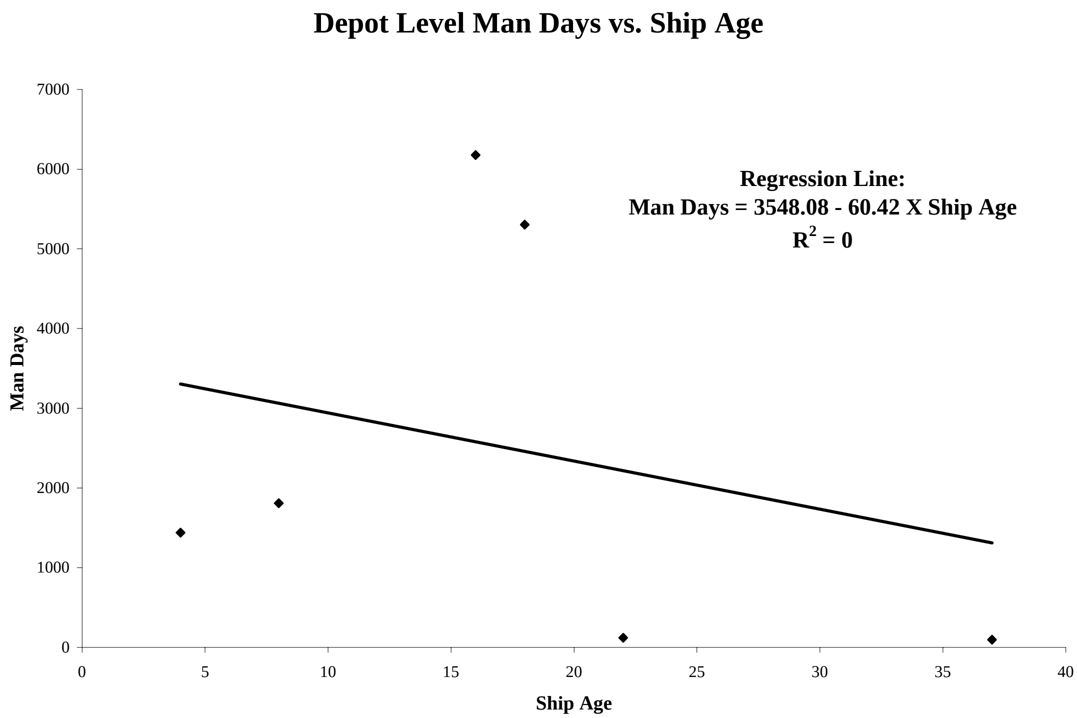


Figure 13. Depot Level Man Days vs. Ship Age

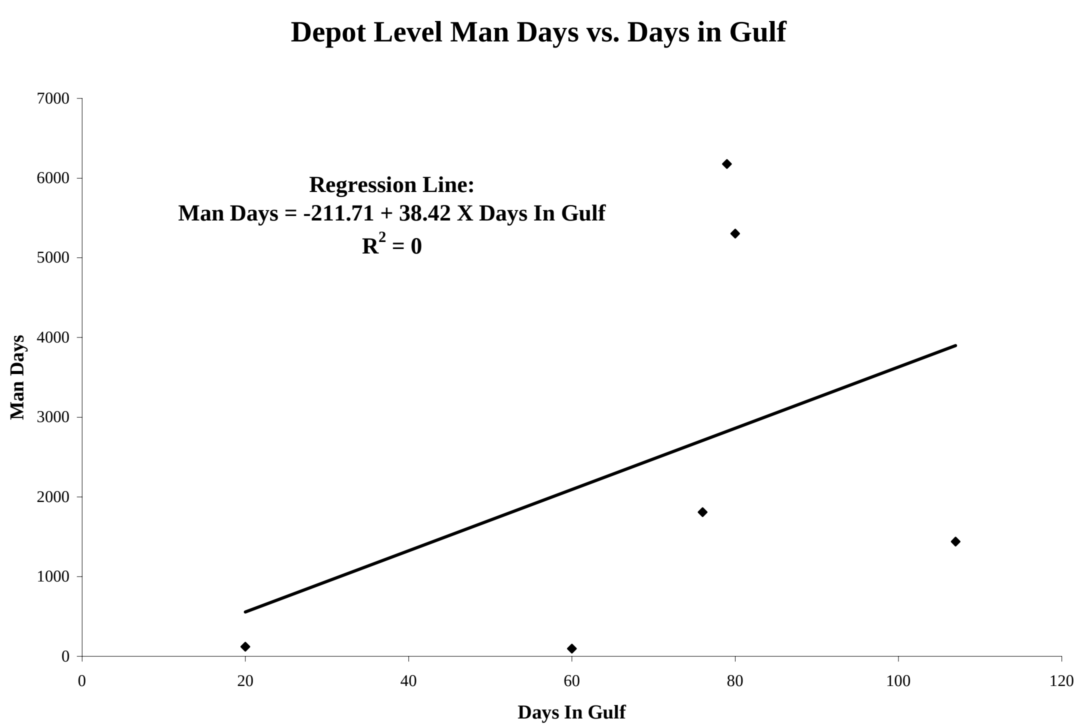


Figure 14. Depot Level Man Days vs. Days in Gulf

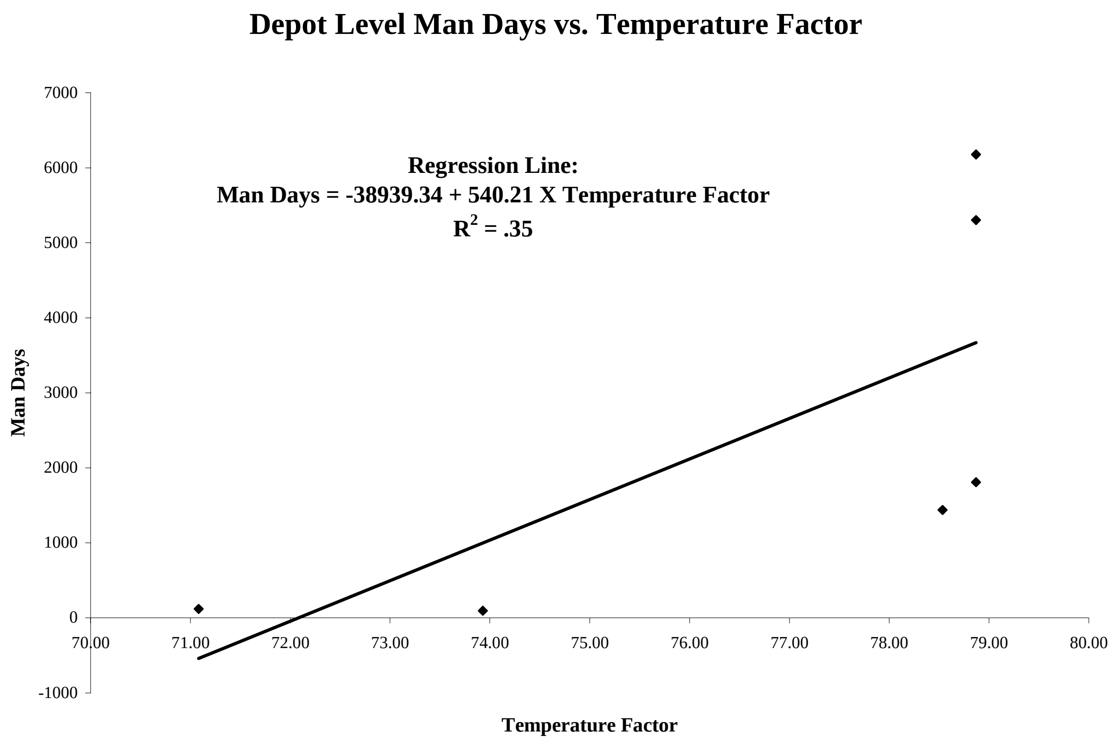


Figure 15. Depot Level Man Days vs. Temperature Factor

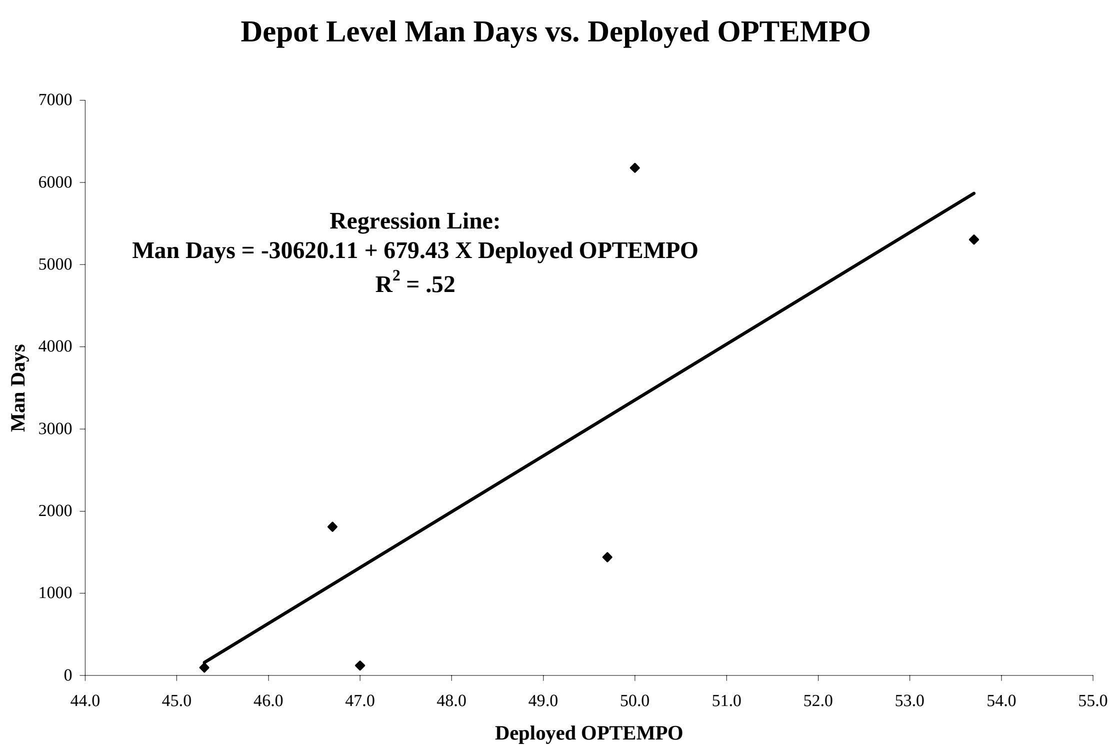


Figure 16. Depot Level Man Days vs. Deployed OPTEMPO

Although the time lag for depot level maintenance data was obvious in relation to a completed deployment cycle, only one variable showed a statistically significant relationship for predicting future maintenance.  The variables relating the environmental effects of the Gulf to forecasted maintenance were surprisingly poor statistically.

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# IV. CONCLUSIONS AND RECOMMENDATIONS

## A. SUMMARY

PBD 096 has changed the way the DoN budgets for Arabian Gulf operations. The cost of operations in the Arabian Gulf is now required to be submitted as part of the DoN's annual budget. In order to justify increased incremental costs for operations in the Gulf, we must present a defendable argument, such as a valid regression model, to defend the budget requests. The severe environmental factors of the Gulf seemed to be an obvious research topic to predict incremental costs over other AORs such as the Mediterranean Sea. However, using maintenance trends and environmental variables for ships operating the Gulf has not proven to be the right approach for justification of increased costs associated with Gulf operations, at least for the ships chosen for this study.

The maintenance data available for analysis proved to have significant inconsistencies. The number of outliers that had to be removed from the analysis greatly affected the statistical significance of the regression model developed. Although the maintenance database had historical data for FY 1990 through FY 2000, the research was limited by the available operational data, which was for the period FY 1996 through FY 2000. The restricted time period caused only six data points to be available for the depot level maintenance analysis which also greatly degraded the statistical relevance of the depot level regression model. By reducing the amount of data available for inclusion as the dependent variable the amount of error in the regression analysis was compounded. The CSMP database is maintained by ships force personnel, and based on past personal experience of duty at sea, there were likely widespread inconsistencies in maintaining an accurate maintenance picture based upon the human factor of inputting man hours spent working each job.

As far as independent variables are concerned, only deployed OPTEMPO showed any statistical relevance in the depot level model. Not one of the explanatory variables proved to be significant in the intermediate level analysis. In addition, the temperature factor variable should not be used as independent variable for future research models.

The temperature factor variable does not have a large enough range, i.e., the data are too tightly grouped to be a valid independent variable in the model. The reason is that the smaller the range of a variable, the smaller the prediction range the variable can be used for. In other words, it is mathematically inappropriate to forecast values that lie outside the range of your independent variables. Since the range is limited, the forecast model is also limited with its ability to accurately predict future maintenance.

Surprisingly, age also proved to be an insignificant explanatory variable for maintenance costs of A/C systems. The most appropriate explanation is that the timing of A/C systems replacement is based on usage vice age of the platform. The variable days in the Gulf was assumed to have a temperature factor built in. However, the random spread of maintenance costs in relation to this variable showed no significance in either model.

## B. RECOMMENDATIONS

This thesis was based upon the assumption that the severe environmental variables of the Arabian Gulf would affect maintenance costs for A/C systems since they are directly affected by the seawater temperatures and ambient air temperatures of the operational area. However, the regression models could not prove this assumption to be true.

Selecting A/C systems is most likely a valid target for proving there are incremental affects of the Arabian Gulf on our equipment, but maintenance costs is not the proper dependent variable to choose. Future research could be directed at historical A/C system usage for ships that operate in the Gulf versus the Mediterranean AOR.

While deployed on USS Chancellorsville (CG62) to the Arabian Gulf in the summer of 1995, the author noticed a constant battle against the heat inside the ship. It was common to have all three A/C plants in operation during the hottest time of the day. Conversely, on a second deployment on CG62 in support of Counter Drug Operations off the coast of Colombia in the Eastern Pacific, the engineers never had to bring all three A/C plants online at the same time. In fact, it was rare to have more than one A/C plant in operation at any given time. However, the study shows that the impact of increased use of A/C plants on maintenance man hours kept on official ship records is not clear.

Therefore, conducting an analysis of plant total hourly usage for operations in the Gulf may be a better predictor for the effects of the environment of the Gulf versus other operating areas.

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# APPENDIX A. LIST OF ACRONYMS

| | |
|---|---|
| 3M | Maintenance and Material Management System |
| A/C | Air Conditioning |
| AOR | Area of Operations |
| C4I | Command Control Communications Computer and Intelligence |
| CINCLANTFLT | Commander in Chief, Atlantic Fleet |
| CINCPACFLT | Commander in Chief, Pacific Fleet |
| COMNAVAIRPAC | Commander, Naval Air Forces, Pacific |
| CNO | Chief of Naval Operations |
| CSMP | Current Ship's Maintenance Project |
| DOD | Department of Defense |
| DODFMR | Department of Defense Financial Management Regulation |
| DoN | Department of the Navy |
| EIC | Equipment Identification Code |
| FCU | Fan Coil Unit |
| FMB | Office of Budget (Navy) |
| GAO | General Accounting Office |
| IMA | Intermediate Maintenance Activity |
| IMAV | Intermediate Maintenance Availability |
| MOODS | Master Oceanographic Observation Data Set |
| NAVOCEANO | Naval Oceanographic Office |
| NIMA | Navy Intermediate Maintenance Activity |

| | |
|---|---|
| O&M | Operations and Maintenance |
| OCOTF | Overseas Contingency Operations Transfer Fund |
| OPNAVINST | Office of the Chief of Naval Operations |
| OPTEMPO | Operational Tempo |
| PBD | Program Budget Decision |
| PMS | Preventive Maintenance System |
| SIMA | Ship Intermediate Maintenance Activity |
| SUPSHIP | Supervisor of Shipbuilding |
| TYCOM | Type Commander |
| QDR | Quadrennial Defense Review |
| UN | United Nations |

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