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An analysis of port-visit costs of U.S. Navy aircraft carriers

Adams, Jason W.

Monterey California. Naval Postgraduate School

NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

THESIS

AN ANALYSIS OF PORT-VISIT COSTS OF U.S. NAVY AIRCRAFT CARRIERS
by
Jason W. Adams
June 2008
Thesis Advisor: Robert. A. Koyak Second Reader: Daniel. A. Nussbaum

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The United States Navy is seeking substantial cost savings in the operation of its aircraft carrier fleet, including the costs of port visits. This thesis analyzes data on aircraft carrier port visits from fiscal years 2002 through 2007 to develop statistical models for characterizing and predicting port-visit costs. The models account for explanatory factors that include the ship and port, whether the ship is moored pier side or at anchor, length of the port visit, and the arrival date. A total of 13 U.S. Navy Carrier Vessel (CV) and Carrier Vessel Nuclear (CVN) aircraft carriers made 118 visits to ports in 25 countries during the period under study. For each port visit, individual line-item expenses are aggregated into four categories and by total cost. Regression modeling is then used to identify factors that explain these categorized and total costs. For total costs, the average regression prediction error is about 17 percent. Costs are found to vary across ships and, more substantially, across ports. These findings can be used in the formulation of initiatives aimed at reducing the costs of aircraft carrier port visits. An automated spreadsheet tool is developed to implement the model1ing techniques presented in the thesis.

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AN ANALYSIS OF PORT-VISIT COSTS OF U.S. NAVY AIRCRAFT CARRIERS

Jason W. Adams
Lieutenant Commander, Supply Corps, United States Navy
B.S., University of Utah, 1998
M.B.A., Arizona State University, 2005

Submitted in partial fulfillment of the
requirements for the degree of

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NAVAL POSTGRADUATE SCHOOL
June 2008

Author: Jason W. Adams

Approved by: Robert A. Koyak
Thesis Advisor

Daniel A. Nussbaum
Second Reader

James N. Eagle
Chairman, Department of Operations Research

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ABSTRACT

The United States Navy is seeking substantial cost savings in the operation of its aircraft carrier fleet, including the costs of port visits. This thesis analyzes data on aircraft carrier port visits from fiscal years 2002 through 2007 to develop statistical models for characterizing and predicting port-visit costs. The models account for explanatory factors that include the ship and port, whether the ship is moored pier side or at anchor, length of the port visit, and the arrival date. A total of 13 U.S. Navy Carrier Vessel (CV) and Carrier Vessel Nuclear (CVN) aircraft carriers made 118 visits to ports in 25 countries during the period under study. For each port visit, individual line-item expenses are aggregated into four categories and by total cost. Regression modeling is then used to identify factors that explain these categorized and total costs. For total costs, the average regression prediction error is about 17 percent. Costs are found to vary across ships and, more substantially, across ports. These findings can be used in the formulation of initiatives aimed at reducing the costs of aircraft carrier port visits. An automated spreadsheet tool is developed to implement the modeling techniques presented in the thesis.

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LIST OF SYMBOLS, ACRONYMS, AND/OR ABBREVIATIONS

AIC	Akaike Information Criterion
APCM	Automated Port Cost Model
APRE	Average Percentage Relative Error
CER	Cost Estimating Relationships
CFFC	Commander, Fleet Forces Command
CHT	Collection, Holding, and Transfer
CLIN	Contract Line Items
CNAF	Commander Naval Air Forces
COD	Carrier Onboard Delivery
COMNAVAIRPAC	Commander Navy Air Forces, Pacific
CRAFT	Cost Reporting, Analysis and Forecasting Tool
CV	Carrier Vessel
CVN	Carrier Vessel Nuclear
Depfrac	Deployment Fraction
DoD	Department of Defense
FISC Dets	Fleet Industrial Supply Center Detachments
FY	Fiscal Year
FYDP	Future Year Defense Plan
GLS	Generalized Least Squares
GWOT	Global War on Terror
HSC	Husbanding Services Contracts
HSP	Husbanding Services Provider
LOGREQ	Logistics Request
MASS	Modern Applied Statistics with S-Plus
NAS	Naval Air Station
NAVSUP	Navy Supply Systems Command
NCCA	Naval Center for Cost Analysis
O&M, N	Operating and Maintenance, Navy

OFC	OPTAR Fund Categories
OLS	Ordinary Least Squares
OPTAR	Operating Target
PVCR	Port Visit Cost Reports
QQ plot	Quantile-Quantile plot
S&E	Supplies and Equipage
SUPPO	Supply Officer
TYCOMS	Type Commanders
USFF	U.S. Fleet Forces Command

EXECUTIVE SUMMARY

The United States Navy is seeking substantial cost savings in the operation of its aircraft carrier fleet, including the costs of port visits. In fiscal year 2007 (FY07), the Navy spent over $18 million dollars conducting aircraft carrier port visits around the globe. This is a modest fraction of the approximately $160 million dollars budgeted by Department of Defense (DoD) for the operating and maintenance of these ships, but represents an area targeted for cost savings and avoidances (Devlin, 2008). Commander Naval Air Forces (CNAF) has been tasked with reducing the Ships Operating budget by 20 percent in FY09, and another 20 percent in FY10. This would result in a cost savings and avoidance of $33.6 million. CNAF has been presented with several options to save money and still maintain fleet readiness. These initiatives include:

- Deferring maintenance to future years.
- Underfunding nondeploying aircraft carriers.
- Reducing port-visit costs.

CNAF is interested in identifying cost drivers that contribute to aircraft carrier port-visit costs in an effort to save $4 million.

This thesis analyzes data on aircraft carrier port visits from fiscal years 2002 through 2007 to develop statistical models for characterizing and predicting port-visit costs. The models account for explanatory factors that include the ship and port, whether the ship is moored pier side or is at anchor, length of the port visit, and the arrival date. A total of 13 U.S. Navy Carrier Vessel (CV) and Carrier Vessel Nuclear (CVN) aircraft carriers made 118 visits to ports in 25 countries during the period under study. Information on all Navy port-costs is available in the Cost Reporting, Analysis, and Forecasting Tool (CRAFT) database maintained at Fleet Industrial Supply Center detachments (FISC Dets) Singapore and Sigonella.

For each port visit, individual line-item expenses in CRAFT are aggregated into four cost categories and by total cost. Regression modeling is then used to identify factors that explain these categorized and total costs.

Four submodels are developed for the categories of Force Protection, Port Fees, Transportation, and Utilities. A Total Cost Model is constructed with a resulting average regression prediction error of about 17 percent. Costs are found to vary across ships and, more substantially, across ports. The high-cost ports are estimated to be about 3.32 times as expensive as the low-cost ports. The mid-cost ports are about 1.95 times as expensive as the low-cost ports. Bahrain, which is about 1.57 times as expensive as the low-cost ports, falls somewhere between the mid-cost ports and the low-cost ports. Because the Navy is seeking to reduce port-visit costs, it should consider more cost-efficient port alternatives that satisfy its operational objectives. To some extent, the Navy already is doing this: the most frequently visited ports are found mainly in the lower cost categories.

The decision to have an aircraft carrier at anchor or pier side can also result in cost savings. It is nearly 35 percent cheaper to have a ship pier side than at anchor. For a five day port visit to Jebel Ali, a CVN is estimated to save $140 thousand dollars if it is pier side rather than at anchor.

These findings can be used in the formulation of initiatives aimed at reducing the costs of aircraft carrier port visits. An automated spreadsheet tool is developed to implement the modeling techniques presented in the thesis and to provide a graphical representation of the models. This tool allows a decision maker to compare options such as which port to pull in to, and where to have the ship pier side or at anchor.

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I would like to thank Professors Robert A. Koyak and Daniel A. Nussbaum for their contributions to this thesis. Professor Koyak provided expert oversight during the data analysis piece, without his help with various S-PLUS® commands, this project would not have been possible. Professor Nussbaum was my cheerleader, constantly pushing this project towards completion and providing valuable input to the writing process.

A huge thank you goes to CDR Kevin J. Maher, who stepped up to the plate in my time of need to ensure that this thesis was completed on time.

I would like to thank CDR Dave Devlin at Commander Naval Air Forces (CNAF) for recommending this topic and providing funding and data. I hope that this thesis provides insight into ways to achieve the cost savings and avoidance that will be necessary in the upcoming budget years.

Most importantly, I would like to thank my wife, Amanda, and our two children, Cooper and Camden, for their constant support. Amanda, you are the foundation upon which I stand. You allow me to focus on my naval career by keeping our home in order. I am forever in your debt. My sons, Cooper and Camden, help me to not take myself too seriously, and ensure that I always remember the importance of being a father. Thank you all very much.

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I. INTRODUCTION

This thesis provides a statistical analysis of the costs of recent aircraft carrier port visits in an effort to identify and explain the cost drivers that contribute to port-visit costs. An understanding of the Cost Estimating Relationships (CER) that explain these costs provides a decision maker with a tool that can be used to forecast and monitor future port-visit expenditures.

A. RESEARCH QUESTIONS

The purpose of this study is to develop a method for predicting the cost of an aircraft carrier port visit that utilizes information about the ship, the port, and features of the visit (e.g., length of stay). The ability to predict these costs will benefit decision makers in several ways:

- Improved predictions of cost, leading to better budgeting and resource planning.
- Identification of cost drivers, giving managers information on where to apply effort aimed at reducing or controlling costs.
- Identification of alternatives (e.g., nearby ports), giving managers the ability to choose less-expensive options that satisfy operational objectives.
- Better knowledge of the factors that drive port-visit costs empower managers as they seek to structure contracts or bargain with port authorities to best use the Navy's resources.

In order to develop a tool that is suited to achieving these outcomes, this research starts by assessing the data that are available on aircraft carrier port-visit costs. Analysis of the data is directed to answering the following research questions.

1. Cost Drivers: Can the Cost Drivers for Aircraft Carrier Port-Visit Costs be Identified?

A cost driver is any factor that causes a change in the cost of an activity, or which has a statistical relationship to cost that makes it a surrogate for cost. An activity or event can have more than one cost driver attached to it. The most important factors in any CER are the cost drivers for that relationship. These factors identify the areas that, if controlled, result in estimated cost savings or avoidances (Luthra, 2008). In developing a CER to forecast port-visit costs, several cost drivers that are likely to be important are individual ship, port, region, length of stay, berthing position of the ship (pier side or at anchor), length of deployment, and date of arrival. Although historical port-visit costs have been recorded in several databases, little has been done to identify and examine the cost drivers for these events.

2. Forecasting Model: Can a Model be Developed to Accurately Forecast Port-Visit Costs, Providing Information on the Factors that Drive Port Costs, in an Effort to Reduce Variability and Save Money?

Although Commander Naval Air Forces has a method to forecast future port-visit costs, the method does not identify those cost categories that drive the price of these activities. A CER can be established to identify and explain the cost drivers associated with port-visit costs.

B. BACKGROUND

Due to the unique operating structure and cultural climate of the United States Navy and the Department of Defense (DoD), a discussion of the following terms is necessary in order to properly frame the analysis to follow. Several concepts specific to the United States Navy and its financial management structure are addressed below.

1. Department of Defense (DOD) Budget

The DoD is the United States' single largest agency, receiving more that half of the discretionary federal budget (DoD, 2007). With the exception of the costs of conducting the current Global War on Terror (GWOT), the largest DoD resource allocation is the operations and maintenance of military equipment. Figure 1 depicts the breakdown of DoD resources.

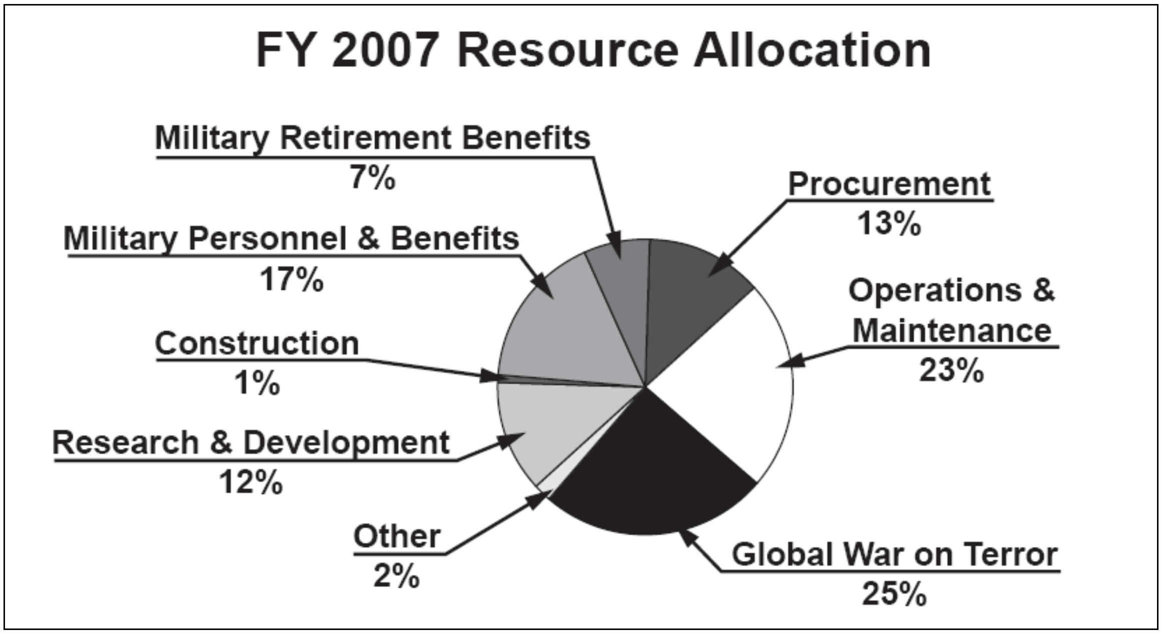

Figure 1. FY 2007 Department of Defense Resource Allocation (From DoD, 2007)

In an effort to offset the costs incurred by GWOT, DoD continues to search for cost savings and cost avoidances across all accounts, including operations and maintenance. As a result, U.S. Fleet Forces Command (USFF), which is responsible for organizing, manning, training, and equipping naval forces for assignment to combatant commanders, is seeking to cut costs in the operation and maintenance of Navy ships. One area that may lead to substantial cost savings without reducing fleet readiness is U.S. Navy aircraft carrier port-visit costs.

2. Carrier Vessel (CV) and Carrier Vessel Nuclear (CVN)

The United States Navy operates the largest fleet of aircraft carriers in the world. These aircraft carriers serve as vital symbols of our nation's commitment to provide a forward presence around the globe. The aircraft carrier, operating in international waters, is able to provide air assets when access to a foreign country's airfields is not possible. The aircraft carrier provides a broad range of capabilities, from providing presence and "showing the flag" to projecting power deep into enemy airspace (U.S. Navy, 2007). For the past three decades, the United States Navy has deployed both CVs and CVNs. (CV aircraft carriers are powered by boiler plants, while CVNs use nuclear rectors to provide steam to propel the ship). In 2008, the decision was made to decommission the last conventional aircraft carrier, USS KITTY HAWK (CV-64).

3. Port Visits

Although replenishment at sea from support ships and resupply from carrier onboard delivery (COD) aircraft enable an aircraft carrier to remain at sea and on station for extended periods of time, there is value in having aircraft carriers conduct port visits. In addition to "showing the flag," port visits provide rest and relaxation for sailors assigned to those ships, bolster the host country's local economy, and helps strengthen relationships between the host nation and the United States. Port-visit expenses are paid by the ship, out of an Operating Target (OPTAR) fund. OPTAR is discussed in Section E.

4. Operating Target (OPTAR) Funds

The Navy Comptroller provides Commander, Fleet Forces Command (CFFC) with funds from Congress's annually-approved Operating and Maintenance, Navy (O&M, N) obligation authority. CFFC provides Type Commanders (TYCOMs) with funds in separate OPTAR Fund Categories (OFC). The aircraft carrier TYCOM, Commander, Naval Air Forces, apportions money to individual aircraft carriers to cover the expenses incurred during of a port visit. All port-visit funds come from the OFC-20 account, which is the Supplies and Equipage (S&E) category and provides funds for obtaining materials or services used in the daily operation of the activity. These materials and services may include consumable supplies, repair parts, services, and maintenance contracts.

Funds to support aircraft operations are provided by two other accounts, OFC-01 and OFC-50. Figure 2 displays the hierarchical command structure within the DoD, as it applies to an individual aircraft carrier. Operating funds flow from DoD, through the subordinate commands, and to the individual aircraft carrier via the TYCOM.

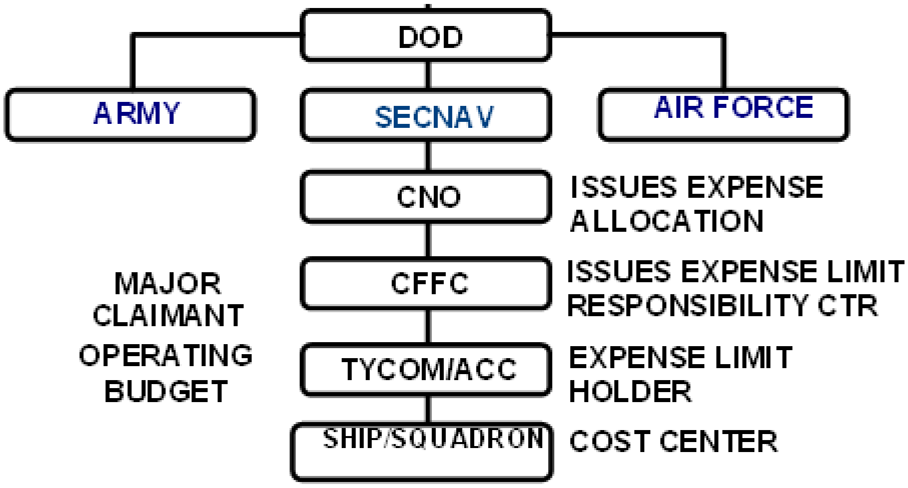

Figure 2. Command Structure from DoD to Individual Ship (from U. S. Navy, 2007)

5. Commander Naval Air Forces (CNAF)

In October 2001, the Chief of Naval Operations designated Commander Navy Air Forces, Pacific (COMNAVAIRPAC) as the aviation Fleet TYCOM, establishing it as Commander Naval Air Forces (CNAF). CNAF is the principal advisor to USFF on all aviation issues for the United States fleet and serves as the TYCOM for all U.S. Navy aircraft carriers located throughout the world. The Navy currently has multiple aircraft carriers home-ported in San Diego, CA., Everett, WA., Norfolk, VA., and one forward deployed in Japan. CNAF is located on Naval Air Station (NAS) North Island in San Diego (Pike, 2008).

C. MOTIVATION FOR THIS THESIS

Historically, predicting costs associated with an aircraft carrier port-visit has been difficult for the following reasons:

Expense categories are numerous and costs within them vary according to the conditions of a particular port visit.

- Short notice is given for upcoming port-visits as a security measure.
- Operations schedules sometimes change, resulting in differences in costs.
- Cost differences reflect the structuring of contracts.

1. Previous Works

There is little in the open literature on identifying relationships between factors that drive the cost of a port visit. It would be helpful if these factors could be identified and formed into a CER that could be used to predict future port-visit costs. Such predictions would provide comptrollers and resource managers with the tools necessary to budget the proper amount of funds for upcoming port visits. The forecasted port-visit costs also would be used to help guide the planning and scheduling process for future aircraft carrier deployments.

Variability in port costs can be attributed to a large number of non-contract line items and variable volume items purchased during a port visit (Gundermir, *et al*., 2007). The structuring of Navy husbanding service provider contracts can also lead to variability in port-visit costs (Verrastro, 1996). Such variability makes constructing accurate CERs difficult.

2. Husbanding Agent Contracts

Husbanding services contracts (HSCs) are requirements contracts established between the Navy and a husbanding services provider (HSP). These contracts provide a commercial means of obtaining services and materials for operating forces, including aircraft carriers. HSCs provide services to U.S. Navy and Coast Guard ships making port calls in non-Navy ports in the absence of permanent logistics infrastructure (Gundermir, 2007). The ship's supply officer works hand in hand with the HSP during a port visit to purchase supplies and services. The costs for purchased services and supplies are received, collected, and retained by the Navy.

3. Port-Visit Process

The Supply Officer (SUPPO) is designated by the ship's Commanding Officer to serve as the Contracting Officer with legal contracting authority. Prior to a port visit, the ship will send a logistics request (LOGREQ) to the HSP, listing the services and goods the ship requires. The HSP will respond with an estimate of each cost, as well as any service or request that is unable to be provided. SUPPO will also receive historical data from CNAF, based on recent aircraft carrier port visits to the same port. This information is provided from the PVCR database. A more in-depth discussion of this process is included in Chapter II A.

During the port visit, SUPPO will work with the HSP and other departments on the ship, to receive all items and services requested. SUPPO will ensure payment is made prior to leaving port. The bills that are paid represent the charges as they are known at the time of the ship's departure, and may not be the final charges. CNAF will ensure that funds are available to pay all bills.

After leaving port, the ship will send a PVCR to the TYCOM and other Navy activities. CNAF will then work with SUPPO to ensure funding is available to account for differences between initial estimates and actual charges. An illustration of this process is included in Figure 3.

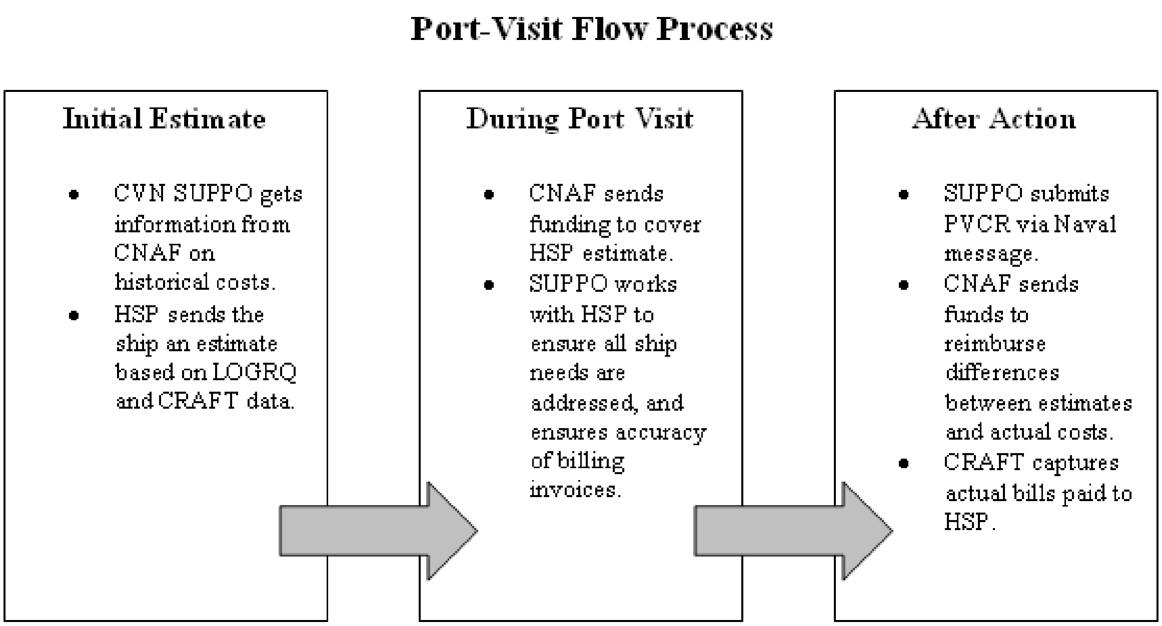

Figure 3. Flowchart of Supply Officer Interaction for a Port Visit

4. Current Port Cost Forecasting Method

In an effort to predict future port-visit costs, CNAF currently uses a three-period moving average model called the "Mac Model." This model has, as an input, PVCR information provided after each ship completes a port visit. For the aircraft carrier making an upcoming port visit, the last three aircraft carrier PVCRs are averaged to create a line item-by-line item estimate. Historical port-visits from previous FYs are normalized to current prices by using a flat 2 percent inflation factor. The resulting cost figures for each line item are provided to the ship's Supply Officer as an initial estimate of each line item (McKlveen, 2008).

D. THE NEED FOR COST SAVINGS AND COST AVOIDANCES

"Pressurization" is a term that has been used to describe a USFF-directed 20 percent cut in the Ship's Operating Account funding (OFC-20) for FY09 and FY10. Without further analysis, it is unclear how this 20 percent cut will affect aircraft carrier operating cycles, including port visits.

Annual budgets for the Mission and Other Ship Operations account are derived from a mathematical formula called the Ship Ops Model that calculates a 2-year moving average based on historical costs. While preparing the budget for Program Review 2009, Ship Operations resource sponsors in the Office of the Chief of Naval Operations, Fleet Readiness Division (N43), challenged the budget quantity produced by the Ship Ops Model and proposed a cut in the Ship's Operating account in favor of other budget objectives. Fleet Forces Command and the TYCOMs were given the opportunity to justify the Ship Ops Model amount, but were only able to defend approximately 80 percent of historical obligations. As a result, N43 proposed a 20 percent cut, or approximately $162 million, from the Ships Operating budget portion of the Mission and Other Ship Operations account to be applied in FY09. Ultimately, the 20 percent "pressurization" was applied across the Future Year Defense Plan (FYDP) out to FY13, amounting to approximately $861 million across the FYDP. To simulate the impact of reduced funding in FY09 and beyond, Fleet Forces Command levied its own 20 percent OPTAR cut for the current FY ending September 2008. In response, CNAF budget officials are harvesting funds from ships in maintenance or training phases to provide for those deployed or getting ready to deploy (York, 2008).

A 20-percent cut in FY09 OFC-20 funds is $33.6 million. CNAF has been presented with several options to save money and still maintain fleet readiness. These initiatives include:

- Deferring maintenance to future years.
- Underfunding nondeploying aircraft carriers.
- Reducing port-visit costs.

Pressurization goals are clearly defined in a recent CNAF memorandum. For FY09 aircraft carrier port-visit costs, CNAF is interested in identifying cost drivers in an effort to save $4 million. For more information on pressurization see the USFF memo in Appendix A.

E. THESIS OUTLINE

Chapter II discusses data collection and organization. The Navy currently uses Port Visit Cost Reports (PVCRs) submitted by ships after each port visit and maintained by Commander Naval Air Forces (CNAF), as well as the Cost Reporting, Analysis, and Forecasting Tool (CRAFT) databases. The CRAFT databases are maintained by Fleet Industrial Supply Center Detachments (FISC Dets) in Singapore and Sigonella, Italy to capture the historical costs associated with aircraft carrier port-visits. A comparison of these two databases is conducted to determine the better source of data for this thesis. The selection of variables believed to be significant as port-visit cost drivers is explored.

Chapter III provides the background information necessary to understand the analysis that was conducted on the data found in the CRAFT database. Linear models are explained, and the properties necessary to have a good linear model are listed. Methods for determining if a linear model is appropriate are discussed, as well as alternatives such as nonlinear models.

Results of these models are presented in Chapter IV. The resulting nonlinear CERs are developed and explained, with important variables and the information they provide being discussed. A model to predict total port-visit costs is introduced, as well as four sub models that help explain the cost drivers associated with aircraft carrier port-visits.

Chapter V presents conclusions and provides recommendations for future areas of work in this subject. Important variables are summarized, along with their contribution to the models is explained. Follow-on work in other fiscal years (FYs), and for other ships, will only serve to enrich the information provided here.

II. DATA COLLECTION AND ORGANIZATION

This chapter discusses the two databases that provide data for analysis in this thesis: CNAF's PVCR database in Norfolk, Virginia, and the CRAFT databases at Fleet Industrial Supply Center Detachments (FISC Dets) in Singapore and Sigonella, Italy. These are the only sources of historical aircraft carrier port-visit data available. One turns out to be more accurate (CRAFT) and is therefore chosen for analysis purposes.

A. PORT-VISIT COST REPORTS (PVCR)

CNAF directed that all aircraft carriers submit a PVCR for each port visited (U.S. Navy, 2006). These PVCRs are drafted by the aircraft carrier's supply department soon after leaving port and are sent to various recipients, including CNAF, to record the costs associated with a port visit. A narrative section at the bottom of the report provides a forum for ships to comment on the level of service received by the husbanding contractor, as well as any circumstances that contribute to unusually high costs. The PVCR gives a line item-by-line item breakdown of each service or purchased item, as well as the quantity and unit of issue. An annotated example of a PVCR is included in Figure 4. CNAF retains the information for historical record and to provide a reference for future visits to the same port. A drawback to sending the report immediately after leaving port is that some of the charges are not finalized. This leads to inaccuracy in the costs reported to the PVCR database. Also absent from the PVCRs is the actual requisition or expenditure number used by the ship, which also contributes to inaccurate recording of the port-visit costs.

SUBJ/PORT VISIT COST FOR PORT KLANG, MALAYSIA//
REF/A/DOC/COMNAVAIRFORINST 4440.2/10MAR2006//

AMPN/REFA IS COMNAVAIRFORCES SUPPLY OPERATIONS MANUAL//
RMKS/1. IAW REF A PARA 1018.2D, THE FOLLOWING COSTS WERE INCURRED DURING PORT VISIT TO PORT KLANG, MALAYSIA FROM 03-06 JUNE 2006:

SERVICE	U/I	QTY	TOTAL
A. HUSBANDING FEES	GP	1	$3,000.00
B. PILOTAGE	GP	1	$7,423.00
C. TUGS	GP	1	$72,779.20
D. LINEHANDLERS	GP	1	$2,600.00
E. BREASTING BARGES	GP	1	$16,000.00
F. YOKOHAMA FENDERS	GP	1	$32,000.00
G. WHARFAGE	GP	1	$163,440.00
H. PORT DUES	GP	1	$9,855.00
I. TRASH REMOVAL	GP	1	$14,400.00
J. BROW SERVICE	GP	1	$18,000.00
K. FORKLIFT	GP	1	$22,300.00
L. CRANE	GP	1	$17,550.00
M. MANLIFT	GP	1	$960.00
N. CHT REMOVAL	GP	1	$141,226.80
O. POTABLE WATER	GP	1	$20,662.20
P. CELL PHONE (PARTIAL FP)	GP	1	$24,880.00
Q. LANDLINE PHONES	GP	1	$3,150.00
R. BUS RENTAL	GP	1	$118,320.00
S. VAN RENTAL	GP	1	$25,725.00
T. SEDAN RENTAL	GP	1	$22,988.00
U. MATERIAL HANDLING	GP	1	$25,990.00
V. LATRINES	GP	1	$34,500.00
W. SECURITY TENTS (FP)	GP	1	$22,470.00
X. METAL DETECTOR/XRAY (FP)	GP	1	$3,500.00
Y. FLOATING PERIMETER (FP)	GP	1	$35,000.00
Z. ANTI SMALLCRAFT SYSTEM (FP)	GP	1	$245,000.00
AA. SECURITY BARRIERS (FP)	GP	1	$110,825.00
BB. SECURITY LIGHTING (FP)	GP	1	$12,250.00
CC. SECURITY TWO WAY RADIOS(FP)	GP	1	$175.00
DD. BUS PARK SECURITY (FP)	GP	1	$43,200.00
EE. GENERATOR POWER SUPPLY	GP	1	$13,475.00
FF. RECEPTION ITEMS	GP	1	$6,358.00
GG. MISC SUPPLIES	GP	1	$2,748.00
TOTAL			$1,292,750.20

Line item breakdown of charges during the port visit

2. HUSBANDING SERVICES WERE PROVIDED BY GLENN DEFENSE MARINE (ASIA)
SDSN
BHD. HUSBANDING AGENTS, CARMEN EDMONDS AND NEIL PETERSON, PROVIDED EXCELLENT SUPPORT AROUND THE CLOCK.
3. REMARKS: ORIG PULLED INTO PORT KLANG ON A MALAYSIAN HOLIDAY AND THE VISIT WAS CONDUCTED OVER A WEEKEND, RESULTING IN INCREASED PAGE 04
RHOVJQI0829 UNCLAS CHARGES FOR SEVERAL SERVICES.// BT
#0829
NNNN

Area for comments on charges and service

Figure 4. Example of a PVCR Message from (McKlveen, 2008)

B. COST REPORTING ANALYSIS AND FORECASTING TOOL (CRAFT)

The FISC Dets in Singapore and Sigonella maintain their own stand-alone databases (CRAFT) that include a collection of past PVCRs that have been compared to the actual bills paid to husbanding contractors. Each database contains ten years of data for CVN port visits within the region served by the individual FISC Det. Because CRAFT is operated by different FISC Dets, there are formatting, but not content, differences between the two databases. The CRAFT data are grouped by the type of service or item purchased. Unlike the data collected from the PVCR, data in the two CRAFT databases are entered with the actual requisition or expenditure number that the ship used to pay for the service or item. As a result, the CRAFT databases are more accurate reflections of the true costs of services or items. An example of a CRAFT report from Singapore is included in Appendix B.

C. NORMALIZATION OF DATA

The data for the aircraft carrier port visits contained in the PVCR and CRAFT databases dates back to 1997. In order to make comparisons between port visits in different years, the costs for each visit must be adjusted for inflation. In order to remove the effect of inflation during this analysis, all values are normalized to FY07 dollars. The standard approach to normalizing financial data is to apply an inflation index. The inflation index used is found in the Naval Center for Cost Analysis (NCCA) Inflation Calculator FY09 version 1 (Naval Center for Cost Analysis, 2008). The inflation factors for O&M, N are used to normalize all data to FY07 dollars.

An example of normalizing two port visits from the database is provided in Table 1. It compares CVN 76, which made a port visit in June 2006 to Hong Kong and spent $474.8 thousand in 2006 dollars (474.8 FY06$K), and CVN 72, which made a port visit in December 2004 to Hong Kong and spent $461.0 thousand in 2005 dollars (461.0 FY05$K). The conversion of both amounts to FY07$K units is obtained by dividing each cost by the appropriate inflation index for the year in which the cost originated. This information is displayed in Table 1.

Ship	Port	Arrival Date	Cost	Inflation Index	Cost (FY07$K)
CVN 76	Hong Kong	6/10/2006	474.8 (FY06$K)	.9737	487.67
CVN 72	Hong Kong	12/24/2004	461.0 (FY05$K)	.9444	488.14

Table 1. Normalization of Data from Two Port-Visit Observations

In the initial cost column, it appears that the CVN 76 port visit was more expensive than the CVN 72 port visit. When both costs are normalized to FY07$K using the inflation indexes available from the NCCA Website, the CVN 72 port visit is shown to be slightly more expensive than the CVN 76 port visit.

D. COMPARING DATABASES

Although, the PVCR and CRAFT databases contain historical port-visit information dating back to 1997, the decision was made to analyze the data from FY03 through FY07. Aircraft carrier deployment cycles, and resulting port visits, have radically changed as a result of the GWOT.

A comparison of CV and CVN port-visit costs for FY03 through FY07 reveal substantial differences between the PVCR and CRAFT databases. The visit of the USS GEORGE WASHINGTION (CVN 73) to the port of Souda Bay, Crete from 6 February 2004 to 10 February 2004 is illustrative. While charges in several categories shown in Table 2 match exactly in the two databases (husbanding contractor fees, barges, and buses) and differ by small amounts in others (crane services and rental cars), there is a large difference in tug costs. A stand-by tug charge was included in the CRAFT database, but not in the PVCR data.

Charge	PVCR (FY07$)	CRAFT (FY07$)	Difference (FY07$)
Husbanding Contractor Fee	11,315	11,315	0
Brows rentals	13,107	13,107	0
Buses	73,384	73,384	0
Crane services	20,780	22,242	1,462
Rental cars	22,957	22,147	–810
Tugs	39,191	182,398	143,207

Table 2. Table of Charges in PVCR and CRAFT for CVN 73 Port Visit to Souda Bay, Crete from 6 February 2004 to 10 February 2004

While the differences between the PVCR and CRAFT databases are not always as large as this example indicates, there are minor differences in the data for many port visits. One reason for the differences might be due to the time frame associated with the submission of the PVCR. As mentioned previously, the PVCR is sent out shortly after leaving port and all bills might not be finalized. Because the format includes requisition numbers for services and items purchased, the CRAFT database is a more accurate record of the costs associated with a port visit because reconciliation has been conducted between the PVCR and the actual requisition numbers assigned to the payment of dealer bills.

After discussions with CNAF, the decision was made to use the CRAFT Website data for the purpose of this thesis.

E. GROUPING OF COSTS

Information in the CRAFT database is presented by line item of the service provided or purchased during the port visit. Costs are broken down into nearly 100 line items, many of which are shown in the CRAFT report in Appendix B. For analytical purposes, these line items are grouped into the following six categories:

- Force Protection
- Material Handling
- Port Fees
- Transportation
- Utilities
- Miscellaneous Supplies

The decision to use these categories reflects CNAF's desire to capture the costs of items from centrally-funded pools of money, such as Utilities and Force Protection, as well as those charges that might lend themselves to a standardized packaging of goods, such as Transportation.

The mapping from the full list of line items to the six categories identified above is given in Table 3.

FORCE PROTECTION	**MATERIAL HANDLING**	**MISC SERVICES/SUPPLY**
Beach Guard Office Rental	Cargo Drayage	Crew Repatriation
Beach Guard Phone Rental	Cargo Lighterage	Crew Support-Medical
Beach Guard Transportation	Crane	Crew Support-Other
FP Diving Services	Forklift Service	Hazmat
FP Generators	Mail Delivery Charge	Laundry
FP Metal Detector	Material Handling	Misc. Services and Supplies
FP Passenger Terminal Hire	Stevedoring	Mobilization/Demobilization
FP Transportation		Paint Float
FP Tug		Paint Services
FP Vetting Barge	**UTILITIES**	Portable Toilets
FP Vetting Services	Cell Airtime	Reefer Rental
FP Barricade	Cell Phone Rental	Tent Rental
FP Barrier	CHT Barge	
FP Beach Guard Office/Tent	CHT Disposal	
FP Bomb/Dog Handlers	CHT Holding Tank Rental	**PORT FEES**
FP Divers	CHT Removal	Barges
FP Fencing	CHT Removal by Truck	Berthing Fee
FP Floating Perimiters	Communication Service/Equipment	Mooring Boat
FP Lighting	Feed Water	Brow
FP Other	Firemain Service	Camels
FP Picket Boat	Fuel Service Charge	Customs
FP Police Support	Fuel F76	Fender Fixed
FP Portable Latrines	Gas	Fender Rental
FP Radios	Generator	Fleet Landing Fee
FP Security Guards	Landline Usage	H/A Fees
FP Warning Signs	Landlines	Immigration Fee
FP X-Ray Machine	Lost Cell Phone	Launching Fee
FP Guard Shack	Oil Boom	Line Handlers
	Oily Waste Tank Rental	Line Boat
	Oily Waste Removal	Pilot
TRANSPORTATION	Potable Water Connection	Port Fees
Bus Rental	Potable Water	Pratique
Drivers	Shore Power	Tugs
Rental Sedans	Trash Removal	
Rental Truck	Waste Oil Disposal	
Rental Van	Waste Water Disposal	
Standby Truck Service	Water Connection	
Transportation		
Water Taxi		

Table 3. Mapping of Line Item Charges Into Six Charge Categories

F. SELECTION OF EXPLANATORY VARIABLES

In an effort to capture the cost drivers and attempt to explain the variability in port-visit costs, explanatory factors are developed based on events that are believed to have an impact on cost. The corresponding independent variables are displayed in Table 4. A more detailed description of several factors follows the table.

Variable Name	Description
Ship	The CVN making the port visit
Port	The port where the port visit occurred
Arrival Date	The julian date on which the ship started the port visit
Pier side	Binary variable that indicates if the ship was pier side or at anchor for the port visit
Length of Stay	The number of days that the ship was in port
Deployment Number	A chronological number of deployments the ship made in the database
Visit Number	The chronological number of visits on a given deployment in the database
Depfrac	The fraction of the current port visit over the number of port visits made throughout that deployment, expressed as a decimal

Table 4. Description of Independent Variables

A detailed understanding of the variables is necessary to better explain the results of the models and the hypotheses that were tested. The results of the inclusion of these variables in the resulting models are described in Chapter V.

1. The Ship Variables

It is of interest to consider whether the individual ship is an important factor in determining port-visit costs. A Ship variable is created for each aircraft carrier in the database. In subsequent statistical analysis, a ship variable equals 1 if the record pertains to that ship and is equal to 0 otherwise. No special consideration was given for the fact that different commanding officers and supply officers served on the ships during the visits recorded in the database. Table 5 lists the ship variables.

Aircraft Carrier Name	Variable Name
CVN 72 USS ABRAHAM LINCOLN	CVN72
CVN 70 USS CARL VINSON	CVN70
CV 63 USS CONSTELLATION	CV63
CVN 69 USS DWIGHT D EISENHOWER	CVN69
CVN 65 USS ENTERPRISE	CVN65
CVN 73 USS GEORGE WASHINGTON	CVN73
CVN 75 USS HARRY S. TRUMAN	CVN75
CVN 74 USS JOHN C. STENNIS	CVN74
CV 67 USS JOHN F. KENNEDY	CV67
CV 64 USS KITTY HAWK	CV64
CVN 68 USS NIMITZ	CVN68
CVN 76 USS RONALD REAGAN	CVN76
CVN 71 USS THEODORE ROOSEVELT	CVN71

Table 5. List of Ship Variables

2. The Port Group Variables

It is of interest to consider whether the individual port is an important factor in determining port-visit costs. Due to the large number of ports that are visited, taken in conjunction with the 13 ships represented in the data base, the ports are grouped for analytical purposes. Any port that isrequently visited and has a substantial number of observations is treated as their own groups. Jebel Ali, Hong Kong, Singapore, and Bahrain compose this category. Ports with fewer observations must be pooled together. When total port costs of these ports are examined, a natural separation exists between high-, medium-, and low-cost ports. High-cost ports include: Brisbane, Koper, Laem Chabang, Lisbon, Port Klang, Portsmouth, and Tarragona. Medium-cost ports are: Corfu, Freemantle, Limassol, Marseille, Naples, Palma, Rhodes, Souda Bay, and Valletta. Low-cost ports are: Cannes, Cartagena, Split, and Sydney. Table 6 shows the port groups. In subsequent statistical analysis, a group variable equals 1 if the port that was visited belongs to the respective group and to 0 otherwise.

Port Visit Location	Variable Name
Singapore	Singapore
Brisbane, Koper, Laem Chabang, Lisbon, Port Klang, Portsmouth, Tarragona	High Cost
Hong Kong	Hong Kong
Jebel Ali	Jebel Ali
Cannes, Cartagena, Split, Sydney	Low Cost
Manama	Manama
Corfu, Fremantle, Limassol, Marseille, Naples, Palma De Mallorca, Rhodes, Souda Bay, Valletta	Medium Cost

Table 6. List of Port-Visit Locations

3. Arrival Date

All costs are normalized to a base of 2007 U.S. dollars. Nonetheless, there is a possibility that a temporal trend will remain after such adjustment. This may be due to the inflation adjustment not being completely accurate, or to changes in spending patterns that cannot be accounted for in an inflation adjustment. We test the hypothesis that the date the ship arrives in port is an important factor in determining port-visit costs. Arrival Date is a quantitative variable based on the day the aircraft carrier enters port. Arrival Date is expressed as the number of days that transpired since 1 January 1960.

4. The Pier Side Variable

It is of interest to consider whether the berth of the ship, either pier side or at anchor, is an important factor in determining port-visit costs. Pier side is a variable that equals 1 if the aircraft carrier is moored pier side at the port, and equals 0 if the aircraft carrier is at anchor. Typically, the costs of offloading trash and sewage and providing increased force protection, as well as the additional transportation cost of shuttling sailors to shore, make port visits at anchor more expensive than those that are pier side.

5. Length of Visit

It is expected that some of the costs incurred during a port visit have an increasing relationship with the duration of the visit. For this reason, the length of stay, in days is considered as an explanatory variable.

6. Deployment Fraction

It is of interest to consider whether a ship's spending habits change over the course of a deployment. In particular, does a ship spend money more liberally in the first stages of a deployment, in anticipation of asking for money once the allocated funds have been spent? Or, does a ship spread money equally over the course of a deployment? Does a ship stockpile funds for a later port visit, in anticipation of a "better" port visit at the end of the deployment? A deployment fraction (Depfrac) variable is derived as an explanatory variable in an attempt to capture these effects.

Depfrac is the fraction of the current port visit over the number of port visits made throughout that deployment, expressed as a decimal. As an example, a Depfrac of 0.25 would mean that the port visit occurred when the ship was 25 percent of the way through the deployment for that ship that occurred during the time frame of the database.

III. CONCEPTS OF ANALYSIS

This chapter addresses the models that are constructed from the normalized data in the six cost categories, as well as the total costs associated with each port visit. Contained in the database are records of port-visit costs for 13 aircraft carriers making 118 port visits in 25 countries. The port visit to Chennai, India by the USS NIMITZ (CVN 68) in July 2007 was an isolated event, resulting in extremely high port costs, and therefore did not add value to any attempt to forecast future port-visit costs. For this reason, that particular port visit was excluded from the database.

The following topics are addressed in this chapter:

- Development of linear models.
- Choosing a transformation for the cost variable.
- Use of stepwise regression for final model selection.
- Reexpression of the regression to enhance explainability.

A. LINEAR MODELS

Linear models are simple tools for deriving CERs, although their flexibility is limited by their mathematical form. Let Y denote the cost of a port visit (in FY07$) either in total or within a specific category such as Utilities. Let $X_1, X_2, \ldots, X_p$ denote a collection of potential explanatory variables. A linear model takes the following form:

$$Y = \beta_0 + \beta_1 X_1 + \cdots + \beta_p X_p + \varepsilon,$$

where ε is a random error term (residual) assumed to be distributed as a normal random variable with mean 0 and constant standard deviation denoted by σ. A linear model of this type is commonly estimated from data using ordinary least squares (OLS), for which a wide variety of software packages are available. Several features of this model are important to determining whether it is appropriate for a particular situation:

- **Linearity.** The term "linear model" derives from the relationship of the coefficient terms ($\beta_0, \beta_1, \ldots, \beta_p$) to the response variable (Y) ignoring the error term (ε). It implies an additive relationship that is not always applicable. It is, however, flexible enough to encompass models in which the explanatory variables are transformed or combined with each other to form interaction terms. For example, the following is a linear model:

  $$Y = \beta_0 + \beta_1 \log(X_1) + \beta_2 X_1 X_2 + \varepsilon .$$

  In this model, the term $X_1 X_2$ is an interaction between two of the explanatory variables.

- **Normality.** The error term (ε) is assumed to have a normal distribution. In some cases, the error term may have skewed or heavy-tailed distributions that are indicative of nonnormality. In this case, remedial action or a different modeling technique may be required.

- **Homoscedasticity.** The error term (ε) is assumed to have a constant standard deviation, regardless of the values of the explanatory variables. In many instances, this assumption is violated (a condition known as heteroscedasticity), and remedial action or a different modeling technique may be required.

- **Independence.** The error term (ε) is assumed to be independent across observations. If the error terms are correlated in time sequence (serial correlation) or show other patterns of dependence, techniques such as generalized least squares (GLS) are preferred to OLS.

It is not uncommon to find that violation of one of the first three assumptions implies violation of the others, in which case, remedial action may address all three violations simultaneously. Typically, the appropriateness of a linear model is assessed by examining the residuals obtained by fitting the model to data using OLS. Suppose that the fitted model is expressed as follows:

$$\hat{Y}_i = b_0 + b_1 X_{i1} + \cdots + b_p X_{ip}, \ i = 1, \ldots, n,$$

where n is the sample size. The residuals are the differences of the predicted values ($\hat{Y}_i$) from the actual value of the response variable (Y_i):

$$e_i = Y_i - \hat{Y}_i, \ i = 1, \ldots, n$$

It is useful to examine plots of the residuals versus the fitted values to detect potential nonlinearity and heteroscedasticity. A normal quantile-quantile plot (QQ plot) of the residuals gives useful information about the appropriateness of the normality assumption. Details on fitting linear models to data can be found in Montgomery (2006).

Detecting violations of the independence assumption is less straightforward in the present case due to the grouping of observations by ships and ports, and the relatively small sample size. Although it is no longer optimal, OLS regression continues to provide unbiased estimates of the true model, even if correlation among the residuals is present (Montgomery, 2006). OLS is used in the analysis of port-visit costs, although detailed consideration of the independence assumption may be worthwhile as more data on port-visit costs are obtained.

Linear models are constructed for the total costs of each port visit, and separately for four of the cost categories listed below:

- Force Protection.
- Port Fees.
- Transportation.
- Utilities.

The other two cost categories are not individually considered, but are included in the Total Cost Model.

Linear models were initially developed using S-Plus® software to explain the cost drivers that affect port-visit costs. An analysis of the plots of the resulting CER shows that a linear model is not appropriate for these relationships. The results of these models are discussed in Chapter V.

B. CHOICE OF TRANSFORMATION

The plots of the linear models indicate that a better model could be fit by introducing a nonlinear CER. Models are therefore constructed using different nonlinear transformations. Analysis of the resulting plots indicates that the best transformation is a logarithm transformation, which is explained in Chapter V.

An advantage to using a logarithm transformation of the cost variable is that linear models take on a multiplicative character when the logarithm transformation is inverted. For example, a log-linear model of the form $\log(Y) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \varepsilon$ is expressible as $Y = \gamma_0 (Z_1)^{\beta_1} (Z_2)^{\beta_2} \times \text{error}$, where $\gamma_0 = \exp(\beta_0)$, $Z_1 = \exp(X_1)$, $Z_2 = \exp(X_2)$, and $\text{error} = \exp(\varepsilon)$. Here, the logarithm refers to the natural logarithm, as it does in the remainder of this thesis. In original (dollar) units, the model suggests that the cost (Y) begins with a base amount (γ_0), which is multiplicatively adjusted by the two explanatory variables (Z_1, Z_2) raised to different powers. The model, not being perfect, is subject to error, which is represented by the final multiplicative term in the model. Multiplicative adjustments account for costs in relative terms, whereas additive adjustments (i.e., without the use of a logarithmic transformation) account for costs in absolute terms. Given that port-visit costs can vary greatly in magnitude depending on the circumstances of a port visit, multiplicative adjustments appear to be more sensible than additive adjustments for the purpose of model development.

A disadvantage to using logarithms is that costs that are represented as equal to zero cannot be handled. This occurred in the Force Protection costs reported in four of the observations associated with one of the aircraft carriers. A possible explanation for this is that the costs are reported under a different category, which brings into question the reliability of these categorized costs as a whole. As a result, the four observations are removed from all categorized-cost analyses. These observations are, however, included in the analysis of total costs.

C. MODEL SELECTION IN REGRESSION

Due to the large number of regressions that must be examined when a CER contains many possible explanatory variables, statistical variable selection routines, such as stepwise regression, are used to develop parsimonious models that have good explanatory power (Montgomery, 2006). In the development of an explanatory model for the logarithm of port costs, stepwise regression is used in conjunction with the Akaike Information Criterion (AIC) to penalize over-fitting of the model. AIC is defined as follows:

$$\mathrm{AIC} = n\log(\mathrm{RSS}/n) + 2(p+1),$$

where $\mathrm{RSS} = \sum_{i=1}^{n} e_i^2$ is the residual sum of squares and $p+1$ is the total number of parameters in the model (Venables, 2002). Stepwise regression seeks a model that minimizes AIC.

The S-Plus command **stepAIC**, available in the Modern Applied Statistics with S-Plus (MASS) library (Venables, 2002), is used to implement this technique. The results of this model-building exercise are discussed in Chapter V, with the presentation of the final models.

D. BASE LINING

The regression models developed provide for the possibility of effects due to individual ships and ports. These effects are estimated through the use of indicator variables. For example, the indicator variable CVN74 is equal to 1 if a particular data record corresponds to USS JOHN C STENNIS and is equal to 0 otherwise. Taken as a group, there are 13 indicator variables for ships. In regression modeling, however, it is necessary to omit one of these variables to prevent singularity in the design matrix. In many statistical software packages, including S-Plus, the default is to exclude the first indicator variable of a set. In the present case, this implies that regression is conducted by omitting CVN72, which is the first of the named ship variables in alphanumeric sorted order. The effect for CVN72 is formally treated as 0 (although the effect is actually captured by the constant term in the model), and the effects for the other 12 ships are expressed as differences from the CVN72 effect. In other words, CVN72 is a base line against which all other ships are compared. The choice of baseline is, however, arbitrary, and it may be more appealing to center the ship effects relative to the “average” ship effect. This is done by linearly transforming the 13 ship effects so that they sum to 0. Under this base lining, a negative coefficient implies that the ship has below-average costs (relative to all ships) and a positive coefficient implies that the ship has above-average costs. This base lining is a reexpression of the original model that does not change its mathematical properties. Similarly, the effects for Port Groups can be expressed so that they sum to 0, which is a base lining to the average Port Group effect.

Base lining to the average is applied to all CER models that include Ship and Port Group indicator variables.

E. EVALUATING COST ESTIMATING RELATIONSHIPS (CER)

When a regression relationship is estimated from data, there is statistical uncertainty in the estimated coefficients and in how well the regression predicts the response variable. There is a well-established theory of the statistical properties of OLS regression estimation, as can be found in Montgomery (2006) and many other sources. For example, to test whether explanatory variable X_1 has predictive value, attention focuses on its coefficient β_1. A test of the null hypothesis that $\beta_1 = 0$ versus the alternative that $\beta_1 \neq 0$ is based on the standardized estimated regression coefficient:

$$t = \frac{b_1}{SE(b_1)},$$

where $SE(b_1)$ is the estimated standard error of the estimated regression coefficient. Under the null hypothesis, and assuming that the assumptions of the model are valid, the standardized estimated regression coefficient has a Students *t* distribution with $n - p - 1$ degrees of freedom. To test whether a set of *k* explanatory variables (such as the Ship or Port Group indicator variables) has predictive value, the following quantity is used:

$$f = \frac{(\mathrm{RSS}_1 - \mathrm{RSS}_2)/k}{\mathrm{RSS}_1/(n-p-k-1)},$$

where RSS_1 is the sum of squared errors for the regression with the *k* explanatory variables (and $p+1$ others included in the model), and RSS_2 is the sum of squared errors for the regression omitting the *k* explanatory variables. Under the null hypothesis, *f* has an *F*-distribution with *k* and $n-p-k-1$ numerator and denominator degrees of freedom, respectively.

A commonly-used goodness-of-fit measure in regression is the coefficient of determination, denoted R^2, which is interpreted as the proportion of variance explained by the regression. For example, $R^2 = .75$ suggests that 75 percent of the variance of *Y* is accounted for by the explanatory variables in the regression. As explained in Section D, model selection based on goodness-of-fit measures needs to incorporate a penalty for over-fitting the data, which is included in the AIC criterion.

In a regression where the explanatory variable *Y* has been transformed, R^2 does not give a useful measure of how well the regression explains *Y* in its original units. If a logarithmic transformation is used in the regression, a useful goodness-of-fit measure is the average percentage relative error (APRE) defined as follows:

$$\mathrm{APRE} = 100\% \times \frac{1}{n}\sum_{i=1}^{n}\frac{|Y_i - \hat{Y}_i|}{Y_i},$$

where $\hat{Y}_i$ is the exponentiated regression prediction based on the logarithm of *Y*, and *n* is the sample size. For example, $\mathrm{APRE} = 15\%$ suggests that, on average, the prediction error is 15 percent of the true value of *Y*.

Prediction of a future value of *Y* based on knowledge of the explanatory variables is subject to two sources of uncertainty: estimation of the model parameters and the inherent variability of port-visit costs, even if the true regression relationships are known. If a logarithm transformation produces a linear model with a normally distributed error term (ε), a 95 percent prediction interval for $\log(Y)$ can be obtained using classical techniques outlined in Montgomery (2006). This interval takes the form $\hat{\ell} \pm 1.96\hat{\sigma}_{\text{PRED}}$, where $\hat{\ell}$ is the predicted value for $\log(Y)$ based on the explanatory variables, and $\hat{\sigma}_{\text{PRED}}$ is the estimated standard error of the prediction. If a different confidence level is desired, the coefficient 1.96 is changed accordingly, using either the standard normal (large sample) or Student's *t* (small sample) distribution. An equivalent prediction interval for Y can be obtained by exponentiating the endpoints of the prediction interval for $\log(Y)$, thus expressing the interval in dollar units.

IV. RESULTS OF THE ANALYSIS

Chapter III outlines an analysis that is applied to the CVN port-cost data. This chapter presents the results of the analysis. It also introduces an automated user interface in Microsoft Excel that allows the user to obtained estimated port-visit costs by supplying a small number of inputs. The tool can be used to not only anticipate the costs of an upcoming port visit, but also to focus on aspects of the port visit that drive costs. It also facilitates comparison of alternatives, which gives cost managers flexibility in attempting to reduce port-visit costs.

A. LINEAR MODELS

Linear models with untransformed cost variables are initially developed in an attempt to describe the cost drivers for port-visit costs. Models are constructed for total costs and costs in the four subcategories of Force Protection, Port Fees, Transportation, and Utilities. Diagnostic plots of these model-fitting exercises suggest violations of the basic assumptions outlined in Chapter IV. Figure 5 shows a plot of the residuals versus fitted values for the total-cost regression, which exhibits a pattern typical of heteroscedasticity. The larger dispersion of observations on the right-hand side of the plot, compared to the small dispersion of observations on the left-hand side of the plot, resulting in a funneling pattern that implies heterscedasticity. This suggests that high-cost port visits are more variable (in absolute terms) than low-cost port visits. Figure 6 shows a normal QQ plot for the residuals from the same model. Again, a violation of assumptions is indicated by the lack of linearity suggested by the QQ plot, particularly for larger residuals.

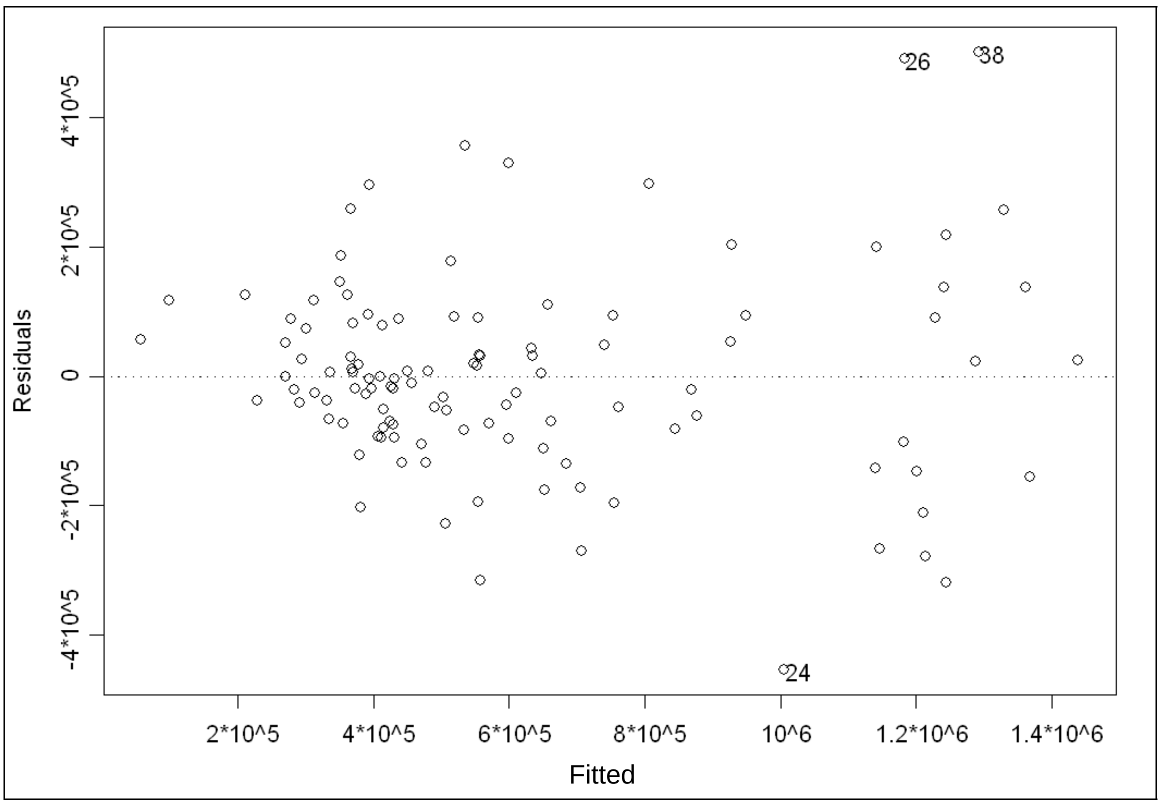

Figure 5. Residuals Versus Fitted Values for the Linear Total-Cost Model

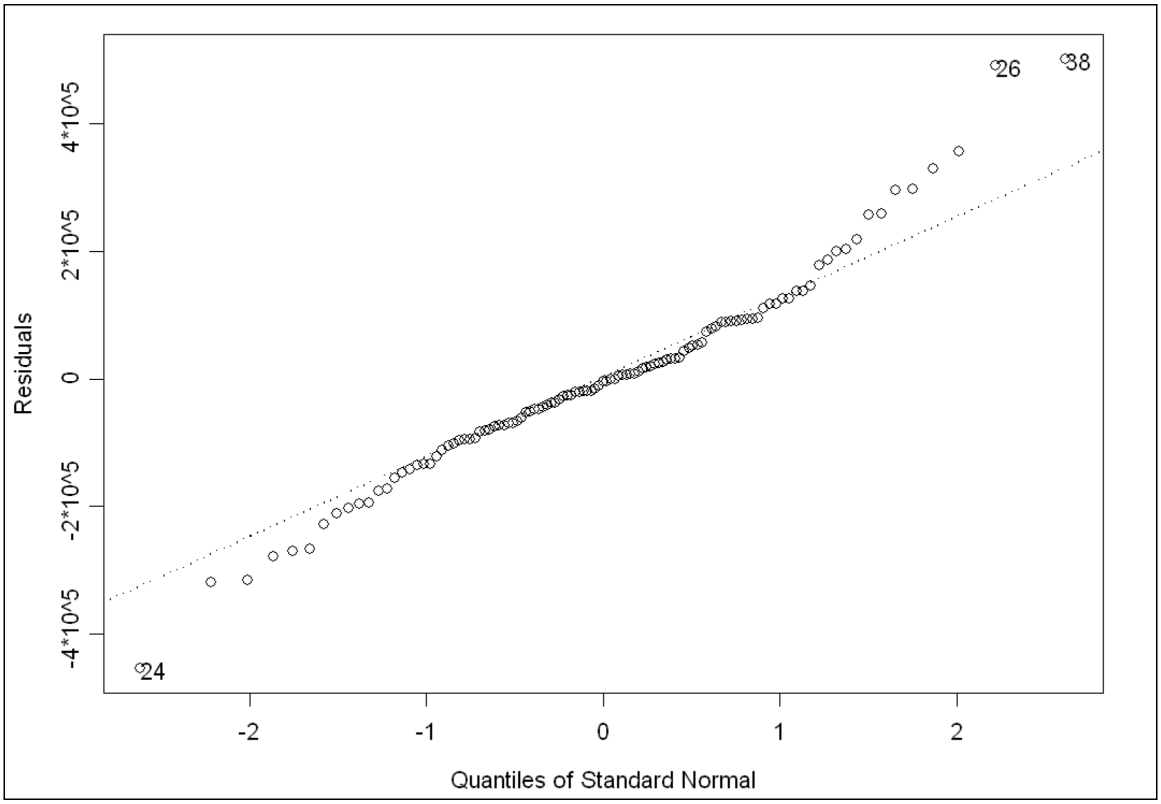

Figure 6. Residual Normal QQ Plot for the Linear Total-Cost Model

Because of the deficiencies seen in linear model's fit to untransformed cost variables, models based on transformed cost variables are considered. These models retain their linear structure on a transformed cost-measurement scale, and become nonlinear when the transformation is inverted. These models are described in Section B.

B. NONLINEAR MODELS

Several transformations of port-visit costs (reciprocal, power, and logarithmic) are evaluated in an attempt to fit linear models that are homoscedastic and which produce residuals that follow a normal distribution reasonably well. Residual plots of these transformed, nonlinear models are examined. The best transformation is found to be the logarithmic one, as supported by the plot of residuals versus fitted values (Figure 7) and the residual QQ plot (Figure 8).

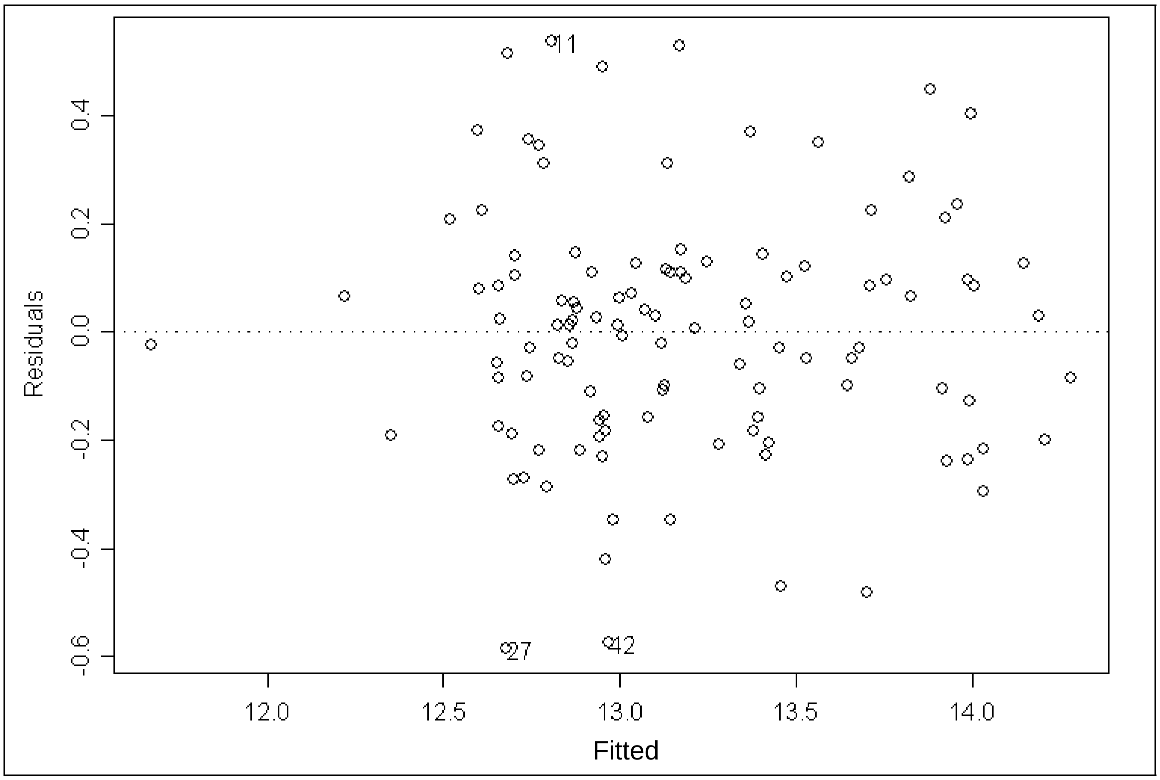

Figure 7. Residuals Versus Fitted Values Plot for the Log–Transformed Total-Cost Model

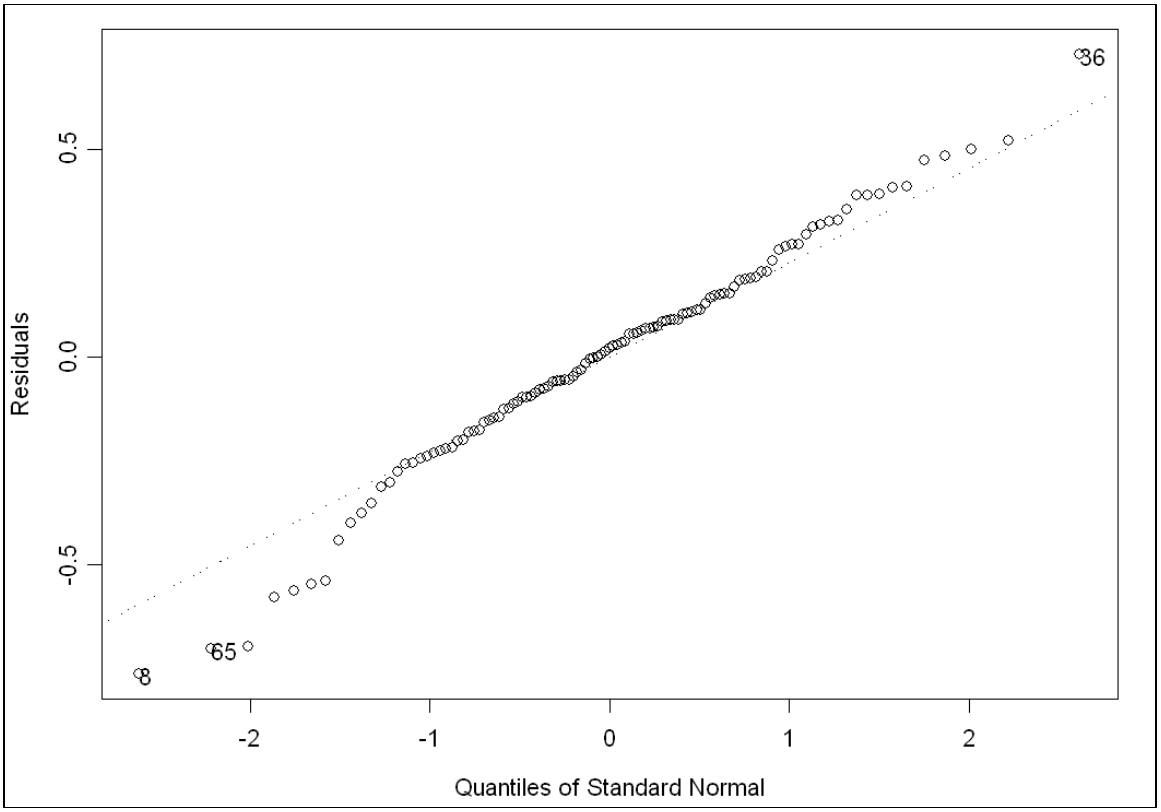

Figure 8. Residual Normal QQ Plot for the Log-Transformed Total-Cost Model

That a logarithmic transformation improves statistical modeling of port-visit costs is clear from the analysis presented in this section. It is also intuitively reasonable that such costs be expressed on a log-linear scale. If the logarithm of cost is explained as a series of additive effects due to ships, ports, length of port visit, etc., then cost itself is explained as a series of multiplicative effects. Prediction of a port-visit cost begins with a base cost, followed by multiplicative adjustments for the ship, port, and other factors, until a final predicted cost is obtained.

C. RESULTING SUBMODELS

Nonlinear models are developed for the four charge categories of Force Protection, Port Fees, Transportation, and Utilities. Utilities, Port Fees, and Transportation are the three largest cost drivers in the database for aircraft carrier port-visit costs. Savings initiatives and cost-controlling measures should be focused in these three categories. The majority of the charges in Port Fees are fixed costs that do not vary from port visit to port visit. The variability in Transportation might be controlled through effective policy implementation. A standardized package of water taxis, rental cars, and support trucks could be prescribed in order to reduce variability. The variability in Utilities is largely due to variability in collection, holding and transfer (CHT) disposal costs from port visit to port visit. Close monitoring of the volume of offloaded CHT and trash can greatly reduce the variability in this category. Figure 9 summarizes the impact of each category on overall port-visit cost.

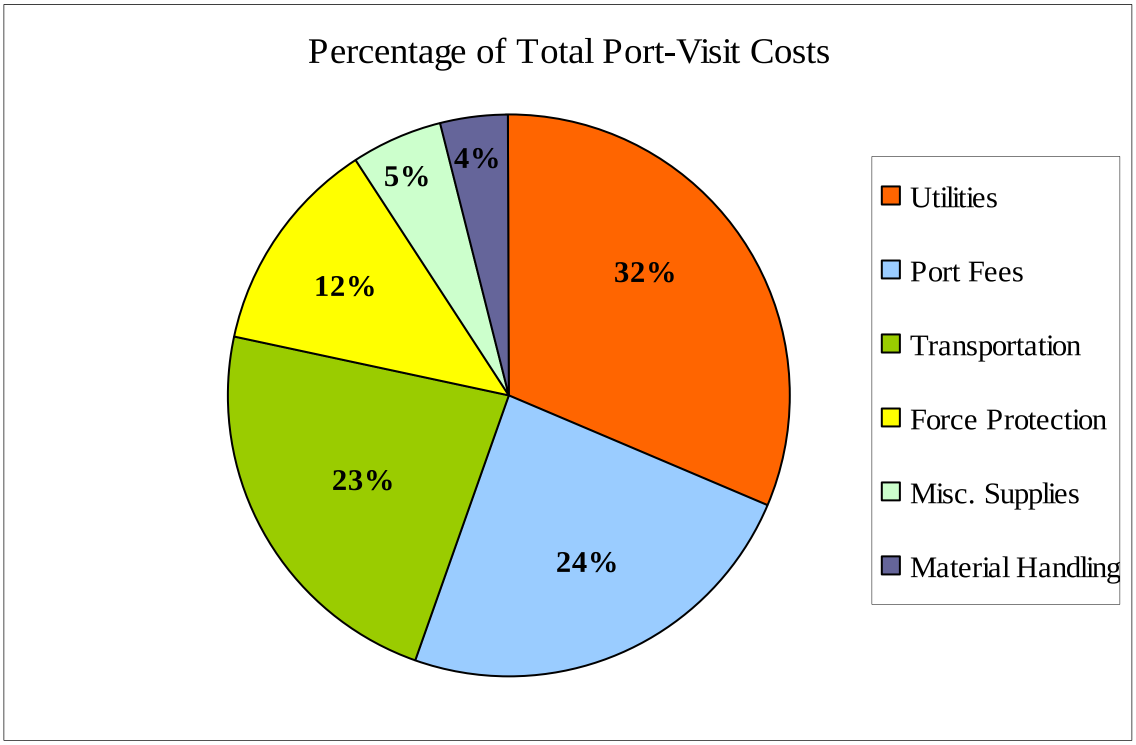

Figure 9. Percentage of Total Port-Visit Costs FY03-FY07

The resulting nonlinear models for the four charge categories are displayed in the following subsections.

1. The Force Protection Model

The resulting Force Protection Model can be expressed in the nonlinear form in terms of log(dollars) as:

$$\log(Y_{\text{ForceProtection}}) = \beta_0 + \sum_{s=1}^{13} \beta_{1,s} X_{1,s} + \sum_{r=1}^{7} \beta_{2,r} X_{2,r} + \beta_3 X_3 + \beta_{3,4} X_3 X_4 + \beta_{4,5} X_4 \log(X_5),$$

where β_j represents the coefficient for the following terms (Table 7):

Coefficient	Explanatory Effect
β_0	Intercept
$\beta_{1,s}, s = 1, \ldots, 13$	Individual Ship variables
$\beta_{2,r}, r = 1, \ldots, 7$	Individual Port Variables
β_3	Pier Side (1 = Yes, 0 = No)
$\beta_{3,4}$	Interaction between Arrival Date and Pier Side
$\beta_{4,5}$	Interaction between log (Length of Stay) and Arrival Date

Table 7. Explanation of Coefficients for the Force Protection Model

The coefficients for the Force Protection Model are displayed in Table 8.

Explanatory Variable	Coefficient Value	Standard Error	t -ratio	P-value
(Intercept)	10.41	0.139	74.892	0.000
CVN73	–0.388	0.297	–1.306	0.191
CVN75	–0.313	0.256	–1.223	0.221
CVN71	–0.323	0.258	–1.252	0.211
All other ships	0.102	0.046	2.217	0.027
High Cost	0.803	0.178	4.511	0.000
Hong Kong	0.565	0.248	2.278	0.023
Manama	0.203	0.269	0.755	0.450
Med Cost	0.154	0.176	0.875	0.382
All other ports	–0.576	0.122	–4.721	0.000
Pier Side	–14.863	3.676	–4.043	0.000
Arrival Date x Pier Side	0.0007	0.0002	3.500	0.000
log(length) x Pier Side	1.893	0.417	4.540	0.000

Residual standard error: 0.7994 on 102 degrees of freedom
Multiple R-Squared: 0.4183
F-statistic: 7.335 on 10 and 102 degrees of freedom, the p-value is 1.164e-008

Table 8. Table of Coefficients for the Force Protection Model

The Force Protection Model has a large percentage of unexplained variability in the regression. This may be due to the high variability of threat conditions that prevailed across the time period of the study and across ports dispersed around the globe. High priority is necessarily placed on having the level of force protection needed to safely conduct a port visit. The large negative coefficient for Pier Side implies that force protection costs are much cheaper if an aircraft carrier is pier side versus at anchor. While it is reasonable to believe that costs related to picket boats and harbor patrols might be more expensive for a ship at anchor, it is important to remember that the CER for force protection is not a very strong fit, allowing for an increased margin of error in the estimate. The presence of an interaction term including Arrival Date suggests that there is a temporal effect in the Force Protection Model. The small coefficient for Arrival Date is due to the relatively large magnitude of the Julian date used in the computation. The presence of the Length of Stay variable in the Force Protection Model is intuitive, due to the large number of variable costs in the Force Protection charge category.

2. The Port Fees Model

The resulting Port Fees Model can be expressed in the nonlinear form in terms of log(dollars) as:

$$\log(Y_{\text{PortFees}}) = \beta_0 + \sum_{s=1}^{13} \beta_{1,s} X_{1,s} + \sum_{r=1}^{7} \beta_{2,r} X_{2,r} + \beta_3 X_3 + \beta_4 X_4 + \beta_5 \log(X_5) + \beta_{5,6} X_6 \log(X_5) \,,$$

where β_j represents the coefficient for the following terms (Table 9):

Coefficient	Explanatory Effect
β_0	Intercept
$\beta_{1,s}, s = 1,\ldots,13$	Individual Ship variables
$\beta_{2,r}, r = 1,\ldots,7$	Individual Port Variables
β_3	Arrival Date
β_4	Pier Side (1 = Yes, 0 = No)
β_5	Log(Length of Stay)
$\beta_{5,6}$	Interaction between log(Length of Stay) and Pier Side

Table 9. Explanation of Coefficients for the Port Fees Model

The coefficients for the Port Fees Model are included in Table 10.

Explanatory Variable	Coefficient Value	Standard Error	t -ratio	P-value
(Intercept)	6.082	1.803	3.373	0.001
CVN75	0.217	0.174	1.247	0.212
CVN68	0.481	0.142	3.387	0.001
All other ships	–0.067	0.020	–3.350	0.001
High Cost	0.899	0.141	6.389	0.000
Hong Kong	–0.607	0.152	–3.993	0.000
Med Cost	0.465	0.108	4.306	0.000
All other ports	0.020	0.048	0.417	0.677
Arrival Date	0.0004	0.0001	4.000	0.000
Pier Side	–1.936	0.736	–2.630	0.009
log(Length)	–0.818	0.363	–2.253	0.024
log(Length) x Pier Side	1.138	0.432	2.634	0.008

Residual standard error: 0.5083 on 103 degrees of freedom
Multiple R-Squared: 0.5546
F-statistic: 14.25 on 9 and 103 degrees of freedom, the p-value is 1.066e-014

Table 10. Table of Coefficients for the Port Fees Model

The Port Fees Model also has a large percentage of unexplained variability. Port fees are highly correlated with the ports in which the services are provided. This inhibits the ability to obtain a good fitting CER. The large negative coefficient for the Pier Side variable suggests that Port Fees are cheaper for a ship at anchor than a ship that pulls pier side. This seems reasonable. An example is Hong Kong. U.S. Navy aircraft carriers normally anchor in Hong Kong harbor, partly due to the large price associated with pier space at the docks. The presence of Arrival Date in the model implies a temporal effect in the Port Fees Model, suggesting that the constant-dollar price of these goods is increasing over time. The presence of the Length of Stay variable in the model is intuitive, due to the large number of variable costs in the Port Fees charge category.

3. The Transportation Model

The resulting Transportation Model can be expressed in the nonlinear form in terms of log(dollars) as:

$$\log(Y_{\text{Transportation}}) = \beta_0 + \sum_{s=1}^{13} \beta_{1,s} X_{1,s} + \sum_{r=1}^{7} \beta_{2,r} X_{2,r} + \beta_3 X_3 + \beta_{3,4} X_3 X_4 + \beta_{3,5} X_3 \log(X_5) ,$$

where β_j represents the coefficient for the following terms (Table 11):

Coefficient	Explanatory Effect
β_0	Intercept
$\beta_{1,s}, s = 1,\ldots,13$	Individual Ship variables
$\beta_{2,r}, r = 1,\ldots,7$	Individual Port Variables
β_3	Pier Side (1 = Yes, 0 = No)
$\beta_{3,4}$	Interaction between Arrival Date and Pier Side
$\beta_{3,5}$	Interaction between log(Length of Stay) and Pier Side

Table 11. Explanation of Coefficients for the Transportation Model

The coefficients for the Transportation Model are included in Table 12.

Explanatory Variable	**Coefficient Value**	**Standard Error**	**t -ratio**	**P-value**
(Intercept)	12.001	0.069	173.928	0.000
CVN70	0.221	0.136	1.625	0.104
CVN76	0.232	0.139	1.669	0.095
CVN71	0.260	0.128	2.031	0.042
All other ships	–0.071	0.021	–3.381	0.001
High Cost	0.860	0.089	9.663	0.000
Hong Kong	–0.154	0.121	–1.273	0.203
Jebel Ali	–0.685	0.095	7.211	0.000
Low Cost	–0.051	0.145	0.352	0.725
Manama	0.109	0.131	0.832	0.405
Med Cost	0.343	0.088	3.898	0.000
Singapore	–0.422	0.118	3.576	0.000
Pier Side	–6.536	1.781	–3.670	0.000
Arrival Date x Pier Side	0.0002	0.0001	2.000	0.046
log(Length) x Pier Side	1.95	0.207	9.420	0.000

Residual standard error: 0.3929 on 100 degrees of freedom
Multiple R-Squared: 0.8113
F-statistic: 35.82 on 12 and 100 degrees of freedom, the p-value is 0

Table 12. Table of Coefficients for the Transportation Model

The Transportation Model accounts for a large percentage of the variance in transportation costs for aircraft carrier port visits. The large negative coefficient in the explanatory variable Pier Side suggests that transportation costs are higher for a ship at anchor than a ship pier side. This seems reasonable. The Transportation charge category includes water taxi charges. These charges are only incurred by a ship at anchor, and add to the estimated transportation costs for vehicle rentals that would be required regardless of the ship's mooring location. The coefficient of Arrival Date is smaller than the other submodels, suggesting that there is less of a temporal effect in the Transportation charge category than the other categories.

4. The Utilities Model

The resulting Utilities Model can be expressed in the nonlinear form in terms of log(dollars) as:

$$\log(Y_{\text{Utilities}}) = \beta_0 + \sum_{s=1}^{13} \beta_{1,s} X_{1,s} + \sum_{r=1}^{7} \beta_{2,r} X_{2,r} + \beta_3 X_3 + \beta_4 X_4 + \beta_{3,4} X_3 X_4 + \beta_{4,5} X_4 \log(X_5),$$

where β_j represents the coefficient for the following terms (Table 13):

Coefficient	**Explanatory Effect**
β_0	Intercept
$\beta_{1,s}, s = 1,\ldots,13$	Individual Ship variables
$\beta_{2,r}, r = 1,\ldots,7$	Individual Port Variables
β_3	Arrival Date
β_4	Pier Side (1 = Yes, 0 = No)
$\beta_{3,4}$	Interaction between Pier Side and Arrival Date
$\beta_{4,5}$	Interaction between log(Length of Stay) and Pier Side

Table 13. Explanation of Coefficients for the Utilities Model

The coefficients for the Utilities Model are included in Table 14.

Explanatory Variable	Coefficient Value	Standard Error	t -ratio	P-value
(Intercept)	4.072	2.147	1.897	0.058
CV63	–0.393	0.203	–1.936	0.053
CVN69	–0.141	0.173	–0.815	0.415
CVN65 and CVN73	–0.105	0.106	–0.991	0.322
CVN74	–0.153	0.165	–0.927	0.354
CVN68	–0.020	0.112	–0.179	0.858
CVN71	–0.119	0.130	–0.915	0.360
All other ships	0.173	0.045	3.844	0.000
High Cost	1.003	0.089	11.270	0.000
Hong Kong	–0.866	0.129	–6.713	0.000
Jebel Ali	–0.380	0.099	–3.838	0.000
Manama	0.177	0.142	1.246	0.213
Med Cost	0.272	0.091	2.989	0.003
All other ports	–0.103	0.080	–1.288	0.198
Arrival Date	0.0005	0.0001	5.000	0.000
Pier Side	4.025	2.769	1.454	0.146
Arrival Date x Pier Side	–0.0005	0.0002	–2.500	0.126
log(Length) x Pier Side	2.140	0.213	10.047	0.000

Residual standard error: 0.395 on 96 degrees of freedom
Multiple R-Squared: 0.7987
F-statistic: 23.81 on 16 and 96 degrees of freedom, the p-value is 0

Table 14. Table of Coefficients for the Utilities Model

The Utilities Model accounts for a large percentage of the variability in the CER. The negative coefficient for the interaction term between Arrival Date and Pier Side offsets the positive coefficient for the Pier Side variable, and suggests that the estimated cost of a ship pier side is less than a ship at anchor. This seems reasonable. The Utilities charge category contains charges for services such as trash and CHT removal that are more expensive to provide to a ship at anchor than pier side.

D. RESULTING TOTAL COST MODEL

In addition to the four submodels that were fit, the total cost of each port visit was used to construct a CER for total cost. The resulting Total Cost Model can be expressed in the nonlinear form in terms of log(dollars) as:

$$\log(Y_{\text{Total}}) = \beta_0 + \sum_{s=1}^{13} \beta_{1,s} X_{1,s} + \sum_{r=1}^{7} \beta_{2,r} X_{2,r} + \beta_3 X_3 + \beta_4 X_4 + \beta_{3,5} X_3 \log(X_5),$$

where β_j represents the coefficient for the following terms (Table 15):

Coefficient	Explanatory Effect
β_0	Intercept
$\beta_{1,s}, s = 1,\ldots,13$	Individual Ship variables
$\beta_{2,r}, r = 1,\ldots,7$	Individual Port Variables
β_3	Pier Side (1 = Yes, 0 = No)
β_4	Arrival Date
$\beta_{3,5}$	Interaction between log(Length of Stay) and Arrival Date

Table 15. Explanation of Coefficients for the Total Cost Model

Coefficients for the Total Cost Model are presented in Table 16.

Explanatory Variable	Coefficient Value	Standard Error	t -ratio	P-value
(Intercept)	9.978	0.768	12.992	0.000
CVN68	0.104	0.068	1.529	0.126
CVN76	0.120	0.085	1.412	0.158
All Other CVs and CVNs	–0.020	0.009	–2.222	0.026
High Cost Ports	0.868	0.053	16.377	0.000
Manama (Port)	0.119	0.080	1.488	0.137
Low-Cost Ports, Singapore, Hong Kong, Jebel Ali	–0.332	0.023	–14.435	0.000
Medium Cost Ports	0.339	0.051	6.647	0.000
Pier side	–1.975	0.208	–9.495	0.000
Arrival Date	0.0002	0.000	20.000	0.000
log(Length) × Pier side	1.039	0.121	8.587	0.000

Residual standard error: 0.2418 on 104 degrees of freedom
Multiple R-Squared: 0.8149
F-statistic: 57.22 on 8 and 104 degrees of freedom, the p-value is ≈ 0

Table 16. Table of Coefficients for the Total Cost Model

As discussed in Section III.F, the coefficient of determination, R^2, is not a useful goodness-of-fit measure when the explanatory variable *Y* has been transformed. A better measure is the average percentage relative error (APRE). The Total Cost Model has an APRE of 17 percent.

E. TOTAL COST MODEL CONCLUSIONS

Based on the log-linear regressions that were developed, which were based on data from the aircraft carrier CRAFT database, several important conclusions can be drawn. Cost drivers are identified and explained which will help CNAF make decisions on budgeting for and scheduling of future aircraft carrier port visits.

The variable for deployment fraction, Depfrac, is included in order to test the hypothesis that ships spend money differently during different stages of a deployment. Ship variables are included to test the hypothesis that ships spend money differently. As a result of the stepwise nonlinear regressions that are constructed, Depfrac is not significant in the total model. Therefore, no evidence was found to support the hypothesis that spending habits varied from the start to the end of a deployment. Individual ship variables are significant in all models, but most ships look statistically similar to each other. Among all variables tested, region and the port in which the port visit takes place are the most significant cost drivers.

1. The Ship Variables

The variable for each ship was initially included in the full linear model that served as the upper basis of the stepwise regression. After the stepwise model selection was applied, only CVN68 and CVN76 showed significant statistical differences from the other ships in their effects on total cost.

CVN 68 is the oldest nuclear carrier in the database, and CVN 76 is the newest. It is not the case that CVN 76 and CVN 68 are different based on a fewer number of observations. There are several ships that have fewer or more observations than these two ships, yet were not statistically different from the other ships.

All other ships are treated equally for cost-estimation purposes as a result of the stepwise regression procedure, finding their individual effects to be not significant. The estimated regression coefficient for 11 of the 13 ships (excluding CVN 68 and CVN 76) is –0.020, with a standard error of 0.010. CVN 68 has a coefficient of 0.104, with a standard error of 0.068. This suggests that the total cost for the USS NIMITZ (CVN 68) to make a port visit is 11 percent higher (exp (0.104) = 1.11) than the average ship effect (which is 1.00). The coefficient for CVN 76 is 0.120, with a standard error of 0.085. This suggests that the adjustment to the total-cost estimate for the USS RONALD REAGAN (CVN 76) is 13 percent higher (exp(0.12) = 1.13) than the average ship effect. Adjustments for all ships are summarized in Table 17.

Ship	Coefficient	Standard Error	Exponential of Coefficient
All ships except CVN68 and CVN76 (11 ships)	–0.020	0.010	0.98
CVN68	0.104	0.068	1.11
CVN76	0.120	0.085	1.13
Sum of all ships	**0.00**		

Table 17. Ship Variable Coefficients in Total Cost Model

An examination of the four submodels reveals that USS NIMITZ has the largest Port Fees cost of any of the ships. The CVN 68 coefficient for Port Fees is .4815 with a standard error of 0.142, compared to the other ship's coefficient of –0.067, with a standard error of 0.020. This suggests that the USS NIMITZ will have Port Fees costs that are 73 percent higher than the average ship effect. These results are listed in Table 18.

Ship	Coefficient	Standard Error	Exponential of Coefficient
All ships except CVN68 and CVN75 (11 ships)	–0.067	0.020	0.94
CVN68	0.482	0.142	1.62
CVN75	0.252	0.174	1.29
Sum of all ships	**0.00**		

Table 18. Ship Variable Coefficients for All 13 Ships in Port Fees Model

An examination of the four submodels reveals that the USS RONALD REAGAN (CVN 76) has Transportation and Utilities costs that are higher than most ships. The Transportation coefficient for CVN 76 is 0.232, with a standard error of 0.139, compared to the other ships' coefficient of –0.071, with a standard error of 0.021. This suggests that the USS RONALD REAGAN will have Transportation costs that are 35 percent higher than the average ship effect. These results are shown in Table 19.

Ship	Coefficient	Standard Error	Exponential of Coefficient
All ships except CVN68, CVN71 and CVN76 (10 ships)	–0.071	0.021	0.93
CVN68	0.221	0.136	1.25
CVN76	0.232	0.139	1.26
CVN71	0.260	0.128	1.30
Sum of all ships	**0.00**		

Table 19. Ship Variable Coefficients For All 13 Ships in Transportation Model

CVN 76 also has a higher coefficient for Utilities. The USS RONALD REAGAN coefficient is 0.173, compared to the CVN 74 coefficient of –0.153. This suggests that CVN 76 will have Utilities costs that are 76 percent higher than some other ships. These results are summarized in Table 20.

Ship	Coefficient	Standard Error	Exponential of Coefficient
CV63	–0.393	0.203	0.67
CVN74	–0.153	0.165	0.86
CVN69	–0.141	0.173	0.87
CVN71	–0.120	0.130	0.89
CVN65 and CVN73	–0.105	0.107	0.90
CVN68	–0.020	0.112	0.98
All other ships	0.173	0.045	1.19
Sum of all ships	**0.00**		

Table 20. Ship Variable Coefficients for All 13 Ships in Utilities Model

2. The Port Group Variable

The variable for port group was initially included in the full linear model. Several of the ports are statistically similar, and the resulting beta coefficients for these terms are the same. This allows for the inclusion of Singapore, Hong Kong, and Jebel Ali into the low-cost port category. There are, however, some large differences in ports. The high-cost ports are estimated to be about 3.32 times as expensive as the low-cost ports.

The mid-cost ports are about 1.95 times as expensive as the low-cost ports. Manama, which is about 1.57 times as expensive as the low-cost ports, falls somewhere between the mid-cost ports and the low-cost ports. Figure 11 depicts the cost ordering of the port groups.

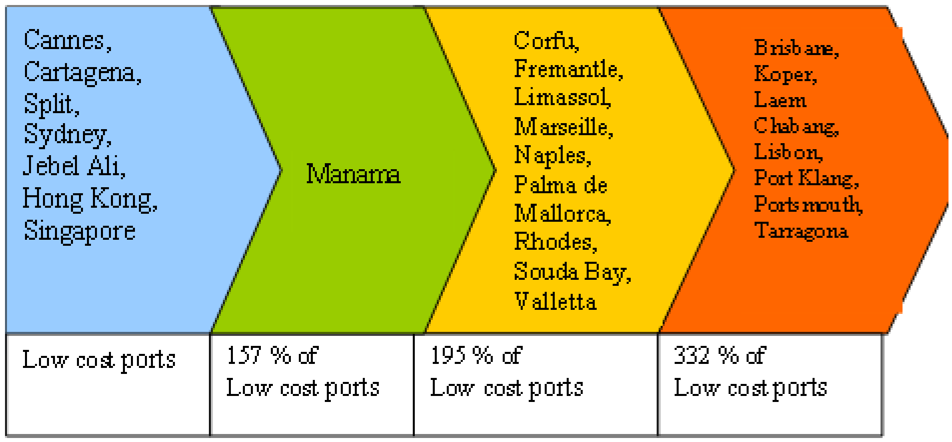

Figure 10. Cost Ordering of Different Ports

Because there is a port-region effect in the Total Cost Model, the port that a ship visits is a significant cost driver. It makes sense that the cost of doing business varies from country to country. Several ports are found to be much less expensive than others in their geographical vicinity. Because the Navy is seeking to reduce port-visit costs, it should consider more cost-efficient port alternatives that satisfy its operational objectives. To some extent, the Navy already is doing this: the most frequently visited ports are found mainly in the lower cost categories. There is, however, room for improvement. For example, the analysis presented in this thesis shows that it is not as cost effective to pull a CVN operating in the Persian Gulf into Bahrain as it would to have it visit Jebel Ali. In the absence of other planning factors, such as operational commitments, diplomatic clearance, a desire to show U.S. presence, etc., preference should be given to conducting a port visit in Jebel Ali for ships operating in the Persian Gulf. Similarly, when a CVN is operating in Southeast Asia, port visits to Singapore and Hong Kong are less expensive than visits to Port Klang, Malaysia or Laem Chabang, Thailand. The cost difference between conducting a port visit in Singapore, Hong Kong, and Port Klang is presented in Figure 12. This graphic is constructed using the Automated Port Cost Model (APCM) interface that is described in Section D. The graph is a depiction of the differences in total-cost estimates for CVN68 arriving on 3 June 2007 into Singapore, Hong Kong, or Port Klang for a five-day port-visit. The Pier Side parameter is "yes" for Singapore and Port Klang, and "no" for Hong Kong. This graphic provides a visual tool for decision makers and planners developing a future port-visit plan for CVN68.

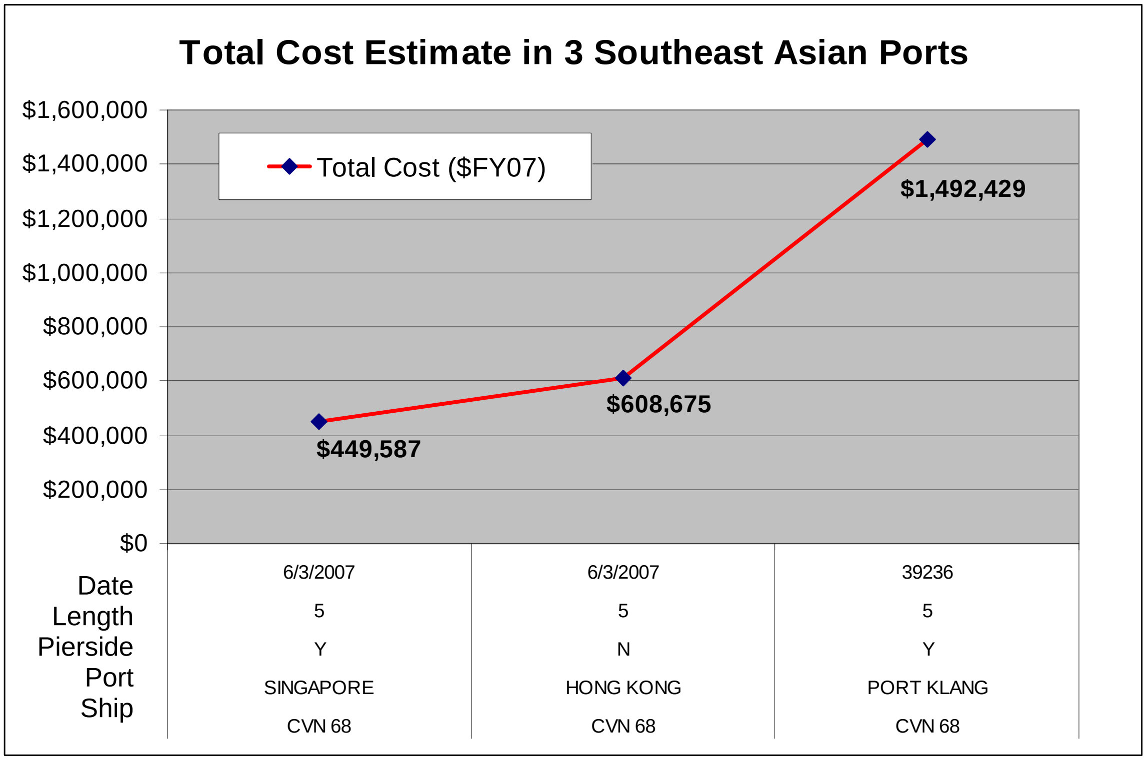

Figure 11. Comparison of Total Costs for Three Southeast Asian Port Visits Developed in the Automated Port Cost Model (APCM).

3. Arrival Date

The variable Arrival Date is significant in the Total Cost Model, as well as each of the four submodels. This implies that port-visit costs exhibit a temporal effect and the CERs are influenced by time. The positive coefficient on Arrival Date in all models suggests that the costs of carrier port visits increase over time. Because the data was previously normalized for inflation, one of two possibilities exists: either the costs related to port visits are rising faster than overall inflation, or the inflation index applied to the data does not accurately reflect the inflation rate in port-visit costs over the period of time (2002 through 2007) covered in the data analysis.

4. Pier Side

Pier Side is present in the Total Cost Model, as well as each of the four submodels. The negative coefficient for Pier Side in the total model suggests that it is cheaper to have an aircraft carrier pull pier side in a port than to go to an anchorage.

Conducting a port visit at anchorage is in fact, more expensive than pulling pier side. Additional costs to transport personnel, offload CHT and trash, and provide force protection increase the estimated price of the port visit. At a low-cost port such as Jebel Ali, the difference between pulling pier side and conducting the port visit at anchorage can be as large as 35 percent of the total cost. Figure 13 illustrates the estimated cost difference using the Total Cost Model for the same ship (CVN74) conducting a nominal five-day port visit in Jebel Ali, starting on 3 June 2007. The estimated price difference is due to the changing of the Pier Side variable between “yes” and “no.”

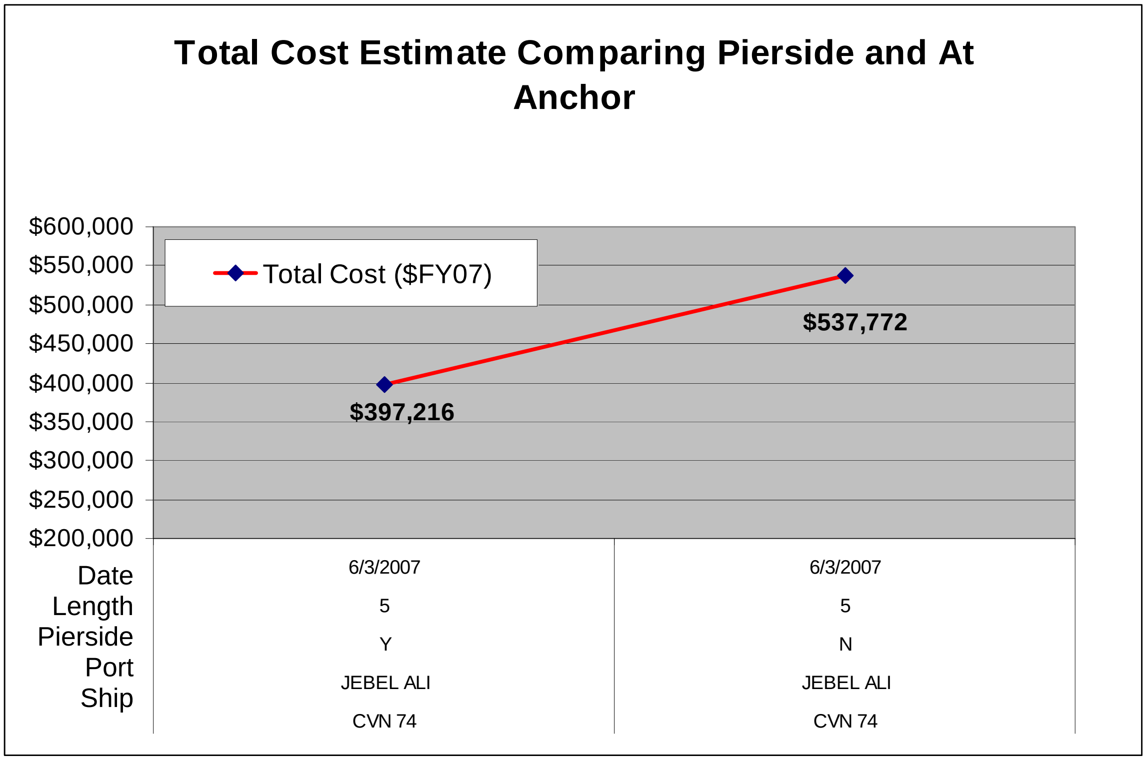

Figure 12. Total Cost Estimate Comparison for Pier Side and At Anchor for a Given Port Visit

5. Length

The length of port visit (in days) is present in the Total Cost Model, as well as each of the four submodels. The inclusion of length in the CER is intuitive, and suggests that the length of stay of an aircraft carrier in a port affects the cost of the port visit.

F. AUTOMATED PORT-COST MODEL (APCM)

A user interface is developed in Microsoft Excel that allows CNAF to input parameters for the cost drivers that affect the costs of an aircraft carrier port visit without working with the nonlinear CER or having access to the S-Plus software used to construct the regression equations. For a given set of inputs, the APCM provides an estimate of the total cost, in $FY07, expected for a future port visit. Values for Force Protection, Port Fees, Transportation, and Utilities are also automatically computed. A plotting macro is recorded to allow the user to provide a graphical representation of port costs, as well as conduct sensitivity analysis on different decision options available. This APCM interface has been delivered to CNAF. A descriptive example of the user interface is provided in Appendix C.

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V. CONCLUSIONS AND RECOMMENDATIONS

Port visits by U.S. Navy aircraft carriers have been identified by Commander Naval Air Forces (CNAF) as an area for potential cost savings. In order to realize these savings, it is necessary to identify the factors that contribute to these costs. This thesis addresses both of the study questions presented in Chapter I, it:

- Presents a statistical methodology, based on data from past port visits, for identifying port-visit cost drivers and quantifying their effects, and
- Presents predictive models for total port-visit costs and for categorized port-visit costs. As part of the research, a spreadsheet tool that implements this methodology is developed and its usage is described.

A. MAINTAINING AND IMPROVING MODEL ACCURACY

The predictive model for total port-visit costs is accurate to within 17 percent of the true cost, on average. It is possible, with additional data providing greater detail of these costs, that accuracy of the model could be improved. It is, however, unlikely that any statistical model can identify all of the important factors that contribute to port-visit costs, or do so over an extended period of time. The changeable nature of naval operations and port economics, together with the quality of data, suggest that updating of the model on a periodic basis be undertaken to maintain its applicability.

B. RECOMMENDATIONS FOR FURTHER STUDY

A full analysis of the cost estimating relationships (CERs) for aircraft carrier port-visit costs was hindered by the small number of aircraft carrier port-visits in the database. As ships continue to make port visits, and the information continues to be recorded, the construction of a better-fitting model may be possible.

1. Reducing Cost Variability between Ships

The models developed in this thesis identify cost effects due to ships that are statistically significant. For example, it is found that the USS RONALD REAGAN (CVN 76) has port-visit costs that are about 15 percent greater than those of the USS JOHN C. STENNIS (CVN 74) controlling for all other factors. Although this may reflect factors that are not fully captured in the models, it would be useful to examine more carefully how these ships incur expenses during port visits. It is possible that some ships have adopted better practices than others, which may suggest strategies for controlling costs across all ships.

2. Selection of Ports

An important finding is that the ports visited by aircraft carriers vary considerably in their costs. A typical port visit to Singapore, for example, costs about one million dollars less than a comparable visit to nearby Port Klang, Malaysia. It is understandable that decisions on which ports to visit are governed by more than economics, but it is useful to have the difference in costs quantified nonetheless. This study provides input to future research on optimizing the visiting of ports, subject to both economic and noneconomic constraints that decision makers normally confront.

3. Testing FY08 Data

The CERs that are developed are based on data collected from FY04 to FY07. As ships continue to make port visits, the applicability of the CERs will gradually diminish. It would be useful to develop formal guidelines for when new CERs should be developed; that is, to define control limits whose violationwould trigger a reevaluation of CERs.

4. Applicability to Other Ship Classes

The methodology used here identifies several cost drivers for CV and CVN aircraft carriers of the U.S. Navy fleet. This methodology could be applied to other classes of ships to determine it would be useful to decision makers at other TYCOM staffs when attempting to understand the drivers of port visit costs.

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APPENDIX A

The following is a copy of an internal CNAF memo discussing the subject of pressurization and the possible sources of cost avoidance and savings (Devlin, 2008).

Subj: FFC Tasker – Feedback Solicited on a Potential FY09 Twenty Percent Cut across Ship Operations Accounts (SR/SO/SX)

Issue: What is the readiness impact of a twenty percent cut to the Ship Operations Accounts?

Discussion:

- Monetary Impact of Cut:
    - o FY09 Ship Operations budget is $168.3M

	East	West	Total
SR-Repair Parts	27,892	40,745	68,637
SO-Other	46,185	42,649	88,834
SX- TAD	2,732	8,076	10,808
Total	76,809	91,470	168,279

    - o Twenty Percent Cut will equate to $33.7M ($15.3M East/$18.3M West).
    - o Twenty Percent Cut ($33.7M) cut is roughly 2.3 months of operating costs across both coasts.
- Operational Environment in FY09:
    - o FY09 will see us start with 10 CVNs and grow to 11 in early FY09 (Nov)
    - o FY09 will see the following deployments: 5 Total (3 West/2 East)
    - o FY09 will see the following availabilities:
        - ▪ VIN: Completion of RCOH/PSA/SRA *
        - ▪ GHWB: Delivery/PSA/SRA *
        - ▪ TR: Commence RCOH
        - ▪ ENT: EDSRA
        - ▪ NIM: Completion of PIA
        - ▪ LIN: PIA (6 mos)
        - ▪ GWA: SRA (4mos in Japan)
        - ▪ HST: end of PIA

        * Note: Historical averages indicate $5-6M required to restore/finish new construction and ships exiting RCOH.
- Anticipate the following cuts will negatively impact deployments preparations and execution of availabilities. The following will be considered as potential targets to absorb the twenty percent cut:
    - o SR - SFOMS/EQOL ($10.2M)
        - ▪ Impact #1: Defer maintenance to future years therefore creating a bow wave in equipment/repairs.
            - • Increased maintenance costs due to failing to utilize ships force to perform self help projects such as heads, beds, facilities, laundry, decking, etc.
            - • Lost lead time to obtain material for self-help projects for future maintenance availabilities.
            - • Cancel Standardization and Evaluation Assistance Team (SEAT) contract for laundry and galley equipment.

            - Defer parts and maintenance for Propulsion and Secondary Plant valves and pumps, Aviation Fuel systems, Aircraft Launch and Recovery Equipment, Damage Control fittings, etc.
        - Impact #2: Preclude ability to fund improvements required to support manpower/efficiency initiatives.
            - Galley and Food Service equipment modifications to support Large Afloat Franchise Menu will be deferred until funded by Ships Maintenance. Galley standardization will not be achieved.
- SR - Misc Hab/Waterfront Contracts ($4.0M)
    - Impact #1: Defer habitability maintenance to future years therefore creating a bow wave in equipment/repairs.
    - Material condition of ship will suffer (damage control, painting, etc)
        - Decking repairs, equipment phased replacements, renovations, etc. will not be accomplished.
    - Impact #2: Preclude ability to fund improvements required to support manpower/efficiency initiatives.
        - Storeroom/space configuration changes to support initiatives such as CVN Workload Realignment will not be funded.
- SR - C5RAs ($2.0M)
    - Impact: Manage equipment to CASREPs. Potential for ships to deploy without sufficient C4 equipment up and running. Inspection dollar limitations will affect ship's readiness.
- SO - Port Visits ($4.0 M)
    - Cut number and duration of port visits…FFC will need to liaison with numbered Fleets/State Department for affordable port visits.
    - Institute measures to minimize port visits costs by reducing port service requirements (# of liberty boats, vehicles, etc).
    - Singling up port reports/financial responsibility.
- SO - RCOH/Offloads ($2.2M)…cut contract costs by 50%
    - Material (RAB) will be retained shipboard…limited offloads to V88…ships will become inundated with processing A4_ referrals against excess stock on hand
    - Potential inventory discrepancies on RCOH material.
- SO - FAST/DRST (SMI/SMA/TAV) ($1.5M)…reduce contract costs by 33%
    - Reduction in ship visits for training and assists.
    - Ships will perform EOFY closeouts and/or software implementations without FAST support.
    - Limited or no contractor support for implementation of initiatives.
    - Contractor support currently covering staff requirements to alleviate impact of IAs.
- SX - TAD/Travel (SX) $2.2M … reduce travel/training by 20%.
    - Unfunded requirements from TAD (SX) used to support deployed units. Shortfall will come from SO, further impacting the SO/SR shortfall.
    - Crew knowledge, skills and abilities will be reduced from obtaining NECs to beach guard unit support.
    - Quality of Life and readiness will be impacted.
- SR/SO - Remaining $7.6M will be addressed by under funding non-deployers.
    - Limit maintenance to CASREPs/must haves. Manage non-deployed units with daily grants.
    - Defer phased replacements of DC, CBR, EEBDs, until ship reaches deploying status…potential for deployment without proper personnel protective equipment.
    - Defer phased replacements of crew mattresses, bedding and linen, furniture, organizational clothing, office equipment (printers/copiers).

APPENDIX B

Sample CRAFT report for USS JOHN C. STENNIS to Singapore in Dec 2004.

Services	Quantity	U/I	Total Cost
GARBAGE REMOVAL	30	BINS	$ 7391
TENT RENTAL	3	DAYS	$ 4599
PORT SVCS COORDINATION FEE	4	DAYS	$ 2354
CHT DISPOSAL	787500	GALLONS	$ 137969
ADMIN CHARGES	1	GROUP	$ 11
MISC SERVICES/SUPPLY	1	GROUP	$ 13983
PROVISIONS	1	GROUP	$ 341578
SHIP STORE ITEMS	1	GROUP	$ 22704
LIBERTY 40 PAX BUS RENTAL	1677	HOURS	$ 28371
SEDAN RENTAL	221	HOURS	$ 2736
FORKLIFT SERVICES	70	HOURS	$ 1610
VAN RENTAL	882	HOURS	$ 11930
VIP SEDAN	260	HOURS	$ 5132
CRANE SERVICE	45	HOURS	$ 6373
PILOT	5	HOURS	$ 709
TUGS	40	HOURS	$ 14454
CELL PHONE AIRTIME	1	LOT	$ 594
TRANSPORTATION OF GFE	1	JOB	$ 3394
FP - ARMED SECURITY	2	EACH	$ 244
FP - FLOATING PERIMETER	1	EACH	$ 17410
PORTABLE TOILET	10	EACH	$ 2464
MANLIFT	2	EACH	$ 5174
CELLULAR PHONE	44	EACH	$ 922
BREASTING BARGE	1	EACH	$ 7117
BROW RENTAL	2	EACH	$ 5913
FENDER RENTAL	10	EACH	$ 37503
LINEHANDLERS	32	EACH	$ 4428
POTABLE WATER	2221	CUBIC METER	$ 2579
		Sum	**$689646**
		Num of Days	**4**
		Average Daily Cost	**$172411.5**

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