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Optimal Scheduling and Operating Target (OPTAR) cost model for aircraft carriers in the fleet response plan

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THESIS

OPTIMAL SCHEDULING AND OPERATING TARGET (OPTAR) COST MODEL FOR AIRCRAFT CARRIERS IN THE FLEET RESPONSE PLAN

by

Michael A. York

September 2008

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The Fleet Response Plan was developed to provide persistent readiness of the carrier fleet to respond to a variety of situations. This capability is developed through the Fleet Readiness Training Plan (FRTP) where the Navy's carriers are scheduled in staggered 32-month cycles consisting of four phases of progressive readiness levels. Required operating target funds, or OPTAR, are budgeted to each carrier by Commander Naval Air Forces to achieve and maintain that readiness. Future OPTAR budgets, however, will be constrained by a 20-percent reduction in fiscal years 2009 through 2013. To compensate, funding priority is given to carriers in higher readiness phases at the expense of carriers conducting baseline training and maintenance, adversely impacting the fleet's ability to exercise the Fleet Response Plan as originally intended. This thesis optimizes scheduling synchronously across all carriers to meet established FRTP readiness goals. Then, using a cost model based on recent historical spending and employment data, this thesis generates an estimate of required funding to operate all carriers. Ultimately, this thesis provides a link between operational requirements and OPTAR budget requirements.

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OPTIMAL SCHEDULING AND OPERATING TARGET (OPTAR) COST MODEL FOR AIRCRAFT CARRIERS IN THE FLEET RESPONSE PLAN

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requirements for the degree of

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ABSTRACT

The Fleet Response Plan was developed to provide persistent readiness of the carrier fleet to respond to a variety of situations. This capability is developed through the Fleet Readiness Training Plan (FRTP) where the Navy's carriers are scheduled in staggered 32-month cycles consisting of four phases of progressive readiness levels. Required operating target funds, or OPTAR, are budgeted to each carrier by Commander Naval Air Forces to achieve and maintain that readiness. Future OPTAR budgets, however, will be constrained by a 20-percent reduction in fiscal years 2009 through 2013. To compensate, funding priority is given to carriers in higher readiness phases at the expense of carriers conducting baseline training and maintenance, adversely impacting the fleet's ability to exercise the Fleet Response Plan as originally intended. This thesis optimizes scheduling synchronously across all carriers to meet established FRTP readiness goals. Then, using a cost model based on recent historical spending and employment data, this thesis generates an estimate of required funding to operate all carriers. Ultimately, this thesis provides a link between operational requirements and OPTAR budget requirements.

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LIST OF ABBREVIATIONS AND ACRONYMS

BOR	Budget OPTAR Report
CIA	Carrier Incremental Availability
CNAF	Commander Naval Air Forces
CV	Multi-purpose Aircraft Carrier
CVN	Multi-purpose Aircraft Carrier (Nuclear Propulsion)
DPIA	Docking Planned Incremental Availability
EDSRA	Extended Docking Selected Restricted Availability
ESRA	Extended Selected Restricted Availability
FDNF	Forward Deployed Naval Force
FRP	Fleet Response Plan
FRTP	Fleet Readiness Training Plan
FYDP	Future Year Defense Plan
IDTC	Inter-Deployment Training Cycle
O&M,N	Operations and Maintenance, Navy
OPTAR	Operating Target
PIA	Planned Incremental Availability
PSA	Post Shakedown Availability
RCOH	Refueling Complex Overhaul
SIC	Standard Identification Code
SRA	Selected Restricted Availability

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EXECUTIVE SUMMARY

The Fleet Response Plan calls for the availability of six carriers within 30 days and an additional carrier within 90 days. This capability is developed through the Fleet Readiness Training Plan (FRTP) where the Navy's eleven aircraft carriers are scheduled in staggered 32-month cycles consisting of four phases: basic (unit level training), integrated, sustainment, and maintenance. Current policy modifies the FRTP readiness goal to "3+3+1+3" broken down as follows: six total carriers (3 deployed + 3 others) in sustainment provide the 30-day response; one carrier in basic or integrated (+1) provides the 90-day response; and three carriers in maintenance (+3) with an additional carrier on overhaul. Commander Naval Air Forces (CNAF), as the air Type Commander, is responsible to the fleet for the carriers' readiness during each phase, and budgets each ship's operating funds to achieve and maintain that readiness.

All ships, squadrons, and other units receive their annual operating funds from their Type Commander in the form of an Operating Target (OPTAR) that can be considered an annual budget. These operating funds are defined generally as an estimate of the amount of budget authority required to operate a ship to support organizational maintenance and to purchase repair parts and general supplies. Operating Target funds derive from the Operation and Maintenance, Navy (O&MN) account appropriated every year by Congress and are budgeted to the Type Commanders by Fleet Forces Command.

Increased operational tempo by the carriers during Operation Enduring Freedom and Operation Iraq Freedom led to higher than expected OPTAR spending. In recent years, CNAF received additional funding as part of larger Department of Defense supplemental funding to cover the increased cost of operations associated with the global war on terror. Future OPTAR budgets, however, will be constrained by a 20 percent reduction to the ship operations account that funds OPTAR in fiscal years 2009 though 2013. When forecast OPTAR costs exceed what is provided, CNAF gives highest funding priority to carriers in sustainment phase. To satisfy the higher spending required by ships in sustainment, CNAF harvests funding from carriers in basic and maintenance phase. Reduced OPTAR funding during these phases, however, adversely impacts the fleet's ability to exercise the Fleet Response Plan as originally intended.

As an alternative, we will explore whether the scheduled Fleet Response Training Plan phases can be stretched or contracted synchronously across all carriers to meet operational commitments without sacrificing baseline maintenance and training, and ultimately produce an estimate of required funding to operate all carriers. The first step of the analysis will be to derive a statistically sound estimator of future spending based on recent historical data. Then we will determine if the scheduled phases can be adjusted to meet the "3+3+1+3" readiness goal. Finally, once we generate an optimal schedule we will propose a realistic profile of required OPTAR funding levels.

We ultimately discover that the FRTP goal of "3+3+1+3" is not achievable given the current force structure and projected funding levels. However, we demonstrate that both operational and maintenance planners can benefit from long-range, synchronous planning of all the FRTP phases to produce the readiness posture required by the Fleet Response Plan. Additionally, we present a feature to estimate carrier fleet spending to provide a link between operational readiness and budget requirements.

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I. INTRODUCTION

A. BACKGROUND

1. Fleet Response Plan

The Carrier Strike Group is the cornerstone of United States naval power. In the past, carriers and other units of their battle group trained for deployment to areas around the world using the traditional Inter-Deployment Training Cycle (IDTC). Following a shipyard maintenance period, units progressed through escalating levels of unit and multi-unit training culminating in deployment with a battle group. However, this typically produced a “bath tub” effect following deployment as ships entered maintenance periods and wholesale crew turnover severely degraded unit readiness.

Today, Combatant Commanders need a more agile and flexible Navy to respond to emergent requirements. The global war on terror requires better planning to ensure trained Navy forces are available to surge on short notice, a capability not possible under the IDTC. The Navy developed the Fleet Response Plan to deliver that capability, while continuing to provide rotationally deployed forces to areas around the world.

The Fleet Response Plan, and its associated Fleet Readiness Training Plan (FRTP), consists of four phases (basic, integrated, sustainment, and maintenance) designed to ensure naval forces are trained and certified in progressive levels of employability. An FRTP cycle begins at the completion of a maintenance phase, and continues through the end of the following maintenance phase and is typically 32 months long. The manning level and training requirements of each carrier are tailored to achieve the appropriate proficiency and mission readiness targets at the beginning of each FRTP phase. The following definitions are summarized from the Navy’s Fleet Response Plan instruction [OPNAV 2006]:

a. Basic Phase (Unit-Level Training)

The basic phase is the first in an FRTP cycle and focuses on Type Commander (TYCOM) unit-level training. A unit completes basic phase after meeting TYCOM certification criteria, which for an aircraft carrier occurs upon successful completion of the Final Evaluation Period (FEP). Aircraft carriers successfully completing basic phase are designated as Independent Unit Ready for Tasking, and may be tasked with independent operations in support of Homeland Security, Humanitarian Assistance or Disaster Relief, or other specific operations. Units in basic phase are considered able to deploy within 90 days of receipt of orders.

b. Integrated Phase

Training in the integrated phase is designed to organize units and staffs into coordinated strike groups capable of operating in multi-dimensional warfare. Units completing integrated phase are designated either Maritime Security Surge (MSS), Major Combat Operations Surge (MCO-S), or Major Combat Operations Ready (MCO-R). Units classified MCO-S have demonstrated the capability to function as part of a naval combat force, whereas units classified as MCO-R are certified as fully capable of conducting all forward-deployed operations and have demonstrated the ability to lead joint and coalition forces. Aircraft carriers typically achieve MCO-S following successful completion of a Composite Training Unit Exercise (COMPTUEX) and later MCO-R status following completion of Joint Task Force Exercise (JTFEX).

c. Sustainment Phase

The sustainment phase follows the integrated one and continues through the post-deployment period until commencement of the maintenance phase. The sustainment phase now provides a longer period of time during which a ship is employable than was typically the case under the former IDTC. Units maintain war fighting readiness through group, unit, or multi-unit exercises and will typically deploy in support of Combatant Commander requirements. Units in sustainment phase are considered able to deploy within 30 days upon receipt of orders.

d. Maintenance Phase

The maintenance phase is a critical part of the FRTP where major depot-level repairs, upgrades and modernizations are accomplished. Depot level maintenance for Atlantic Fleet carriers is provided by Northrop Grumman Shipbuilding in Newport News, Virginia, or Norfolk Naval Shipyard in Portsmouth, Virginia, and for Pacific Fleet carriers by Puget Sound Naval Shipyard in Bremerton, Washington. The Ship Repair Facility in Yokosuka, Japan, provides depot level maintenance for the Forward Deployed Naval Force carrier, currently USS Kitty Hawk (CV 63). Northrop Grumman Shipbuilding also provides mid-life refueling for all nuclear powered aircraft carriers [OPNAV 2006].

2. Fleet Response Plan in Practice

The Fleet Response Plan was tested for the first time in 2004 when seven aircraft carriers were simultaneously underway between June and August of that year. The carriers USS George Washington, USS John C. Stennis, and USS Kitty Hawk were on scheduled deployments around the globe. In addition, USS John F. Kennedy, USS Enterprise, and USS Harry S. Truman were underway conducting joint and international training exercises. The USS Ronald Reagan was also underway conducting operations in U.S. Northern Command and U.S. Southern Command areas of responsibility during her inter-fleet transfer from Norfolk, Virginia, to San Diego, California.

3. Current Operations

The original goal of the Fleet Response Plan, when it was introduced in 2003, was to maintain a “6+2” readiness posture of Carrier Strike Groups (CSGs). This concept promised six CSGs available for employment within 30 days and an additional two CSGs available for employment within 90 days [OPNAV 2003]. The first six carriers were drawn from those that achieved MSS, MCO-S, or MCO-R during the integrated phase, and those currently in sustainment phase. The two 90-day carriers were to be drawn from those in basic or integrated phase.

Current policy from CNAF modifies the FRTP readiness goal to "3+3+1+3" broken down as follows: six total carriers (3 deployed + 3 others) in sustainment phase; one carrier in basic or integrated (+1); and three carriers in maintenance (+3). The Forward Deployed Naval Force (FDNF) carrier in Yokosuka, Japan, is always considered one of the six in sustainment unless she is in scheduled depot maintenance. An additional carrier is always conducting a 3-year midlife Refueling and Complex Overhaul (RCOH) and is not included in the FRTP readiness goal. Figure 1 shows a notional FRTP cycle with each phase's approximate length [OPNAV 2006].

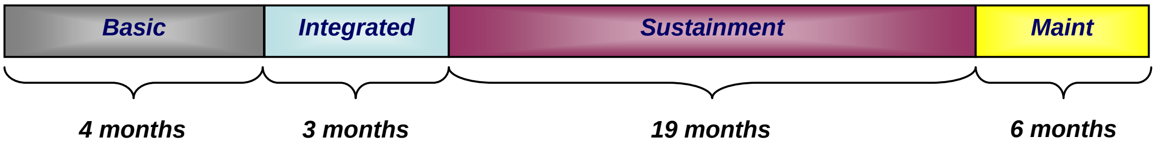

Figure 1. Notional 32-Month FRTP Cycle

4. Operating Target (OPTAR) Defined

All U.S. ships, squadrons, and other units receive their annual operating funds from their Type Commander (TYCOM) in the form of an Operating Target (OPTAR) that can be considered an annual budget. These operating funds are defined generally as an estimate of the amount of budget authority required to operate a ship to support organizational maintenance and to purchase repair parts and general supplies [Department of the Navy 1990]. Other operating expenses by ships such as fuel, payroll and food costs are funded separately from OPTAR. Operating Target funds derive from the Operation and Maintenance, Navy (O&MN) account appropriated every year by Congress. Specifically, Operating Target funds are budgeted under line 1B1B-Mission and Other Ship Operations of the O&MN account, and are divided amongst the aviation, surface, and submarine Type Commanders by Fleet Forces Command. The TYCOM then provides each unit under his command an OPTAR using TYCOM-specific business rules. Aircraft carriers fall under the administrative command of the aviation TYCOM, Commander Naval Air Forces (CNAF) in San Diego, California. Table 1 displays the actual total CNAF OPTAR spending for fiscal years 2003 through 2007, and the projected OPTAR budgets for fiscal years 2008 and 2009. Converting all amounts to constant-year dollars, and dividing by the number of active carriers each year gives an average OPTAR spending per carrier each year.

Fiscal Year	CNAF OPTAR Budget (TY$K)	CNAF OPTAR Budget (FY09$K)	Number of Carriers	OPTAR (FY09$K) per Carrier
2003	355,044	430,420	12	35,868
2004	210,574	246,919	12	20,577
2005	235,912	265,684	12	22,140
2006	189,095	201,140	12	16,762
2007	246,362	255,231	11	23,203
2008	141,810	143,980	11	13,089
2009	134,579	133,664	11	12,151

Table 1. CNAF OPTAR Spending by Fiscal Year

5. Ship Operations Pressurization

The amount to budget for Mission and Other Ship Operations funding every year is derived from a mathematical formula called the Ship Ops Model [Gantt 2003] that calculates a 2-year moving average of 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 amount estimated by the Ship Ops Model and proposed a cut in OPTAR funding in favor of other budget objectives. Fleet Forces Command and the Type Commanders, given the opportunity to justify the Ship Ops Model estimate, were only able to defend approximately 80% of historical certified obligations. As a result, N43 proposed a 20% cut, or approximately $162M, from the Mission and Other Ship Operations account to be applied in fiscal year

2009. Ultimately, the 20% "pressurization" was applied across the Future Year Defense Plan affecting fiscal years 2009 through 2013, amounting to approximately $861M in total budget reductions [Maldonado 2007].

B. PREVIOUS WORK ON AIRCRAFT CARRIER SCHEDULING

Given the aircraft carrier's importance in U.S. military strategy, numerous studies in the last decade analyze the problem of optimal aircraft carrier scheduling. In a study requested by the Deputy Chief of Naval Operations (Resources, Warfare Requirement and Assessment) N-8, Brown, et.al [1997] analyzed the role of forward-deployed naval forces in U.S. national security strategy and joint military strategy. Three major issues were studied:

- The strategic value of forward-deployed naval forces within predominantly diffuse, relatively low-level threats, and with crises that are difficult or impossible to anticipate;
- The economic benefits of forward-deployed naval forces, as illustrated by the impact of naval crisis response on oil futures' prices during three previous crises in the Persian Gulf; and
- The effectiveness of naval forces at providing forward presence, as measured by the amount of coverage or carrier presence in forward areas and by the response times of carriers to widely-dispersed locations throughout the world [Brown, et. al 1997, p. i].

The study relies on the Coverage and Response Estimation (CoRE) model, an optimization model that estimates coverage and response times achievable by the number of carriers in the Navy. At the time of the study the Navy had twelve active carriers, and the study concluded that a twelve-carrier force could achieve 65% and 70% coverage to European Command and Central Command areas of responsibility, respectively, during the period of 1997 to 2006.

Ayik [1998] extended the CoRE model to include scheduling aircraft carrier depot level maintenance periods and deployments synchronously. That study concluded 15%

more coverage to EUCOM, CENTCOM and PACOM AORs could be achieved by shifting maintenance periods by 1 month allowed by Department of Navy policy.

Aircraft carrier employment changed with the advent of the Fleet Response Plan. Hall [2004] investigates the personnel preparedness and maintenance factors that constrain the carrier force's ability to meet requirements and the effect of depot-level maintenance under the Fleet Response Plan. He models various scenarios varying Fleet Response Plan training schedules from 21 to 27 months and their impact on meeting the "6+2" readiness goal. His analysis generates potential schedules as columns in a set partitioning problem, and selects the "best" using a time-indexed, monthly resolution optimization model. Hall concludes that with current personnel and maintenance constraints, we cannot maintain the "6+2" Fleet Response Plan goal with the current force. He offers alternatives by extending the employable portion of a carrier's FRTP cycle or reducing the requirement to "5+2" and the associated effects of these potential policy changes.

In a study for the Assessments Division of the Deputy Chief of Naval Operations for Resources, Requirements, and Assessments (OPNAV N81), the RAND National Defense Research Institute examined the feasibility and implications of increasing aircraft carrier forward presence by proposing alternative lengths between depot maintenance periods. In the study Yardley et.al [2008] analyze the impact of a shorter cycle lasting 18-24 months consisting of one deployment, or a longer cycle lasting up to 42 months that could accommodate two deployments. The latter was of particular interest to N81, permitting a carrier to perform two deployments between major depot availabilities. The study concluded that the longer cycle increases the carrier fleet's forward presence and ability to meet a "6+1" Fleet Response Plan goal, but the increased operational tempo may adversely affect the Navy's ability to meet maintenance demands.

C. PROBLEM STATEMENT

The full impact of reduced OPTAR funding on the carrier fleet as a result of the ship operations account pressurization is unknown. However, Commander Naval Air Forces fears he will not be able to meet the "3+3+1+3" Fleet Response Plan goal in fiscal year 2009 and beyond. In the past, when increased operational tempo during Operation Enduring Freedom and Iraqi Freedom led to higher than expected OPTAR spending, CNAF received additional OPTAR funding authority as part of larger Department of Defense supplemental funding to cover the increased cost of operations. The future availability of these “Cost of War” supplementals, however, is in doubt, putting additional funding pressure on the carrier fleet. When forecast OPTAR costs exceed what is provided, CNAF gives highest funding priority to carriers in sustainment phase. To satisfy the higher spending required by ships in sustainment, CNAF harvests funding from carriers in basic, integrated and maintenance phase. Reduced OPTAR funding during these phases, however, adversely impacts the fleet’s ability to execute the Fleet Response Plan as originally intended.

As an alternative, we will explore whether the scheduled Fleet Response Training Plan phases can be stretched or contracted synchronously across all carriers to meet operational commitments without sacrificing baseline maintenance and training, and ultimately produce an estimate of required funding to operate all carriers. The first step of the analysis will be to derive a statistically sound estimator of future spending based on recent historical data. Then we will determine if the scheduled phases can be adjusted to meet the “3+3+1+3” readiness goal. Finally, once we generate an optimal schedule we will propose a realistic profile of required OPTAR funding levels.

II. DATA ANALYSIS AND AIRCRAFT CARRIER SCHEDULING FACTORS

A. DATA GATHERING AND ORGANIZATION

Our analysis of historical OPTAR spending and employment data focuses on the period from fiscal year 2003, the first year of the Fleet Response Plan, through fiscal year 2007, the last full fiscal year prior to this research. Several sources were considered for spending data, however, the monthly Budget OPTAR reports submitted by the ships is the most readily available source providing the fidelity we seek.

1. Aircraft Carrier Operating Target (OPTAR) Data

All units that receive an OPTAR are required to submit a monthly Budget OPTAR Report (BOR) to their Type Commander documenting all obligations against the ship operations account for the month. The Ship Operations program manager at Commander Naval Air Forces maintains a database of these monthly reports for all aircraft carriers, which provides the spending data we need.

The Budget OPTAR Report is a report of obligations, which differ from expenditures in the Navy accounting system. This can be an important, and complicating distinction. An obligation, according to Navy comptroller instruction, is a "request document for material or services," made by the ship to be paid for from the Ship Operations funds held by the TYCOM [NAVSO P-3013-2, App I-7]. An expenditure is defined as "a disbursement or payment of appropriated funds," that occurs when the supply system issues material or a disbursing officer makes a payment [NAVSO P-3013-2, App I-3]. In short, money is not "spent" from the Ship Operations account until the obligation and expenditure document are electronically matched in the Navy accounting system. Discrepancies can occur when the obligation value transmitted by the ship does not match the expenditure transmitted from the supply system. In practice, however, these discrepancies are transmitted electronically to the carriers and adjustments are reconciled daily to ensure the ship has the most current information, especially before a

Budget OPTAR Report is generated and sent to the Type Commander. As a result, the Budget OPTAR Reports are assumed to be the most accurate source available of monthly aircraft carrier spending.

The operating target data is normalized to constant year dollars based on fiscal year 2009 using the Operations & Maintenance, Navy-Composite index provided by the Naval Center for Cost Analysis. The indices used are listed in Table 2.

Base Year	Index used to normalize to FY09
2003	1.2200
2004	1.1842
2005	1.1378
2006	1.0728
2007	1.0439

Table 2. O&MN-Composite Inflation Indices

2. Aircraft Carrier Employment Data

Commander Naval Air Forces provided an unclassified past, current, and future carrier schedule for our analysis. The detailed schedules were translated into monthly periods of the four FRTP phases according to the following phase transitions established by CNAF policy:

- Basic phase begins immediately following completion of the prior maintenance period and lasts until the completion of Final Evaluation Problem (FEP). Representing the culmination of unit level training, FEP evaluates the ship’s ability to conduct combat missions, support functions, and survive complex casualty control situations;
- Integrated phase follows basic and lasts until completion of the Composite Training Unit Exercise (COMPTUEX). This exercise is focused on

developing the carrier and air wing into a cohesive unit, and integrating them with other units assigned to the deploying Carrier Strike Group;

- Sustainment phase follows integrated and lasts until the beginning of the ship's next depot level maintenance period; and
- Maintenance phase concludes at the commencement of sea trials, which are conducted after all depot maintenance availabilities [CNAF 2005].

When transitions occur mid-month the month is classified according to which phase spans the majority of the month based on the criteria above. For example, if a carrier completed its Final Evaluation Problem on January 20, 2008, then January 2008 would be classified as a basic phase month for that carrier. Conversely, if the carrier completed FEP on January 10, 2008, then the month would be classified as an integrated phase month. On the rare occasion that a transition event concluded on the 15th day of a 30-day month (or the 14th of February), that month is be classified according to the upcoming phase. Applying the criteria mentioned above to USS Harry S. Truman (CVN 75) provides an example of one complete FRTP cycle and the transitions between phases (see Figure 2).

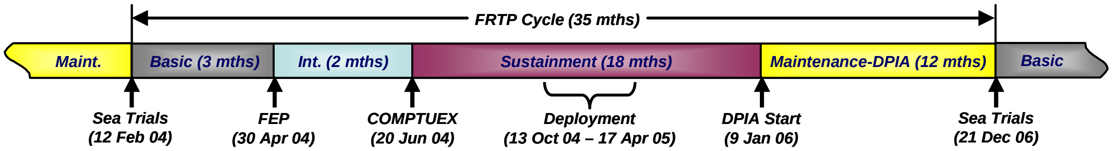

Figure 2. FRTP Example for USS Harry S. Truman (CVN 75)

B. OPERATING TARGET COST MODEL

Commander Naval Air Forces provides each carrier with its OPTAR budget based on a three-year historical average of actual obligations by FRTP phase and by coast (Pacific and Atlantic). These averages are then applied to the upcoming year's schedule to produce each ship's budget amount.

A linear regression analysis of monthly historical aircraft carrier Operating Target spending and employment factors is used to generate a cost model for future spending by carrier in each FRTP Phase. Assuming that varying the duration of a FRTP phase influences its OPTAR cost, we seek a cost model that relies on prescriptive explanatory variables we can adjust. First, the monthly OPTAR and employment data have been aggregated into observations of complete FRTP phases, with total OPTAR obligations for the phase as the dependent variable and the following independent variables:

- *Length* – the length of the FRTP phase in months;
- *Fleet* – a categorical variable representing the parent fleet of the carrier [Atlantic or Pacific]; and
- *FRTP_Phase* – a categorical variable representing the FRTP phase [basic, integrated, sustainment, maintenance].

The resulting regression produces the equation in Figure 3 that predicts total OPTAR cost for the given FRTP phase in constant year 2009 dollars. The intercept ($2,791,729) establishes a starting point for phase cost. The coefficients for the two levels of *Fleet* indicate that Atlantic fleet ships cost more than Pacific fleet ships. The coefficients for the four levels of *FRTP_Phase* indicate that integrated, maintenance, and basic phases (in ascending order) incur less OPTAR cost than sustainment phase. The positive coefficient for *Length* adds $1,456,617 for each month in the phase. All cost numbers, including the estimated *PhaseTotalObligations,* are in $FY09.

$$PhaseTotalObligations = 2,791,729 + Fleet \times \begin{pmatrix} "Atlantic" \Rightarrow 2,749,689 \\ "Pacific" \Rightarrow -2,749,689 \end{pmatrix} +$$

$$FRTP\_Phase \times \begin{pmatrix} "Basic" \Rightarrow -1,426,519 \\ "Integrated" \Rightarrow -1,748,213 \\ "Sustainment" \Rightarrow 4,578,489 \\ "Maintenance" \Rightarrow -1,403,757 \end{pmatrix} + Length \times (1,456,617)$$

Figure 3. Total OPTAR Obligation per FRTP Phase Cost Model Equation

Complete model statistics are included in Appendix A. The test for significance of regression (*F* test) for this model has a p-value of less than 0.0001, indicating a strong linear relationship exists between the response (total phase OPTAR obligation) and at least one of the predictor variables. The model's coefficient of determination (R^2) is 0.86 indicating 86% of the variability of the response variable (total phase OPTAR obligation) is explained by the model. This is a good fit.

C. AIRCRAFT CARRIER SCHEDULING FACTORS

The scheduling of carriers to meet the Fleet Response Plan readiness goal is impacted by the following factors: i) number of available ships; ii) depot level maintenance; iii) personnel tempo restrictions; and iv) annual OPTAR budget.

1. Number of Available Ships

The Navy currently has 11 aircraft carriers split between Pacific and Atlantic Fleets as shown in Table 3. The carrier fleet will be reduced to 10 active ships following the decommissioning of USS Kitty Hawk (CV 63) in October 2008. The next carrier scheduled for decommissioning is USS Enterprise (CVN 65) sometime in fiscal year 2013. The Navy's newest carrier, USS George H. W. Bush (CVN 77), will be delivered in November 2008. The USS George Washington (CVN 73) will relieve USS Kitty Hawk as the Forward Deployed Naval Force carrier in Yokosuka, Japan, in July 2008. In addition, USS Carl Vinson will return to San Diego, California, after completing its Refueling Complex Overhaul at Northrop Grumman Shipbuilding in late 2009.

2. Depot Level Maintenance

The Fleet Maintenance Board of Directors (FMBOD) administers aircraft carrier depot maintenance, and its members represent Naval Sea Systems Command, the Deputy Chief of Naval Operations (N4), Fleet Commanders, Type Commanders, and the various shipyards. The current aircraft carrier depot maintenance schedule showing the planned maintenance periods for all carriers is coordinated by the carrier maintenance planning activity of Naval Sea Systems Command, a snapshot of which is included as Appendix C.

Changes to the approved schedule are vetted through the FMBOD unless the proposed schedule change is less than 35 days in duration or 3% of total cost. In these cases, schedule changes can be approved by the Type Commander [O'Malley 2008].

3. Annual OPTAR Budget

Commander Naval Air Forces receives budget authority for ships' OPTAR from Fleet Forces Command. The authorized budget amount for fiscal year 2009 is $133.7 million (in constant year 2009 dollars) with the ship operations pressurization already applied.

Aircraft Carrier	Hull Number	Year Commissioned	Expected Retirement	Homeport
USS Kitty Hawk	CV 63	1961	2008	Yokosuka, Japan
USS Enterprise	CVN 65	1961	2013	Norfolk, VA
USS Nimitz	CVN 68	1975	2027	San Diego, CA
USS Dwight D Eisenhower	CVN 69	1977	2029	Norfolk, VA
USS Carl Vinson	CVN 70	1982	2034	Norfolk, VA
USS Theodore Roosevelt	CVN 71	1986	2038	Norfolk, VA
USS Abraham Lincoln	CVN 72	1989	2041	Everett, WA
USS George Washington	CVN 73	1992	2044	Norfolk, VA
USS John C Stennis	CVN 74	1995	2047	Bremerton, WA
USS Harry S Truman	CVN 75	1998	2050	Norfolk, VA
USS Ronald Reagan	CVN 76	2003	2055	San Diego, CA
USS George H W Bush	CVN 77	2008	2060	East Coast

Table 3. Current and Planned U.S. Navy Aircraft Carrier Fleet [from Yardley, et.al 2008]

III. MODEL INPUTS AND ASSUMPTIONS

A. CARRIER FORCE INITIAL STATE

The number of carriers considered is constant at eleven. The USS Kitty Hawk (CV 63) is eliminated from the planning scenario due to her decommissioning in fall 2008. We also assume USS Enterprise (CVN 65) is available until her anticipated deactivation period scheduled to begin in December 2012. The initial phase state of each carrier considered is displayed in Table 4. We include the pre-planning horizon start month of each phase to apply the OPTAR cost equation at the beginning of our planning horizon.

Ship	Fleet	Pre-Planning Horizon Phase Start Month	Phase as of First Planning Month (October 08)
USS Enterprise (CVN 65)	Atlantic	April 2008	Maintenance
USS Nimitz (CVN 68)	Pacific	June 2008	Maintenance
USS Dwight D. Eisenhower (CVN 69)	Atlantic	October 2008	Integrated
USS Carl Vinson (CVN 70)	Pacific	November 2005	Maintenance
USS Theodore Roosevelt (CVN 71)	Atlantic	June 2008	Sustainment
USS Abraham Lincoln (CVN 72)	Pacific	December 2007	Sustainment
USS George Washington (CVN 73)	Pacific	April 2008	Sustainment
USS John C. Stennis (CVN 74)	Pacific	July 2008	Integrated
USS Harry S. Truman (CVN 75)	Atlantic	September 2008	Maintenance
USS Ronald Reagan (CVN 76)	Pacific	April 2008	Sustainment
PCU George H. W. Bush (CVN 77)	Atlantic		Maintenance

Table 4. Aircraft Carrier Initial State

B. FLEET READINESS TRAINING PLAN PHASE DURATION

1. Basic, Integrated and Sustainment Phase

Navy policy does not enforce a minimum or maximum duration for each phase. Basic and integrated phase are, by definition, training periods, and CNAF policy requires certain training evolutions in each to progress from one phase to the next. The collection of training evolutions necessary during basic phase require at least 45 days to complete, and the one evolution in integrated phase (COMPTUEX) requires at least 21 days to complete [CNAF 2005]. Therefore, we assume a minimum duration for basic and integrated phase of two months and one month, respectively. We also establish a minimum duration for sustainment phase of six months to remain consistent with personnel tempo (PERSTEMPO) regulations [OPNAV 2007a]. Maximum durations for basic, integrated, and sustainment phases are set at the maximum observed durations of each phase in the historical data collected (see Table 5).

Phase	**Minimum Duration (months)**	**Maximum Duration (months)**
Basic	2	15
Integrated	1	4
Sustainment	6	22

Table 5. Minimum and Maximum FRTP Phase Durations

2. Maintenance Phase

Maintenance phase durations are governed by the aircraft carrier depot maintenance schedule promulgated by the carrier maintenance planning activity of Naval Sea Systems Command. A current version of this schedule is included as Appendix C. We reduce the actual schedule to show only the major maintenance availabilities we define to include: Planned Incremental Availability (PIA); Docking Planned Incremental Availability (DPIA); Extended Selected Restricted Availability (ESRA); Extended Docking Selected Restricted Availability (EDSRA); Selected Restricted Availability (SRA); Post Shakedown Availability (PSA); and Refueling Complex Overhaul (RCOH). We consider the 1-month Carrier Incremental Availabilities (CIA) shown in Appendix C as general upkeep coincident to the current phase state of the carrier, not as unique maintenance phases that mark the end of an FRTP cycle. Figure 4 shows the simplification of the actual carrier maintenance schedule used as an input for our planning purposes.

	FY 2009 (10/08-9/09)												FY 2010 (10/09-9/10)												FY 2011 (10/10-9/11)												FY 2012 (10/11-9/12)												FY 2013 (10/12-9/13)											
Ship	**O**	**N**	**D**	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**
CVN 65	X	X	X	X	X	X	X	X	X	X																				X	X	X																			X	X	X	X	X	X	X	X	X	X
CVN 68	X	X	X																								X	X	X	X	X	X	X	X	X	X	X	X	X	X	X																			
CVN 69																							X	X	X	X	X	X																										X	X	X	X	X	X	X
CVN 70	X	X	X	X	X					X	X	X	X																																	X	X	X	X	X	X									
CVN 71										X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X										
CVN 72						X	X	X	X	X	X	X	X																																									X	X	X	X	X	X	X
CVN 73				X	X	X	X									X	X	X	X									X	X	X	X									X	X	X	X									X	X	X	X					
CVN 74																					X	X	X	X	X	X																													X	X	X	X	X	X
CVN 75	X	X	X	X	X																						X	X	X	X	X	X	X	X	X	X	X	X																						
CVN 76														X	X	X	X	X	X																						X	X	X	X	X	X	X	X	X	X	X									
CVN 77	X					X	X	X	X	X																														X	X	X	X	X	X														

Figure 4. Simplified Carrier Maintenance Schedule.

In this figure, marked boxes indicate scheduled maintenance periods. For instance, CVN 65 begins the planning scenario in maintenance through July 2009. The schedule shows two more maintenance periods for CVN 65 in March through May 2011 and December 2012 until the end of our planning horizon.

To comply with current maintenance policy, we allow only one-month shifts to the start of scheduled maintenance periods (earlier or later), and only for maintenance periods exceeding four months in duration, and one-month changes to duration (shorter or longer). Start month or duration months may be changed for maintenance periods exceeding four months, but not both at once. Figure 5 displays these admissible adjustments.

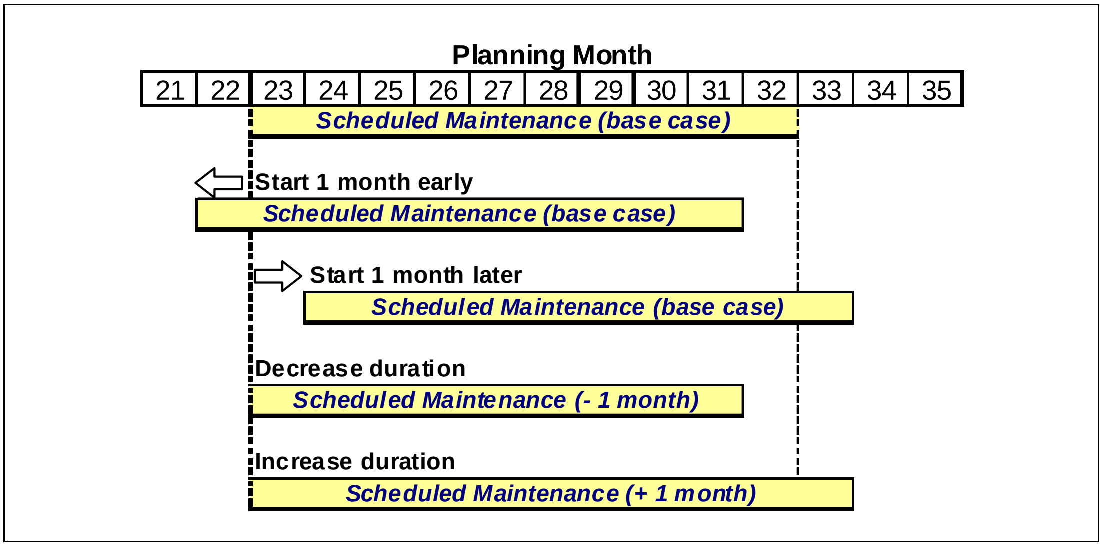

Figure 5. Admissible Changes to Scheduled Depot Maintenance Availabilities

IV. IMPLEMENTATION

A. ASSUMPTIONS

This model has monthly fidelity over a 5-year planning horizon. The model begins by assigning each carrier to its initial phase state according to Table 4 then schedules the carriers in successive planning months according to allowable phase transitions. The FRTP phases are forced to be followed in order, that is, basic follows maintenance, integrated follows basic, etc. The decision to transition from one phase to the next is Markovian in the sense that there is no long-term record-keeping by carrier. Each phase transition depends only on the prior phase termination.

Total phase OPTAR costs are calculated for each scheduled carrier-phase-duration combination and then amortized over all months in the phase. The model then attempts to minimize overall OPTAR cost imposing a financial penalty to planning months where the FRTP goal is not met.

The model does not have visibility of future deployments. As a result, we do not apply personnel tempo (PERSTEMPO) restrictions, and we reduce the "3+3+1+3" goal to "6+1+3" (total sustainment + basic or integrated + maintenance) in the formulation. The model also has no visibility of maintenance types, and therefore, does not distinguish between docked, undocked, or overhaul (RCOH) maintenance phases.

1. Special Case Considerations

The carrier forward-based in Japan, USS George Washington, does not follow the typical FRTP cycle as it has been defined here. The FDNF carrier is considered one of the sustainment carriers in the "3+3+1+3" readiness goal between its annual depot maintenance availabilities. To accommodate these short cycles, the model forces USS George Washington to conduct a 2-month basic phase followed by a 1-month integrated phase followed by sustainment phase months until the next scheduled maintenance availability.

The USS George H. W. Bush (CVN 77) is assumed to be in basic phase in the period following her delivery in November 2008 until the start of her post shakedown availability scheduled in March 2009. This post shakedown availability is assigned to newly-built ships to correct defects and discrepancies discovered during the shakedown period. Following that, CVN 77 is considered available for normal scheduling.

B. MATHEMATICAL FORMULATION

Index Use [~cardinality]

$c \in C$	carrier [~11]
$s \in S$	state of carrier [3]
$p \in P$	phase of FRTP cycle [4]
$p \in P_s \subseteq P$	phases of FRTP cycle associated with each state
$m \in M$	planning month, alias *m'* [60]
$m \in M_c \subseteq M$	carrier *c* available planning months [~60]
$d \in D_p$	admissible durations of phase *p* [~6]
$y \in Y$	planning year [5]
$m \in M_y \subseteq M$	months in planning year *y* [12]
$y(m)$	year of planning month *m*
$f \in F$	fleet [2]

Data [units]

$cost_{cfpmdm'}$	cost of carrier *c* in fleet *f* carrying out phase *p* starting in planning month *m* for duration *d* months incurred during month *m'* [OPTAR 2009 $]

$optar_y$	OPTAR budget by planning year [OPTAR 2009 $]
$state\_req_s$	CNAF readiness requirement expressed as number of carriers required to be in state s [cardinality]

Variables [units]

X_{cpmd}	=1 if carrier c is in phase p during months $\{m, m+1, ..., m+d-1\}$, 0 otherwise [binary]

Formulation

$$\min_{X} \quad policy\ penalties \tag{0}$$

$$s.t. \quad \sum_{\substack{p\in P, d\in D_p, \\ m-d+1\le m'\le m}} X_{cpm'd} = 1 \qquad \forall c\in C, m\in M_c \tag{1}$$

$$\sum_{\substack{d\in D_{\text{'maintenance'}}, \\ m\le m'\le m+2}} X_{c,\text{'maintenance'},m',d} = 1 \qquad \forall c\in C, m\in M_c$$

$$|\{c, \text{'maintenance',m-1,}d\in D_{\text{'maintenance'}}\} = \Omega$$

$$\wedge\{c, \text{'maintenance',m,}d\in D_{\text{'maintenance'}}\} \neq \Omega \tag{2}$$

$$\sum_{\substack{c\in C, p\in P_S, d\in D_p, \\ m\in M_C | m-d+1\le m'\le m}} X_{cpm'd} \ge state\_req_s \qquad \forall s\in S, m\in M \tag{3}$$

$$\sum_{\substack{d\in D_{p,} \\ m'=m-d+1}} X_{cpm'd} \le \sum_{d\in D_{p++1}} X_{c,p++1,m+1,d}$$

$$\forall c\in C, p\in P\backslash\text{'sustainment'}, m\in M_c \tag{4}$$

$$\sum_{\substack{c\in C, p\in P, m'\in M_C\wedge M_y, \\ d\in D_p, \\ m'-d+1\le m\le m'}} cost_{cpmdm'} X_{cpmd} \le optar_y \qquad \forall y\in Y \tag{5}$$

$$X_{cpmd} \in \{0,1\} \qquad \forall c\in C, p\in P,$$

$$m\in M_c, d\in D_p \tag{6}$$

This model has monthly fidelity over a 5-year planning horizon. The objective function assesses penalty costs for deviations from policy (constraint violations). For simplicity, these are not shown here. Each constraint (1) requires a carrier to be employed in exactly one phase each month. Each constraint (2) requires that when a maintenance period appears with alternate start months and durations, exactly one alternative will be selected. Each constraint (3) requires a minimum number of carriers to be in a readiness state each month. Each constraint (4) specifies for a carrier, phase, and month, whether or not a phase transition can take place to the next phase the following month. The notation “++” signifies circular succession in the phase set. There is no such constraint linking ‘sustainment’ to its ordinal successor ‘maintenance’ so that a maintenance phase can follow any other one. Each constraint (5) limits OPTAR expenses for some year. The decision variables (6) are binary.

1. OPTAR Cost Calculation

The data $cost_{cfpmdm'}$ is generated by the following function:

$$cost_{cfpmdm'} = 2,791,729 + \left(if\ \ f = \begin{Bmatrix} "Atlantic" \Rightarrow 2,749,689 \\ "Pacific" \Rightarrow -2,749,689 \end{Bmatrix} \right) +$$

$$\left(if\ \ p = \begin{Bmatrix} "Basic" \Rightarrow -1,426,519 \\ "Integrated" \Rightarrow -1,748,213 \\ "Sustainment" \Rightarrow 4,578,489 \\ "Maintenance" \Rightarrow -1,403,757 \end{Bmatrix} \right) + d \times (1,456,617)$$

2. Solver

The mixed integer program model is implemented with the algebraic modeling language GAMS and solved using CPLEX version 10 [GAMS 2008].

3. Alternative Model

A stronger model for this situation would be a large-scale set partition [e.g., Ayik 1998], with a row for every month-phase, and a column for every alternate schedule each carrier could adopt. Such a model would permit keeping track of the complete history of each ship. However, manually enumerating alternate schedules and/or programming automated enumeration is tedious, and is not necessary in the case at hand.

Our model has about three thousand constraints and 30 thousand binary decision variables, and solves to optimality in less than a minute.

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V. RESULTS AND CONCLUSIONS

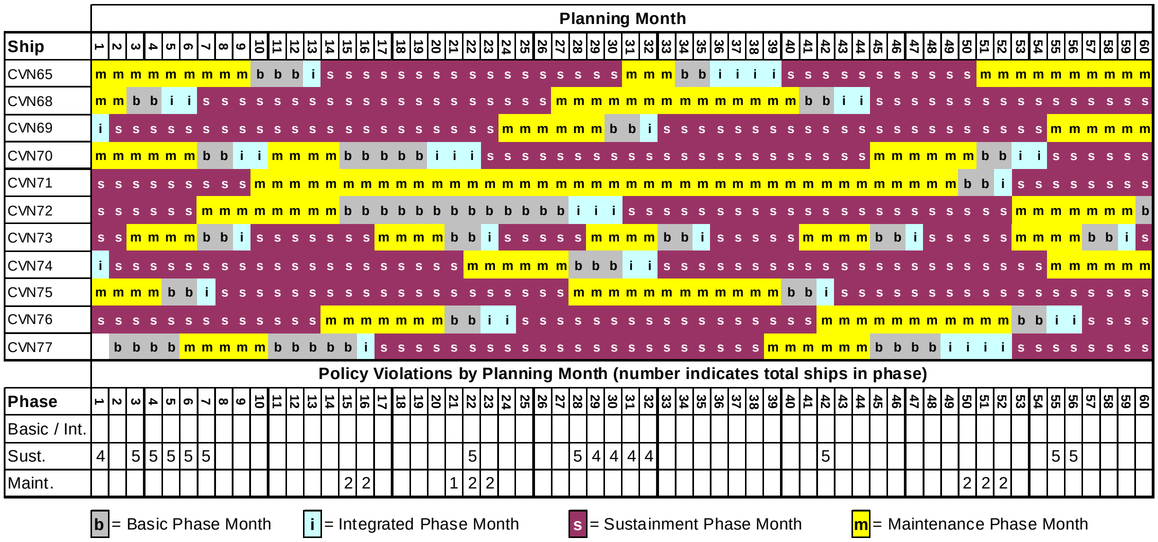
A. RESULTS

1. Optimized Schedule

The optimized schedule output is displayed in Figure 6. The model's objective function penalizes violations to the sustainment goal more strongly than violations to other phase goals. In this way, the model favors scheduling carriers in sustainment over the other phases when competing to meet phase goals. General inspection of the output reveals that the model schedules long sustainment periods, in many cases utilizing the maximum sustainment phase duration of 22 months. We also see examples of total cycle lengths greater than the published FRP goal of 32 months resulting from our strict adherence to scheduled maintenance policy.

The optimized schedule does not meet the FRTP phase goal of "6+1+3" in all months as we've defined this for sustainment, basic-or-integrated, and maintenance phase. The model immediately repairs the violation of policy in the initial state when only four ships are in sustainment, but quickly encounters an irreparable policy violation in planning month three when USS George Washington (CVN 73) begins a scheduled maintenance availability. The most egregious policy violation occurs in planning month 29, February 2011, when only 4 carriers are scheduled in sustainment, again during a scheduled maintenance period for USS George Washington. The basic-or-integrated goal is never violated.

A close inspection of the schedule output reveals that the model rescheduled all maintenance periods in some way (adjustments to start month, duration or both) except for the Post Shakedown Availability for USS George H.W. Bush (CVN 77) in planning month 6. This suggests that perhaps, given more flexibility, the model might prefer more significant adjustments to maintenance periods to meet overall phase goals.



	Planning Month																													
Ship	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
CVN65	m	m	m	m	m	m	m	m	m	b	b	b	i	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s
CVN68	m	m	b	b	i	i	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s	m	m	m	m
CVN69	i	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s	m	m	m	m	m	m	b
CVN70	m	m	m	m	m	m	b	b	i	i	m	m	m	m	b	b	b	b	b	i	i	i	s	s	s	s	s	s	s	s
CVN71	s	s	s	s	s	s	s	s	s	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m
CVN72	s	s	s	s	s	s	m	m	m	m	m	m	m	m	b	b	b	b	b	b	b	b	b	b	b	b	b	i	i	i
CVN73	s	s	m	m	m	m	b	b	i	s	s	s	s	s	s	s	m	m	m	m	b	b	i	s	s	s	s	s	m	m
CVN74	i	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s	m	m	m	m	m	m	b	b	b
CVN75	m	m	m	m	b	b	i	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s	m	m	m
CVN76	s	s	s	s	s	s	s	s	s	s	s	s	s	m	m	m	m	m	m	m	b	b	i	i	s	s	s	s	s	s
CVN77		b	b	b	b	m	m	m	m	m	b	b	b	b	b	i	s	s	s	s	s	s	s	s	s	s	s	s	s	s

	Planning Month																													
Ship	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
CVN65	m	m	m	b	b	i	i	i	i	s	s	s	s	s	s	s	s	s	s	s	m	m	m	m	m	m	m	m	m	m
CVN68	m	m	m	m	m	m	m	m	m	m	b	b	i	i	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s
CVN69	b	i	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s	m	m	m	m	m	m
CVN70	s	s	s	s	s	s	s	s	s	s	s	s	s	s	m	m	m	m	m	m	b	b	i	i	s	s	s	s	s	s
CVN71	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	b	b	i	s	s	s	s	s	s	s	s
CVN72	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s	m	m	m	m	m	m	m	b
CVN73	m	m	b	b	i	s	s	s	s	s	m	m	m	m	b	b	i	s	s	s	s	s	m	m	m	m	b	b	i	s
CVN74	i	i	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s	m	m	m	m	m	m
CVN75	m	m	m	m	m	m	m	m	m	b	b	i	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s
CVN76	s	s	s	s	s	s	s	s	s	s	s	m	m	m	m	m	m	m	m	m	m	m	b	b	i	i	s	s	s	s
CVN77	s	s	s	s	s	s	s	s	m	m	m	m	m	m	b	b	b	b	i	i	i	i	s	s	s	s	s	s	s	s

Policy Violations by Planning Month (number indicates total ships in phase)

Phase	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Basic / Int.																														
Sust.	4		5	5	5	5	5															5						5	4	4
Maint.															2	2					1	2	2							

Phase	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
Basic / Int.																														
Sust.	4	4										5													5	5				
Maint.																				2	2	2								

b = Basic Phase Month   i = Integrated Phase Month   s = Sustainment Phase Month   m = Maintenance Phase Month

Figure 6. Optimized Schedule Output

For instance, CVN 65 begins in maintenance then enters basic phase in July 2009 (planning month 10), followed by integrated phase in October 2009 (planning month 13) and sustainment phase in November 2009 (planning month 14). CVN 65 enters another maintenance period in April 2011 (planning month 31), followed by basic phase in July 2011 (planning month 34), integrated phase in September 2011 (planning month 36), and sustainment phase in January 2012 (planning month 40). CVN 65 begins its final maintenance period in December 2012 (planning month 51). Violations to the readiness goal (1 in basic-or-integrated, 6 in sustainment, and 3 in maintenance) are annotated along the bottom, with blank cells indicating the goal has been satisfied.

2. OPTAR Costs

Our OPTAR cost model provides a linear relationship between total OPTAR cost for the phase versus total length of the phase in months. Recall that the cost model chooses coefficients based on phase type and parent fleet of the carrier being estimated. The "marginal costs" for phase type and fleet are combined with a "fixed cost" to establish a starting point for an increasing line with slope represented by the coefficient associated with phase length.

The optimization model calculates total OPTAR for each carrier-fleet-phase-duration 4-tuple and amortizes this cost over each month of the scheduled phase. This amortization of costs is displayed in Figure 7. We see a similar relationship between

Atlantic and Pacific fleet ships in basic, integrated, and maintenance phases. The concave curves for Atlantic fleet carriers show unit cost decreases over time, where the convex curves for Pacific fleet carriers show unit cost increases over time. For sustainment phase, both fleets' unit costs decrease over time. From a scheduling perspective, these curves indicate we can profit by scheduling 1-month basic and integrated phases for Pacific fleet ships. We can also conclude that short phases of any type for Atlantic fleet carriers are extremely expensive.

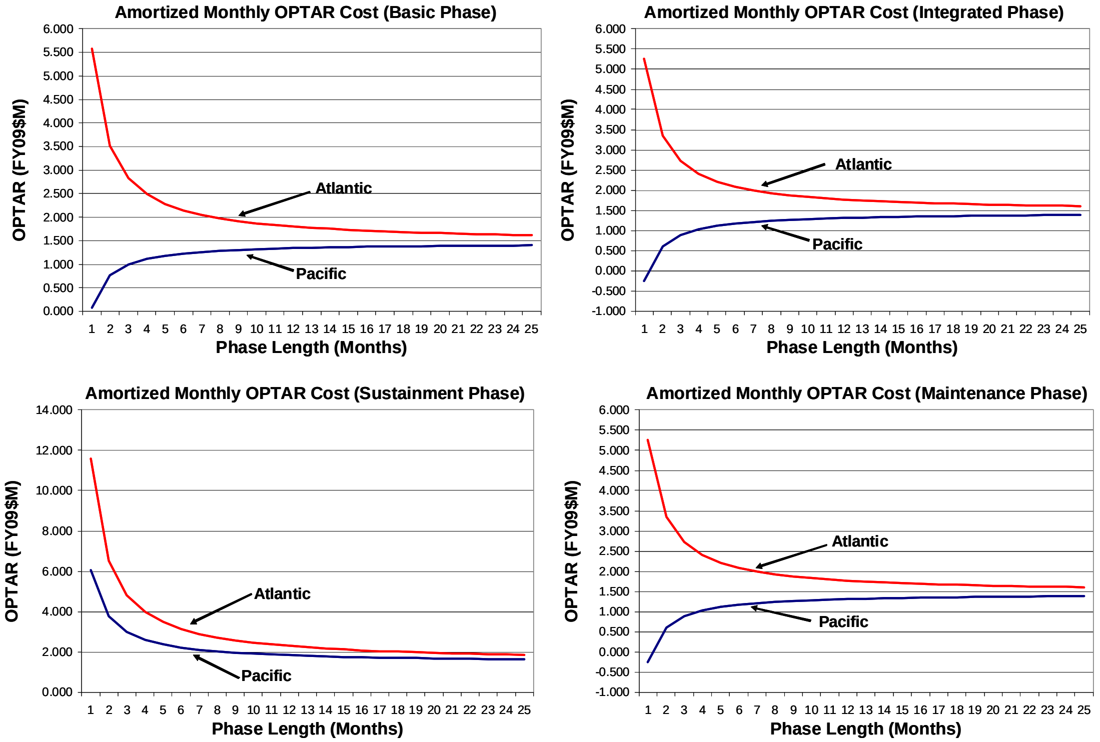


Figure 7. Amortized Monthly OPTAR Cost Curves by FRTP Phase

The graphs show the amortized monthly OPTAR cost for each phase as a function of phase duration. Each curve represents the total phase OPTAR cost divided by the length of the phase in months. For example, the graph in the upper left shows the unit cost for an Atlantic fleet carrier in a 1-month basic phase is $5.6M (FY09$) then decreases to $3.5M (FY09$) for a 2-month basic phase. Conversely, the unit cost for a Pacific fleet carrier in a 1-month basic phase is $72K (FY09$) and increases to $764K (FY09$) for a 2-month basic phase.

Based on our cost estimates, the optimal schedule violates the given annual budget of $133.7M (FY09) by no less than 80% in each planning year (see Figure 8). Strict enforcement of the FRTP readiness goal obviously drives up cost, especially in the case of the forward-deployed carrier, USS George Washington, which is forced to progress into sustainment phase between annually-scheduled maintenance periods.

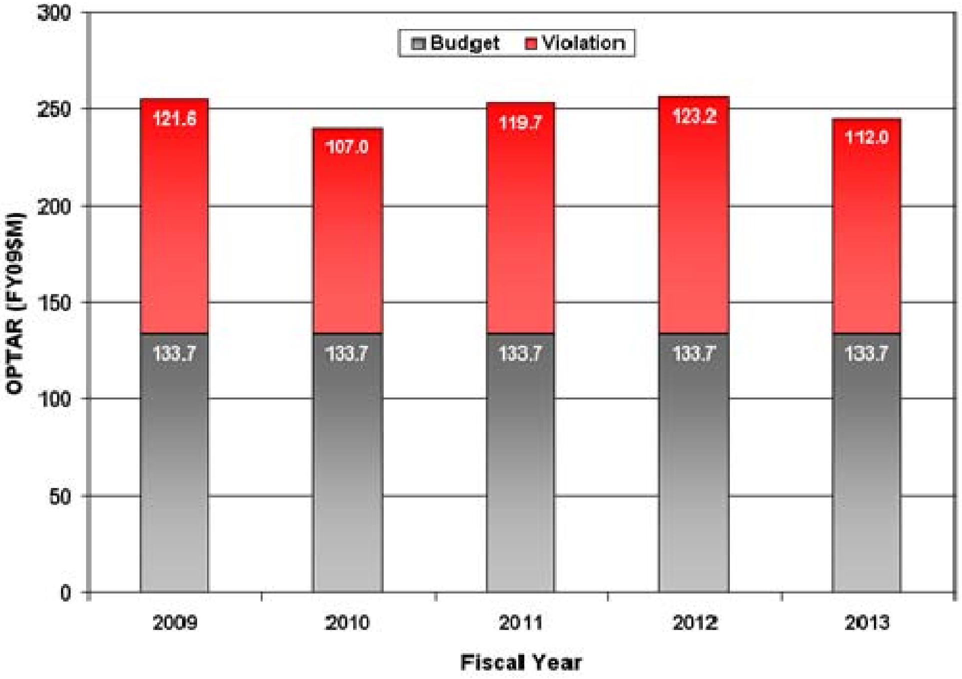


Figure 8. OPTAR Budget Violations by Fiscal Year

This graph shows the total OPTAR spent according to cost estimates and the schedule generated by the optimization model for each fiscal in our planning horizon. For instance, in fiscal year 2009 we project an additional $121.6M (FY09$) over the budget of $133.7M (FY09$) for a total OPTAR cost of $255.3M (FY09$).

To determine the impact of our monthly cost interpretation, we run the model again, this time capping the OPTAR charged per month to the overall fleet averages in each phase. These maximums temper the effect of the amortized OPTAR cost on short FRTP phases, especially those by Atlantic fleet ships. The results show the OPTAR budget is still exceeded, but there is a decrease in overall OPTAR violations to 40% to 50% in each fiscal year (see Figure 9).

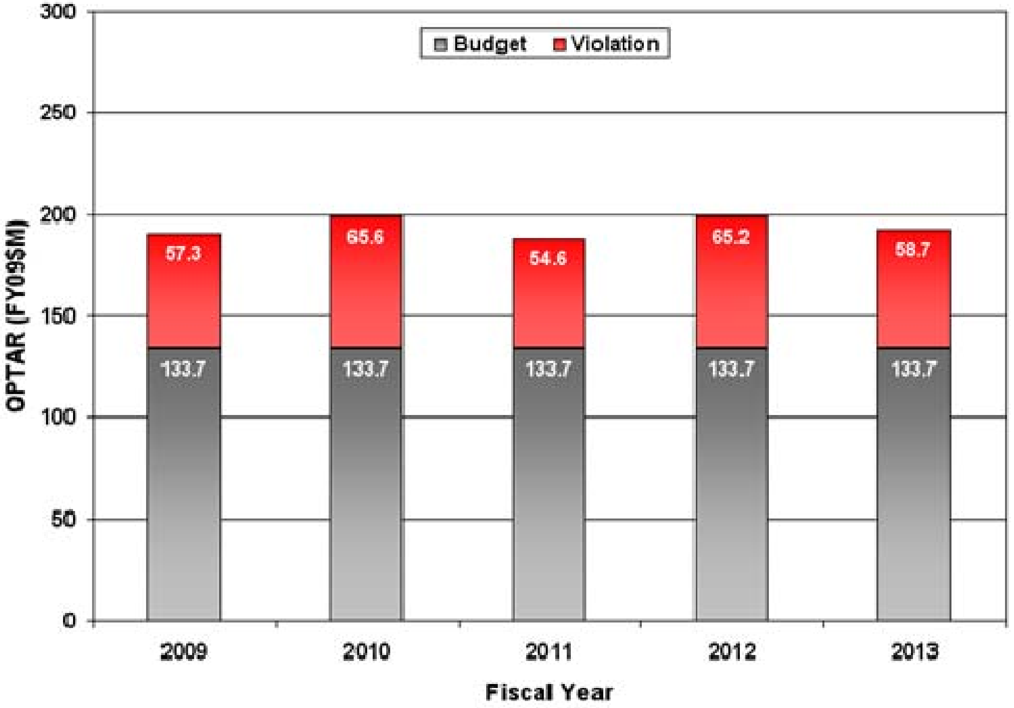


Figure 9. Capped OPTAR Budget Violations by Fiscal Year

This graph shows the total OPTAR spent according to cost estimates and the schedule generated by the optimization model for each fiscal in our planning horizon. In this case, we limit monthly OPTAR charged by our cost model to the fleet average per month in each phase. For instance, in fiscal year 2009 we project an additional $57.3M (FY09$) over the budget of $133.7M (FY09$) for a total OPTAR cost of $191.0M (FY09$).

B. CONCLUSIONS

Assuming that recent history is an accurate indicator of the immediate future, we discover that the FRTP goal of “3+3+1+3” is not achievable given the current force structure and projected funding levels. We began with an analysis of recent historical cost and employment data producing a cost estimating relationship to predict future spending by the aircraft carriers. The passive, descriptive cost model estimates OPTAR spending solely on the parent fleet of the carrier and duration of time spent in each of the four FRTP phase types. The results clearly indicate there is something hidden from view regarding the estimation of aircraft carrier spending habits. This invites more investigation to develop a stronger cost estimating relationship.

A supplementary, descriptive analysis of historical costs by the carriers is included in Appendix C. In that analysis, we attempt to characterize OPTAR spending by the carriers using many different factors such as days underway, number of port visits, the occurrence of major inspections, etc., details not visible to our primary analysis. The relevant conclusion from that analysis is that the data collected does not sufficiently explain all the variability in OPTAR spending across the carrier fleet.

This research ultimately proves, however, that a relatively simple optimization model provides valuable insight into this type of problem. Previous studies show the utility of long-term depot maintenance scheduling. However, we demonstrate that training, operational commitments, and maintenance availabilities are explicitly linked. An optimal solution to aircraft carrier scheduling incorporates all these facets of carrier employment.

In the past when carriers prepared for deployment to areas around the world using the Inter-Deployment Training Cycle, schedulers were concerned with area of responsibility (AOR) coverage. The advent of the Fleet Response Plan removes the notion of AOR coverage, to some degree, and replaces it with a persistent readiness posture of the carrier fleet to respond to a variety of situations. The results of this research demonstrate that both operational and maintenance planners can benefit from long-range, synchronous planning of all phases of the Fleet Readiness Training Plan to produce that readiness state. Additionally, the feature we present to estimate carrier fleet spending provides a link between operational readiness and budget requirements. Considering the fiscal constraints now facing fleet planners, the decision-support optimization model presented here has much to offer.

APPENDIX A: OPTAR COST ANALYSIS

A. LINEAR REGRESSION ANALYSIS OVERVIEW

The test for significance of regression (or *F* test) is used to determine if a linear relationship exists between the response (dependent) variable and at least one of the predictor (independent) variables. In general, the procedure is thought of as a global test of model adequacy. Specifically, the procedure tests the following hypotheses:

$$H_0 : \beta_1 = \beta_2 = \cdots = \beta_k = 0$$
$$H_1 : \beta_j \neq 0 \text{ for at least one } j$$

Rejection of the null hypothesis in this test implies that at least one of the predictor variables contributes significantly to the regression model [e.g., Montgomery, et.al 2006, p. 80]. In statistical hypothesis testing, the null hypothesis is rejected when the calculated *p*-value is less than a user-defined level of significance. The *p*-value is defined as the probability of obtaining a value of the test statistic, in this case the *F* ratio, at least as extreme as the one observed, given the null hypothesis is true.

Once overall validity of the model is determined using the *F* test, the validity of individual predictor variables is determined using the *t* test that evaluates the contribution of each predictor to the regression model in the presence of the other predictors [e.g., Montgomery, et.al 2006, p. 84]. The *t* test examines the following hypotheses and is evaluated in the same manner as the *F* test described previously:

$$H_0 : \beta_j = 0$$
$$H_1 : \beta_j \neq 0$$

Finally, the coefficient of determination, or R^2, is used to measure the variability of the response variable explained by the predictor variables. The coefficient of determination takes values between zero and one, higher being better, indicating the proportion of the variability in the response explained by the regression model [e.g., Montgomery, et.al 2006, p. 35]. Evaluating a model's validity by R^2 alone is problematic because the statistic's value can be inflated by including additional terms in the model. Therefore, the R^2 statistic is considered only after the *F* and *t* tests prove significant.

B. FRTP PHASE COST MODEL

1. Model Statistics

The analysis of variance results (see Table 6) show the *F*-test of this model has a very low p-value indicating a linear relationship exists between total phase OPTAR cost and at least one of the independent variables. A graphical representation of the test for significance of regression is displayed in Figure 10.

Source	**Degrees of Freedom**	**Sum of Squares**	**Mean Square Error**	***F* Ratio**	**p-value**
Model	5	6.6285e+15	1.326e+15	65.3980	<.0001
Error	62	1.3176e+15	2.027e+13		
C. Total	67	7.9461e+15			

Table 6. Analysis of Variance (ANOVA) for FRTP Phase Cost Model

Table 7 shows the estimates of the parameters in the linear regression model, and a *t*-test for each. The p-values for the variables *Fleet* and *Length* are very low, indicating these parameters are contribute significantly to the overall model. The high p-values for the levels of *FRTP_Phase* indicate these parameters are less significant in the overall model, and an additional test is required to determine the overall contribution of the *FRTP_Phase* variable.

To confirm the variable *FRTP_Phase* does have an effect on the overall model, we calculate an effect test which evaluates the contribution of all parameters of a variable (see Table 8 below). In this case, the *p*-values for each effect are very low indicating strong evidence that all three variables contribute significantly. We can infer from this result that the fourth level of the *FRTP_Phase* variable not listed in Table 7 (for sustainment phase) has the most significant contribution on total phase OPTAR cost.

Term	Estimate	Standard Error	*t* Ratio	p-value
Intercept	2,791,729	1,242,610	2.25	0.0281
Fleet[Atlantic]	2,749,689	548,615	5.01	<0.0001
FRTP_Phase[Basic]	-1,426,519	1,010,329	-1.41	0.1627
FRTP_Phase[Integrated]	-1,748,213	1,202,502	-1.45	0.1508
FRTP_Phase[Maintenance]	-1,403,757	932,592	-1.51	0.1371
Length (mths)	1,456,617	159,452	9.14	<.0001

Table 7. Parameter Estimates and *t*-tests for FRTP Phase Cost Model

This table displays the statistics to test the significance of each parameter in the linear regression model. The *t*-ratio is the ratio of the parameter estimate to its standard error, and p-values less than 0.05 indicate the associated parameter is significant in the model.

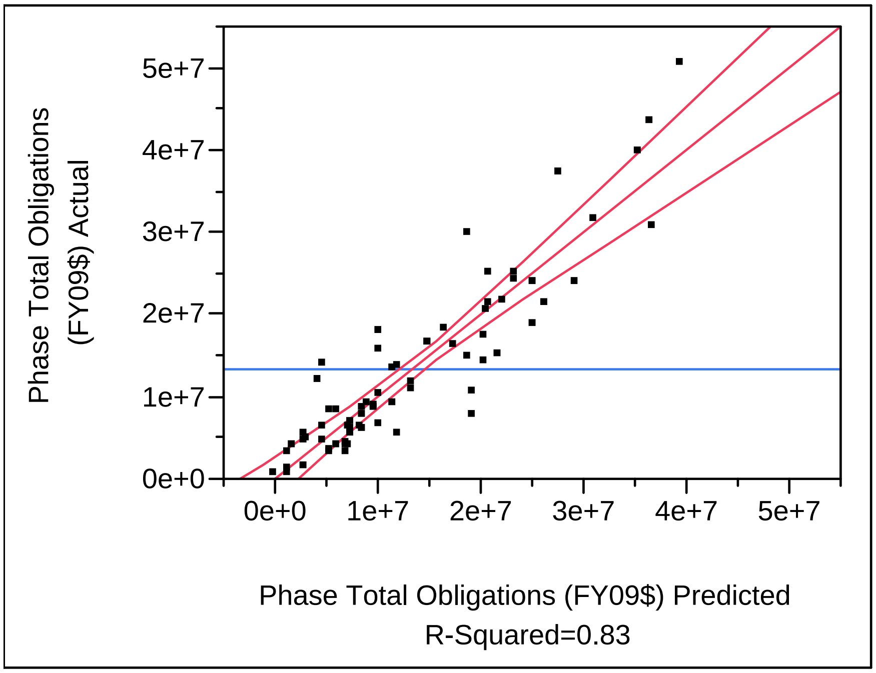


Figure 10. Actual Phase Total Obligation versus Predicted Phase Total Obligation

The confidence curves (dotted red diagonal lines) show a 95% confidence region for the line of fit (solid red diagonal line). When the confidence curves do not contain the response sample mean (dotted blue horizontal line), as in this case, the effect of the model is significant. The, R^2 value of this regression model is 0.83 indicating 83% of the variability in the response (Phase Total Obligations) is explained by the linear regression model.

Source	Degrees of Freedom	Sum of Squares	*F* Ratio	p-value
Fleet	1	5.0923e+14	25.1207	<0.0001
FRTP Phase	3	2.7127e+14	4.4607	0.0065
Length (mths)	1	1.6917e+15	83.4511	<0.0001

Table 8. Effect Tests for FRTP Phase Cost Model

This table displays the effect test statistics for each variable in the linear regression model. The *F* ratio is the mean square error for the effect (defined as sum of squares divided by degrees of freedom) over mean square for error of the overall model (from Table 6). Small p-values (less than 0.05) indicate the effect contributes significantly to the overall model.

The final model diagnostic considered is the variance in the model residual values. This is done by plotting the model residual values against predicted values. One of the assumptions underpinning a linear regression model is the model residual values have equal variance, indicated by an even scatter of points above and below zero (blue horizontal line) in this plot. Figure 11 shows a slight clustering of points close to zero on the horizontal axis indicating possible unequal variances. This can be corrected by applying a power transformation to the response variable, typically by using the log or square-root functions. In this case, however, transforming the response variable did not improve the results displayed in the residual versus predicted plot.

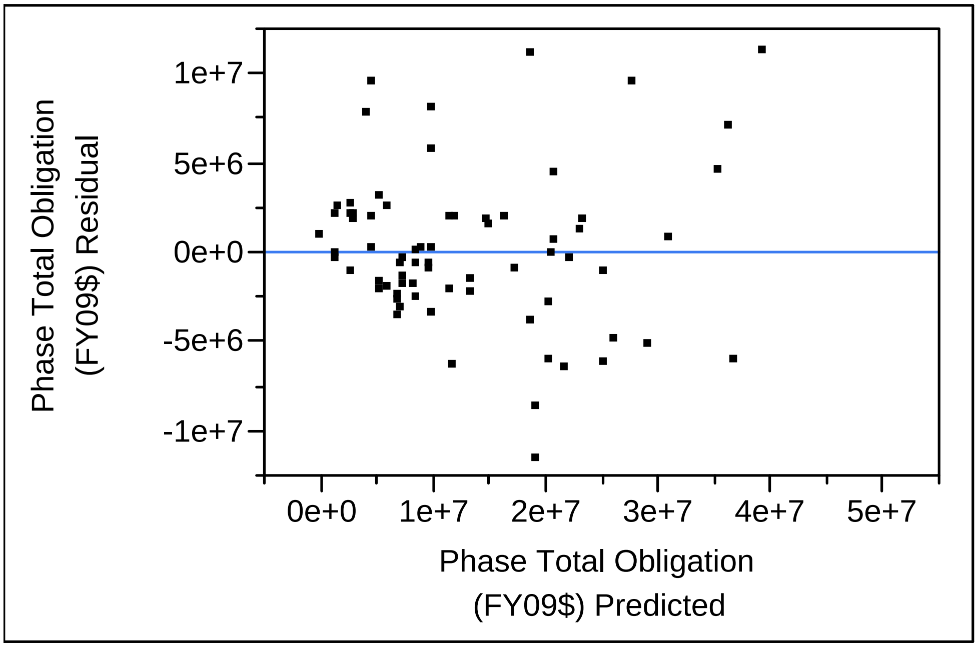


Figure 11. Model Residual Values vs. Model Predicted Values Plot

An even distribution of points above and below the horizontal line plotted at zero on the y-axis indicates the sum of residual values is equal to zero, validating the assumption in linear regression of homoscedastic residual values.

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APPENDIX B: SUPPLEMENTAL ANALYSIS OF OPTAR OBLIGATION AND EMPLOYMENT DATA

A. DATA ORGANIZATION

We attempt an additional investigation of monthly OPTAR spending to reveal potential relationships between schedule-driven factors and OPTAR spending. Obligations are categorized under 31 individual fund codes on the Budget OPTAR Report, and can be generally categorized by their respective Standard Identification Code (SIC) [NAVSO P-3013-2, App. II]. A summary analysis of OPTAR obligations by SIC in Figure 12 shows that SR and SO obligations comprise the vast majority (94% to 96%) of the total, and therefore were initially used as the response variables in our regression analysis.

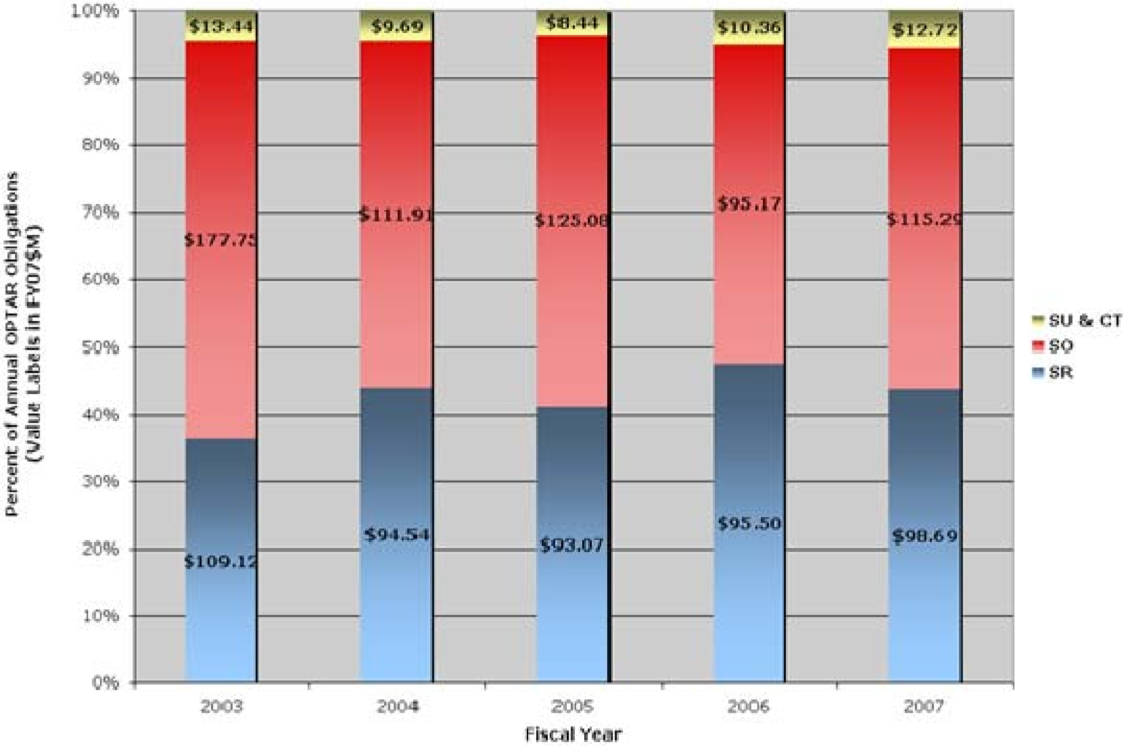

Figure 12. Comparison of Annual OPTAR Obligations

The graph above shows the percentage of total OPTAR spent in each Standard Identification Code (SIC) category by fiscal year. The four SIC categories described are: SR for organizational level repair expenses, e.g., purchasing aviation and shipboard depot level repairable components and other equipment maintenance related material; SO for general use items and administrative supplies; SU for purchased utilities; and CT for counter-terrorism and force protection expenses. In fiscal year 2003, for example, the carrier fleet spent \$109.12M in SR, \$177.75M in SO, and \$13.44M in CT & SU combined (all in FY07\$).

B. LINEAR REGRESSION ANALYSIS OF MONTHLY OPTAR OBLIGATIONS

1. Discussion of Predictor Variables

Possible predictor variables were developed through investigation of the data provided and discussions with both former aircraft carrier supply officers and officials at Commander Naval Air Forces familiar with OPTAR budget estimation. A description of each is included here:

- *Airwing* – true if the carrier's airwing is embarked during any part of the month, false otherwise;
- *Month* – a categorical variable corresponding to each month of the year [1-12];
- *Hull_Number* – a categorical variable representing the carrier's hull number [CV63, CV67, CVN65, CVN68-76];
- *Fleet* – a categorical variable representing the parent fleet of the carrier [Atlantic, Pacific];
- *FRTP_Phase* – a categorical variable representing the FRTP phase [basic, integrated, sustainment, maintenance];
- *Phase_Detail* – a categorical variable to provide specific maintenance type and deployment location [PIA, DPIA, RCOH, CENTCOM, WESTPAC, MED];

- *Month_Of_Maint* – a numeric variable to count maintenance phase months sequentially starting at 1 for the first month, 0 for non-maintenance months;
- *POM_Month* – true if observation immediately precedes a deployment, false otherwise;
- *Inspection* – a categorical variable to represent significant inspections or evolutions observed in a month [TSTA, FEP, C2X, JTFEX, ORSE, INSURV];
- *Last_Maint_Type* – a categorical variable representing the last depot maintenance accomplished [PIA, DPIA, RCOH, NewConstruction];
- *Next_Maint_Type* - a categorical variable representing the next depot maintenance to be accomplished [PIA, DPIA, RCOH];
- *Months_Till_Maint* – a numeric variable for number of months until the next scheduled depot maintenance period, zero for maintenance period months;
- *Months_Since_Maint* – a numeric variable for number of months since the last scheduled depot maintenance period, zero for maintenance period months;
- *Cycle_Month* – a numeric variable to count the months in a FRTP cycle sequentially beginning with 1 for the first month of the cycle;
- *UW_Days* – a numeric variable for number of days underway during the observed month;
- *Nbr_Port_Visits* – a categorical variable for number of port visits observed in a month [0,1,2,3];
- *Ship_Age_Mths* – a numeric variable for the age of the carrier in months, calculated from commissioning month; and
- *Not_Maint* – zero if observed month is during maintenance phase, one otherwise (when interacted with *UW_Days* variable will only consider underway days during non-maintenance months).

2. Analysis of All Observations

Separate regression models generated for SR and SO monthly obligations pass the *F* test, and many of the variables mentioned previously are significant in each model according to *t* tests using a 0.05 level of significance. However, we fail to achieve an R^2 value higher than 0.48 in either model indicating the chosen predictor variables explain only 48% of the total variability of SR and SO obligations.

A regression model for the aggregated total of all SICs (SR + SO + SU + CT) as the response variable achieved only marginally better results (increased R^2 from 0.48 to 0.61), however, this analysis provided some insight into the interactions of the predictor variables. Specifically, the predictor variables *Month*, *Cycle_Month*, *Last_Maint_Type*, *Next_Maint_Type*, *Fleet*, and *UW_Days* showed strong influence when interacted with the *FRTP_Phase* predictor variable, indicating that FRTP phase has some effect on monthly OPTAR spending.

3. Analysis of Monthly OPTAR Obligations during Complete Fleet Readiness Training Program Cycles Only

In an alternative approach, we analyzed only the observations during complete FRTP cycles. Table 9 shows a summary of the seven carriers that completed a full FRTP cycle during the time period for which we have data. Parsing the data in this manner provides an analysis of "steady state" operations, eliminating the observations from the early part of the data set when multiple carriers were underway operating in wartime conditions supporting both Operation Enduring Freedom and Operation Iraqi Freedom. Additionally, applying the insight from earlier analyses, we developed separate regression models of total monthly OPTAR obligations for each of the four FRTP phases. Grouping the data in this way delivered substantially better results. Complete results for each model are included later in this chapter, and are summarized in Table 10. Predictor variables for each linear regression model were chosen based on their individual *t*-tests. The log transformation of the response variable was used where applicable to ensure homoscedasticity of the model residual values. The subset of complete FRTP cycles contained only 12 observations of integrated phase months, and a statistically significant model could not be generated on these observations alone, therefore, basic and integrated phase observations were analyzed together.

		Months in FRTP Phase				
Ship	**Fleet**	**Basic**	**Integrated**	**Sustainment**	**Maintenance**	**Total**
CVN 65	Atlantic	4	1	11	13	29
CVN 68	Pacific	4	1	13	6	24
CVN 71	Atlantic	2	1	12	10	25
CVN 72	Pacific	3	2	22	10	37
CVN 73	Atlantic	6	1	11	11	29
CVN 74	Pacific	8	4	12	10	34
CVN 75	Atlantic	5	2	16	12	35
Average	---	4.57	1.71	13.86	10.29	30.43

Table 9. Complete FRTP Cycles, Fiscal Years 2003-2007

This table shows the seven instances of a carrier completing a full FRTP cycle during the time period for which we have data. For example, CVN65 spend 4 months in basic phase, 1 month in integrated phase, 11 months in sustainment phase, 13 months in maintenance phase for a total cycle length of 29 months.

Phase	**Model Parameters**	**F Statistic & p-value**	**R^2**
Basic-and-Integrated	log*(Total_Obligation) ~ Intercept + Month + Fleet + Airwing + Month:Fleet + Airwing:Fleet*	F statistic = 4.096 p-value = 0.002	0.86
Sustainment	log*(Total_Obligation) ~ Intercept + Month + Fleet + POM_Month + Cycle_Month + Cycle_Month:POM_Month + Cycle_Month:Fleet*	F statistic = 7.012 p-value = <0.0001	0.75
Maintenance	*Total_Obligation ~ Intercept + Month + Month_Of_Maint + Cycle_Month + Month:Month_Of_Maint + Month:Cycle_Month*	F statistic = 14.689 p-value = <0.0001	0.93
Deployment	*Total_Obligation ~ Intercept + Month + Phase_Detail*	F statistic = 6.331 p-value = <0.0001	0.74

Table 10. Linear Regression Analysis of Total OPTAR Obligations by FRTP Phase

This table shows a summary of the linear regression analysis performed for OPTAR obligations separated by FRTP phase type. All pass the *F* test (test for significance of regression) with very low p-values. R^2 values range from 0.74 (for deployment months) to 0.93 (for maintenance phase months).

C. LINEAR REGRESSION DETAILS

1. Basic and Integrated Phase Model

Source	Degrees of Freedom	Sum of Squares	Mean Square Error	*F* Ratio	p-value
Model	25	20.122649	0.804906	4.0959	0.0020
Error	17	3.340745	0.196514		
C. Total	42	23.463394			

Table 11. Analysis of Variance (Basic-and-Integrated Phase Model)

The analysis of variance results show the *F*-test of this model has a very low p-value (0.002) indicating a linear relationship exists between the response (dependent variable) and at least one of the predictors (independent variables).

Term	Estimate	Std Error	*t* Ratio	p-value
Intercept	14.165677	0.089809	157.73	<.0001
Month[1]	-0.371151	0.264691	-1.40	0.1789
Month[2]	-0.42576	0.269956	-1.58	0.1332
Month[3]	0.4160488	0.311334	1.34	0.1990
Month[4]	-0.081434	0.311334	-0.26	0.7968
Month[5]	-0.187217	0.264691	-0.71	0.4890
Month[6]	-0.19276	0.228923	-0.84	0.4115
Month[7]	0.3575921	0.276511	1.29	0.2132
Month[8]	0.3534696	0.228923	1.54	0.1410
Month[9]	0.9357826	0.264484	3.54	0.0025
Month[10]	-0.308289	0.293152	-1.05	0.3077
Month[11]	-0.102246	0.250136	-0.41	0.6878
Fleet[Atlantic]	0.4409769	0.089809	4.91	0.0001
Airwing[F]	-0.226355	0.123018	-1.84	0.0833
Month[1]*Fleet[Atlantic]	0.2444043	0.264691	0.92	0.3687
Month[2]*Fleet[Atlantic]	-0.090697	0.269956	-0.34	0.7410
Month[3]*Fleet[Atlantic]	0.8419102	0.311334	2.70	0.0150
Month[4]*Fleet[Atlantic]	0.4175941	0.311334	1.34	0.1975
Month[5]*Fleet[Atlantic]	0.224502	0.264691	0.85	0.4081
Month[6]*Fleet[Atlantic]	-0.176531	0.228923	-0.77	0.4512
Month[7]*Fleet[Atlantic]	0.3007165	0.276511	1.09	0.2920
Month[8]*Fleet[Atlantic]	-0.659902	0.228923	-2.88	0.0103
Month[9]*Fleet[Atlantic]	-0.077273	0.264484	-0.29	0.7737
Month[10]*Fleet[Atlantic]	-0.600674	0.293152	-2.05	0.0562
Month[11]*Fleet[Atlantic]	-0.51125	0.250136	-2.04	0.0568
Fleet[Atlantic]*Airwing[F]	-0.436475	0.123018	-3.55	0.0025

Table 12. Parameter Estimates (Basic-and-Integrated Phase Model)

This table displays the statistics to test the significance of each parameter in the linear regression model for basic-and-integrated phase months. In this analysis, we assume a predictor variable is significant if at least one of its levels has a p-value less than 0.05.

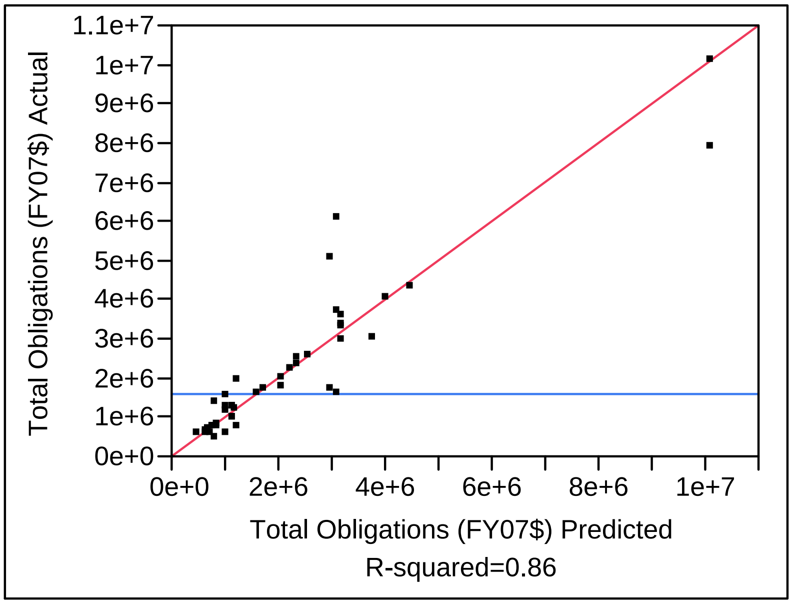

Figure 13. Actual versus Predicted Plot (Basic & Integrated Phase Model)

The solid red diagonal line is the fit with the predicted response of the whole model along the x-axis and actual values along the y-axis. In this case, the line of fit crosses the response sample mean (solid blue horizontal line) indicating the effect of the whole model is significant. The, R^2 value of this regression model is 0.86 indicating 86% of the variability in the response (Total Obligations) is explained by the linear regression model.

2. Sustainment Phase Model

Source	Degrees of Freedom	Sum of Squares	Mean Square Error	*F* Ratio	p-value
Model	16	19.082883	1.19268	7.0115	<.0001
Error	37	6.293785	0.17010		
C. Total	53	25.376668			

Table 13. Analysis of Variance (Sustainment Phase Model)

The analysis of variance results show the *F*-test of this model has a very low p-value (<0.0001) indicating a linear relationship exists between the response (dependent variable) and at least one of the predictors (independent variables).

Term	Estimate	Std Error	*t* Ratio	p-value
Intercept	14.412676	0.229773	62.73	<.0001
Month[1]	-0.226971	0.171393	-1.32	0.1935
Month[2]	0.2359395	0.250879	0.94	0.3531
Month[3]	0.00652	0.214846	0.03	0.9760
Month[4]	-0.008038	0.20599	-0.04	0.9691
Month[5]	0.0300478	0.208539	0.14	0.8862
Month[6]	0.4394658	0.202427	2.17	0.0364
Month[7]	0.0744153	0.189563	0.39	0.6969
Month[8]	-0.349712	0.171232	-2.04	0.0483
Month[9]	1.0151306	0.186137	5.45	<.0001
Month[10]	-0.245974	0.208913	-1.18	0.2466
Month[11]	-0.401206	0.1921	-2.09	0.0437
Fleet[Atlantic]	0.1816021	0.068309	2.66	0.0115
POM_Month[0]	0.331436	0.081121	4.09	0.0002
Cycle_Month	-0.042635	0.016759	-2.54	0.0153
POM_Month[0]*(Cycle_Month-13.5556)	0.0396967	0.017342	2.29	0.0279
Fleet[Atlantic]*(Cycle_Month-13.5556)	-0.036984	0.014988	-2.47	0.0184

Table 14. Parameter Estimates (Sustainment Phase Model)

This table displays the statistics to test the significance of each parameter in the linear regression model for sustainment phase months. In this analysis, we assume a predictor variable is significant if at least one of its levels has a p-value less than 0.05.

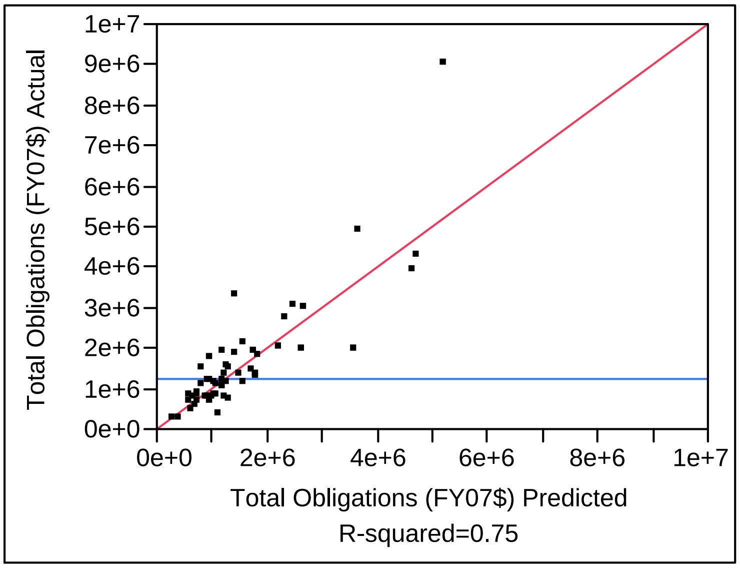

Figure 14. Actual versus Predicted Plot (Sustainment Phase Model)

The solid red diagonal line is the fit with the predicted response of the whole model along the x-axis and actual values along the y-axis. In this case, the line of fit crosses the response sample mean (solid blue horizontal line) indicating the effect of the whole model is significant. The, R^2 value of this regression model is 0.75 indicating 75% of the variability in the response (Total Obligations) is explained by the linear regression model.

3. Maintenance Phase Model

Source	Degrees of Freedom	Sum of Squares	Mean Square Error	*F* Ratio	p-value
Model	35	9.096e+13	2.599e+12	14.6892	<.0001
Error	36	6.3693e+12	1.769e+11		
C. Total	71	9.733e+13			

Table 15. Analysis of Variance (Maintenance Phase Model)

The analysis of variance results show the *F*-test of this model has a very low p-value (<0.0001) indicating a linear relationship exists between the response (dependent variable) and at least one of the predictors (independent variables).

Term	**Estimate**	**Std Error**	***t* Ratio**	**p-value**
Intercept	1354873.8	296582.5	4.57	<.0001
Month[1]	-992293	349096.7	-2.84	0.0073
Month[2]	380036.54	275030.1	1.38	0.1755
Month[3]	-257724.7	223898.9	-1.15	0.2573
Month[4]	65012.952	184168.6	0.35	0.7261
Month[5]	-256989.8	161718.3	-1.59	0.1208
Month[6]	-232931.3	163813.7	-1.42	0.1637
Month[7]	-396007.3	190678.1	-2.08	0.0450
Month[8]	-69155.21	233579.4	-0.30	0.7689
Month[9]	2670870.3	163475.8	16.34	<.0001
Month[10]	-345235.3	176893.1	-1.95	0.0588
Month[11]	-459402	194234.7	-2.37	0.0235
Month_Of_Maint	114804.89	25123.15	4.57	<.0001
Cycle_Month	-32162.41	12694.21	-2.53	0.0158
Month[1]*(Month_Of_Maint-5.84722)	-380782.7	124118	-3.07	0.0041
Month[2]*(Month_Of_Maint-5.84722)	107219.18	89459.44	1.20	0.2385
Month[3]*(Month_Of_Maint-5.84722)	-96528.01	86188.01	-1.12	0.2701
Month[4]*(Month_Of_Maint-5.84722)	106754.32	86188.01	1.24	0.2235
Month[5]*(Month_Of_Maint-5.84722)	-79409.4	86188.01	-0.92	0.3630
Month[6]*(Month_Of_Maint-5.84722)	-70670.46	86188.01	-0.82	0.4176
Month[7]*(Month_Of_Maint-5.84722)	-100407.9	88432.48	-1.14	0.2637
Month[8]*(Month_Of_Maint-5.84722)	223752.05	88432.48	2.53	0.0159
Month[9]*(Month_Of_Maint-5.84722)	324390.95	49417.2	6.56	<.0001
Month[10]*(Month_Of_Maint-5.84722)	-34126.82	60060.48	-0.57	0.5734
Month[11]*(Month_Of_Maint-5.84722)	52499.125	60060.48	0.87	0.3879
Month[1]*(Cycle_Month-25.9861)	74401.306	50971.64	1.46	0.1531
Month[2]*(Cycle_Month-25.9861)	-26487.37	38372.86	-0.69	0.4945
Month[3]*(Cycle_Month-25.9861)	26732.232	38180.08	0.70	0.4883
Month[4]*(Cycle_Month-25.9861)	14613.935	38180.08	0.38	0.7041
Month[5]*(Cycle_Month-25.9861)	91928.157	38180.08	2.41	0.0213
Month[6]*(Cycle_Month-25.9861)	13152.987	38180.08	0.34	0.7325
Month[7]*(Cycle_Month-25.9861)	-30513.3	49785.34	-0.61	0.5438
Month[8]*(Cycle_Month-25.9861)	-43752.65	49785.34	-0.88	0.3853
Month[9]*(Cycle_Month-25.9861)	-235151.1	37073.4	-6.34	<.0001
Month[10]*(Cycle_Month-25.9861)	51131.758	37896.98	1.35	0.1857
Month[11]*(Cycle_Month-25.9861)	-28058.72	37896.98	-0.74	0.4639

Table 16. Parameter Estimates (Maintenance Phase Model)

This table displays the statistics to test the significance of each parameter in the linear regression model for maintenance phase months. In this analysis, we assume a predictor variable is significant if at least one of its levels has a p-value less than 0.05.

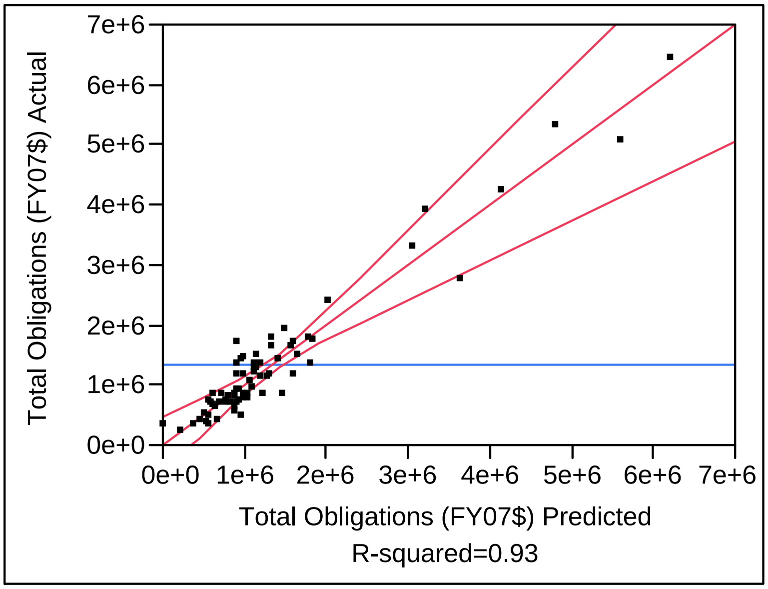

Figure 15. Actual versus Predicted Plot (Maintenance Phase Model)

The confidence curves (dotted red diagonal lines) show a 95% confidence region for the line of fit (solid red diagonal line). When the confidence curves do not contain the response sample mean (dotted blue horizontal line), as in this case, the effect of the model is significant. The, R^2 value of this regression model is 0.93 indicating 93% of the variability in the response (Total Obligations) is explained by the linear regression model.

4. Deployment Model

Source	Degrees of Freedom	Sum of Squares	Mean Square Error	*F* Ratio	p-value
Model	13	2.5751e+13	1.981e+12	6.3305	<.0001
Error	29	9.0741e+12	3.129e+11		
C. Total	42	3.4825e+13			

Table 17. Analysis of Variance (Deployment Model)

The analysis of variance results show the *F*-test of this model has a very low p-value (<0.0001) indicating a linear relationship exists between the response (dependent variable) and at least one of the predictors (independent variables).

Term	**Estimate**	**Std Error**	***t* Ratio**	**p-value**
Intercept	2506566.9	119959.9	20.90	<.0001
Month[1]	-532765.3	308784.3	-1.73	0.0951
Month[2]	-393490.8	248799.2	-1.58	0.1246
Month[3]	157965	275667.2	0.57	0.5710
Month[4]	461835.44	275667.2	1.68	0.1046
Month[5]	-517745.3	275667.2	-1.88	0.0704
Month[6]	337873.85	271949.9	1.24	0.2240
Month[7]	-690760	271949.9	-2.54	0.0167
Month[8]	-621981.3	313096	-1.99	0.0565
Month[9]	2163810.2	373020.9	5.80	<.0001
Month[10]	-200607.2	272398.9	-0.74	0.4674
Month[11]	-463509.1	308784.3	-1.50	0.1441
Phase_Detail[CENTCOM]	92610.107	135260.7	0.68	0.4990
Phase_Detail[MED]	628343.56	214862.5	2.92	0.0066

Table 18. Parameter Estimates (Deployment Model)

This table displays the statistics to test the significance of each parameter in the linear regression model for deployment months. In this analysis, we assume a predictor variable is significant if at least one of its levels has a p-value less than 0.05.

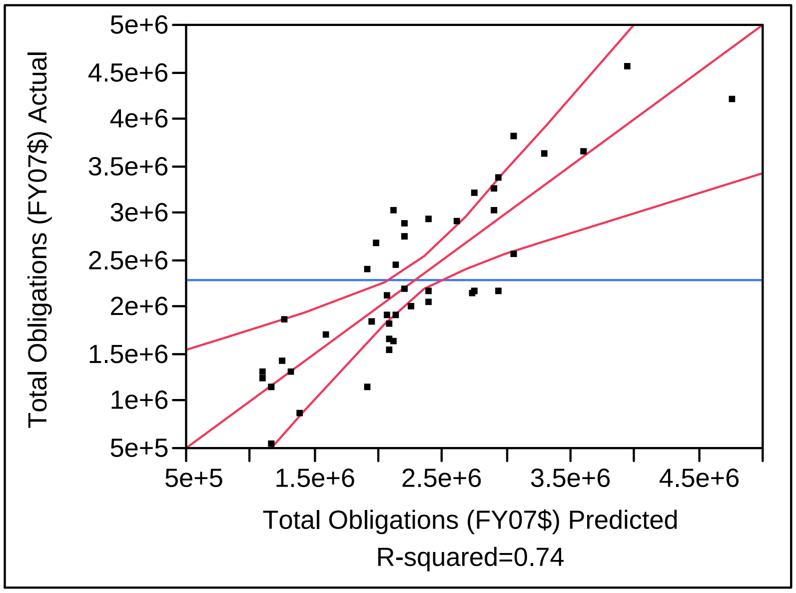

Figure 16. Actual versus Predicted Plot (Deployment Model)

The confidence curves (dotted red diagonal lines) show a 95% confidence region for the line of fit (solid red diagonal line). When the confidence curves do not contain the response sample mean (dotted blue horizontal line), as in this case, the effect of the model is significant. The, R^2 value of this regression model is 0.74 indicating 74% of the variability in the response (Total Obligations) is explained by the linear regression model.

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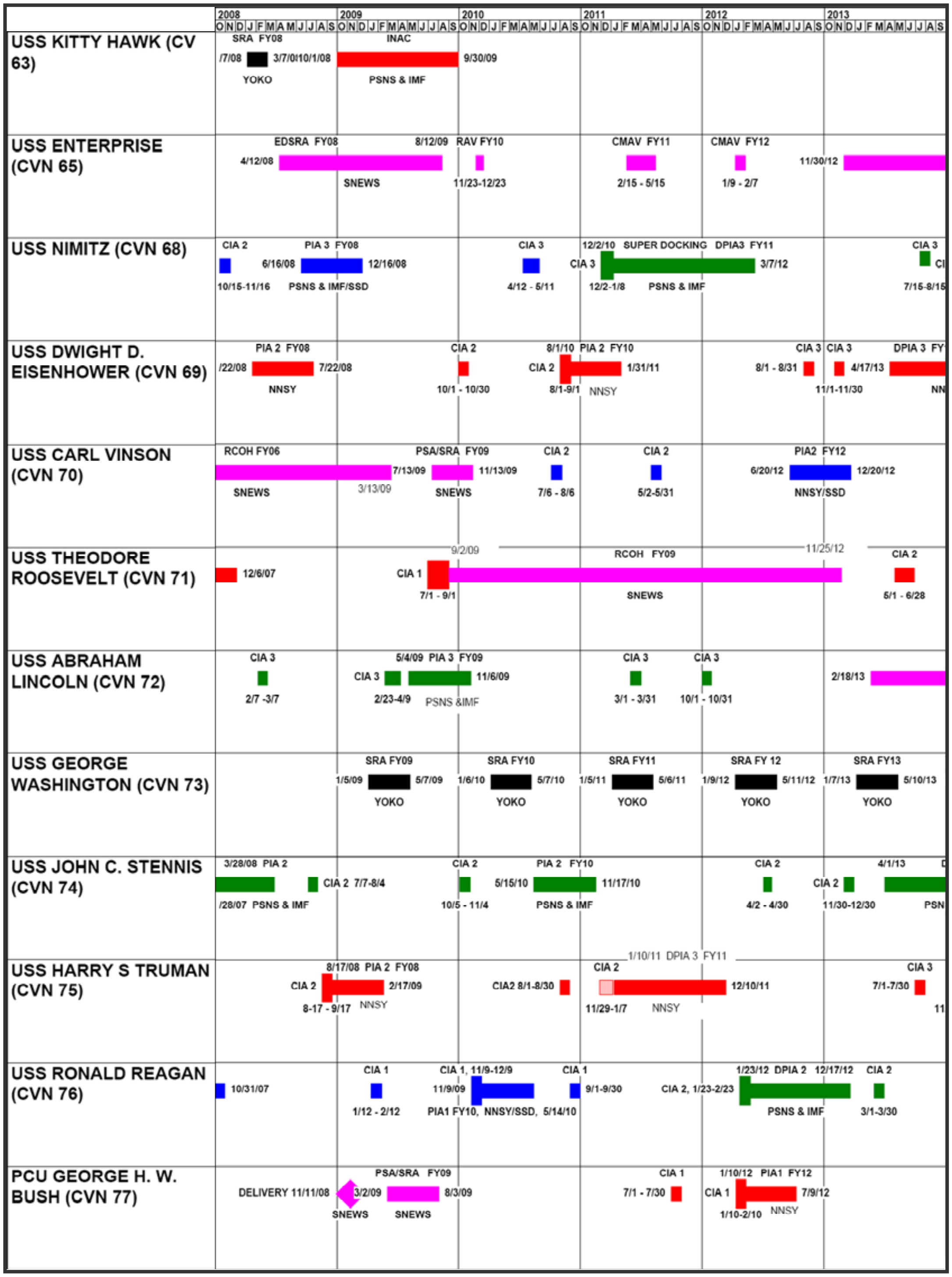
APPENDIX C: CV/CVN AVAILABILITY SCHEDULE



From: Naval Sea Systems Command carrier maintenance planning activity, 1 May 2008

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LIST OF REFERENCES

Ayik, M. 1998, *Optimal Long-Term Aircraft Carrier Deployment Planning With Synchronous Depot Level Maintenance Scheduling*, M.S. Thesis in Operations Research, Naval Postgraduate School, Monterey, CA (March).

Brown, R.L.; Lawphongpanich, S.; Looney, R.; Schrady, D.; Wirtz, J.; Yost, D. 1997, "Forward Engagement Requirements for U.S. Naval Forces: New Analytical Approaches," Technical Report Prepared for Deputy Chief of Naval Operations (Resources, Requirements and Assessments) N-8, Office of the Chief of Naval Operations, Washington, D.C.

Commander Naval Air Forces 2005, *Aircraft Carrier Training and Readiness Manual*, Instruction 3500.20A, Commander Naval Air Forces, San Diego, CA.

Commander Naval Air Forces 2006, *Supply Operations Manual*, Instruction 4440.2, Commander Naval Air Forces, San Diego, CA.

Department of the Navy 1990, *Financial Management of Resources (Operating Forces) Operating Procedures*, NAVSO P-3013-2, Department of the Navy, Office of the Comptroller, Washington, D.C.

Department of the Navy 2008, *Fiscal Year (FY) 2009 Budget Estimates, Operation and Maintenance, Navy Vol 1*, Justification of Estimates, February 2008, Department of the Navy, Washington, D.C., http://www.finance.hq.navy.mil/fmb/09pres/BOOKS.htm (accessed 19 June 2008).

General Algebraic Modeling System Development Corporation. Solver descriptions: CPLEX. http://www.gams.com/solvers/solvers.htm#CPLEX (accessed 25 July 2008).

Gantt, W.K., Gyarmati, M.; Hajdu, Z.; Hascall, A.M.; Matthews, A.M. 2003, *Analysis of the Ship Ops Model's Accuracy in Predicting U.S. Naval Ship Operating Cost*, M.A. Professional Report in Business in Administration, Naval Postgraduate School, Monterey, CA (June).

Hall, M.H. 2004, *The Impact of Long-Term Aircraft Carrier Maintenance Scheduling on the Fleet Readiness Plan*, M.S. Thesis in Operations Research, Naval Postgraduate School, Monterey, CA (September).

Kahnke, V.A. 2007, *A Statistical Analysis of Pacific Fleet Los Angeles Class OPTAR Spending by Activity*, M.A. Thesis in Business Administration, Naval Postgraduate School, Monterey, CA (December).

Maldonado, Commander Fernando, United States Navy, OPNAV N814D1. 2007. Interview by author. December 10.

Montgomery, D.C.; Peck, E.A.; Vining, G.G., 2006. *Introduction to Linear Regression Analysis*, John Wiley & Sons, Inc., Hoboken, New Jersey.

O'Malley, Commander Sean, United States Navy, CNAF N431. 2008 Interview by author. July 10.

OPNAV 2003a, *Maintenance Policy for U.S. Navy Ships,* Instruction 4700.7K, Office of the Chief of Naval Operations, Washington, D.C.

OPNAV 2003b, *Policy for Expeditionary Strike Force, Carrier Strike Groups, Expeditionary Strike Groups, Surface Strike Groups, and Missile Defense Surface Action Groups*, Instruction 3501.316A, Office of the Chief of Naval Operations, Washington, D.C.

OPNAV 2006, *Fleet Response Plan*, Instruction 3000.15, Office of the Chief of Naval Operations, Washington, D.C.

OPNAV 2007a, *Personnel Tempo of Operations Program*, Instruction 3000.13C, Office of the Chief of Naval Operations, Washington, D.C.

OPNAV 2007b, *Representative Intervals, Durations, Maintenance Cycles, and Repair Mandays for Depot Level Maintenance Availabilities of U.S. Navy Ships,* Notice 4700, Office of the Chief of Naval Operations, Washington, D.C.

Yardley, R.J.; Grammich, C.A.; Kallimani, J.G.; Schank, J.F. 2008, "Increasing Aircraft Carrier Forward Presence: Changing the Length of the Maintenance Cycle." RAND National Defense Research Institute Report Prepared for the Assessments Division of the Deputy Chief of Naval Operations (Resources, Requirements, and Assessments), OPNAV N81, Office of the Chief of Naval Operations, Washington, D.C.

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