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Navy Expeditionary Readiness Cost Modeling

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MONTEREY, CALIFORNIA

NAVY EXPEDITIONARY READINESS COST MODELING

by

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Military services estimate the budget for activities associated with operational readiness using mathematical models. OPNAV N834 (Expeditionary Readiness) presently uses an N81 accredited Capability Costing Model (CCM) to inform the annual sustainment requirements for the Navy Expeditionary Combat Enterprise. This research aims to analyze the CCM, execution data, and phases of the Optimized Fleet Response Plan to evaluate the computational and analytical performance of the model. We dissected the existing CCM, assessed the importance of factors in accurately predicting sustainment spending, and explored avenues for model enhancement.

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readiness, budget planning, Capability Costing Model (CCM), Optimized Fleet Response Plan (OFRP), Navy Expeditionary Combat Enterprise (NECE)

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I. INTRODUCTION

Military services estimate the budget for activities associated with operational readiness using mathematical models (CBO, 2012). OPNAV N834 (Expeditionary Readiness) presently uses an N81 accredited Capability Costing Model (CCM) to inform the annual sustainment requirements for the Navy Expeditionary Combat Enterprise (NECE). This research aims to analyze the CCM, execution data, and phases of the Optimized Fleet Response Plan (OFRP) to evaluate the computational and analytical performance of the model. We dissected the existing CCM, assessed the importance of factors in accurately predicting sustainment spending, and explored avenues for model enhancement.

The CCM exists in an Excel Visual Basic for Applications (VBA) tool. The remainder of this chapter provides context for the tool's use, defines the ten tabs in the POM23 Excel Workbook, and the Programming Phase of Planning, Programming, Budgeting, and Execution (PPBE).

A. BACKGROUND

OPNAV N834 (Expeditionary Readiness) uses an N81 accredited cost model to inform the annual sustainment requirement for NECE (Navy Expeditionary Combat Enterprise) during the Program Objective Memorandum (POM) process. The Navy budget model is built around the Optimized Fleet Response Plan (OFRP), a structured training process used to prepare and train Navy forces for routine deployment and, if necessary, for contingency operations overseas (CBO 2012). Specifically, the OFRP is a fleet force generation model that maximizes employability while preserving essential maintenance, modernization, and work-up entitlements to ensure a predictable operational and personnel tempo for forces.

The cost model is referred to as the "Solver" operation in the high-level view of the cost model process shown in Figure 1.

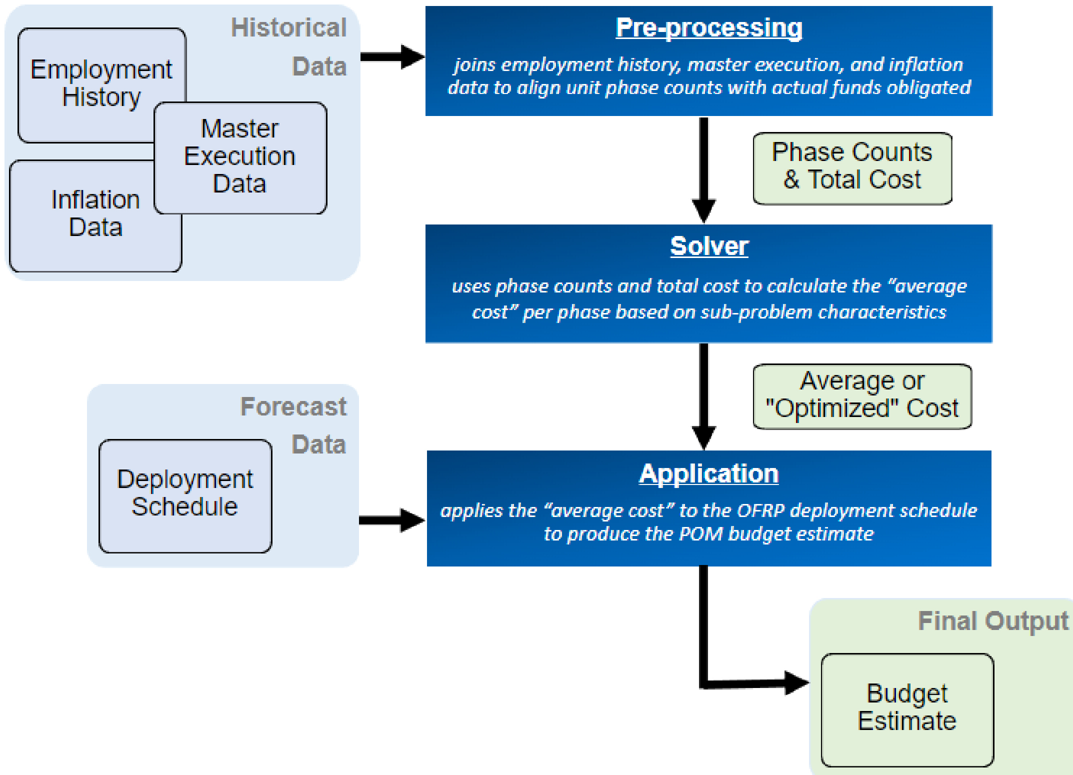

Figure 1: Overview of the cost model process

1. Process for Cost Model Usage

Historical employment history and master execution data are combined with inflation tables to assign unit phase counts and constant year costs to each month in the time horizon (corresponding to the "Pre-processing" operation Figure 1.1). The unit phase counts and costs are input into an Excel File that utilizes Solver to find the "optimized" costs. The "optimized" costs are applied to future schedules or notational deployment data to forecast the total required cost for this dataset. NECC then rolls up this value into the final budget estimate.

B. SUMMARY TAB

The first tab, labeled Summary, consists of 10 variables split between columns.

1. Unit Program

The Unit Program field identifies the organizational command responsible for managing the program. In this instance, there are eight unique variables in this field:

1. Navy Expeditionary Combat Command (COMNECC CM)
2. Coastal Riverine Force (CRF)
3. Explosive Ordnance Disposal (EOD)

4. Expeditionary Mine and Counter Measures (EXMCM)
5. Navy Mobile Diving and Salvage Unit (MDSU)
6. Navy Expeditionary Logistics Support Group (NAVELSG)
7. Naval Construction Force Seabees (NCF)
8. Navy Expeditionary Intelligence Command (NEIC)

2. JON

The JON (Job Order Number) field is the source of information needed for the preparation of reports which require detail below the funding level. This variable varies by type of appropriation, system, or fleet/shore activity and is the last element of the Navy accounting classification code. There are 123 unique JON variables with some data intersection between the unit programs in this instance.

3. PILLAR

The PILLAR field identifies four out of the seven pillars of readiness (PEST). These pillars include personnel (P), equipment I, supply (S), and training (T).

4. APPN

The APPN (appropriation) field identifies the type of funds used. The variables in this field include Operations and Maintenance Navy (OMN) and Operations and Maintenance Navy Reserve (OMNR).

5. BSO

The Budget Submitting Offices (BSO) field includes offices and major commands that the CNO gives resources for their respective program and support activities. The two variables in this field include 60 (Commander, U.S. Fleet Forces) and 70 (Commander, U.S. Pacific Fleet).

6. Summary Tab Values across Five Phases of OFRP

The fields following phase month consist of the five phases of the OFRP cycle. They include the maintenance phase (M), the basic phase (B), the advanced phase (A), deployment (D), and the sustainment phase (S). The values in this field are equal to the optimized cost across the five OFRP phases at various programmatic levels of data (per unit program by JON). Instead of deleting deployment from the current cost model in POM23, NECC adjusted the VBA code in FY21 based on the administrative change to group the sustainment and deployment phases together.

a. Maintenance Phase

The maintenance phase is the beginning of the ORFP cycle. All deployable elements of Navy forces have a maintenance phase. The maintenance phase is critical to the success of the OFRP since it is the optimal period in which major shipyard or depot-level repairs, upgrades, force reconstitution, and platform modernization occur. In addition to the timely completion of the maintenance package, units and staff must complete appropriate inspections, certifications, assist visits, and focus on individual and team training while maintaining a solid foundation of readiness (Howard, 2014).

b. Basic Phase

The basic phase focuses on developing unit core capabilities and skills through completing basic-level inspections, certifications, assessments and visits, and training requirements and achieving required levels of personnel, equipment, supply, and ordnance readiness (Howard, 2014).

c. Advanced Phase

The advanced phase applies to independent deploying Navy forces not part of a deploying group (i.e., CSG, expeditionary strike group, or amphibious ready group). The advanced phase provides sufficient time to complete required inspections, certifications, assist visits, and training and achieve requisite levels of personnel, equipment, supply, training, and ordnance readiness. Upon completion of the advanced phase, forces will be certified for deployment (Howard, 2014).

d. Deployment Phase

The OFRP cycle provides a rotation of forward-deployed forces to fulfill Global Force Management (GFM) commitments and continued surge capability. The deployment phase begins with the departure of the ship or unit. The length of deployment varies by unit but typically lasts around six to seven months (Howard, 2014).

In POM23, NECC made programmatic changes to the cost model. They grouped the deployment phase with the sustainment phase due to security reasons and deployment schedule variability. Theoretically, there should be no calculations for deployment in the Summary tab based on the changes made in POM23. The current cost model also zeroes out the deployment phase values for OMNR in post-processing. The logic behind this was that OMNR does not have funds allocated in the deployment phase because Navy Reserve is funded by OMN during deployment.

e. Sustainment Phase

The sustainment phase begins after the advanced phase, continues throughout the post-deployment period, and ends with the following maintenance phase. Units may conduct deployments within the sustainment phase. Sustainment consists of various evolutions designed to sustain and enhance warfighting readiness as a group, multi-unit, or unit (Howard, 2014).

C. CONSTRAINTS TAB

The second tab, "Constraints," consists of a four-by-four matrix: OMN and OMNR APPN vs. percentage and inverse. The inverse row is the complement of the percentage row (i.e., the inverse equals one less the percentage). The current cost model applies these constraints equally to each unit program. Results indicate that the "percentage" value indicates a relative minimum optimized cost for specified phases. This topic is discussed in follow-on sections.

A supposition from NECC is that there should be a difference in the application of constraints between the unit programs with the largest total cost (i.e., NCF and EOD) and unit programs with substantially fewer costs (i.e., MDSU and NEIC).

D. OTHER TABS IN EXCEL WORKBOOK

Apart from the Summary and Constraints tabs, the other tabs separate the data by unit program. The values in the OFRP phases for each unit program tab represent the number of units in that phase each month. It is an aggregation of forces derived from a calendar that lays out all the NECC forces by their BSO and what phase they are in each month. These tabs contain additional fields, which include:

- MONTH: actual 1st day of the month
- PHASE FY: respective fiscal year in the OFRP phase
- PHASE MONTH: respective month in the OFRP phase
- TOTAL COST: total amount of dollars expended by the units for all phases each month by JON
- YEARS: OFRP cycle length in years by JON
- Pred: a formula that multiplies the array of units in a phase per month and the array of Avg cost (aka "optimized" cost) and returns the sum product
- Square Error: a formula that calculates the difference between Total cost and Pred squared
- Avg cost: a decision variable better characterized as the optimized cost rate rather than the "average" cost. Theoretically, this value is an optimized cost rate by JON for an entire OFRP cycle based on the constraint relationship enforced by the cost model.

The remaining fields are additional calculations derived by the VBA macro to validate constraint relationships.

E. PROGRAMMING PHASE OF PPBE

OPNAV's PPBE is the government's resource allocation process used to apply military leadership priorities and make sure that there are proper levels of support across all Navy efforts and activities. The programming phase is the second phase of PPBE. Programming pinpoints available resources and prioritizes the needs for the next five years in the Future Years Defense Program (FYDP) and outlines them in the POM (Blickstein et al., 2016).

The primary deliverable in the programming phase is the POM resource database which can be accessed and modified in the Program Budget Information System. The POM is essentially a five-year statement of intent, and specific figures are less certain past the first two years. NECC is responsible for capturing and pricing their requirements to inform the POM build. Note that entry into POM does not necessarily guarantee out-year support, however failure to capture the full requirement or underfunding requirements in the POM will likely negatively impact future funding for their respective programs by OSD and Congress (Blickstein et al., 2016).

This cost model assists NECC in calculating the optimized cost of their programs and applying it to the deployment schedule to capture the total funding requirement for the POM.

F. EXCEL TOOL USAGE

The N81 accredited cost model is implemented in Excel supplemented with VBA. This analysis focuses on the POM23 model (corresponding to FY23 and onward planning) and uses the POM21 model (corresponding to FY21 and onward planning) for comparison.

II. MATHEMATICAL PROGRAMMING MODEL

The existing model used to produce budget forecasts was developed many years ago by contractors who are no longer connected to its continued usage. Documentation on the model is not available. The model itself is implemented in VBA. Below, we provide a formal mathematical description of the model.

A. QUADRATIC PROGRAMMING FORMULATION

a. Indices and Sets

- $P = \{b, a, s, m, d\}$ – set of ORFP phases
- T – time periods

OFRP is how the Navy trains and deploys.

b. Parameters

- $r_{p,t}$ – allocation factor for phase $p \in P$ at time $t \in T$
- c_t – total cost during time period $t \in T$
- $\alpha \in [0,1]$ – percentage (based on Unit Program and APPN)
- $\beta \in \{1,2\}$ – weight (based on Unit Program and APPN)

$r_{p,t}$ distributes the number of units of actions between the phases. The unit value is an aggregation of forces from a calendar in excel that lays out all of the Navy Expeditionary Combat Command (NECC) forces by their BSO and what they have done (separated by phases) each month for these years.

c. Decision Variables

- x_p – average cost allocated to phase $p \in P$

d. Quadratic Programming Model

$$\text{Minimize} \quad \sum_{t \in T} \left(c_t - \sum_{p \in P} r_{p,t}\, x_p \right)^2 \qquad (1)$$

$$\text{subject to} \quad \sum_{t \in T} \sum_{p \in P} r_{p,t}\, x_p = \sum_{t \in T} c_t \qquad (2)$$

$$x_s - \beta x_b \geq 0 \qquad (3)$$

$$x_s - \beta x_a \geq 0 \qquad (4)$$

$$x_b - x_m \geq 0 \qquad (5)$$

$$\alpha x_m - (1 - \alpha)(x_b + x_a + \beta x_s) \geq 0 \qquad (6)$$

$$\alpha x_a - (1 - \alpha)(x_b + x_m + \beta x_s) \geq 0 \qquad (7)$$

$$x_p \geq 0, \ \ \forall p \in P \qquad (8)$$

The objective (1) minimizes the differences between total cost and the cost allocation decision at each time step. Constraint (2) ensures total cost is allocated. Constraints (3), (4), (5), (6) and (7) enforce relationships between the allocations of pairs of phases. However, the reason for these relationships is not clear. The final constraint (8) ensures all budget allocations are non-negative.

B. CIVPERS DECISION MODEL

$$x_{\tilde{p}} = \frac{1}{|T|} \sum_{t \in T} \frac{c_t}{\sum_{p \in P} r_{p,t}} \qquad \forall \tilde{p} \in P \quad (9)$$

$$\text{Squared Error} = \sum_{t \in T} \left(c_t - \frac{c_t}{\sum_{p \in P} r_{p,t}} \right)^2 \qquad \forall \tilde{p} \in P \quad (10)$$

The decisions are independent of phase for CIVPERS. Equation (9) normalizes the ratio of total cost based on the total allocation, by time step. The squared error in equation (10) is measured as the difference between total cost and total cost normalized by allocation.

III. COMPUTATION EXPERIMENTS

We performed computational experiments on “POM23 Solver file for NCCM.xlsm”, which consisted of 678 problems: 668 quadratic programs and 10 CIVPERS instances. The original tool developed in VBA and using the GRG Nonlinear method in Solver ran all 678 subproblems in 3002 seconds. We redeveloped the models in Python using Gurobi optimizer and reduced the total run time to 63 seconds, an improvement in speed of 48 times faster.

A. COMPARISON OF RESULTS

We compared the results obtained from Excel to those obtained from our Python model to ensure consistency of the Python implementation. We measured the difference between the objective and decision variable values for each of the 678 problems. An absolute or relative difference above 0.01 was the threshold set to classify solutions as different. We identified 31 problems with such differences, whereas VBA and Python tools produced equivalent solutions for the other 647 problems. Many of the 31 differences are attributed to multiple solutions with the same objective value in the quadratic programming model.

IV. DISCUSSION

A. UNINTENDED MODEL EFFECTS

A lack of continuity between the model developers and those currently tasked to maintain it has led to some implementation updates that are methodologically problematic. When reviewing the VBA code in use, one such update we discovered was a post-processing treatment of the deployment phase cost decisions for OMNR. The model had been allocating positive dollar amounts to deployment phase decision variables for OMNR. However, when Navy Reserves deploy, they are funded by OMN, so this operational model would suggest that funds should not be allocated to OMNR for the deployment phase. To address this, at some point, the VBA code was updated to zero out such allocations. Within the code, though, this zeroing out was handled in post-processing rather than through the constraint system of the mathematical model itself. The unintentional effect of this post-processing was that it invalidated the intended constraint system and objective. In our modeling updates, we addressed this by implementing constraints in the model to ensure no allocations to deployment phase decision variables for OMNR.

B. MULTIPLE SOLUTIONS WITH EQUIVALENT OBJECTIVE VALUES

Another aspect we observed about the current model is that multiple solutions may exist with the same objective value. While this is true of mathematical programming models in general, this particular model is not highly constrained, so non-unique solutions may have significant practical differences. Requirements-driven modeling would alleviate this issue; however, it requires domain expertise and a modified organizational process.

C. MODEL PARAMETER WEIGHTS

The origin of the parameter values for α and β in section II.A.b are not known by the current parties involved in maintaining and executing the model. The β parameter appears to have been introduced in the POM 23 model, as it is not present in the POM 21 model. Let $\overline{x}_p$ be the decision variables for POM 23 and x_p be the decision variables for POM 21. Our best guess is that whoever modified the program between POM 21 and POM 23 assumed that since $\overline{x}_s$ represents both x_d and x_s that $\overline{x}_s = x_s + x_d \approx 2x_s$. However, this logic is not sound because x_p represents an "average" cost per unit in phase p (per time period). A better assumption might be $\overline{x}_s = qx_s + (1-q)x_d$ where $q \in [0,1]$; let q be the proportion of troops in phase "S" compared to the total number of troops in "S" or "D" (i.e., $q = \left(\sum_{t \in T} r_{s,t}\right) / \left(\sum_{t \in T} r_{s,t} + r_{p,t}\right)$). The effects on the specific constraints are addressed next.

D. CONSTRAINT REQUIREMENTS

The combination of constraints (3) through (7) set minimum values and relationships for all x_p variables. However, the reasoning behind constraints (3) through (7) is not evident. Some general guidelines include the maintenance phase being greater than or equal to 0.35 time the average cost of the rest of the phases. Maintenance is the least costly phase and sustainment is the most costly.

Constraint (3) through (5) are intuitive relationships saying one "average" cost must be greater than another. In the POM 21 model, there were four constraints that were converted into POM 23 constraints (3) and (4):

$$x_d - x_b \geq 0 \qquad x_d - x_a \geq 0$$
$$x_s - x_b \geq 0 \qquad x_s - x_b \geq 0.$$

Our best guess is that the $\beta = 2$ parameter is used when x_d is included in the model (i.e. when the APPN is OMN). In constraints (3) and (4), $\beta = 1$. If x_d and x_s must be greater than or equal to the $\max(x_b, x_a)$, then some value between x_s and x_d (e.g. $\overline{x}_s$) must also be greater than those values. By multiplying x_a and x_b by $\beta = 2$, it may be forcing the model to return higher average costs for the sustainment phase. Constraints (3), (4) and (5) set minimum values for x_s and x_b, respectively.

Constraints (6) and (7) are less intuitive but appear to set minimum values for x_m and x_a, respectively. Constraint (6) can be rearranged as follows:

$$\alpha \geq \frac{x_b + x_a + \beta x_s}{x_b + x_a + x_m + \beta x_s} \quad \equiv \quad (1 - \alpha) \leq \frac{x_m}{x_b + x_a + x_m + \beta x_s}.$$

This transformation illustrates that a minimum relative proportion of average costs for the units is being set. If our theory is accurate, the result may not be as intended. Adding the aforementioned proportions together is not justified because the units do not entirely match up. Since these constraints set a minimum relative proportion of the average cost, the $\beta = 2$ parameter might be intended to incorporate deployment phase allocations without representing them explicitly.

E. INTERPRETATION OF DECISION VARIABLES

The decision variables are referred to as "average" or "optimized" costs. The optimized cost by JON for the number of years based per OFRP cycle is based on the phase relationships and total cost. The models appear to be a least squares regression with constraints. Our best guess of the interpretation of the decision variables is that they represent the expected cost to have a unit in phase p for a month. However, there is little evidence of a relationship between the deployment phases and the cost.

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V. SUMMARY

A. RECOMMENDATION FOR FUTURE RESEARCH

The cost model was originally designed with constraints presumably based on outdated assumptions that are largely unknown. The uncertainty surrounding the constraint value logic stems from a lack of documentation and discontinuity of personnel. We recommend that future studies and analyses focus on validating if the cost model design is suitable/effective. Redesign proposals must provide actionable solutions with a concrete plan to implement such a solution in incremental phases. This type of research would greatly benefit the NECC cost model improvement effort. Although it is a more complex problem set, it is feasible to accomplish. It would arguably be more beneficial than simply verifying if the cost model works according to the technical specifications of an outdated original design that may no longer be operationally relevant.

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