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Report Documentation Page	*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE **2005**	2. REPORT TYPE	3. DATES COVERED **00-00-2005 to 00-00-2005**

4. TITLE AND SUBTITLE **Modernizing the U.S. Aircraft Carrier Fleet. Accelerating CVN 21 Production Versus Mid-Life Refueling**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Rand Corp,1776 Main Street,Santa Monica,CA,90407-2138**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR’S ACRONYM(S) 11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
The original document contains color images.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**		**126**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

This product is part of the RAND Corporation monograph series. RAND monographs present major research findings that address the challenges facing the public and private sectors. All RAND monographs undergo rigorous peer review to ensure high standards for research quality and objectivity.

MODERNIZING THE U.S. AIRCRAFT CARRIER FLEET

Accelerating CVN 21 Production Versus Mid-Life Refueling

John Schank ▫ Giles Smith ▫ Brien Alkire ▫ Mark V. Arena
John Birkler ▫ James Chiesa ▫ Edward Keating ▫ Lara Schmidt

Prepared for the United States Navy

RAND NATIONAL DEFENSE RESEARCH INSTITUTE

The research described in this report was prepared for the United States Navy. The research was conducted in the RAND National Defense Research Institute, a federally funded research and development center supported by the Office of the Secretary of Defense, the Joint Staff, the unified commands, and the defense agencies under Contract DASW01-01-C-0004.

Library of Congress Cataloging-in-Publication Data

Modernizing the U.S. aircraft carrier fleet : accelerating CVN 21 production versus mid-life refueling / John Schank ... [et al.].
p. cm.
Includes bibliographical references.
"MG-289."
ISBN 0-8330-3720-X (pbk. : alk. paper)
1. Aircraft carriers—United States—Design and construction. I. Schank, John F. (John Frederic), 1946–

V874.3.M64 2005
359.94835—dc22

2004028962

Cover design by Barbara Angell Caslon

Cover photo courtesy of JOCS, Public Affairs, USS Ronald Reagan, United States Navy.
USS Ronald Reagan Exiting the Straits of Magellan.

Published 2005 by the RAND Corporation
1776 Main Street, P.O. Box 2138, Santa Monica, CA 90407-2138
1200 South Hayes Street, Arlington, VA 22202-5050
201 North Craig Street, Suite 202, Pittsburgh, PA 15213-1516
RAND URL: http://www.rand.org/
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Preface

The U.S. Navy is currently designing the next generation aircraft carrier, the CVN 21. This class of carriers will use the same basic hull form as the current *Nimitz* class but will include a substantial redesign of the interior of the ship for improved weapons handling and stores management functions. It will also incorporate several new technologies, including a new propulsion plant and new aircraft launch and recovery systems. These improvements not only will increase the operational capability of the ship but also are anticipated to lower the ship's manpower requirements and maintenance costs.

Under current force modernization plans, new ships of the CVN 21 class will be introduced every four or five years as the ships of the *Nimitz* class reach the end of their planned 50-year operational life. Under this strategy, *Nimitz*-class carriers will be operating for more than 50 more years and it will take decades to transform the aircraft carrier fleet to ships of the new class.

On the basis of some preliminary calculations that appeared promising, the RAND Corporation proposed to the Program Executive Office (PEO) for Aircraft Carriers an examination of a way to accelerate the transformation of the carrier force: replacing *Nimitz*-class carriers as they reach midlife instead of refueling them. In this report, we identify specific fleet management options for building new instead of refueling, and we evaluate their advantages and disadvantages. This report should be of interest to Navy and Office of Secretary of Defense planners examining fleet modernization options, especially those organizations addressing the costs of alternative force structure options.

The research documented in this report was carried out within the Acquisition and Technology Policy Center of the RAND National Defense Research Institute, a federally funded research and development center sponsored by the Office of the Secretary of Defense, the Joint Staff, the unified commands, and the defense agencies.

For more information on RAND's Acquisition and Technology Policy Center, contact the Director, Philip Antón. He can be reached by e-mail at atpc-director@rand.org; by phone at 310-393-0411, extension 7798; or by mail at the RAND Corporation, 1776 Main Street, Santa Monica, California 90407-2138. More information about RAND is available at www.rand.org.

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Summary

The U.S. Navy is currently building the last of the *Nimitz* class of aircraft carriers. The next ship to be started will belong to a new class, designated CVN 21. This new design will incorporate numerous improvements over the *Nimitz* design. Among the most important will be improved weapons handling, a propulsion plant that will generate more electricity to support functions now controlled by steam and hydraulics, an electromagnetic aircraft launch system, and a general rearrangement to improve operations. It is anticipated that the new class of ship will require fewer personnel to operate and will spend less time in shipyard maintenance, both of which will contribute to reduced operating costs.

The Navy's plan is to continue building aircraft carriers approximately once every four years. Ships of the new class will replace older ones that are retiring. *Nimitz*-class ships are scheduled to retire at approximately age 49, after two 23-year operational periods separated by a three-year midlife refueling and complex overhaul.

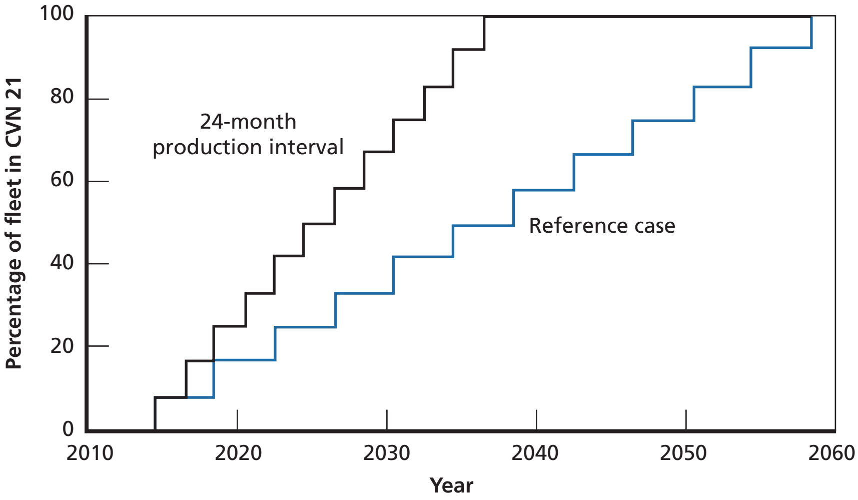
This plan will transform the carrier fleet into one composed of the higher-performance, lower-cost CVN 21 ships at a very slow rate. Even in 2035, half the fleet will be *Nimitz*-class ships.

We here propose a more rapid modernization plan: building new aircraft carriers more often and retiring about half the *Nimitz*-class ships at what would have been their midlife refueling point. We compare several variations of this approach with a reference case approximating the Navy's current plan. Criteria for comparison include rate of fleet modernization, average number of ships sustained

(total and operational), present value of acquisition and operating costs, and near- and midterm funding required. Our central finding is that the fleet can be modernized much faster, even twice as fast, for a cost premium no greater than 12 percent. That premium can be reduced through decreasing fleet size by 5 to 10 percent or possibly through aggressive cost reduction efforts. We also find that the industrial base is adequate to support the higher production rate.

The gain from a shorter interval between carrier production starts is depicted in Figure S.1, which shows the percentage of the total carrier fleet made up by the CVN 21 class as of the dates shown.[1] If the time between new carrier construction starts is halved—that is, if the production interval is dropped from the cur-

Figure S.1
A Build-New Strategy Can Modernize the Fleet Twice as Fast



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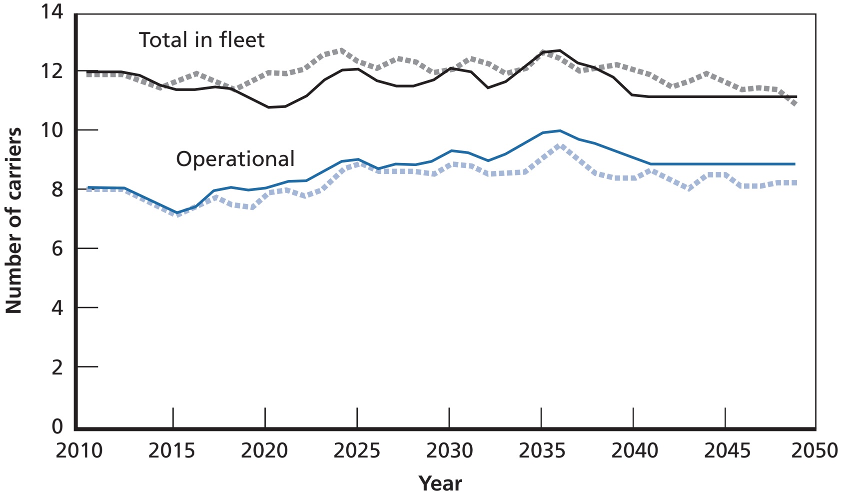
[1] Note that we show the CVN 21 percentage reaching and staying at 100 percent. However, we assume in all our analyses that CVN 21–class carriers are also retired when their initial fuel load is exhausted and that they too are replaced by carriers (presumably a follow-on class) built new.

rent notional 48 months to 24 months, the fleet is modernized twice as fast. CVN 21s will make up the fleet majority 12 years earlier, and the fleet will be transformed 22 years earlier.

As shown in Figure S.2, a 24-month interval sustains a fleet that is about half a ship short of the reference fleet in size. However, the number of operational ships (those not in the shipyard) is at least as great as in the reference case. This bonus emanates from the lower maintenance requirements designed into the CVN 21. More CVN 21s in the fleet mean more ships available for deployment or training.

These benefits come at a cost. Although the larger number of CVN 21s in the fleet translates into lower personnel and maintenance costs, the fleetwide savings are not large, particularly for personnel, for two reasons. First, it still takes a number of years for the fleet to evolve from a *Nimitz*-class fleet to a CVN 21 fleet; second, the greater savings many years in the future are worth much less than

Figure S.2
A Build-New Plan Sustains at Least as Many Operational Ships and Almost as Many Total as the Navy's Current Plan (Reference Case)



NOTE: Reference case data displayed as dotted lines.
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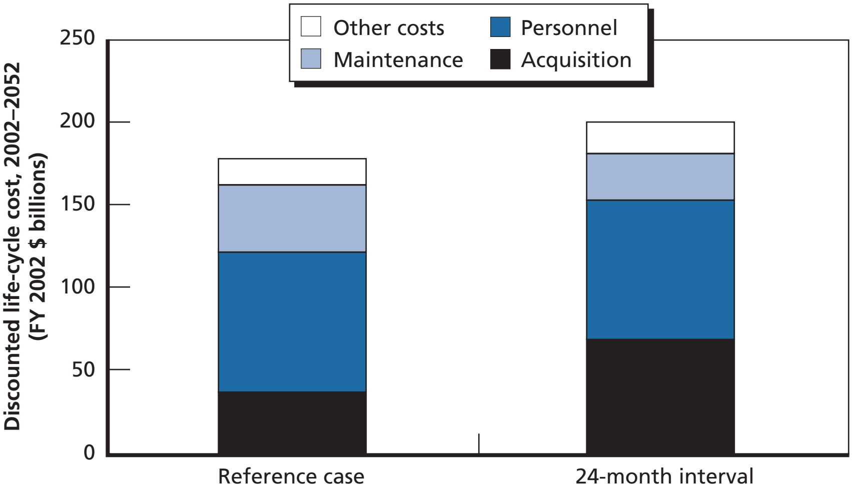
their nominal value today—that is, they must be discounted. Furthermore, a multibillion-dollar charge is incurred when an extra carrier is built every fourth year. Less than half those charges are offset by avoiding refueling a *Nimitz*-class ship. If the various costs and savings offsets in the construction, personnel, and operations and maintenance budgets are calculated for the 50-year period beginning in 2002, the net result is a cost premium for the build-new plan. That premium amounts to 12 percent, or $22 billion in present discounted value (see Figure S.3).[2] The extra costs would manifest themselves as an added $700 million annual budgetary requirement from 2005 to 2015 alone.

We examined two approaches to reducing that cost premium. First, we varied the specifics of the build-new strategy. Instead of 24 months, we tried a 30-month interval, which would modernize the

Figure S.3
Increasing the Production Interval to 24 Months Costs an Extra 12 Percent



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[2] For lack of data, our estimates do not include the cost of defueling and demilitarizing retired carriers, activities that will occur earlier and more frequently under the build-new plan than in the reference case. Our cost premium estimate may thus be somewhat conservative.

fleet almost as fast as the 24-month option. We tried retaining the 24-month interval but running one fewer *Nimitz* refueling (stopping with CVN 71 instead of CVN 72). Finally, we analyzed an option combining these two variants.

The results are shown in Table S.1. The first row under "After CVN 72" represents the nominal build-new plan and the other three cells (where each cell comprises *w*/*x* *y*% (*z*%)) represent the three alternatives just specified (further explanation follows).

The 30-month variants solve the cost problem. The cost premiums relative to the reference plan are near zero or even negative (see the numbers outside parentheses on the right side of each cell in Table S.1). However, the variants have the effect of taking one or more ships out of the fleet (see the numbers at the left under both the "After CVN 72" column and the "After CVN 71" column; the total reference fleet averages 12.1 ships). The penalty in operational ships ranges from almost nothing for the 24-month plan with one less refueling and complex overhaul (RCOH) to half a ship or more for the 30-month plans (see the numbers on the left side of each cell, to the right of the slash; the reference fleet averages 8.4 operational ships).

Our second approach to reducing the cost premium was to examine several cost reduction measures:

- Multiship buys: The faster build schedule might promote two-ship contract packages that could lower costs for engineering and for materials and equipment.

Table S.1
Build-New Options with Best Cost Implications Have Worst Fleet Size Implications

	When to Stop Performing RCOHs			
How Long to Allow Between CVN 21 Starts	After CVN 72		After CVN 71	
24 months	11.7/8.7[a]	+12% (+6%)[b]	10.9/8.2[a]	+8% (+1%)[b]
30 months	10.6/7.9[a]	+1% (–4%)[b]	9.8/7.3[a]	–3% (–8%)[b]

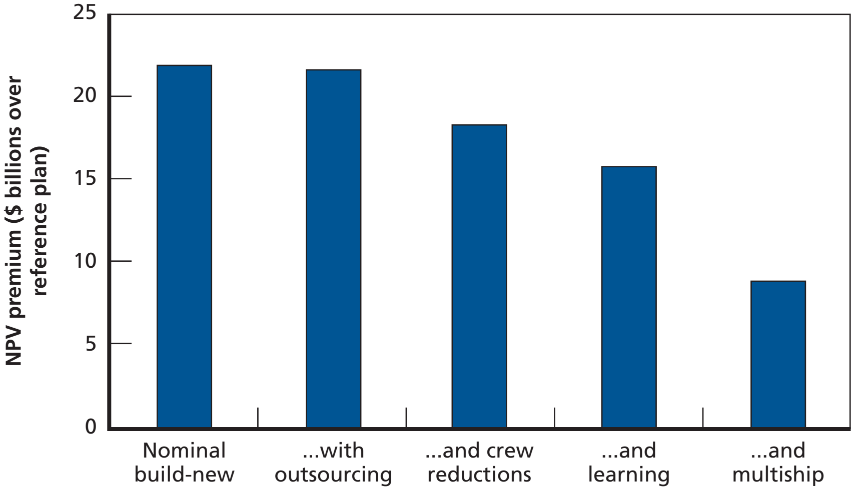
[a]Numbers represent total fleet/operational fleet.
[b]Numbers represent nominal cost premium (additional saving).

- Learning: A faster build schedule could allow for lower costs on repeated production tasks. We assumed for the build-new strategy a slight advantage over the lack of learning we assumed (from historical precedent) in the reference case.
- Additional crew reduction: The Navy postulates a crew reduction of as many as 800 for the CVN 21 versus the *Nimitz* class. We adopted 800 as the reference case reduction and postulated that an additional 200 crew members could be removed with aggressive measures to reduce ship manning.
- Outsourcing: We assumed a small increase in outsourcing over what is expected, for a modest labor cost savings on the work outsourced.

The cumulative effect of these savings on the original, nominal build-new plan are shown in Figure S.4. The relative effects of the measures are in the order listed above, with multiship buys having the greatest effect and outsourcing the least. Together, these cut the build-new plan's 12-percent cost premium by 7 percentage points, or more than half. Applying these measures to the variant build-new options also cuts their costs by 5 to 7 percent, as indicated by the parenthetical numbers in Table S.1. We regard these cost reduction measures as ambitious but feasible. By adopting them and by eliminating the CVN 72 RCOH (see top right cell in Table S.1), the Navy could modernize faster at hardly any cost premium.

The trade-off between faster modernization and a smaller operational fleet can be quantified in terms of future operational CVN 21 ship-years. Those ship-years can then be multiplied by a factor indicating the ratio between a CVN 21–class ship's capability and a *Nimitz*-class ship's capability, and future operational *Nimitz*-class ship-years can be added in. The result, which needs to be discounted for comparison with discounted costs, is the present value of future operational ship-years, weighted to favor CVN 21–class ships: a measure of the fleet's value to the Navy. The value is higher if the fleet converts more quickly to CVN 21s or if the number of operational ships is typically larger.

Figure S.4
Aggressive Cost Reduction Can Cut the Nominal Build-New Cost Premium in Half



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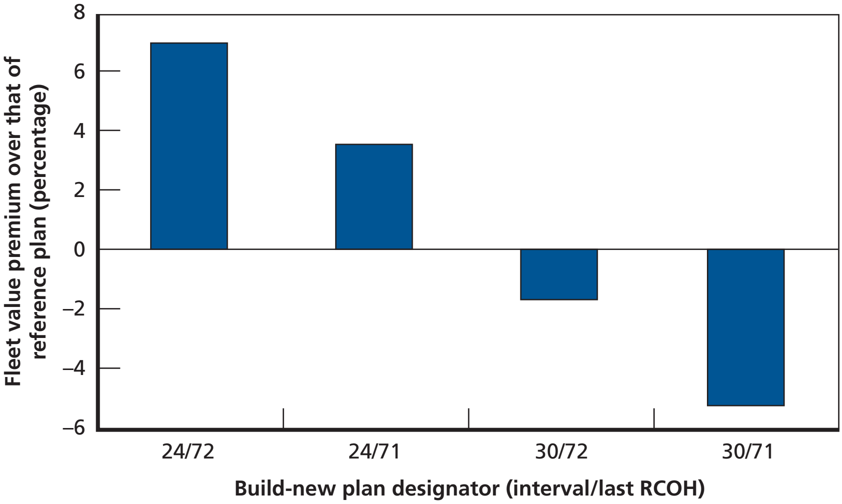
It was not within the scope of this report to predict a most likely CVN-21:*Nimitz* capability ratio. However, we examined several possibilities to get a sense of the fleet value premiums achievable. If, for example, the Navy were to view a CVN 21–class ship as 30 percent more capable than a *Nimitz*-class ship, the nominal build-new plan would result in a 7 percent fleet value premium over the reference case (see Figure S.5). That is, the fleet would have an average operational capability 7 percent higher (in discounted terms) than it would if the reference plan were followed. That may be compared with the 12 percent (or 6 percent) cost premium from Table S.1. Eliminating the CVN 72 RCOH, as noted above, virtually eliminates the cost premium if aggressive cost reduction is pursued. Figure S.5 indicates a fleet value premium of 4 percent. Whether these are good investments or not depends on the importance the Navy attaches to fleet value premiums of those sizes.

Figure S.5
Build-New Options with a 24-Month Production Interval Generate Greater "Fleet Value" than the Reference Plan or 30-Month Plans



NOTE: CVN 21 capability increment = 30%
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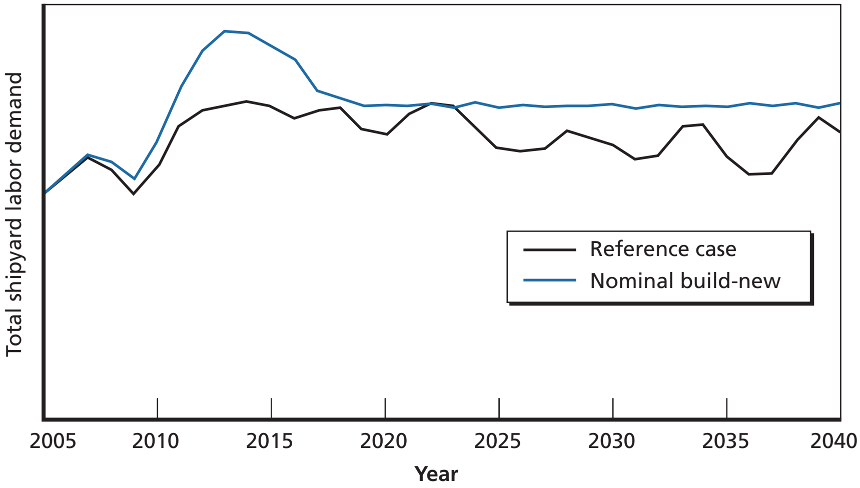
No industrial-base impediments hamper implementation of any of the build-new options defined here. A significant short-term transient in the shipyard labor profile occurs (see Figure S.6, 2017 and before), peaking at 24 percent over the reference plan. This demand must be managed, but the build-new strategy affords an opportunity for greater long-term workforce stability (after 2017). This is true as well for the variant build-new options, although for those both the peaks and the long-run average demands are somewhat lower than in the nominal build-new option.

Some facility upgrades are needed at the shipyard, but there appear to be no critical problems there. Suppliers of parts for the nuclear-propulsion plant will need to undertake some modest upgrades. The challenge there, however, is not really capacity but timing. If a build-new strategy is to be implemented so that the second CVN 21–class ship is started in 2009, propulsion plant supplier upgrades must begin promptly (i.e., long lead item procurement must begin in FY 2005 to support an FY 2009 ship). Vendors of non-nuclear components are generally in place and capable of meeting the higher production rate.

Figure S.6
Build-New Strategy Requires Managing a Labor Demand Peak Until 2017



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Acknowledgments

Our work on this project was greatly facilitated by personnel at the Program Executive Office for Aircraft Carriers, in particular Brian Persons, deputy program executive officer. We also appreciate the efforts made by CAPT Dudley Berthold, former CVN 21 program manager; CAPT Mike Schwartz, current CVN 21 program manager; and CDR Chris Meyer, assistant program manager. At the Naval Nuclear Propulsion Program (NAVSEA 08), Robert Murphy and Karen Henneberger contributed to our endeavors. Kenneth Dieter at NUWC provided the data for Appendix C on the cost of carrier maintenance availabilities and answered our queries regarding its interpretation.

We are grateful to Dan Burton, who acted as our facilitator and interface at Northrop Grumman Newport News. We also received valuable assistance there from Matthew Mulherin, vice president for the CVN 21 program.

Max Buzard at Royer Technical Services played a key role in that firm's execution of a subcontract for RAND related to the amount of outsourcing possible on future carriers. Anne Wolpert of Tecnico Corporation contributed to providing cost estimates for subcontractor efforts.

We owe part of the inspiration for this project to some early calculations by our RAND colleague John Halliday. We are also indebted to our formal reviewers, David Stem of RAND and J. Talbot Manvel, former director of the CVN 21 program at the Naval

Sea Systems Command, both of whose comments instigated significant improvements to this report.

Abbreviations

24/71	24-month production interval, last RCOH on CVN 71
24/72	24-month production interval, last RCOH on CVN 72
30/71	30-month production interval, last RCOH on CVN 71
30/72	30-month production interval, last RCOH on CVN 72
CV	Carrier vessel
CVN	Carrier vessel, nuclear
CVN 21	Next CVN class (following *Nimitz*)
CVNX	Superseded designation for CVN 21
DPIA	Docking planned incremental availability
EMALS	Electromagnetic Aircraft Launch System
FPRA	Forward-Price Rate Agreement
FY	Fiscal year
G&A	General and administrative
HM&E	Hull, mechanical, and electrical
IMP	Incremental Maintenance Plan
LCC	Life-cycle cost

MPN	Manpower and Personnel, Navy
NAVSEA	Naval Sea Systems Command
NGNN	Northrop Grumman Newport News
NGSS	Northrop Grumman Ship Systems
NPV	Net present value
O&I	Organizational and intermediate
OMB	Office of Management and Budget
O&MN	Operations and Maintenance, Navy
OPNAV	Office of the Chief of Naval Operations
OSY	Operational ship year
PEO	Program Executive Office
PIA	Planned incremental availability
PSA	Post-shakedown availability
RCOH	Refueling and complex overhaul
SCN	Ship Construction, Navy
SMD	Ship Manning Document

CHAPTER ONE

Introduction

The U.S. Navy's *Nimitz*-class aircraft carriers are arguably the most powerful warships in any country's naval forces. But the *Nimitz*-class design is more than 35 years old. Its electrical power-generation capability is insufficient to support such improvements as the Electromagnetic Aircraft Launch System (EMALS), self-defense directed-energy systems, or energy-dissipating armor, all now in development. EMALS will be needed to launch unmanned combat air vehicles, and the other systems will be needed to defend against smart antiship weapons, both of which are likely to play important roles in conflict well before the *Nimitz* class retires. Furthermore, with modernizations undertaken over the years, the ships' weight has increased and their center of gravity has risen (i.e., worsened) to the point where further increases in topside weight are unacceptable. The *Nimitz* class's weapon-handling systems and flight deck were designed with tactical nuclear weapons in mind and are optimized neither for high rates of sortie generation nor for the variety of smart weapons coming into the inventory. Finally, the *Nimitz*-class Incremental Maintenance Plan requires substantial periods of time in shipyard maintenance.

The U.S. Navy is currently designing the next generation of aircraft carriers, the CVN 21 class, which will improve on *Nimitz*-class capabilities. Although it will use the same basic hull form as the *Nimitz*, the CVN 21 class will include dramatic improvements to the ship's power-generating capability and electrical distribution. These new systems will be sufficient for EMALS, which will be installed on the first of class and will have enough reserve capacity for advanced defensive systems that could be added later. The layout of the flight deck will be improved: the island will be moved and elevators for aircraft and weapons relocated. There will be a substantial redesign of the interior of the ship for improved weapons handling and stores management functions. All these improvements are designed with the charge to significantly reduce manning and maintenance costs, increase operational availability, and minimize maintenance periods. (For details of the improvements included in or allowed by the CVN 21 design, see Appendix A.)

The current Navy plan is to replace *Nimitz*-class ships as they reach retirement age—i.e., as they exhaust the nuclear fuel supplied in their midlife reactor core replenishment. Under that plan, the carrier fleet will consist mostly of *Nimitz*-class ships until the 2030s and some *Nimitz*-class ships will be operating after 2050.

Recognizing the increased operational capabilities and reduced ownership costs of the CVN 21 class, the Program Executive Office (PEO) for Aircraft Carriers asked RAND to identify and evaluate options that would more quickly transform the carrier fleet to the new class. In conducting the research, we addressed the following questions:

- What options are available to introduce CVN 21–class ships at an accelerated rate? What if *Nimitz*-class ships were replaced at midlife instead of being refueled? How do the options affect the number of carriers in the fleet and the number available for operations (i.e., not in the shipyard for maintenance)? (See Chapter Two.)
- How must the carrier industrial base change to accommodate the accelerated transformation options? (See Chapter Three.)
- How much more will it cost to replace *Nimitz*-class ships at midlife than it would to refuel them? How might the acquisition cost of CVN 21–class carriers be reduced to make accelerated modernization more attractive? (See Chapter Four.)

To address these questions, we worked closely with the CVN 21 program office, the Nuclear Propulsion Directorate (SEA 08) of the Naval Sea Systems Command (NAVSEA), Northrop Grumman Newport News (or NGNN—the only U.S. shipbuilder capable of building nuclear aircraft carriers), and the various nuclear and non-nuclear vendors that support aircraft carrier construction. We identified and collected various cost data and factors and construction workload profiles for the CVN 21 ships as well as for other ship construction and repair projects at NGNN. We used these various data in life-cycle cost (LCC) and industrial base models we created or modified to assist in our analysis.

CHAPTER TWO

Fleet Modernization Options and Their Implications for Fleet Size and Composition

The Navy's present plan calls for constructing one new CVN 21–class carrier about every four years, thus requiring nearly 50 years to completely replace the current fleet of 12 ships. In this chapter, we describe options that would result in much faster modernization of the fleet and examine how those options would affect the fleet size and composition over the next several decades. The costs of the proposed new options are dealt with in Chapters Three and Four. The analysis presented in this chapter is in three parts:

- We first describe in some detail the present policy and show the consequent fleet replacement schedule. This is the *reference case* that will be used as a point of comparison for alternative fleet modernization options.
- We next describe an alternative strategy based on the notion of retiring some of the older *Nimitz*-class carriers after about 23 years of service, and replacing them with new CVN 21–class ships at that time. This is the *nominal build-new strategy*. We show the resulting pattern of fleet composition over time and compare that with the reference case.
- Finally, we explore the fleet size and composition implications of some variations on the build-new strategy, in an attempt to achieve a similar modernization rate while reducing costs.

Today's Policy: The Reference Case

The present fleet of aircraft carriers consists of 12 ships. The exact number of active ships might fluctuate slightly because the commissioning of a new ship does not always coincide exactly with retirement of another ship, but the Navy strives to maintain carrier fleet size at about 12 ships to meet National Security needs. To project the evolution of this fleet over the next 50 years, we need three types of data: the composition of the current fleet, plans for taking ships out of service for maintenance (so we can estimate an operational fleet), and a protocol for ship starts and retirements in the coming decades. The composition of the present fleet is summarized in Table 2.1. The other two items are taken up in each of the next two subsections.

Scheduled Refueling and Maintenance

The service life of nuclear-powered ships is determined largely by the operating life of the reactor core. The cores for *Nimitz*-class ships are refueled during the midlife complex overhaul. These refueling and complex overhauls (called "RCOHs") are a major activity that repairs and modernizes the carrier for the next 23 years of service life. The

Table 2.1
Life Spans of Current Aircraft Carriers

Hull Number	Ship Name	Date Commissioned	Current Projected Retirement Date	Age at Projected Retirement
CV 63	*Kitty Hawk*	4-61	9-08	47
CVN 65	*Enterprise*	11-61	11-13	52
CV 67	*John F. Kennedy*	9-68	9-17	49
CVN 68	*Nimitz*	5-75	5-24	49
CVN 69	*Dwight D. Eisenhower*	10-77	10-26	49
CVN 70	*Carl Vinson*	3-82	3-31	49
CVN 71	*Theodore Roosevelt*	10-86	10-35	49
CVN 72	*Abraham Lincoln*	11-89	11-38	49
CVN 73	*George Washington*	7-92	7-41	49
CVN 74	*John C. Stennis*	12-95	12-44	49
CVN 75	*Harry S. Truman*	7-98	7-47	49
CVN 76	*Ronald Reagan*	7-03	3-52	49
CVN 77	*George H. W. Bush*	mid-08	3-57	49

SOURCE: NAVSEA, 1997, p. 2.3.
NOTE: Projected future retirement dates and expected life at retirement are based on RAND estimates using current Navy planning factors.

entire operation requires about three years in the shipyard, which is not dictated by the time it takes to refuel these ships but rather by the sum of maintenance, modernization, and repair that is required during this maintenance period. The *Enterprise* was the first nuclear-powered aircraft carrier, and its nuclear cores have been replenished three times in order to extend its operational life to more than 50 years.

The *Nimitz*-class ships have a reactor design that was somewhat improved over that of the *Enterprise*. The original expectation was that the core would sustain operations for about 13 years before refueling. When the *Nimitz* (the first of its class) was started, the plan called for an expected total operational life of about 30 years, consisting of two 13-year operational periods plus one midlife RCOH of about three years duration. However, experience with the early *Nimitz*-class ships indicated that the core life could be extended to as much as 22 to 23 years, assuming a normal operations tempo. Thus the overall lifespan of a *Nimitz*-class ship is now expected to typically consist of about 23 years of operation, followed by an RCOH of three years, and then another 23 years of operation, yielding a nominal total life of about 49 years. Those rough planning factors led to the currently-projected schedules shown in Table 2.1.

In addition to a midlife RCOH, an aircraft carrier undergoes several other scheduled periods of maintenance in the shipyard (referred to as *availabilities*). The *Nimitz*-class carriers' Incremental Maintenance Plan (IMP) calls for two kinds of availabilities: a Planned Incremental Availability (PIA) and a Docking Planned Incremental Availability (DPIA) (NAVSEA, 1997). A PIA

> is a ship depot availability of approximately six months duration that restores or maintains material condition and incrementally significantly modernizes the warfighting capabilities to meet current and projected threats.
>
> [DPIAs]. . . are overhaul-like in that they restore the ship . . . to established performance standards. In addition to the work accomplished during a PIA, a DPIA provides a window during which required underwater maintenance is accomplished. The

> DPIA also provides sufficient time to perform more extensive propulsion plant repairs and testing than is possible during the PIA.

A typical DPIA requires ten to eleven months in the shipyard. The nominal plan assumes an operational period of about 18 months between availabilities.[1]

The IMP-prescribed life cycle of a *Nimitz*-class carrier is shown in Figure 2.1. After the ship is commissioned there is a shakedown cruise, followed by a Post-Shakedown Availability (PSA) assessment to repair any discrepancies discovered and to complete any construction and outfitting activities that had been deferred during the original construction period. That shakedown cruise, and corresponding PSA, typically lasts about a year, after which the ship is ready for operational duty. During the following two decades, the ship operates for 18 to 20 months at sea, training and deploying as needed, followed by a PIA or a DPIA during which necessary maintenance actions are performed. After 23 years, the reactor needs to be refueled.

We show the life cycle in Figure 2.1 as we understand it from the IMP. However, when the 18-month operating periods and the prescribed availabilities at their nominal lengths are added up, the duration prior to refueling comes to 25.6 years. To resolve the discrepancy, we took the 23-year refueling interval as correct and adjusted the maintenance protocol to agree with it. Specifically, we deleted one PIA from each of two intervals between DPIAs, thus leaving two operating periods in each of those intervals, and we

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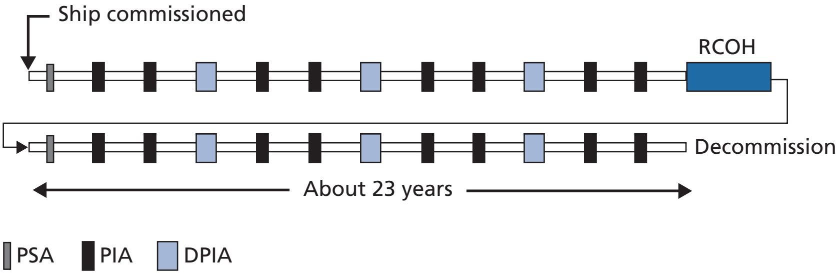
[1] After the research described in this report was completed, the Navy began to investigate different maintenance plans intended to enable the carriers to sustain a longer period of operations between shipyard availabilities, thereby increasing their responsiveness to operational demands. If such revised maintenance schedules are implemented, it might change in some detail the conclusions reached in this report. However, as of publication date no specific plan had emerged, and no attempt was made to incorporate such revisions in our analysis. Furthermore, it is our understanding that any revision in carrier maintenance plan would not reduce the total number of maintenance man-hours required during the carrier's life. It seems unlikely that implementation of such a plan would significantly change the conclusions presented in this report.

Figure 2.1
Operational Life Course of *Nimitz*-Class Carriers



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assumed that all operating periods were 19.5 months. Operating periods of that length conform in the aggregate to recent experience, and yield a slightly higher fraction of the time the ship is in an operational deployment compared with the IMP. Thus, it does not in any way penalize the "reference case" in comparison with the build-new options examined here.

We assume that the second half of the carrier life, after the midlife RCOH, will follow the same pattern as the first half, except that the shakedown cruise and PSA is expected to last only 10 months. (There is little experience with the second half of a *Nimitz* carrier's life. The *Nimitz* came out of its RCOH in 2001.) The ship's life ends with decommissioning, deactivation of the reactor, and disposal of that and the rest of the ship.[2]

With the retirement of the *Constellation* (CV 64) and the activation of the *Ronald Reagan* (CVN 76), the fleet now consists of nine *Nimitz*-class ships and three earlier models. When the *George H. W. Bush* replaces the *Kitty Hawk,* the *Nimitz* program will be complete. The present plan is to introduce a new carrier design, the CVN 21

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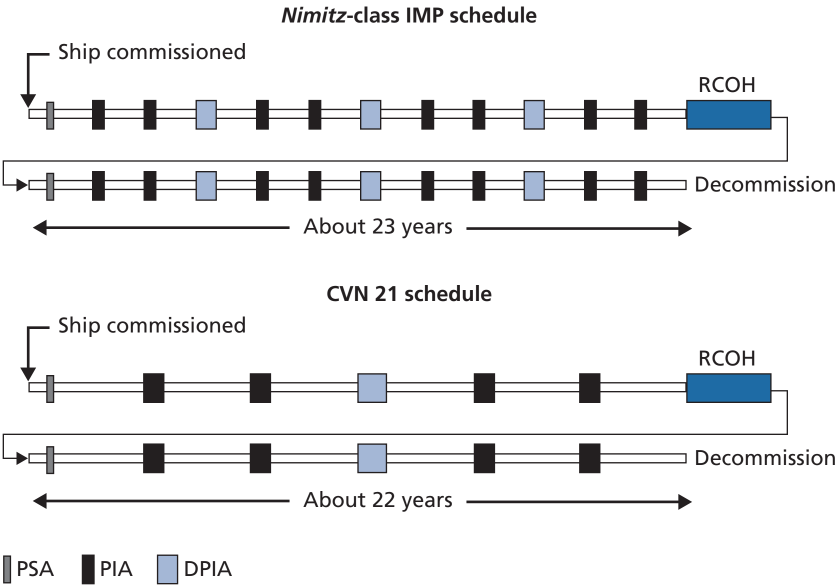
[2] We include these activities in our cost analysis in Chapter Four. We do not include them in the labor demand analysis in Chapter Three or in the fleet replacement protocol in this chapter. Decommissioning and deactivation could make demands on NGNN facilities that might compete with construction or RCOHs. However, it is unlikely that disposal will be accomplished at NGNN and uncertain whether nuclear deactivation will. Such activities could require nontrivial dedication of shipyard resources.

class described above (see also Appendix A), with construction starting in 2007 and first delivery in 2014. That ship is now expected to require far less maintenance than the *Nimitz*-class, with longer periods of operation between shipyard availabilities. The current projection of the CVN 21 life cycle is shown in Figure 2.2, with the information for the *Nimitz*-class carriers repeated for convenience.

Note that a *Nimitz*-class aircraft carrier spends considerable time in the shipyard—one-third of its life, from commissioning to decommissioning. As shown in Figure 2.2, one of the major differences between the *Nimitz*-class ships and the CVN 21–class ships is that the new model is projected to require considerably less time in the shipyard and thus will be available for operational use during a larger fraction of its life.

Figure 2.2
Comparison of *Nimitz*-Class and CVN 21 Life Spans



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Fleet Composition and Size

Given the data from Table 2.1 and Figure 2.2, we can predict a reference case fleet composition if we can project a schedule of new starts for the CVN 21 class. Assuming a nominal lifetime of each ship of about 49 years, to maintain a fleet of 12 ships requires that a new ship be built at intervals of about four years. However, Table 2.1 illustrates that the schedule of construction starts for the present fleet has been quite uneven. Ships were built in rapid succession in the 1960s (four were launched in a span of seven years), while the most recent two were launched at intervals of five years each. The nominal practice of building a new ship when needed to replace a retired ship leads to a very uneven production schedule, with attendant industrial inefficiencies. In our projection of future actions in the reference case, we assume that the CVN 21 ships will be produced at regular four-year intervals, starting with the first delivery in September 2014.

The resulting schedule of fleet composition projected for the 2000–2050 time period is depicted in Figure 2.3.[3] Here we show only the major activities: construction followed by a shakedown cruise and PSA; the initial 22- to 23-year operational period; the RCOH (three years plus 10 months shakedown and PSA); and the second operational period, followed by decommissioning. It can be seen that this does not result in a perfect match of ship commissioning on the same date that an older ship is retired, but deviations from a constant 12-ship fleet size are slight.

To compare the different fleet modernization options, we must establish some measures of merit that can be consistently applied and that would reflect the relative value of each option to the Navy. In terms of fleet size and composition, we will focus on three aggregate measures: the rate at which the older *Nimitz*-class ships are replaced with CVN 21–class ships; the overall size of the fleet, expressed as *average total inventory* over the course of each year; and the number of ships that are not undergoing shipyard maintenance or overhaul, and

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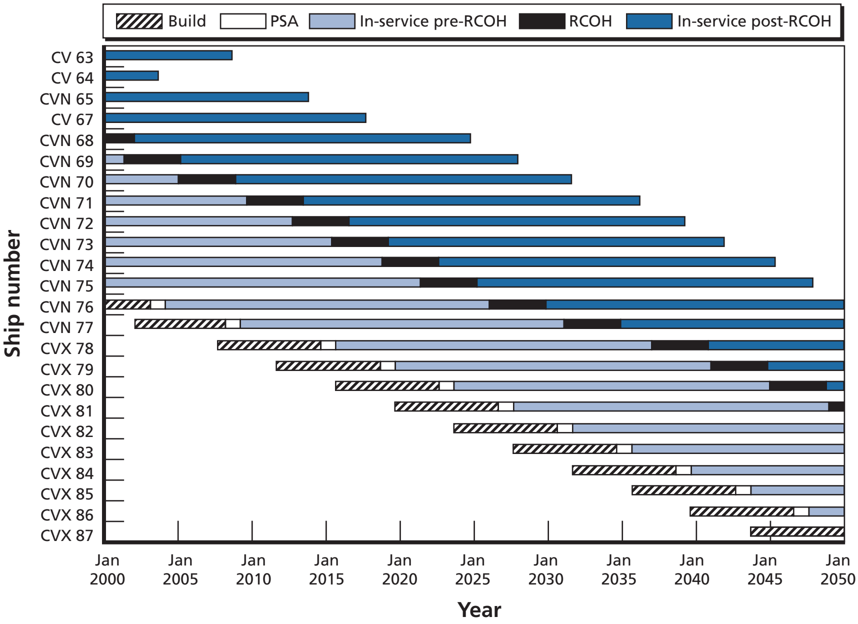
[3] Here, as elsewhere, we use CVX followed by a hull number to denote the CVN 21–class ships. We cut the projection off at 2050—near our cost estimation cutoff. Thus, only the first 10 ships of the planned 12-ship CVN 21 program are shown.

thus are *operationally available,* averaged over the course of each year. These measures have the advantage of being quantitative and relatively easy to estimate.

Under the schedule shown in Figure 2.3, the last *Nimitz*-class ship, CVN 77, is not replaced until the late 2050s. The replacement profile is depicted in Figure 2.4.

The average inventory of carriers in any year for the reference case is shown in Figure 2.5, compared with the average number of ships available for operations during that year. The reference case sustains the Navy's target inventory of 12 ships, with about eight of those in operational status at any one time.[4]

Figure 2.3
Evolution of Fleet Composition for the Reference Case



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[4] The minor fluctuations from one year to the next are a consequence of the uneven intervals between historical construction starts for the present fleet and our assumed four-year new-start interval for CVN 21–class ships to replace the older carriers.

Figure 2.4
Fleet Modernization Profile for the Reference Case

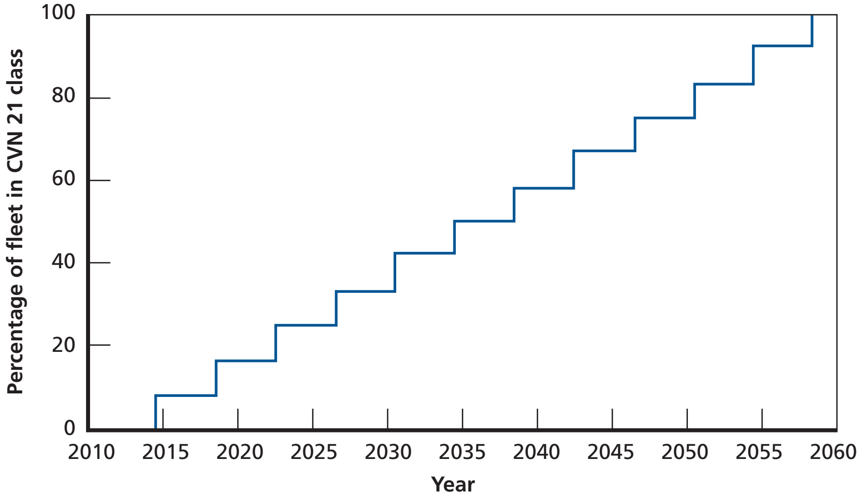

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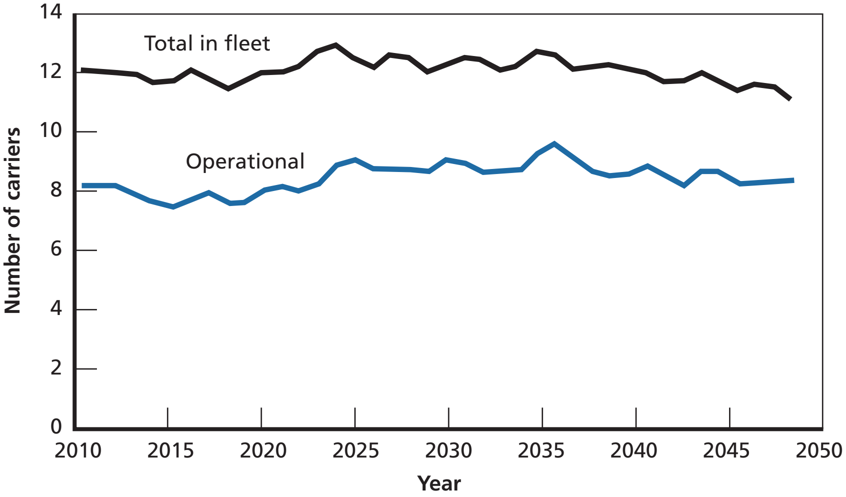
Figure 2.5
Fleet Size for the Reference Case, 2010–2050



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A Nominal Build-New Strategy

To achieve a faster modernization of the carrier fleet, we propose a strategy whereby in the future each ship would face the standard set of availabilities during the initial 22- to 23-year period but, at the end of that period, the ship would be retired and replaced with a new one instead of being refueled. That goes for both the *Nimitz* class and the CVN 21 class (see Figure 2.6). This strategy would require that CVN 21–class ships be built at intervals of about two years instead of the four year intervals characteristic of the *Nimitz*-class ships. To roughly sustain the present levels of total inventory and number of operational ships, it would also be necessary to continue performing RCOHs on CVNs 70, 71, and 72. (See Figure 2.7: Only nine operational life spans cross the January 2030 line without those of the refueled ships.) We will refer to this as the "nominal build-new" strategy or the 24-month/CVN 72 RCOH (24/72) case, to distinguish it from some variations we will explore later. Note from Figure 2.7 that

Figure 2.6
Assumed Life Cycle of *Nimitz*- and CVN 21–Class Carriers for the Build-New Strategy

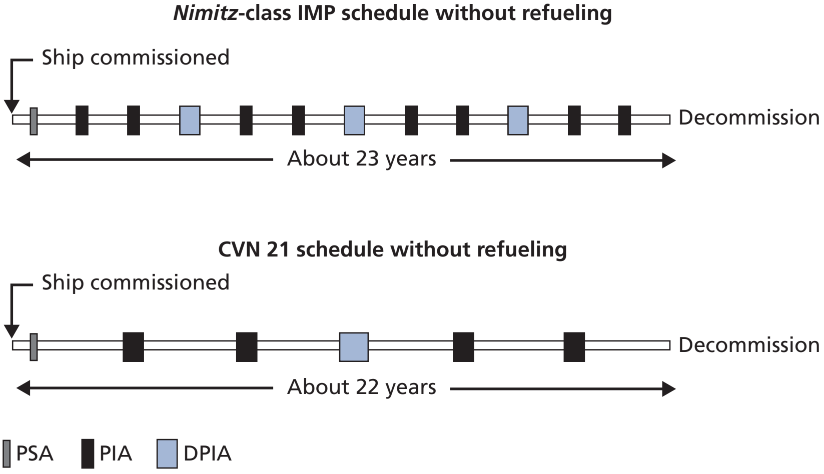

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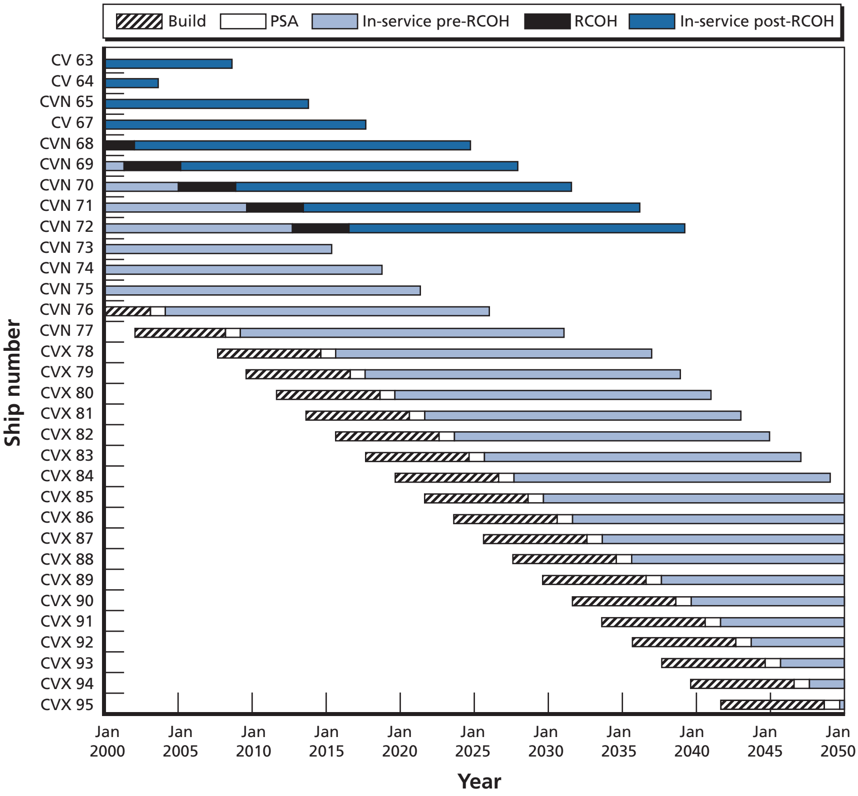
Figure 2.7
Evolution of Fleet Composition for the Nominal Build-New Case



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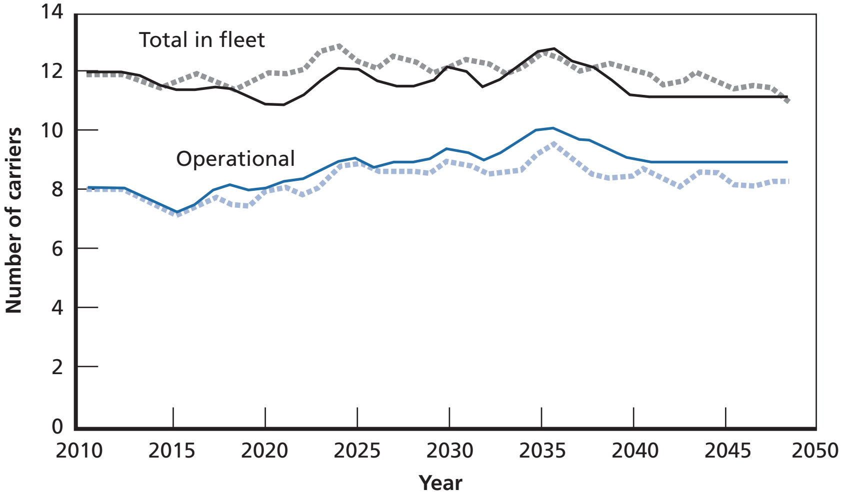
under the build-new plan, construction of a new carrier will be started every 24 months (extending beyond the currently planned 12-ship CVN 21 program).

The average fleet inventory is slightly lower than for the reference case, averaging close to 12 ships but never dropping below 11 (see Figure 2.8). The lower steady-state fleet size is a consequence of the 23-year life span now projected for the CVN 21 class, combined with the assumed delivery interval of 24 months. To sustain a 12-ship fleet with a 23-year life span would require a build interval of 23 months.

The number of operational carriers shown by the solid blue line in Figure 2.8 is slightly larger for the reference case, achieving by about 2025 an average of nine or more ships operationally available. This is entirely because the CVN 21 class spends only one-fourth of its life cycle in the shipyard, compared with one-third for the *Nimitz*-class ships. In summary, the nominal build-new option yields a slightly lower ship inventory during most of the time period examined, but it also yields a slightly greater number of ships that are operational.

Of course, the reason for undertaking the build-new strategy would be to more rapidly modernize the fleet. The difference in modernization rate is shown quantitatively in Figure 2.9. As would be expected from doubling the rate of adding new ships, it takes exactly half as long to modernize the fleet; the fleet is all CVN 21 by 2036 (22 years from launch of the first CVN 21 ship) instead of 2058 (44 years).

Figure 2.8
Fleet Size Sustained by Nominal Build-New Strategy, 2010–2050



NOTE: Reference case data displayed as dotted lines.
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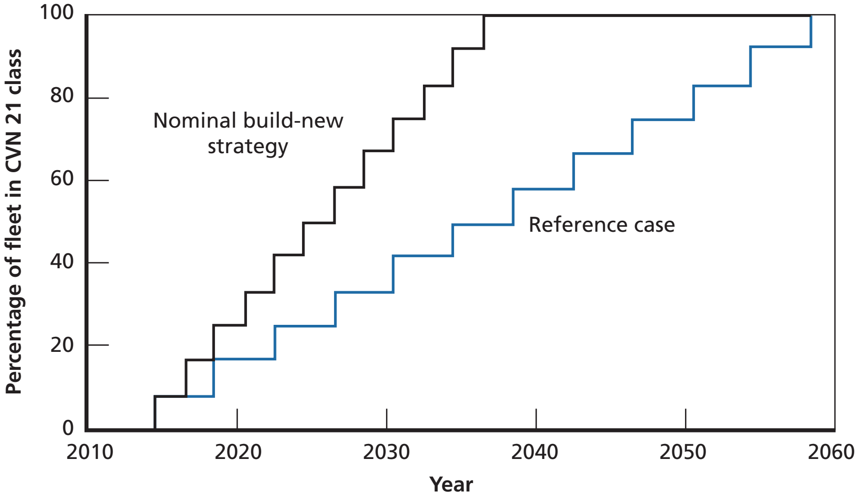
Figure 2.9
Fleet Modernization Rate, Reference Case Versus Build-New Strategy



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Other Build-New Options with a 22-Year Unrefueled CVN 21 Life Span

The nominal build-new case presented above demonstrates that today's fleet composition and operational capability can be approached by management strategies very different from the reference case, which approximates the strategy now being followed by the Navy. We expected, however, that the build-new strategy could cost more, because it requires substituting new construction for RCOHs, and building a new ship costs about twice as much as performing an RCOH on an old one. We also expected some savings to accrue to the build-new strategy, because the operating and maintenance costs of the CVN 21 ships will be lower than *Nimitz*-class ships. As it turns out, these will not be sufficient to offset the extra up-front cost of building new versus refueling (see Chapter Four). We sought ways to achieve the faster modernization of the build-new strategy while reducing its cost premium. We identified two options for doing so:

- Extending the build-new strategy's production interval from 24 months to 30 months (the 30/72 case). This would result in building fewer ships over the time interval examined and thus lower costs. *Nimitz*-class ships would still be coming out of the fleet at the time that they would have been refueled had the reference case applied.
- Skipping the RCOH on CVN 72—i.e., the last RCOH would be the one performed on CVN 71 (the 24/71 case). This would simply save the cost of one RCOH. The remainder of the refueling and production protocol would be the same as in the nominal build-new strategy.

A third possibility is to combine the two cost-saving approaches—i.e., extend the build interval to 30 months *and* make CVN 71's RCOH the last one (the 30/71 strategy). For easy comparison, all the cases we analyze for ships with 22-year life spans are outlined in Table 2.2.[5]

How do the build-new variants affect fleet size? Extending the production interval from 24 to 30 months—i.e., slowing the production rate, causes a steady erosion in total fleet size until it reaches a steady-state value of about nine (see Figure 2.10). That number is

Table 2.2
Characteristics of Fleet Management Options Analyzed

	When to Stop Performing RCOHs	
How Long to Allow Between CVN 21 Starts	**After CVN 72**	**After CVN 71**
24 months	24/72 Nominal Build-New Plan	24/71 Fewer RCOHs
30 months	30/72 Slower Build Rate	30/71 Slower and Fewer

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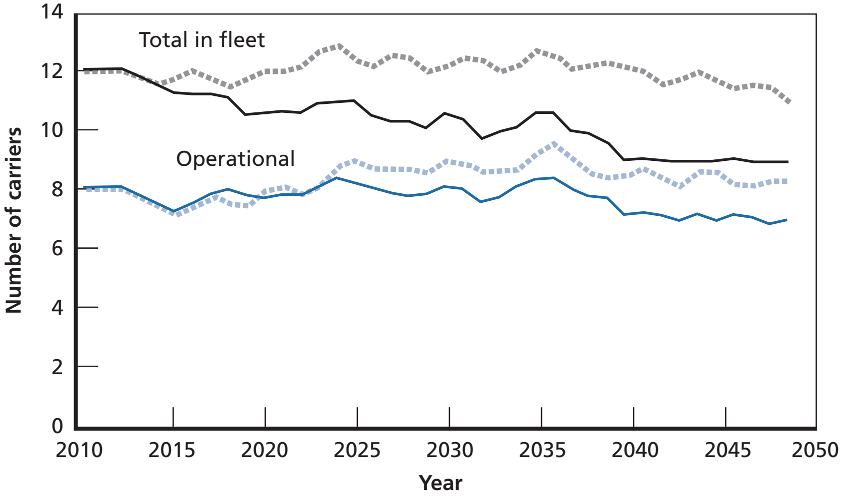
[5] The order of columns in the table is logical—i.e., the nominal plan first—not chronological. The CVN 71 RCOH is to precede that for CVN 72 (see Figure 2.3).

Figure 2.10
Fleet Size Sustained by Build-New Strategy with Extended New Start Interval (30/72)



NOTE: Reference case data displayed as dotted lines.
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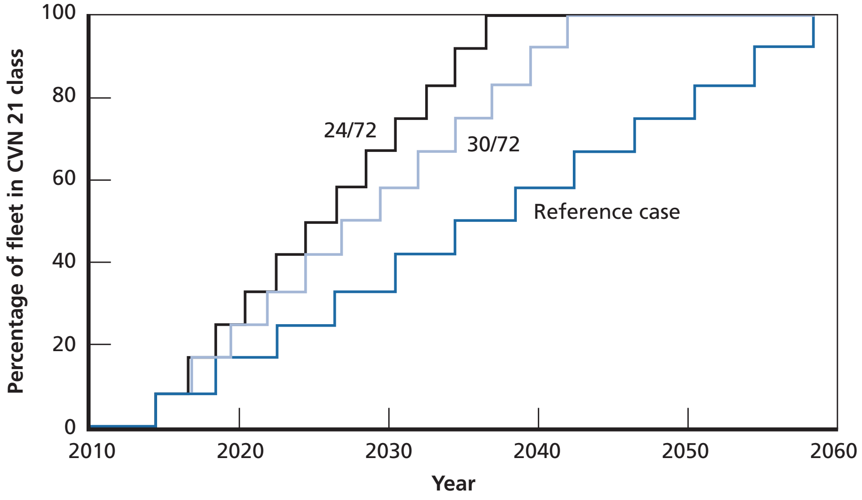
what would be expected from introducing ships every 2.5 years into a fleet of ships with 23-year life spans. It represents a 25 percent drop in fleet size from the reference case. The rate of modernization is also easily calculated (Figure 2.11). In the 30/72 case, the fleet is fully modernized in 2042, six years behind the 24/72 option but 16 years ahead of the reference case.

The number of operational ships is sustained at or near that for the reference case until the mid-2020s, when it falls almost a full ship short, eventually dropping to a steady-state value of about seven in 2040. The Navy would have to decide whether the one-ship deficit was important. If so, the shortfall could not be remedied by a simple fix—e.g., building an extra ship—because of facility constraints discussed in the next chapter.

Avoiding the cost of performing an RCOH on CVN 72 would effectively remove a ship from the inventory after about 2013. The

Figure 2.11
Fleet Modernization Rate, Reference Case Versus 24/72 and 30/72 Options



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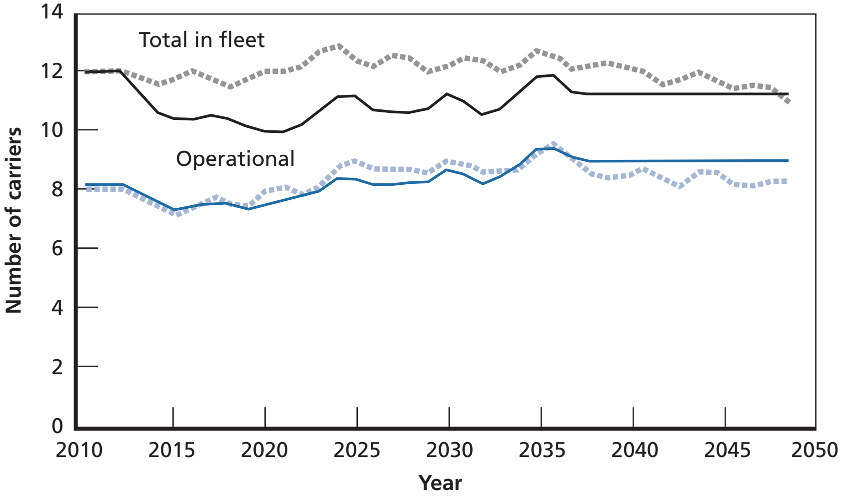
consequences for inventory and number of operational ships are shown in Figure 2.12. In terms of the number of ships in the inventory, the 24/71 option has the same disadvantage vis-à-vis the reference case as does the nominal 24/72 option, plus the loss of an additional ship (CVN 72). That additional deficit would be remedied in 2040 when the refueled CVN 72 would have left the inventory anyway. The number of operational ships, however, compares favorably with that of the reference case although during the 2020s and early 2030s, the 24/71 operational fleet is short about a half a ship. This appears to be an inevitable consequence of not performing an RCOH on CVN 72.

Each of the two options just described results in fleet size deficits compared with the reference case. The anticipated effect of combining the two would result in a greater deficit than that of either alone, and that would in fact be the case. As shown in Figure 2.13, this combination would yield ten or fewer ships in the inventory and fewer than eight operational ships from 2020 on.

Figure 2.12
Fleet Size Sustained by Build-New Strategy with No RCOH After CVN 71 (24/71)



NOTE: Reference case data displayed as dotted lines.
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To summarize, in Table 2.3 we show the average total and operational fleet size over 2010–2040 for each case.[6] The nominal build-new case (24/72) nearly matches the reference case in fleet size. It would reduce long-term total inventory below the 12.1 ships provided by the reference case but provide at least as many operational ships as the reference case (8.4) and yield the fastest modernization of the fleet. However, the nominal build-new case is also the most challenging and costly to implement, with one new start required every two years and three more RCOHs needed after completion of the one now under way on CVN 69. Stopping RCOHs after CVN 71 would reduce fleet size by one ship until about 2040 but have somewhat less

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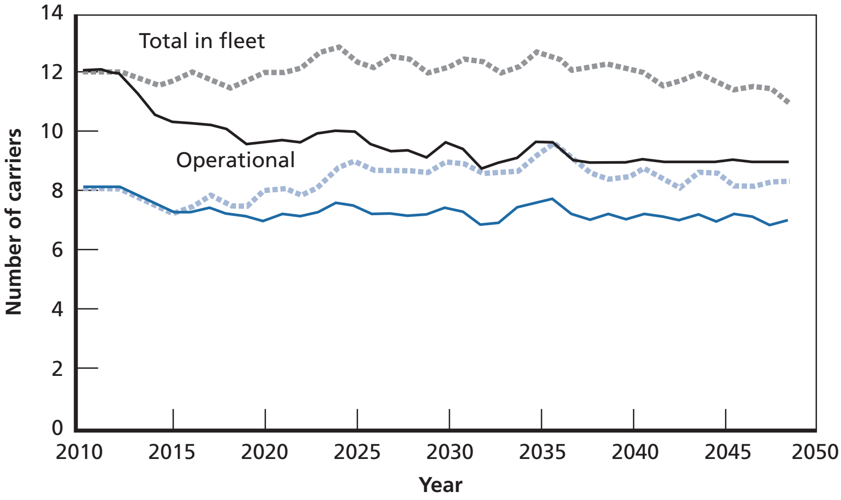
[6] We stop the series at 2040 (rather than 2050 as in the preceding figures) because after 2040 the fleet reaches steady state and no more change occurs. The series can be arbitrarily extended from that point on with a corresponding arbitrarily large influence of the long-term differences on the averages.

Figure 2.13
Fleet Size Sustained by Build-New Strategy with Combined Cost-Saving Variants (30/71)



NOTE: Reference case data displayed as dotted lines.
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Table 2.3
Average Fleet Size for Build-New Options, 2010–2040

How Long to Allow Between CVN 21 Starts	When to Stop Performing RCOHs			
	After CVN 72		After CVN 71	
24 months	11.7[a]	8.7[b]	10.2[a]	8.2[b]
30 months	10.6[a]	7.9[b]	9.8[a]	7.3[b]

[a] Total Fleet number.
[b] Operational fleet number.

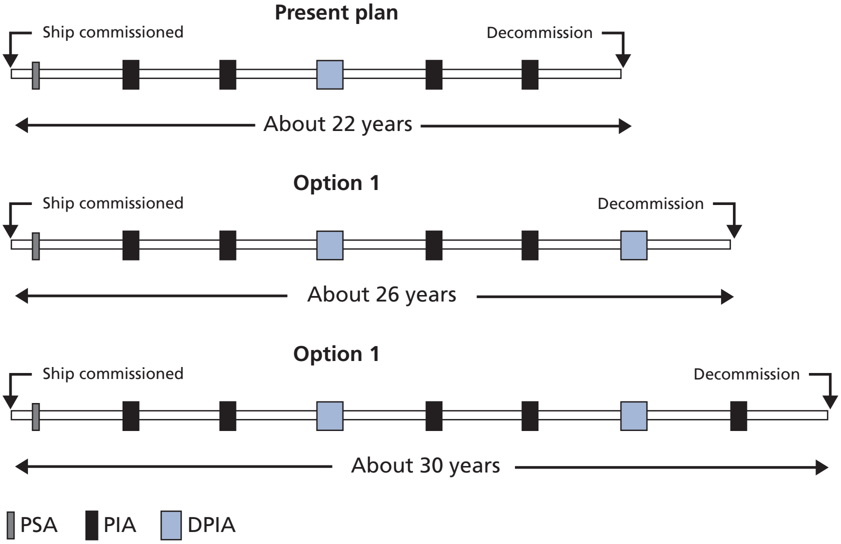
effect on the size of the operational fleet. Extending the new-ship start interval to 30 months would result in reductions in size of the total fleet from about 2020 on and the operational fleet from about 2025. Eventually, with a 30-month start interval, total fleet size falls to nine and operational fleet size to seven, both being direct and inevitable consequences of the relatively short unrefueled life of the CVN 21 class, currently projected to be about 23 years.

A Build-New Option with Unrefueled CVN 21 Life Span Extensions

If we want to realize the cost advantage of a 30-month build interval with a fleet of more than nine ships, we need a longer unrefueled ship life. The extent to which the service life of the CVN 21 class can be lengthened, or the cost of such an extension, is unknown. We therefore conducted a "what if" exercise: what if the life could be extended for several years, and how much extension would be required to make a 30-month start interval yield at least the equivalent of the current fleet size?

We hypothesize two extended unrefueled life cycles (see Figure 2.14). The first consists of adding a DPIA after the sixth operational phase and one more three-year operational period. That would pro-

Figure 2.14
Two Hypothesized Extended Unrefueled Life Cycles for CVN 21–Class Ships



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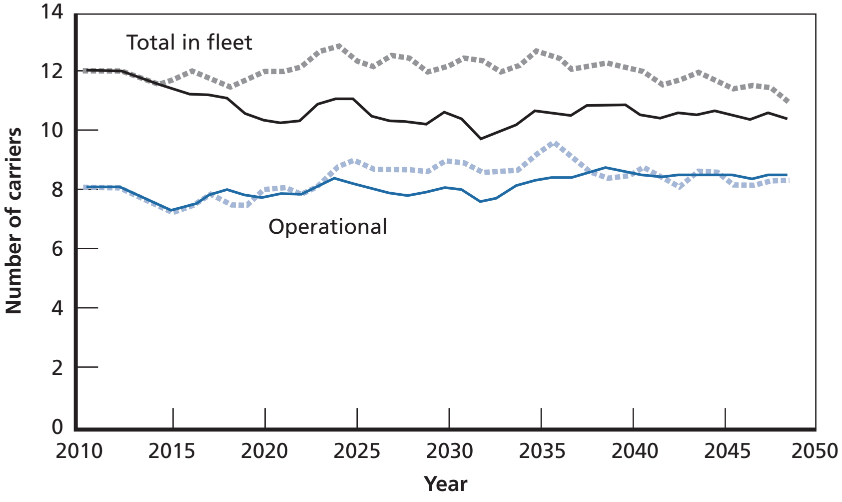
vide a total ship life of about 26 years. For a further extension, we suppose that another PIA and one additional three-year operational period could be added, yielding a total ship life of about 30 years. In both cases, we assume a 30-month production interval and RCOHs through CVN 72.

A total ship life of 26 years, together with a new-start interval of 30 months, would sustain an operational fleet of about eight ships, as shown in Figure 2.15. That is an improvement over the 30/72 plan after 2035, when the first CVN 21–class ship would have retired under that plan. It roughly parallels the reference case. However, it would yield a steady-state total fleet size of only about 10.5 ships.

A more interesting result is obtained with a total ship life of 30 years. Combined with a new-start interval of 30 months, that would cause the total fleet size to fall as low as 10 ships in the late 2020s, but the fleet would grow back to 12 ships by the mid-2040s and sustain

Figure 2.15
Fleet Size Sustained by 30-Month Build-New Interval and 26-Year Unrefueled Life Span



NOTE: Reference case data displayed as dotted lines.
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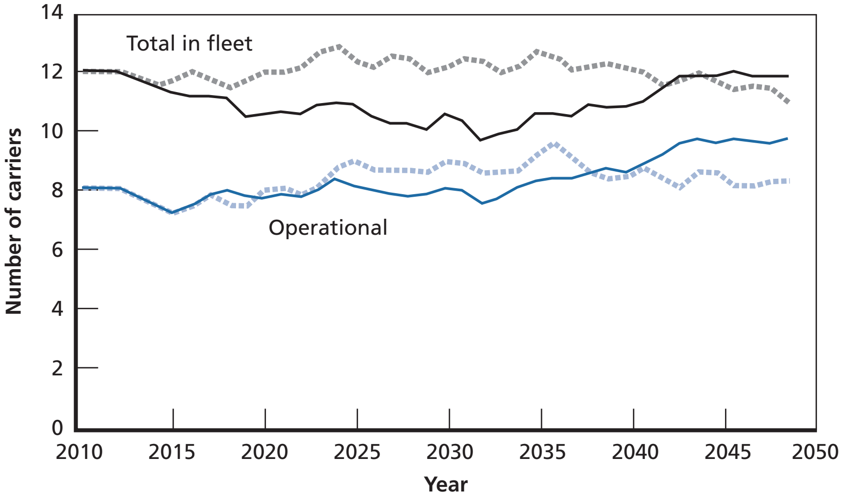
that level thereafter (see Figure 2.16). The size of the operational fleet would be sustained at about eight ships until the late 2030s and then increase over time as the CVN 21–class ships replaced the *Nimitz*-class ships, eventually reaching a steady-state value of between nine and ten ships. That would represent more than a 10 percent increase in the size of the operational fleet, compared with the reference case.

In summary, extending the unrefueled life of the CVN 21–class ships would make the build-new strategy more attractive by allowing a 30-month interval between new starts, while sustaining and even increasing the size of the operational fleet, compared with that of the reference case. As noted earlier, we have no information on the cost or technical practicality of such a life extension. This analysis is offered as an illustration of how the build-new strategy would perform under a different set of assumptions about the CVN 21 class of ships.

Figure 2.16
Ship Life Sustained by 30-Month Build-New Interval and 30-Year Unrefueled Life Span



NOTE: Reference case data displayed as dotted lines.
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CHAPTER THREE
Adequacy of the Industrial Base

Under current modernization plans, the Navy will contract for, and NGNN will deliver, a new carrier to the fleet every four to five years. The various build-new options described in the previous chapter raise the question of how the carrier industrial base must change, if at all, to accommodate the delivery of a new carrier every 24 to 30 months. Is sufficient capacity available, in terms of facilities, equipment, and workforce, to achieve the accelerated production? If not, what are the cost and schedule implications of obtaining additional production capacity? These questions apply to both NGNN and the nuclear and nonnuclear vendors that provide components and equipment for carrier construction. Also, stopping the *Nimitz*-class RCOHs and doubling the procurement of CVN 21–class carriers may have an impact on the U.S. Navy, especially the management and oversight functions provided by the Naval Sea Systems Command (NAVSEA), the Program Executive Officer for Aircraft Carriers (PEO Carriers), and their subordinate organizations.

This chapter describes the impact of the build-new options on the industrial base. It describes the facility enhancements needed at NGNN and the impacts on the NGNN workforce. We also discuss the ability of the various vendors to support increased CVN 21 production. Finally, we briefly describe potential impacts on the Navy's program management structure.

NGNN

Various tasks and functions are accomplished during the approximately eight-year build period of an aircraft carrier. A contract is signed, the production design is finalized, material is ordered,[1] and initial steel is cut to start forming major sections of the ship. These major sections, termed "super lifts" by NGNN, place demands for skilled labor—mostly welders, fitters and fabricators, and construction support personnel—and for production shops and facilities. Approximately three years after the contract is signed, the keel for the new ship is said to be laid when super lifts are placed and joined in the dry dock. Additional super lifts and subassemblies are built, and construction continues in the dry dock for approximately three more years. This period continues to place demands for construction labor and shop facilities as well as the dry dock. Approximately six years after the contract signing, the ship is launched from the dry dock and is moved to a pier for final outfitting. During the time by the pier, outfitting and electrical skills are in demand. As the ship nears completion, testing and trials are conducted culminating with the delivery of the ship to the Navy. Table 3.1 shows the time in months for the various construction phases for the current *Nimitz*-class ships.

As shown in Table 3.1, considerable variability occurs in the times spent in the various stages of construction. Importantly, all of the *Nimitz*-class carriers have required more than two years in the dry dock (second column minus first in Table 3.1), and only one dry dock at NGNN is suitable for the construction of CVN 21 carriers. From these data alone, it would appear that doubling the production rate of carriers would not be possible without facility enhancements and workforce expansion at NGNN. However, an examination of the impact on NGNN facilities and workforce must consider not only

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[1] Some material and equipment, especially major components of the nuclear propulsion plant, are ordered several years before the contract for a new carrier is signed. For example, funds for the manufacture of certain propulsion plant components are appropriated four years before the full funding for the carrier.

Table 3.1
Times to Construction Milestones for *Nimitz*-Class Carriers

	Months from Contract Award to		
Carrier Name (Number)	**Keel Laying**	**Launch**	**Delivery**
Nimitz (CVN-68)	22	68	103
Eisenhower (CVN-69)	21	83	106
Vinson (CVN-70)	36	89	112
Roosevelt (CVN-71)	18	54	78
Lincoln[a] (CVN-72)	22	61	82
Washington[a] (CVN-73)	44	91	114
Stennis[a] (CVN-74)	33	65	89
Truman[a] (CVN-75)	65	99	120
Reagan (CVN-76)	38	75	105
Average (all)	33	76	101
Average (minus CVN-73 and -75)	27	71	96

[a] Part of a two-ship buy.

the increased demands from doubling the rate of new carrier construction but also the decreased demands from eliminating future RCOHs. We now turn to these issues.

Production Facilities

Facility improvements at NGNN can be grouped into three categories: upgrades necessary for the new systems on CVN 21, regardless of build rate; additional facility upgrades needed to support accelerated carrier construction; and planned facility upgrades to support the RCOH program. We worked closely with NGNN to understand the implications for the facility of each modernization option through 2012, by which time the facilities needed to support the alternative modernization options would be implemented. They provided estimates of the facility upgrade cost of each option and a preliminary schedule of when the upgrades could be accomplished.

CVN 21 Facility Upgrades Involve Two Types of Improvements. The first type includes those needed to replace or refurbish existing facilities and construction equipment because of age and wear. They are needed to maintain carrier construction capability at the shipyard, regardless of the class of carrier or the time between building new carriers. The second type is the unique facility improvements needed to build the CVN 21 class of carriers. They are needed for the specific systems, equipment, or construction plans of CVN 21.

The *normal facility improvements* include shop upgrades, manufacturing equipment replacement, a mechanical overhaul of the 900-ton crane, construction of a new single-sided test pier, and replacement of keel blocks, pedestal stands, and shoring equipment. The estimated cost of these normal facility improvements is $118 million. (This and other costs in this section are in 2002 dollars.)

The facility upgrades required to build the CVN 21 class of carriers include the following:

- Adding platen space
- Upgrading additional shops
- Constructing of a new outfitting facility
- Upgrading electrical/mechanical systems
- Constructing a trades/program support facility
- Upgrading the 900-ton crane to 1,050 tons
- Purchasing special tools, rigging, and construction equipment.

The total cost of these CVN 21–related facility upgrades is $159 million. Therefore, the total cost of upgrading the construction facilities at NGNN for the current modernization plan totals $277 million.

NGNN plans to make the necessary facility upgrades for the CVN 21 class of ships from the start of 2003 to the end of 2011. Construction of the test pier has begun and ends in 2006. Construction of the outfitting facilities will start in 2005 and finish in 2011.

Accelerated Production Facility Upgrades Are for New Facilities to Accommodate the Delivery of a CVN 21–Class Carrier Every 24 to 30 Months.[2] These upgrades are in addition to the facility upgrades for the current modernization plan. The primary upgrades include lengthening dry dock 12 ($45 million) and deepening the outboard

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[2] The facility upgrades cited here are sufficient for a 24-month interval. We did not attempt to determine whether less extensive upgrades might be required for a 30-month interval. Any differences would likely have been too small to affect our conclusions.

end of the dock ($40 million),[3] buying and installing a second 1,050-ton crane for dry dock 12 ($50 million), and doubling the size of the CVN 21 outfitting facility ($60 million beyond the cost of the current modernization plan). Other upgrades and equipment purchases include the following:

- Extending platen 21 and building a new platen
- Building a consolidated pipe shop
- Upgrading platen 18
- Purchasing additional 30-ton and 50-ton cranes
- Additional equipment purchases and shop upgrades.

The additional cost of accelerated CVN 21 production is $428 million. With the costs of the upgrades for the current modernization plan of building a new CVN 21–class ship every four to five years, the total facility upgrade cost for any of the accelerated production options is $705 million.

One of the proposed facility upgrades is to deepen dry dock 12. Deepening this dry dock would allow greater degrees of advanced outfitting during ship construction. (Depth constrains outfitting because outfitting makes the ship heavier, requiring greater draft when the dock is flooded to float the ship out.) This would lower the total man-hours required to build the ship (under the widely held premise that more hours are required to do outfitting on the completed ship versus during the construction of super lifts) thereby reducing acquisition cost. Additional advanced outfitting while in the dock would also reduce the outfitting required after the ship is launched. Note that although this facility upgrade is not required for the accelerated production of CVN 21–class carriers, we have included it in our estimate of total facility improvements. In the next chapter, we estimate the impact on the cost of the carriers from increased levels of advanced outfitting.

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[3] Chewning and Eto (2001) estimated a total cost of $123 million to both deepen and lengthen dry dock 12. Their estimate is $38 million more than the one provided by NGNN for deepening and lengthening the dry dock. We accept the NGNN estimate for consistency.

Lengthening dry dock 12 and adding another 1,050-ton crane (for a total cost of $95 million) are needed so two carriers can be constructed at the same time. However, for the modernization options involving delivery of a new carrier every 30 months, it may be possible to meet the construction commitments without the additional dry dock capacity and crane. It might be possible to build the ships in succession in one dry dock. While a 30-month time in the dock has never been accomplished for a *Nimitz*-class carrier, the *Stennis* was in the dock for only 32 months, suggesting that 30 months is at least a possibility for CVN 21. If a 30-month dry-dock interval can be reliably met in CVN 21 construction, our cost estimates for the options assuming a 30-month production interval are high by $95 million.

NGNN has hypothesized a schedule for the facility improvements supporting accelerated production of the CVN 21 class of ships. The key task in this schedule is the work on dry dock 12. NGNN suggests that this work must begin by mid-2006 and end by the start of 2009 for the dock to be ready for the first CVN 21 super lifts. The work on the outfitting facilities would run from the beginning of 2013 to the end of 2015.

In the following chapters, we assume that these improvements will permit NGNN to meet a 24-month production interval without difficulty. Historically, the *Nimitz*-class ships have averaged 43 months in the dry dock (see Table 3.1, which contains the difference between keel-laying and launch milestones), and they have been commissioned at about the same interval (see Table 2.1). Although this record suggests that two dry dock spaces should be ample for meeting a 24-month build interval,[4] not much slack appears to be available should dry dock times prove longer for the CVN 21 class. However, the time in dry dock has to some extent reflected the time available. When, in the case of the two-ship buys, a greater premium accrued to clearing the dry dock, the first ship of each buy went through more quickly (39 months for CVN 72 and 32 months for CVN 74). We also assume that total shipyard dock and pier space

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[4] Note that RCOHs are accommodated by a separate dry dock dedicated to, and designed for, that purpose.

will be sufficient to accommodate four ships in the yard at once versus two under the reference plan (compare Figure 2.7 and Figure 2.3). We further assume that the other facility expansions planned will permit construction to proceed on the two additional ships.

Future RCOH Facility Upgrades Are Required If RCOHS Are to Be Performed Beyond CVN-71. After that point, the M-290 facility will require refurbishment[5] and a new floating steam test facility, including a new barge, will be needed. The estimated cost of these facility enhancements to continue RCOHs is $110 million.

For the modernization options that involve RCOHs on CVN 72 or subsequent ships, we add $110 million to the facility improvement costs. For the build-new options involving a CVN 72 RCOH, this is conservative (i.e., generous) in that it may be possible to extend the useful life of the current RCOH facilities to after the RCOH on CVN-72 is complete. If a modernization option stops RCOHs after CVN-71, we do not add the cost of RCOH facility upgrades.

Summary. Table 3.2 summarizes the cost of various facility improvements at NGNN. The $277 million for the normal upgrade of facilities to build CVN 21 ships is in all our options. The $428 million for additional facilities to support accelerated carrier construction is included in the options where we stop RCOHs and deliver CVN 21–class carriers every 24 or 30 months. Finally, the $110 mil-

Table 3.2
NGNN Facility Costs for Options Analyzed

Reason for Investment	Cost ($ millions)	How We Treat in Our Analysis
Normal upgrade for CVN 21 construction	277	Included in all cases
Support higher production rate	428	Included for all build-new cases
Support RCOHs for CVN 72 and beyond	110	Included for reference case and build-new options with RCOH on CVN 72

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[5] However, the principal use of this $60 million facility would be to support deactivation of retiring nuclear-powered carriers. It has not yet been determined whether this work will occur at NGNN.

lion for RCOH upgrades is included in the reference case of continuing RCOHs and in the build-new cases where we stop RCOHs only after CVN-72. We include the cost of all facility upgrades in NGNN overhead rates, amortizing the costs over a 30-year period.

Workforce

To understand the source and magnitude of workforce impacts for the build-new options, we collaborated with NGNN to predict future construction and repair projects from 2005 to 2040, along with the workforce requirements, at the skill level, of each project.[6] The projection included

- new construction and RCOHs scheduled with the current and alternative carrier modernization options,
- various carrier availabilities, including those for the USS *Enterprise* (CVN 65),
- new *Virginia*-class submarine construction,[7]
- other military and commercial work.

For each of these projects, we had both a profile of the labor demands over time for various skills (covering construction and engineering support, including support for certain nonrecurring tasks) and the projected start and completion dates of the projects.[8]

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[6] Of course, a good deal of uncertainty accompanies future projects at NGNN as well as the workforce requirements for each project. For example, in the next chapter we examine several assumptions that would result in reduced man-hours for CVN 21 construction. These assumptions include a higher degree of learning, and therefore lower man-hours, for accelerated production as well as reduced man-hours for higher degrees of advanced outfitting or outsourcing.

[7] We assumed that one *Virginia*-class submarine would be authorized each year until FY 2006 with two submarines authorized annually in subsequent years. (Plans for the *Virginia* class are still in flux. Since we conducted our analysis, ramp-up to two boats per year has been moved back to FY 2009.) We also assumed that the teaming arrangements between NGNN and Electric Boat would continue with each shipyard building approximately half of each submarine and taking turns assembling those halves into the complete submarine.

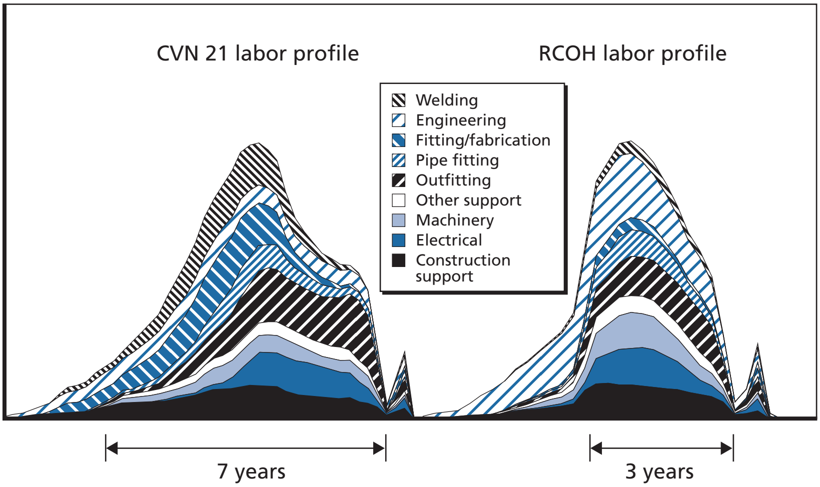
[8] After we received the data from NGNN, the Navy Cost Engineering and Analysis Division (NAVSEA 017) provided us a revised total man-hour estimate, and we adjusted the NGNN skill-specific profiles proportionally.

The demand profile, by skill, for new CVN 21 construction and RCOHs is shown in Figure 3.1. Although new construction will require about half again as many man-hours as an RCOH, the peak workforce demands for an RCOH are slightly higher than the peak demand for new construction because of the shorter project time line. The demand for different trades also varies with new construction versus RCOH. A heavier demand for the steel construction trades (welding and fitting and fabrication) occurs during new construction, and a heavier demand for engineering skills occurs during an RCOH.

With the help of such demand profiles as these, we can calculate total shipyard labor demand to 2040, along with total demand by skill. We can estimate the peak shipyard labor demand, the rate of run-up to the peak, the long-term average demand, and the long-term variability in demand.

Effects of Faster Modernization on Labor Demand. What does the total shipyard labor demand look like as the CVN 21 program

Figure 3.1
Workload Profile for CVN 21 Construction and RCOH



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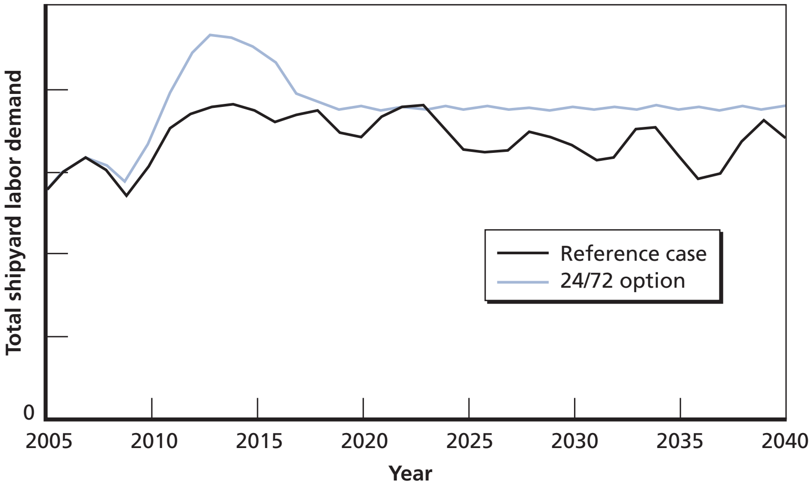
starts up? Figure 3.2 shows the total workload demand at NGNN under the current carrier modernization plan (the black line) and for the nominal build-new option defined in the previous chapter (the 24/72 case). As the figure shows, demand for workers peaks in the 2013 timeframe, especially for the build-new option. During this transition period, new construction is doubling while the final RCOHs are wrapping up. Another contributing factor is that the number of *Virginia*-class submarines authorized each year is doubled beginning in 2007. As a result, the demand for submarine workers doubles between 2007 and 2011. After the 2013 peak, the workforce demand for the build-new option is a little higher than the workforce demand for the base case, but the build-new demand varies less.

The shipyard labor peak is lower for the build-new options involving a longer production interval or an earlier RCOH halt, or both (see Figure 3.3). Stopping RCOHs one ship earlier than in the nominal build-new plan (24/71 versus 24/72) removes from the labor peak the workers necessary to perform the RCOH on CVN 72. Once

Figure 3.2
Total Shipyard Labor Demand for Reference Case and Nominal Build-New Option



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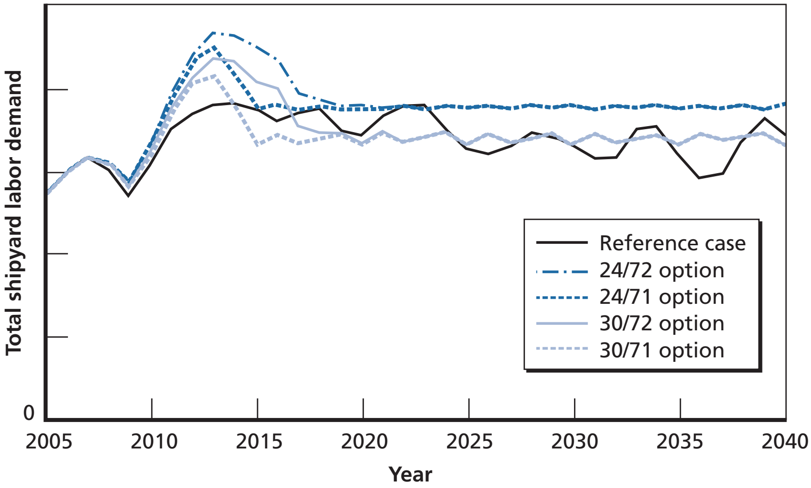
the RCOH is finished in the 24/72 option, labor demand for the two options is identical. The 30/71 and 30/72 options have an analogous relationship. Each, however, requires a peak lower than its 24-month counterpart because the ship construction schedule is more spread out. The workforce demands for the options that start new carriers every 30 months approximate the demands for the reference case, although with much lower variability.

The total workload profiles do not convey the demands for specific skills and the timing of those demands over the project time line. Figure 3.4 shows the demand for outfitting skills for the reference case and for the 24/72 case, the build-new option that places the greatest demands on the workforce. Outfitting is the skill with the greatest rate of change for the build-new options.[9] Note the

Figure 3.3
Total Shipyard Workforce Demand for Alternative Carrier Modernization Plans



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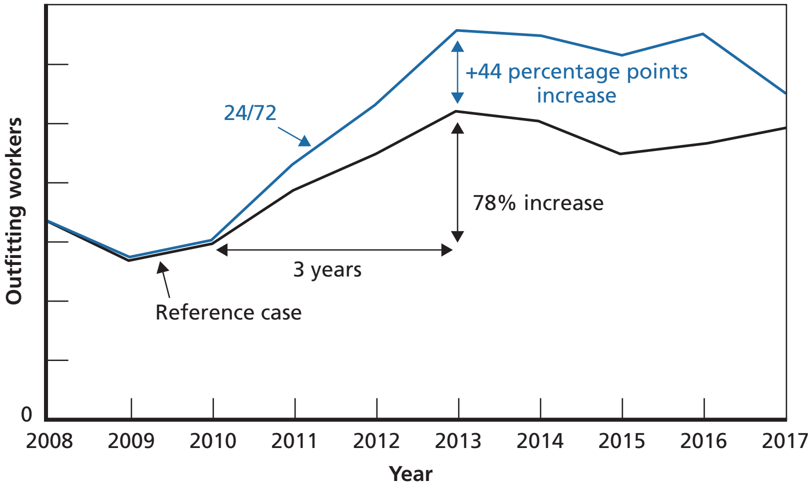
[9] Information on the rate of change, average and variability in the labor demand for each of the nine skills is detailed in Appendix B.

Figure 3.4
Total Shipyard Outfitting-Labor Demand for Reference Case and Nominal Build-New Option



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increases for outfitting workers are proportionally greater than for all workers. The reference case reflects an increase in demand for outfitting skills of 78 percent over the three-year period from 2010 to 2013. The 24/72 option results in a demand amounting to an additional 44 percent of the 2010 baseline.

Managing the Labor Demands of Faster Modernization. Under the build-new options, the real challenge for NGNN would be managing the total increased workforce demand during the transition period from 2012 to 2017. The challenge is finding enough qualified, available workers in the vicinity of Newport News to accommodate such increases.

In the event that such a worker pool is not available, NGNN can satisfy the peak demand in several ways. These include the following:

- The start and completion dates of some of the projects in this time window can be moved to help flatten the peak.

- Some level of work can be outsourced to other providers. These providers might be subcontractors[10] or the Northrop Grumman Ship Systems (NGSS) shipyards in the Gulf Coast region. Additional benefits may accrue to using those yards for some of the work: They have lower wage and overhead rates compared to NGNN, plus workload demands might also be smoothed at those shipyards if troughs in their demand profile coincide with the peaks at NGNN.
- The NGNN workforce could be augmented with workers from NGSS. This is similar to the above alternative except the workers would move to the work versus the work moving to the workers. NGNN has used electricians from NGSS on some recent projects.

Each of the above options must be reviewed with NGNN (and NGSS) and evaluated to determine how best to meet the peak demands associated with the build-new options during the transition period.

Once the transition period passes, each of the build-new options simplifies workforce management at NGNN compared to the reference case. As shown in Figure 3.3, workforce demands for the build-new options vary little after 2017, especially compared with those for the reference case. Variation in demand for individual skills shows similar relations (see Figure 3.5 for welders). Avoiding the reference case's peaks and valleys in demand should result in lower levels of hiring and termination and therefore, lower total workforce costs.

Summary. The build-new options result in higher workforce demands in the short term but provide very stable demands in the

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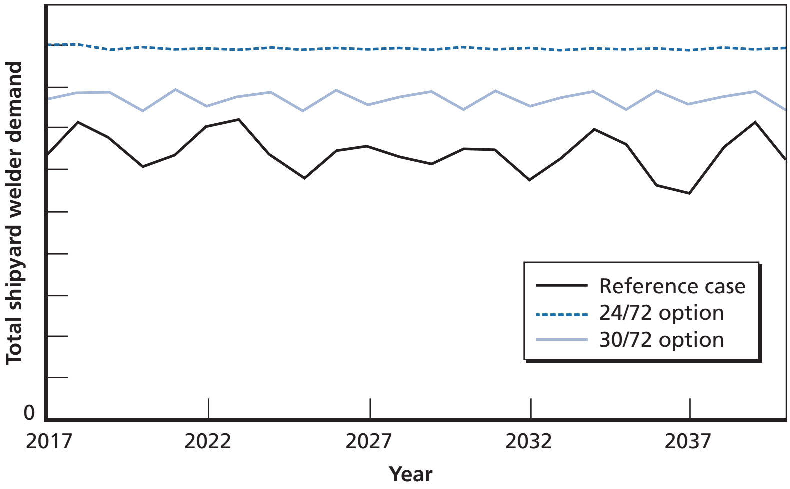
[10] NGNN currently uses subcontractors for some high-end outfitting tasks such as the captain's visitor area on new carriers and has recently used a subcontractor for steel fabrication. The next chapter discusses the potential cost implications of a greater use of subcontractors for outfitting tasks.

Figure 3.5
Total Shipyard Welder Demand After 2016 for Alternative Shipyard Modernization Plans



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long-term. Stopping RCOHs after CVN 71 can reduce the short-term peak.

Management Functions

Stopping RCOHs and accelerating the construction of the new class of carriers will also have an impact on the management at NGNN. In many ways, RCOHs are a hybrid between new construction and repair projects. Currently, NGNN manages two workforces, one for such repairs as the RCOHs and one for new construction. Although some movement of workers takes place between these two workforces as the work in the shipyard varies, such movements usually disrupt the schedules of different projects. Also, repair projects are very different from new construction projects, requiring different types and mixes of skills and different management philosophies. Very few, if any, other shipbuilders in the world are able to manage new construction and repair at the same yard.

Vendors

In addition to the impact on the facilities and workforce at NGNN, any build-new options that accelerate the delivery of CVN 21–class carriers may also have impacts on the vendors that support carrier construction. We next describe potential impacts on these nuclear and nonnuclear vendors.

Nuclear

We worked closely with the Nuclear Propulsion Directorate (SEA 08) of NAVSEA to understand the potential impact on the nuclear vendors that support RCOHs and new carrier construction. We also drew on knowledge and data gained during previous research on the nuclear vendor industrial base.[11]

The end of RCOHs and the increase in new carrier construction would not affect the nuclear vendors that provide the reactor cores and smaller equipment. The workload for these vendors is essentially the same for the two types of projects. However, the vendors that supply the heavy-equipment components (BWXT Nuclear Equipment Division) and the control rod mechanisms (Marine Mechanical Corporation) do not play major roles in RCOHs because their equipment is basically "life of the ship." These vendors would experience an approximate doubling of their workloads for the accelerated delivery options.

Marine Mechanical Corporation identified no "show-stoppers" in supporting an increased carrier build rate. They would have to expand their workforce, but they anticipate no problems in hiring and training the additional labor. Less than $10 million is required to support an increase in facilities and production equipment. MMC estimates that workforce and plant expansion costs should be very roughly offset by savings from the additional volume from the increase in carrier production. The outcome should be at most a neg-

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[11] Previous RAND research that examined the nuclear vendors that support submarine and carrier construction includes Birkler et al. (1998) and Schank et al. (1999).

ligible net cost, if not a favorable impact, on the price of the control rod mechanisms.

BWXT's Nuclear Equipment Division also felt it could expand its capabilities to support increased carrier production. The company would also require an increase in their workforce—of approximately 25 percent—along with additional machine tools and special manufacturing equipment. The costs of the additional tooling, equipment, and fixtures at BWXT's Nuclear Equipment Division would total approximately $130 million. Lehigh Heavy Forge, the sole-source heavy forging supplier to this division of BWXT, would require approximately $35 million for additional equipment. The additional volume would result in a price decrease for the heavy equipment components although the net impact of the additional costs ($165 million) and the decreased price was not provided.

Because of the long lead time for nuclear components, any equipment procurements and workforce expansions must begin almost immediately (i.e., in FY 2005) to support the start of a second CVN 21–class ship in 2009. A very timely start to any expansions is also needed to avoid any disruptions in the production and delivery of submarine and carrier components currently on order.

Nonnuclear

Hundreds of firms supply nonnuclear products used in constructing an aircraft carrier. Many of those products are highly specialized and are used only in carriers. A ship-set of products from a particular firm can usually be produced in a few months, and orders for such a ship set typically arrive once every four or five years. If production of those products requires unique tooling or fabrication skills, then supplying products for aircraft carrier production might not be a very attractive line of business.[12]

Replacing such firms could be a problem if some of them left the business of supplying aircraft carriers or performed so poorly that the shipyard found their performance unacceptable. New suppliers

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[12] Carrier-unique products do, however, typically draw on technical expertise and industrial facilities supported by a much broader market.

would have to be found and their products qualified for the special conditions found on a carrier. It is also possible that some firms supplying carrier products could be small enough that they might find it difficult to increase their production rate to the degree needed to satisfy the demands of the build-new cases examined in this report.

We therefore sought some information on the status of the vendor base that would be called on to support production of the CVN 21 class. We especially wanted to determine if any aspects of that vendor base would seriously constrain the ability to implement the build-new strategy.

Surveying the hundreds of vendors supplying aircraft carrier construction was impractical and unnecessary. We wanted to focus on only those vendors that might conceivably pose some kind of impediment to the build-new strategy being investigated here. As a first step, we asked the shipyard for two lists:

- The ten largest vendors, in terms of dollar value. Such vendors would be hard to replace simply because of the volume of business each represents.
- The 20 vendors that the shipyard considered "at risk" for one reason or another:
  - Some evidence that they might leave the carrier-supply business
  - Problems in prior performance that might require finding a replacement
  - Limited financial resources that might prevent them from increasing their rate of production to the level needed to support the build-new strategy
  - Other similar indicators of possible future problems.

A brief survey form was prepared for circulation to each of those 30 firms. In that survey we asked the following questions:

- What are the kinds of products provided in support of recent aircraft carrier construction?

- Does the firm expect to provide similar equipment in the future (i.e., does the firm expect to stay in that line of business?)? Are any problems foreseen in supplying such products and material in the future?
- What fraction of the firm's total production activity and factory capacity has been devoted to supplying the carrier equipment? We asked this question on the assumption that firms with a large business base would be inherently more capable of responding to fluctuations in carrier-related business than firms devoted largely to carrier-unique products.
- What problems, if any, would be experienced in meeting the accelerated demand of a new ship every two years instead of every four years?
- Would production of a carrier every two years enable the firm to achieve any efficiencies and cost reductions in production of carrier-related products?
- Would ceasing RCOHs on any *Nimitz*-class carriers after CVN 72 have an important effect on the firm's overall business base? Would it affect the costs of the products supplied for new carrier construction?

Usable information was obtained from a dozen firms with some representation from each list provided by the shipyard. From those responses we drew the following observations:

- For the vast majority of firms supplying products and material needed to construct an aircraft carrier, that line of business represents only a small percentage of their overall business base. Those firms foresaw no problems in meeting sizable variations in demand for their carrier-related products.
- One of the firms decided to cease production of the single carrier-related item on its product list. That product (a bridge crane) was a relatively standard commercial product, and a new supplier can almost certainly be found.

- A few firms would require some investment in additional tooling and an increase in specially trained staff to meet the postulated increase in production rate.

In no cases did we find any evidence of problems in the vendor base that would be serious enough to affect a decision on implementing the build-new strategy.

Navy

In addition to changes at the shipbuilder and the major vendors, ending the RCOHs will have an impact on the Navy's management and oversight functions. RCOHs are inherently hard to manage. By their very nature, a large degree of uncertainty surrounds the necessary repair actions during the RCOHs. In many cases, the extent of the repairs is not fully understood until systems and ship structures are opened and inspected. This uncertainty makes it difficult to estimate the true cost of an RCOH in advance. In reality, cost targets are set and as many of the repairs as possible—especially the ones that impact safety and operations—are accomplished within the available budget.[13]

RCOHs require significant management and oversight by the Navy at both PEO Carriers and the Supervisor of Shipbuilding, Conversion, and Repair, Newport News. At PEO Carriers, a program manager must oversee the planning and execution of an RCOH, and other management personnel must prepare and defend the budgets for the project. The RCOH budget, contained in the Ship Construction, Navy (SCN), account, is often a target for budget reductions to pay for other programs. As often happens with repair projects, there is a belief that necessary repairs can be postponed until future maintenance periods, freeing up money for emergent needs.

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[13] For a description of the problems the Navy faces in managing RCOHs, see Schank et al. (2002).

Ending RCOHs will simplify the work at PEO carriers since there will be one less type of project to manage. The end of RCOHs may have little or no impact on staff requirements because the PEO has other functional responsibilities that would be assumed by personnel currently managing RCOHs. In particular, building carriers at twice the currently planned rate could double the required oversight of new construction.

The Supervisor of Shipbuilding, Conversion, and Repair, Newport News, has a staff of approximately ten people that support RCOHs. Eliminating RCOHs could lead to staff reductions there, though again, more new-construction activity would require more Navy oversight at the yard level, also.

Conclusion

The carrier industrial base appears adequate to support and manage a build-new strategy. Some facility upgrades are needed at the shipyard, but no critical problems appear to exist there. A significant short-term transient in the shipyard labor profile must be managed, but the build-new strategy affords an opportunity for greater long-term workforce stability. Suppliers of parts for the nuclear-propulsion plant will need to undertake some modest upgrades. The challenge there, however, is not really capacity but timing. If a build-new strategy is to be implemented so that the second CVN 21–class ship is started in 2009, propulsion plant supplier upgrades must begin promptly. Vendors of nonnuclear components are generally in place and capable of meeting the higher production rate.

CHAPTER FOUR

Life-Cycle Cost Analysis

In this chapter, we will examine the life-cycle cost[1] (LCC) implications of the alternative fleet modernization strategies defined in Chapter Two. By "LCC," we mean the total cost to purchase, operate, maintain, and dispose of a carrier.[2]

The build-new options have broad ramifications in terms of budget, personnel, and industrial base. We attempt to quantify the cost impacts in these areas. For example, increasing the rate of new construction at NGNN will change overhead rates and facilities user fees as a result of requirements to improve or upgrade the shipyard—thus, acquisition and refueling costs may change. Also, newer designs (CVN 77 and CVN 21) are expected to require fewer personnel to operate. Therefore, one would expect personnel cost to decline as newer carriers are introduced. Under the accelerated replacement strategy, personnel costs should fall faster, leading to greater savings.

Approach

Assessing the LCC of any weapons system is difficult. The task is made harder by the aircraft carrier's potential longevity (up to 50

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[1] Throughout this chapter we use the term "cost" in its more general sense. Some analysts make a distinction between cost and price. When we refer to cost, we mean cost to the buyer, including fee and profit—the definition of price.

[2] Note that we do not analyze the "Total Ownership" costs, which would include such other elements as support systems and government infrastructure for management.

years) and its complexity (a carrier is one of the most complicated and expensive weapons systems procured today). It is exceedingly difficult to forecast costs over a 50-year period. In addition, there has been essentially no experience with post-RCOH carrier costs for the *Nimitz* class. Furthermore, some elements of the LCC are one-time expenses, such as the acquisition cost, while others recur every year that the ship operates, such as personnel costs. Thus, both the timing and magnitude of the various LCC elements for the carrier fleet must be understood.

For our study, we consider the following LCC elements:

- Acquisition
  - Nonrecurring
  - Recurring
    - Labor
    - Material and equipment
- Operations and maintenance
  - Maintenance
    - Depot
    - Organizational and intermediate (O&I)
    - Unplanned repair
    - Modernization
  - Personnel
  - Miscellaneous (e.g., consumables, support, training)
- Disposal
  - Defueling and demilitarization
  - Scrapping.

These elements can be easily translated to the three major budget categories: SCN; Manpower and Personnel, Navy (MPN); and Operations and Maintenance, Navy (O&MN).[3]

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[3] Modernization of the carrier fleet could result in some indirect cost savings that we do not attempt to estimate. For example, electromagnetic launch could reduce airframe stresses, leading to longer operational lives for shipboard aircraft.

NAVSEA 017 and NGNN provided all the baseline cost data for the analysis. Except for a few minor elements, we followed the program sponsor's request not to independently estimate any of the cost elements. In particular, we did not estimate costs for defueling and demilitarization, for which we were provided no data. Note that some of these costs have an implicit assumption that the operational tempo is similar to that of the early part of this decade. If the carrier fleet were used more heavily, the "core life" of the reactor would be used more rapidly. This change would lead to more frequent refueling. Also, it could be reasonably expected that maintenance costs and consumable expenses would also increase with increased use.

We report all costs in fiscal 2002 dollars. We assume no real cost growth over the analysis period—i.e., cost and rate increases follow the anticipated escalation trends. All costs are discounted and reported as net present value (NPV) using an annual discount rate of 3.2 percent.[4] The discount periods for the costs are based on their *budget* year relative to 2002.

We examine the LCC of the carrier fleet between 2002 and 2052. We chose such a broad interval (the lifetime of one refueled carrier) to better understand the short-, medium-, and long-term implications of the different replacement strategies. Also, of the cost differences among strategies that have an appreciable effect on NPV, the bulk will have been accounted for by 2052. After 50 years of discounting at a rate of 3.2 percent, the weighting of the costs for 2052 is only about 0.14 relative to that for 2002.

Excluded from the analysis are the conventional carriers and CVN 65. The costs for these carriers are significantly different from the *Nimitz* and CVN 21 baselines. More important, the cash flows for these ships are not affected by the replacement strategies we are exploring.

Many of the cost data are sensitive or considered business proprietary. Therefore, we will not be reporting specific values or amounts used as "inputs" to our analysis.

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[4] This value is the "real interest rate" from Office of Management and Budget Circular A-94.

Modeling LCC

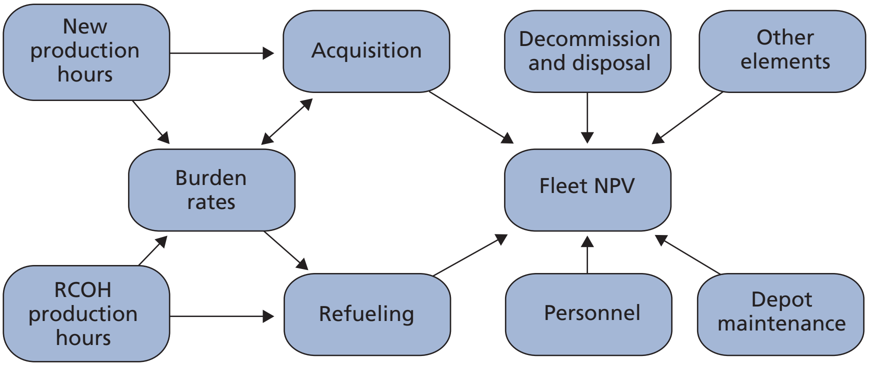
To evaluate multiple replacement strategies, we constructed a model of the carrier fleet LCC. Such a model allows us to explore different options in a consistent and comprehensive manner. We constructed two versions of the model—one version in Excel and another version in Analytica. Building duplicate versions served a few purposes:

- Cross-checking the calculations (i.e., ensuring that the results of the two versions are consistent).
- Exploring the effect of uncertainty in the "input" values through Monte Carlo analysis (more easily done in Analytica).
- Providing a legacy model for the Navy to analyze additional options (of greater utility if in Excel).

The overall structure of the model is shown in Figure 4.1. The figure displays the influence diagram of how the various elements interact to determine the fleet NPV. Details of the methodology for calculating each of the LCC elements are given in Appendix C.

As can be seen from the figure, the elements are largely independent of one another, which greatly simplifies the calculations.

Figure 4.1
Influence Diagram for LCC Elements



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However, the midlife refueling complex overhaul costs (part of maintenance) and acquisition costs do interact. Because work for both elements is done exclusively by NGNN, changing the workload of one will alter the shipyard-wide burden rates and thus change the cost of both. For this reason, we have separated refueling costs from the other depot maintenance costs.

Otherwise, the elements in the diagram generally map to the list given above, except that the "other elements" category comprises a combination of costs that are uniformly allocated on an annual basis. These costs are O&I maintenance, unplanned repair, modernization, and the miscellaneous categories from the LCC breakdown. This combination was done to simplify the calculations.

Metrics for Comparison

To examine the LCC implications of different carrier replacement strategies, we will use two metrics:

- Total NPV: This metric is the total discounted cost of the carrier fleet over the period 2002 though 2052. We discount in recognition of the generally accepted thesis among economists and cost analysts that people prefer to delay expenses if doing so has no cost. Thus, of two options having the same nominal cost, the one deferring the costs further into the future will be preferable. The conventional means of quantifying that preference is to discount costs by a constant percentage each year. (The costs to which the discounting is applied are the real costs—i.e., uninflated. The thesis that people prefer a delayed cost to an equal, undelayed cost assumes the amounts are equal in real terms.)
- NPV per operational ship-year: The different options we explore do not sustain the same number of active ships in the fleet. Left unadjusted, an option might appear more expensive; yet, that option might sustain a greater number of active carriers. To present a more balanced comparison, we have created a metric that is the ratio of the total NPV to the total number of operational

ship-years (discounted) over the analysis period. Operational ships are defined as in Chapter Two. Thus, if a ship is not scheduled for a maintenance availability during a given year, one operational ship-year accrues. If it undergoes a six-month PIA, 0.5 operational ship-year accrues. The total is discounted because having an active carrier today is worth more than having an active carrier in the future. We used the same discount rate as we did for the total NPV.

Baseline Comparison

For our baseline comparison, we will contrast the current replacement plan ("reference case") with the nominal build-new plan in which carriers following CVN 72 are replaced at midlife with new ones, warranting a 24-month production interval ("24/72"). The difference in NPV between the reference case and the nominal build-new option is about 12 percent (see Figure 4.2). As one can see from the figure, the acquisition costs for the nominal build-new strategy are greater than those for the reference case. However, the build-new strategy has reduced maintenance costs because the fleet has a higher percentage of lower-maintenance CVN 21–class ships under that strategy. The fleet-wide savings are not large, particularly for personnel, for two reasons. First, it takes a number of years for the fleet to evolve from a *Nimitz*-class fleet to a CVN 21 fleet. Second, the greater savings many years in the future are worth much less than their nominal value today—that is, they must be discounted.[5] Furthermore, slight differences in personnel costs (lower for build-new) and other costs (lower for the reference case) offset each other.[6]

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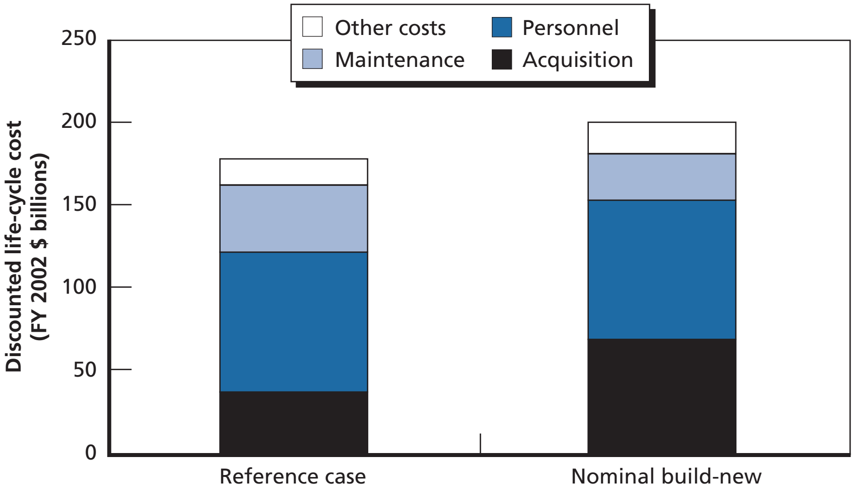
[5] A build-new strategy lowers maintenance costs more than personnel costs. That is partly because the life-cycle maintenance cost reduction percentage for a CVN 21–class ship versus a *Nimitz*-class ship is greater than the corresponding personnel cost-reduction percentage. It is also because we include RCOHs in the maintenance cost category, and under the build-new plan, those costs decrease not only for the CVN 21 class but also for the *Nimitz* class.

[6] In the figure, for clarity's sake, O&I maintenance, a very small cost category estimated separately, is combined with depot maintenance. O&I costs are $2.2 billion for the reference

Figure 4.2
Cost Comparison, Reference Case Versus Nominal Build-New Option



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With the second metric (Figure 4.3), NPV per operational ship-year, the difference between the two strategies narrows, from a 12 percent cost premium for the nominal build-new option to a 6 percent premium. This narrowing arises because the build-new option sustains on average a greater number of operational carriers.

Comparison of All Alternatives

If a 30-month interval is substituted for a 24-month interval, the NPV of future costs for the build-new strategy approximates that of the reference case (see Table 4.1, lower center). The 11 percentage point drop in NPV from the 24/72 case stems from the savings in acquisition costs in building fewer ships and from the savings in per-

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case and $2.0 billion for the 24/72 option. Disposal (scrapping) costs, another small category estimated separately, are included with other costs. Disposal costs are $1.5 billion for the reference case and $3.6 billion for the 24/72 option.

Figure 4.3
Cost Comparison per Operational Ship-Year, Reference Case Versus Nominal Build-New Option

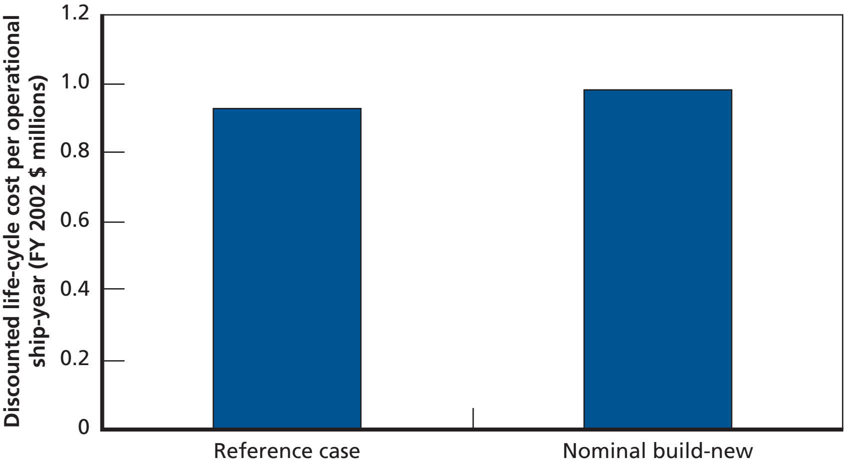

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Table 4.1
Cost Comparison of Build-New Options with Reference Case

How Long to Allow Between CVN 21 Starts	When to Stop Performing RCOHs	
	After CVN 72	After CVN 71
24 months	24/72 +12% NPV, or +6% NPV per operational ship	24/71 +8% NPV, or +6% NPV per operational ship
30 months	30/72 +1% NPV, or +4% NPV per operational ship	30/71 –3% NPV, or +4% NPV per operational ship

sonnel, maintenance, and other costs in running a fleet with one fewer ship on average (see Table 2.3). Omitting the RCOH on CVN 72 decreases the cost of either the 24- or 30-month option by 4 percentage points, relative to the cost of the reference case. The savings derive from not performing the RCOH and, more important, from not incurring the personnel, non-RCOH maintenance, and other costs of running CVN 72 for another 23 years.

The NPV per operational ship-year does not change when the CVN 72 RCOH is dropped (compare NPV per operational ship-year in the second column of Table 4.1 with the analogous numbers in the third). The personnel and non-RCOH maintenance costs per operational ship-year are somewhat higher than average for CVN 72, because it is a *Nimitz*-class ship. However, the one-time costs per operational ship-year are somewhat lower than average, because only an RCOH (rather than new production) is required to keep the ship in operation. These two elements offset each other, so the total NPV per operational ship-year is essentially the same. In moving from a 24-month production interval to a 30-month interval, NPV per operational ship-year drops, but only slightly. Here again, there are nearly offsetting differences from the fleet averages in non-RCOH-related operating costs and in one-time costs per operational ship-year: The number of CVN 21s in the fleet drops, so maintenance and personnel costs per operational ship-year increase. Offsetting that, the number of ships built decreases more than the number of operational ship-years, so production costs per operational ship-year drop.

It is noteworthy that the NPV premiums per operational ship-year are much more similar across strategies than are the unadjusted NPV premiums. That underlines the reliance of both cost-saving measures (cutting an RCOH and lengthening the production interval) on decreasing the number of operational ships in the fleet. That is, if NPV per operational ship-year stays the same and cost (NPV) goes down, the number of operational ship-years must be going down (as we know from Chapter Two).

The modest overall and per-operational-ship-year cost premiums of the build-new strategies result from operational savings that would take many years to materialize. Meanwhile, some substantial budgetary costs would accrue (see Figure 4.4).[7] The 24/72 plan, for exam-

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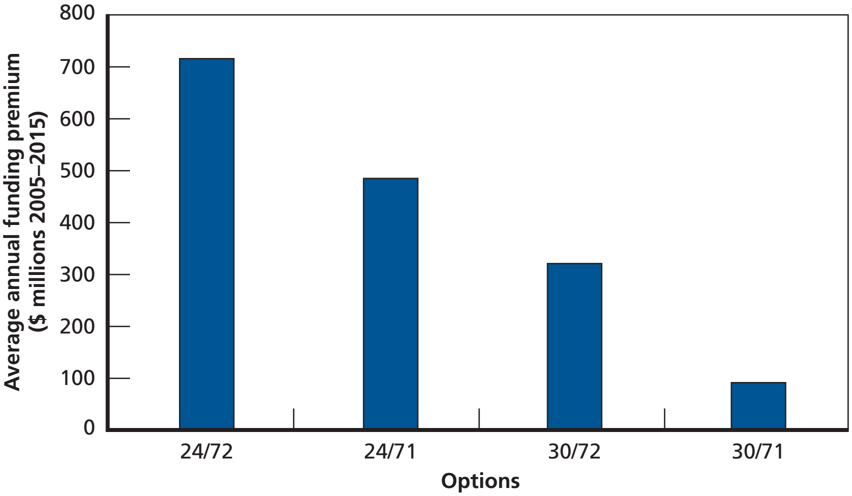
[7] Assumed annual funding for the reference plan is based on notional amounts, consistent with the historical record, that would be associated with the new-construction and RCOH events shown in Figure 2.3. The averages in Figure 4.4 are useful for comparison, but they mask large variations in the annual funding premiums. For example, for the 24/72 plan,

Figure 4.4
Annual Funding Premiums of All Build-New Options Relative to the Reference Case



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ple, would increase the SCN funding needed for the reference plan by an annual average of $700 million from 2005 to 2015. Other options require smaller amounts, but still in the hundreds of millions of dollars. These budgetary premiums do not bear on net present value comparisons, but they could raise concerns among those interested in saving money over the near to mid-future.

Cost Reductions from Other Sources of Savings

Skipping an RCOH or extending the production interval are not the only ways the build-new cost premium can be reduced. In this section, we explore some others.

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those premiums range from a few billion dollars for years in which a carrier not required under the reference plan must be started down to zero when no additional start is needed.

Sources

Outsourcing. One approach to reducing acquisition cost is to introduce more competition in the production process. One possible opportunity for competition is in outfitting the ship. While outsourcing of work could reduce acquisition costs, it seems unlikely that it could offset the 12 percent total NPV difference between the reference case and the nominal build-new strategy that is shown in Figure 4.2. For example, let us assume that the acquisition costs make up roughly 20 percent of the LCC, production labor is 40 percent of the total acquisition cost, 10 percent of the production labor can be outsourced, and that one can save 20 percent for outsourced work.[8] The net impact to LCC would be $0.2 * 0.4 * 0.1 * 0.2 = 0.0016$, or roughly 0.2 percent of the total LCC. Additional outsourcing is thus unlikely to make the nominal build-new strategy financially attractive. For calculating potential additional savings, we assumed that the percentage of production hours outsourced could be increased by 10 points, at a wage rate 20 percent lower than projected for in-house work. (Note that, while we do not assume greater outsourcing for CVN 21–class ships in the reference case, it could be done.)

Multiship Buys. The Navy plans to build 12 CVN 21–class ships. It plans to consider buys of two, three, or four ships at a time (as well as bundling of R&D initiatives with the multiship buys). Under the higher carrier production rate for the build-new strategy, multiship buys should be easier to effect. Multiship buys have been used in the past and have resulted in lower recurring (production) and nonrecurring costs (see Figure 4.5, which includes both recurring and nonrecurring engineering costs). To simulate the effect of a multiship buy, we will assume that the Navy buys new carriers in

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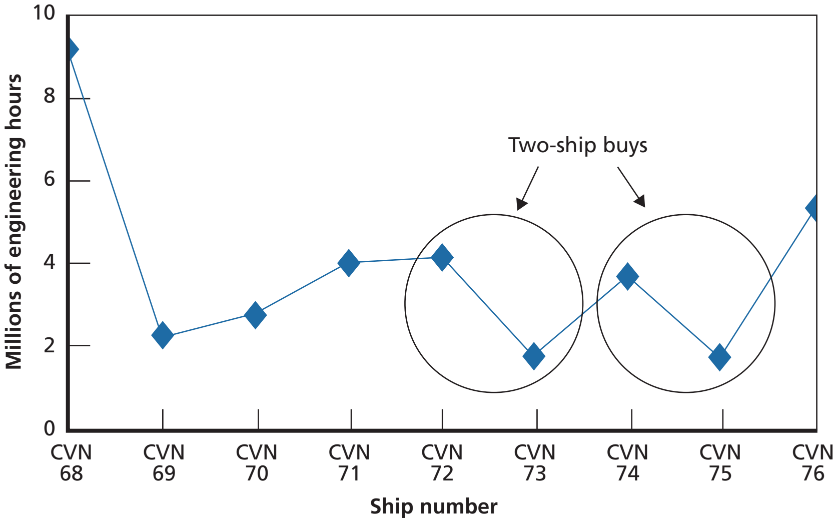
[8] These numbers are notional. Analyses done for this project suggest 5 percent outsourcing, based on a review of all ship elements that have been outsourced. In choosing a 10 percentage point increase, we allow some expansion without departing greatly from experience. Further analyses suggest that 50 percent is a reasonable labor cost savings to expect from outsourcing at the empirically based 5 percent level. For various reasons, savings at higher proportions outsourced may be lower, so we choose the more conservative 20 percent to apply to the next 10 percentage points of outsourcing.

Figure 4.5
Reduction in Engineering Hours with Two-Ship Buys



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pairs, which we believe for budgetary reasons to be the most likely alternative to single-ship purchases.[9] We will further assume that there is no nonrecurring engineering for the second ship. Finally, we assume that material and equipment costs are lower by 15 percent compared with single-ship contracts.

Learning. Repetitive production usually leads to efficiencies as a workforce becomes more experienced with a particular product. The phenomenon is generally referred to as "learning." One might expect under a more frequent and repetitive production schedule that CVN 21 might show reduction through learning. For the analysis that preceded, we assumed no cost reduction through learning. Typically, ship production has seen learning slopes of around 90 percent. However, only one of the seven follow-on *Nimitz*-class ships built so far

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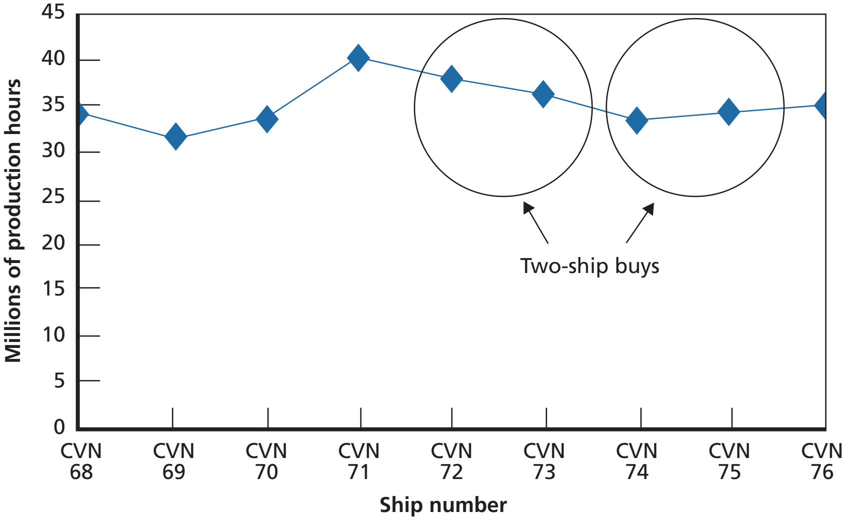
[9] Even single-ship purchases give rise to periodic spikes in the Navy's ship procurement budget. For a way of smoothing out such spikes that might be applicable to the larger spikes that would be associated with two-ship buys, see the discussion of a carrier capital account in Birkler et al. (2002, pp. 29–37).

has taken less time to build than the first of the class (see Figure 4.6). We attribute this lack of improvement to turbulence in the workforce caused by unsteady workload, change in construction methodology (to modular), labor strikes, and design changes. We thus assume 95 percent learning for the build-new options, and 100 percent (no learning) for the reference case.

Additional Crew Reduction. The CVN 21 plan is to reduce the crew size by 500 to 800 relative to the CV 74–Class Ship Manning Document, which calls for a crew of approximately 3,200. It may be possible to find other ways to reduce crew size. As an approximation, we will postulate that the crew could be reduced by an additional 200 sailors, a decrement within the range of the current reduction targets. That reduction is assumed to be entirely in the enlisted ranks. In the cost calculation, further savings beyond personnel costs—savings that indirectly result from crew reductions—are included, based on COMET, a model developed by the Naval Center for Cost Analysis.

Figure 4.6
Workforce Learning on the *Nimitz* Class



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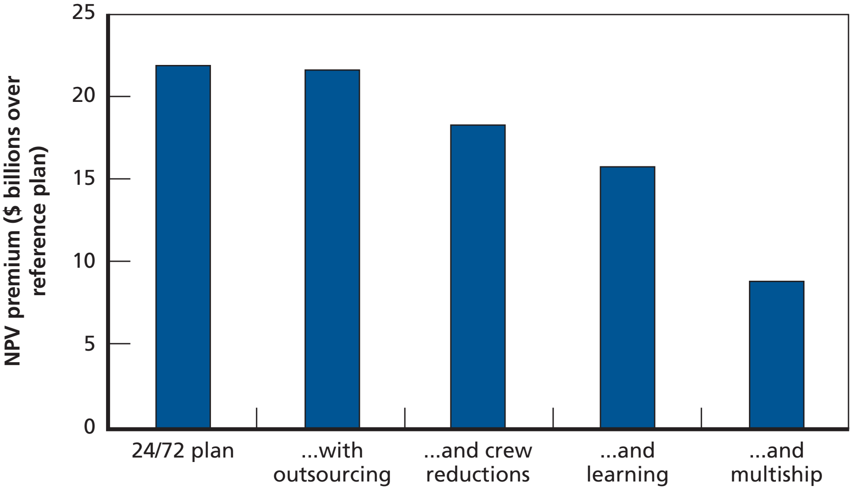
Cost Reductions

If these somewhat aggressive additional savings were achieved for a build-new scenario, could the cost premium for the build-new strategy be reduced or eliminated? Figure 4.7 shows the relative impact of each source of additional savings on the premium for the nominal build-new case. Multiyear buys would lead to the greatest savings. As described earlier, outsourcing does not provide for that much leverage in savings.[10]

Application of all cost-saving measures reduces the build-new cost premium relative to the reference case by a little more than half. If the same set of additional saving measures is applied to the other build-new options, the premium can be reduced almost to zero or

Figure 4.7
Effects of Other Sources of Savings on LCC, Nominal Build-New Option



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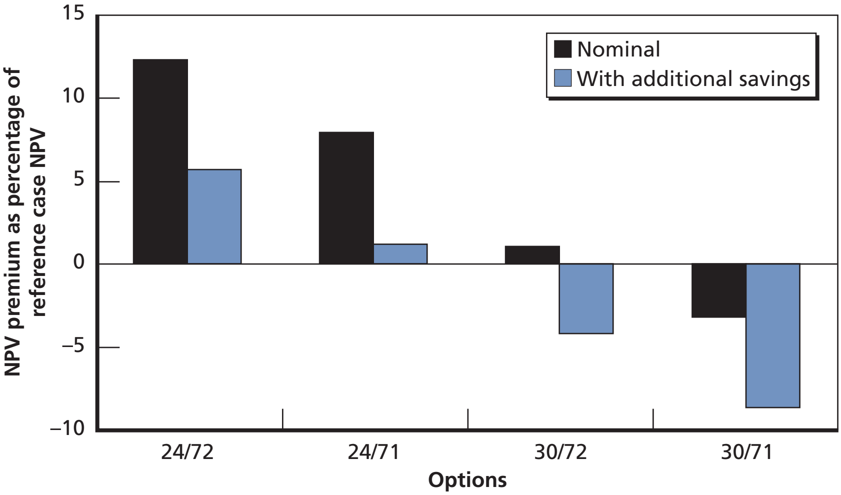
[10] While the figure allows some appreciation of the relative contributions of different cost-reduction measures, the precise rank-ordering of measures apparent in the figure is not generalizable because it depends on the order in which the measures are entered into the analysis. For example, crew reductions may eliminate some costs that might have been eliminated by learning, had learning been considered first.

even reversed (see Figure 4.8).[11] Using the metric of NPV per operational ship-year, we observe that one comes to a nearly break-even position with respect to the reference case (see Figure 4.9).

The value of the additional cost-reduction measures is obvious. If the Navy values faster modernization highly enough, it can cut the NPV premium nearly in half or even eliminate it. To do so, it must move more aggressively and innovatively to save money in production if it wants to attain or approach cost-neutrality.

Some near- to midterm increases in the SCN budget are likely still necessary. The combined effect of all the additional sources of

Figure 4.8
Effect of Other Sources of Savings on LCC in All Build-New Options



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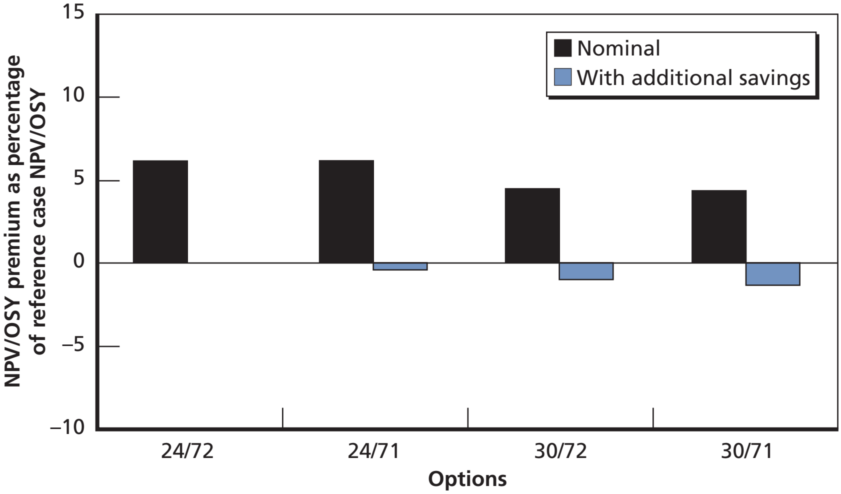
[11] The cumulative cost reduction for the 24/72 option shown in Figure 4.8 is slightly smaller than that shown in Figure 4.7. That is because the cost reduction measures interact —e.g., additional outsourcing reduces the number of hours on which learning can act. Thus, applying all the measures together yields a lower cost reduction than the sum of all of them considered separately. In Figure 4.8, they are applied together. In Figure 4.7, the separate effect of each is shown to make clear their relative potentials, resulting in a slightly exaggerated total effect.

Figure 4.9
Effect of Other Sources of Savings on LCC per Operational Ship-Year in All Build-New Options



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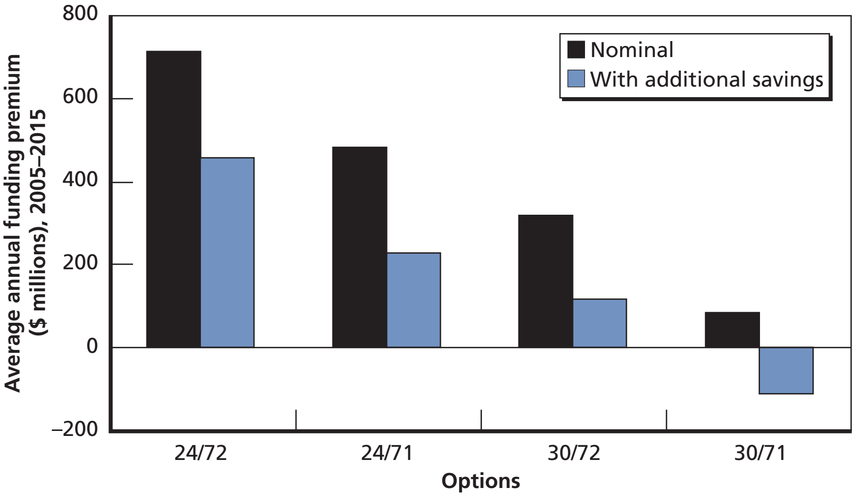
savings is to substantially reduce the average annual short-term funding premiums for the build-new options, particularly those with a 30-month production interval (see Figure 4.10). However, some increase over the current plan is still required in most cases, and the average annual budgetary authority for the 24/72 plan still exceeds that of the reference case by almost half a billion dollars.

Other Considerations

Impact on Other Programs

One effect of the build-new strategy is that other programs might have reduced overhead costs through lower overhead rates. This reduction in rates would stem from an increase in total production hours at NGNN. The increase would be slight, however. As a result, the net NPV decrease to these other programs would be less than 1

Figure 4.10
Effect of Other Sources of Savings on Annual Funding Premiums in All Build-New Options



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percent. Furthermore, this savings assumes that the facility improvements and expansions needed for the build-new program are charged only to new carrier construction.

Extended Core Life

As suggested in Chapter Two, the life of CVN 21's nuclear core might be extended. This would require core redesign that would cost several hundred million dollars in increased design and acquisition costs. Would such an improvement make the build-new strategy more attractive financially? On the surface it seems unlikely that such a change would substantially affect our results. Any benefits would not accrue until after the new ships begin retiring according to the build-new strategy without the core extension—that is, until after 2035. Such benefits would be heavily discounted. We do not have any estimate of the cost to redesign the core so that it can last longer. As these costs would be incurred up front, the savings from 30 years or more in the future could be offset.

Defueling and Demilitarization

After a carrier is retired and before it is scrapped, it must be defueled. It must also be demilitarized—that is, all weapons and other hazardous or sensitive military systems must be removed. Neither of these activities has been carried out on a U.S. nuclear aircraft carrier. Their cost is unknown, but it could be substantial. Under the build-new strategy, essentially twice as many ships are retired per decade as under the reference plan, and retirement of the *Nimitz* class will begin much earlier. Accounting for defueling and demilitarization thus might nontrivially increase the cost premium of the build-new strategy.

Summary

The nominal build-new plan costs more than the reference case. Discounted LCCs are 12 percent higher, and 6 percent higher per operational ship-year. More funding—about $700 million annually—is also required in the initial years. The cost premium can be reduced by extending the build period or forgoing an RCOH. With aggressive cost reduction through multiyear buys and other measures, the NPV premium can be further reduced or even reversed.

CHAPTER FIVE
Synthesis

We have proposed a set of alternatives to the Navy's plan to continue refueling *Nimitz*-class carriers and replace them with CVN 21–class carriers as they retire at close to 50 years of age. The alternatives entail retiring about half the *Nimitz*-class carriers at midlife instead of refueling them and accelerating CVN 21 production to a 24- to 30-month interval. The nominal build-new plan calls for a 24-month production interval and retirement of *Nimitz* carriers following CVN 72 at midlife.

The principal reason for undertaking a build-new strategy is to modernize the carrier force more rapidly. Under the nominal option, all carriers will be CVN 21–class ships by 2036, 22 years ahead of the complete transformation date under a reference plan that extrapolates from the current Navy vision. The nominal option also has the advantage that between 2010 and 2050, there will be on average an additional 0.3 carrier operational (that is, not in the shipyard for maintenance).

A disadvantage of the nominal build-new option is that it will decrease the total number of carriers in the inventory by about 0.4 ship at any given time. It will also cost 12 percent more (in discounted terms) over the next half-century and require, through 2015, an annual average of about $700 million in SCN funding above the reference plan.

Variants on the nominal plan entail forgoing an additional RCOH or extending the production interval to 30 months, either of which would still modernize the force rapidly while cutting costs back closer to those of the reference plan. However, both entail losses in the total carrier inventory and in the number operational and still require additional up-front funding to accomplish. In other words, no option is clearly superior on all criteria.

That conclusion is depicted graphically in Table 5.1, where each of the four options corresponds to a two-row group. The upper row in each group displays the average number of ships in the fleet and operational for the period 2010 to 2040. The reference case numbers for the same period are 12.1 and 8.4. The lower row gives the option's cost premium relative to the reference case without additional sources of savings and, in parentheses, with such savings.

The lighter gray shaded areas indicate the most favorable values, and the darker gray shaded areas express the least favorable. Values on a white background are intermediate. The nominal build-new plan (24/72) sustains the largest fleet but costs the most. The 30/71 plan costs the least but sustains the smallest fleet. The other two options have intermediate criterion values. Of the two, the 30/72 plan is considerably less costly while sustaining a fleet that is about as big as that of the 24/71 plan. The latter plan has the advantage of a somewhat faster modernization rate. None of the build-new options approximates all the values of the reference plan.

Obviously, the choice among options, including the reference plan, depends on how the criteria are weighted. Our own metric of NPV per operational ship-year effectively applies a linear weighting scheme to the cost and operational-fleet criteria. On that criterion,

Table 5.1
Fleet Size and Cost Effects of All Build-New Options

	When to Stop Performing RCOHs			
How Long to Allow Between CVN 21 Starts	After CVN 72		After CVN 71	
24 months	11.7[a]	8.7[b]	10.2[a]	8.2[b]
	+12%	(+6%)	+8%	(+1%)
30 months	10.6[a]	7.9[b]	9.8[a]	7.3[b]
	+1%	(–4%)	–3%	(–8%)

[a] Average number of carriers in fleet.
[b] Average number of operational carriers.

the options are all quite similar but somewhat less favorable (by about 5 percent) than the reference plan. However, the Navy may not subscribe to trading off NPV and operational ship-years by division and may wish to weigh them separately instead.

Two criteria are omitted from Table 5.1. First, the build-new options require more short- and midterm budgetary funding than the reference case. That funding premium varies substantially with the option, scaling roughly with the NPV premiums in Table 5.1.

Second, of course, the build-new options all have a big modernization rate advantage over the reference case, which will allow the CVN 21–class ships, with their performance advantages, to propagate more rapidly through the fleet. The advantages include the following:

- Increased sortie generation.
- Wider range of aircraft sizes supported, including small airframes typical of unmanned vehicles.
- More space and electrical power to support future technologies, including directed-energy defense systems and energy-absorbing dynamic armor.
- Reduced physical vulnerability.
- Larger stores of ordnance.
- More flexibility in managing deployments through longer intervals between availabilities.
- Much more capability to grow and be modified in future cycles of spiral development.

The modernization rate advantage can thus be conceptualized as a package of benefits whose present value is greater the earlier and more widely it propagates within the fleet. Some of the benefits are quantifiable. Sortie generation, for example, is a good measure of the carrier's value to combat operations.

In principle, at least, the capability enhancement effected by modernization can be integrated with the concept of operational ship-years to yield a single fleet value measure. For the package as a whole, we define a capability enhancement variable C. It denotes the ratio of the value to the Navy of having a CVN 21–class ship operationally available for a year to the value of having a *Nimitz*-class ship operationally available for a year. Thus, if C were to equal 1.5, the Navy would value a CVN 21–class ship half again as much as a *Nimitz*-class ship—i.e., it would trade three *Nimitz*-class ships for two CVN 21–class ships.

We can break the data in Chapter Two on operational ships available into *Nimitz* and CVN 21 components, which allows a calculation of the present discounted value of future operationally available CVN 21 ship-years.[1] That would reduce any of our stair-step modernization graphs in Chapter Two into a single quantity expressing the CVN 21 class's penetration of the fleet. Adding the analogous value for the *Nimitz* class to C times the CVN 21 value, the result would be a measure of the present value of the future carrier fleet. It would be larger for options that allowed more rapid modernization and for options that sustained more operational ships in the fleet. It would thus synthesize those two criteria. While the value of C might not be easily determined with general acceptability, it can be parameterized to characterize its effect on the outcome.

The results of such an analysis are shown in Figure 5.1 for the 24/72 plan. For consistency with the cost analysis in Chapter Four, all operational ship-years expected from 2002 on are discounted at 3.2 percent per annum to that year. Results are shown for CVN 21 value premiums of 10 percent to 70 percent over the *Nimitz* class. We assume there will be at least a minimal capability increment, thus the 10 percent. We keep the upper bound somewhat short of 100 percent because, regardless of how much more capable the CVN 21 is than the *Nimitz* class, two ships can be in two places at once and one cannot.

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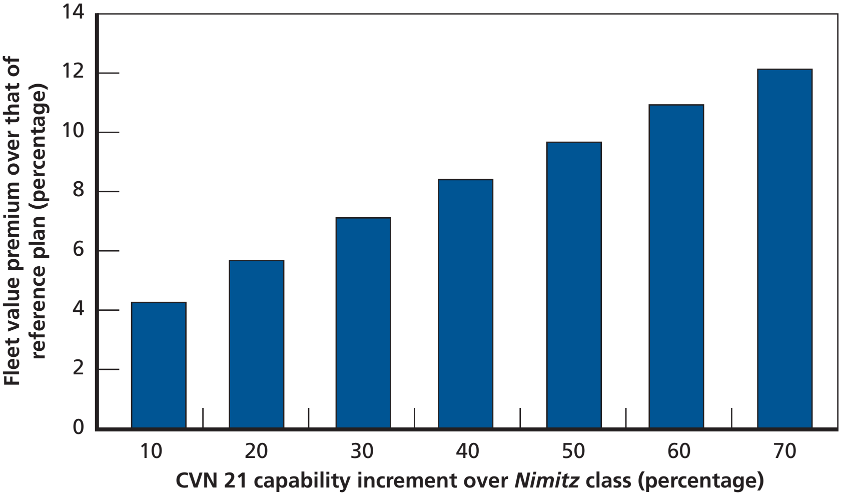
[1] Again, we discount because, lacking knowledge of future threats, the Navy would presumably value having an operational carrier in the near future more highly than one of equal capability in the distant future. Discounting the benefits (operational ship-years) is also necessary because we will want to compare those with costs, which we have also discounted.

Figure 5.1
Fleet Value of 24/72 Plan as Percentage Increment over Reference Plan for Different CVN 21 Capability Increments



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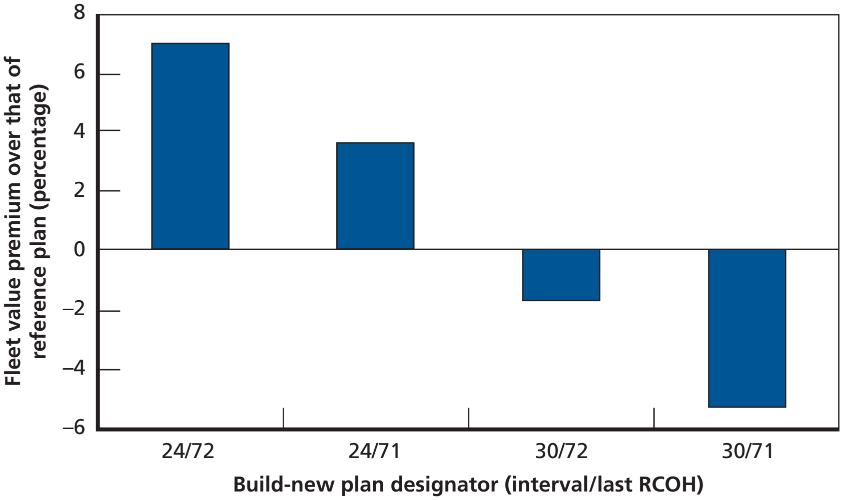
The figure suggests that, for the 24/72 plan, only at relatively optimistic judgments of the CVN 21 capability increment does the value increment of the future operational fleet approach in percentage terms the cost premium to build and operate it. At a 30 percent capability premium, for example, the 24/72 plan increases fleet value over that of the reference case by 7 percent, figured against a 12 percent cost increment. That does not necessarily mean the 24/72 plan is a bad investment. It depends on how important the 7 percent fleet value increment is to the Navy. Further, considered against the 5 percent cost increment when aggressive cost reduction is employed, the fleet value increase from the nominal build-new plan looks more favorable.

In Figure 5.2, all the build-new options are graphed under the assumption of a 30 percent CVN 21 capability premium. The fleet value increment for the 24/71 plan is not as favorable as that for the 24/72 plan, and that for the 30-month plans is negative. There are no

Figure 5.2
Fleet Value as Percentage Increment over Reference Plan for Different Build-New Options



NOTE: CVN 21 capability increment = 30%.
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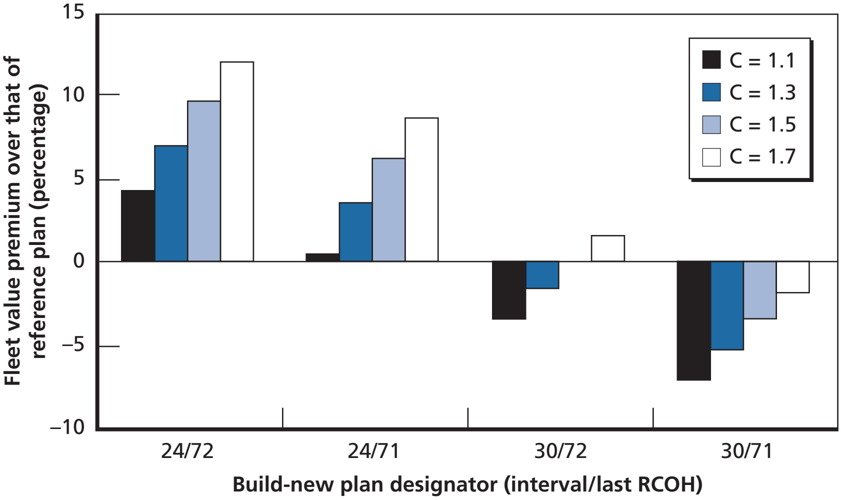
surprises at other capability premiums (see Figure 5.3, where the bars designated “C = 1.3” match those in Figure 5.2). The value premium for all plans increases with increasing capability increment to essentially equal the NPV premium at 70 percent. Thus, basically, you get what you pay for.

Note that the current analysis, in incorporating modernization rate, suggests the 24/71 plan is clearly superior to the 30/72 plan in terms of benefits to be realized. In fact, the 30/72 plan appears to offer no fleet value advantage over the reference case, while the 30/71 plan would be of interest only if the objective were to save money by accepting a fleet of less value.

Variants to this analysis yield results somewhat more favorable to the build-new plans. It could be argued, for example, that the decision point—that is, the base year for discounting—should be later or that the discount rate is too high.

Figure 5.3
Fleet Value as Percentage Increment over Reference Plan for Different Build-New Options and Capability Ratios



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Moving the decision point back six years to 2008 and ignoring fleet differences before that point increase the 24/72 plan's fleet value premium at a 30 percent capability increment by 2 percentage points. It changes the value premiums of the other plans by even less.

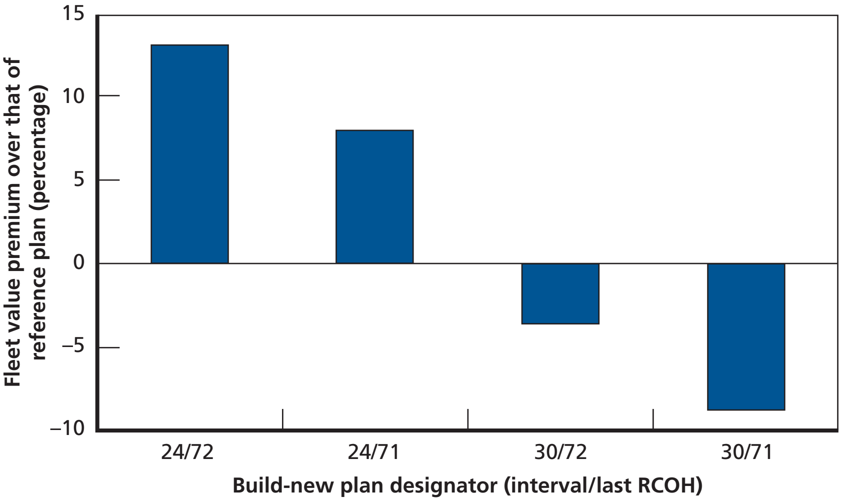
If the discount rate were zero and differences from the reference case were counted only from 2012, the earliest such differences begin under any plan, the value premiums for the 24-month plans look more impressive (see Figure 5.4). At a 30 percent capability increment, the 24/72 plan generates a fleet value 13 percent higher than that of the reference case, amounting to a full *Nimitz*-class ship per year on average from 2012 through 2049 (or 75 percent of a CVN 21–class ship). The 24/71 plan provides an 8 percent premium. Of course, these premiums cannot be compared with the NPV premiums for the various plans.

Even at a zero discount rate, the 30-month plans lose in this analysis. They both result in fleet value decrements at capability increments below 60 percent. At 30 percent, the decrement for the 30/71 plan is an appreciable 9 percent.

Our analysis may be summarized as follows:

- The nominal build-new plan with a 24-month production interval modestly increases operational carrier fleet value over the long term, relative to the Navy's current plan. It does so at a roughly commensurate cost premium and a $700 million annual SCN budget premium over the next decade.
- Omitting the CVN 72 RCOH allows for a cost-neutral approach (if aggressive cost reduction is pursued), relative to the reference plan and cuts the 24/72 plan's next-decade budget premium in half. It also reduces the nominal plan's fleet value advantage by about half, because it reduces the operational fleet by about half a ship over the long term.

Figure 5.4
Fleet Value as Percentage Increment over Reference Plan, for Different Build-New Options, No Discounting



NOTE: CVN 21 capability increment = 30%.

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- Increasing the production interval from 24 to 30 months slows modernization enough that the infusion of CVN 21s is not sufficient to compensate for lower operational fleet sizes. The result is long-term decrements in fleet value.

The preceding analysis could serve as a useful input to choices the Navy will need to make along the following lines:

- Is a mostly CVN 21–class fleet worth the extra cost to the Navy—6 percent to 12 percent more—than a mostly *Nimitz*-class fleet of about the same size?
- If so, is that extra value worth the higher near-term budget required for the nominal build-new strategy?
- Or, is some reduction in total fleet size, as in the build-new variants, an acceptable trade-off for lower cost, while sustaining operational capability?

The answers to these questions will determine whether current fleet replacement plans are more or less preferable to the Navy than a plan in which *Nimitz*-class carriers are retired at midlife and replaced by ships of the CVN 21 class.

APPENDIX A

CVN 21 Design and Technology Advances

Nimitz-class aircraft carriers are arguably the most powerful warships in any country's naval forces. They can steam at 30-plus knots, are self-sustaining for up to 90 days, and can launch a variety of aircraft to strike targets hundreds, if not thousands, of miles away. They have proven to be invaluable naval assets in all contingencies over the past 25 years, most recently in Operation Enduring Freedom and the war against Iraq. With three *Nimitz*-class carriers typically deployed to various parts of the globe, they are truly symbols of the U.S. Navy's ability to project power anywhere in the world.

However, the *Nimitz*-class design is more than 35 years old. The keel of the lead ship, the USS *Nimitz* (CVN 68), was laid in 1968 and the ship was commissioned in 1975. There have been some technology upgrades over the years. For example, the USS *Harry S. Truman* (CVN 75) was built with a shipwide fiber optic cable system and the USS *Ronald Reagan* (CVN 76) has a bulbous bow designed to improve flight operations. Despite these technology upgrades, the basic hull, mechanical, and electrical (HM&E) systems of the *Nimitz* class have not changed in the 35 years since the *Nimitz*'s keel was laid. The nuclear reactor that serves as the heart of the propulsion plant was designed in the mid-1960s. The steam-powered aircraft launch system is basically the same design that has been in use since the late 1950s. Many of the systems still rely on steam and hydraulics as opposed to electricity. Under current modernization plans, *Nimitz*-

class carriers and their HM&E systems will be operated for 50 more years.

The biggest problems facing the *Nimitz* class are the limited electrical power generation capability and the upgrade-driven increase in ship weight and erosion of the center of gravity margin needed to maintain ship stability. These limitations constrain the ability to incorporate many new technological advances, especially those that require additional electrical power or add weight to the ship. For example, the *Nimitz*-class propulsion plant cannot generate enough power for the new electromagnetic aircraft launch system (EMALS) currently under development or for such future technologies as electric guns and dynamic armor.

Recognizing the limitations of the *Nimitz* class, the U.S. Navy is currently designing the next generation of aircraft carriers, the CVN 21 class. This new class will use the basic *Nimitz* hull form but will substantially modify the interior arrangements of the ship to improve weapons handling and stores management as well as make changes to the flight deck to increase sortie generation capability through reduced aircraft movement and handling. More important, the CVN 21 class will have a new propulsion plant providing 2.5 times the electrical power generation capability of the *Nimitz* class. This will allow the CVN 21 class to convert high-maintenance steam and hydraulic systems to electrical systems as well as provide power for modern technologies, such as the new aircraft launch and recovery systems. In addition to providing increased operational capability and survivability, these interior redesigns and new technology systems will reduce ship manpower requirements and maintenance costs. This appendix details the redesign and technology advances of the CVN 21 class.

Redesigning the *Nimitz*-Class Interior and Flight Deck

Weapons-handling paths on *Nimitz*-class ships were designed for the potential nuclear missions of the Cold War. The current flow of weapons from storage areas in the interior of the ship to loading on aircraft involves several horizontal and vertical movements to various staging and build-up locations. These movements around the ship are time-consuming and manpower-intensive and typically involve sailors manually moving weapons loaded on carts. Also, the current locations of some of the weapons elevators conflict with the flow of aircraft on the flight deck, slowing down the generation of sorties or making some elevators unusable during flight operations.

The CVN 21 class will have a major redesign of weapons movement paths, largely eliminating horizontal movements within the ship. Current plans call for advanced weapons elevators to move from storage areas to dedicated weapons-handling areas. Sailors would use motorized carts to move the weapons from storage to the elevators at different levels of the weapons magazines. Linear motors are being considered for the advanced weapons elevators. The elevators will also be relocated such that they will not impede aircraft operations on the flight deck. The redesign of the weapons movement paths and the location of the weapons elevators on the flight deck will not only reduce manpower but also contribute to a higher sortie generation rate.

The second major redesign for the CVN 21 class involves the flight deck itself. On *Nimitz*-class ships, catapult number 4 cannot be used to launch fully loaded aircraft because of wing clearance along the edge of the flight deck. The CVN 21 class will correct this deficiency. More important, several small sections will be added to the flight deck to improve aircraft handling, storage, and flow. Also, the island will be smaller than it is on *Nimitz*-class ships and will be moved aft. Finally, three aircraft elevators and two hangar bays will be on the CVN 21 class compared to four aircraft elevators and three hangar bays on the *Nimitz* class.

The major impact of the flight deck redesign will be an approximately 15 percent improvement in sortie generation through a reduction in the number of times an aircraft must be moved for fueling, checks, and weapons loading. (This is in addition to the improvement in sortie generation arising from weapons movement redesign.) With the CVN 21 flight deck design, an aircraft will require only one “push back” between the time it lands and the time it is ready for the next launch. In addition to improvements in the sortie rate, the fewer aircraft elevators and hangar bays along with the smaller island will contribute to restoring approximately 5 percent of the weight and center of gravity margins of the CVN 21 ships. Finally, reducing aircraft movements on the flight deck will reduce workload and manpower requirements.

New Technologies on the CVN 21 Class

The CVN 21 class will incorporate several new technologies, the most important of which are a new nuclear propulsion plant, a zonal electrical distribution system, and a new aircraft launch and recovery system. It is not possible to retrofit any of these new technologies to *Nimitz*-class ships.

New Propulsion Plant

The current *Nimitz*-class propulsion plant is fixed in its electrical generation capability and energy available from the reactor cores. New technologies added to the *Nimitz*-class ships have generated increased demands for electricity; the current base load leaves little margin to meet expanding demands for power. Should the CVN 21 design changes to reduce manpower and maintenance costs by incorporating electric auxiliaries be incorporated on CVN 68 class ships, these larger base loads lead to a reduction in core life, possibly by as much as 11 years. Furthermore, this energy shortfall prohibits the conversion of the current steam power for the galleys, laundries, pumps, heating, and other auxiliaries to electric power. The current steam-powered auxiliaries require more than six miles of steam pipes on *Nimitz*-class ships as well as more maintenance than would be required with electrical systems. The lack of electrical energy also precludes the installation of many future technologies such as dynamic armor, new radars, EMALS, and directed-energy weapons.

In addition to insufficient electrical power to meet future needs, the *Nimitz*-class reactor is a very large, complex system. There are pipes of more than 30 sizes, more than 1,200 valves, and more than

20 major pumps on a *Nimitz* reactor. Because of the 60-plus watch stations manned when the ship is under way, significant manpower requirements accrue to the reactor room.

The new reactor being designed for the CVN 21 class overcomes many of the shortfalls of the *Nimitz*-class reactor and is an enabler for many of the other technologies and improvements planned for the new class. CVN 21 will generate approximately three times the ship service electrical power of the *Nimitz* class. This increased power results from a number of design changes including a higher core energy density and lower demands for pumping power. The additional power will satisfy the demands of EMALS and other new systems on CVN 21 and will permit the conversion of the steam auxiliaries to electric.

The new reactor will also be a much simpler system with fewer, more reliable components. Compared to the *Nimitz* reactor, the CVN 21 reactor will have approximately 50 percent fewer valves, piping, major pumps, condensers, and generators. The steam-generating system will use less than 200 valves and only eight pipe sizes. These improvements lead to simpler construction, reduced maintenance, and lower manpower requirements as well as to a more compact system that requires less space in the ship.

The new reactor will use modern electronic controls and displays that will result in a reduction in under way watch stations to approximately 20. This reduction in watch stations, coupled with drastic reductions in maintenance requirements, is the single biggest driver for reducing crew requirements on the CVN 21 class.

Overall, the new CVN 21–class propulsion plant will bring several significant improvements over the *Nimitz*-class propulsion plant. Propulsion-related manpower will be reduced by approximately 50 percent and depot level maintenance will be lower by approximately 20 percent resulting in an approximately 20 percent savings in the total LCC of the system. Current plans call for at least 40 months between depot maintenance actions compared to the IMP's 18 months for the *Nimitz* class.[1] This improvement will provide significantly greater operational availability for the CVN 21–class ships.

Zonal Electric Distribution System

Tied to the new propulsion plant on the CVN 21—and enabled by it—will be a new zonal electrical distribution system. The current *Nimitz*-class distribution system uses a radial architecture that distributes power throughout the ship. The system requires more than 26 miles of distribution cable from the central ring bus of the system to the various emergency power and load centers on the ship. In addition to being a very complex distribution system, there are problems reconfiguring the system after battle damage and modernization.

The CVN 21 zonal distribution system not only will eliminate approximately six miles of electrical cable but also will provide a compact architecture that will concentrate various load centers in segregated zones on the ship.

EMALS[2]

For the past 40 years, U.S. aircraft carriers have used steam-powered catapults to launch aircraft. The current version of the steam catapult installed on new *Nimitz*-class carriers can launch an aircraft once every 60 seconds. The ship's four catapults operating together can launch an aircraft once every 20 seconds.

The current steam catapults are very reliable. Each catapult is available, on average, 74 percent of the time. It is possible to launch an aircraft from at least one of the four catapults 99.5 percent of the time. The steam catapults have also proven to be very safe: only 30 major component failures were recorded for the more than 800,000 aircraft launches in a recent ten-year period. Only one of these failures resulted in the loss of an aircraft (Hess, 1999).

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[1] The Navy is considering a revised *Nimitz*-class maintenance plan that would extend the operating interval to as much as 30 months.

[2] Material on the EMALS is extracted from an unpublished RAND research study conducted by Ron Hess in 1999.

Although very reliable and safe, steam catapults have some disadvantages. Current steam catapults supply 70 million foot-pounds of energy to launch aircraft. This limits the maximum weight of the aircraft being launched to approximately 70,000 pounds. In addition to the limitation on the weight of the aircraft at launch, the peak-to-mean ratio of the force applied by the catapult increases at lower energy levels. Thus, lighter aircraft are more difficult to launch. In fact, steam catapults cannot launch current unmanned aircraft. Because the force applied to the aircraft varies over the launch cycle, significant stresses are placed on the airframe. These stresses reduce the fatigue life of manned aircraft and would require significant structural strengthening of unmanned aircraft.

An inability to launch unmanned aircraft could prove a serious shortcoming. Continuing breakthroughs in information technology and the development of ever lighter, smarter weapons will likely make such vehicles capable of combat operations well before the *Nimitz* class retires. No doubt, U.S. political leadership would find very appealing the prospect of air combat with no risk that aircrews would be killed or taken prisoner.

A new aircraft launch technology is being developed for the CVN 21 class to overcome the limitations of the steam catapults. This technology would generate an electromagnetic wave that would travel the length of the catapult. An armature attached to the aircraft launch shuttle would "ride" this wave providing the power and speed necessary for launch. The technology behind such a system is similar to that used on many modern amusement park roller coaster rides and on the Yamanashi Maglev Test Line, an urban transport system in Japan.

An electric launch device provides the option of operating from a variety of power-generation systems other than steam. It could deliver more energy more efficiently than current steam catapults. With better control over acceleration during launch, regardless of the level of energy delivered, the Navy could theoretically launch both heavier and lighter aircraft than those launched by steam catapults. The more controlled application of energy would reduce stresses on the airframe, increasing operational life and reducing maintenance costs.

Potential advantages of EMALS over steam catapults include the following:

- Fewer personnel for operations and on-ship maintenance. Current estimates suggest a reduction with EMALS of approximately 35 personnel compared to the requirements for steam catapults.
- More power. This permits the launch of heavier aircraft.
- Improved peak-to-mean acceleration ratio. This should reduce stress on aircraft airframes.[3]

Other New Technologies

Several other new technologies will be incorporated into the CVN 21 class of ships. In contrast to those discussed so far, these technologies could be backfitted onto current *Nimitz*-class ships. The current arresting gear on *Nimitz*-class carriers is at its design limits for the weight of aircraft that can land on the carrier and cannot recover any of the current or planned unmanned vehicles because of the stresses placed on the vehicle airframes. Also, the current arresting gear requires a large degree of maintenance.

The advanced arresting gear on the CVN 21 class of ships will be optimized for the size, weight, and power of future aircraft. It will permit the recovery of heavier aircraft as well as unmanned vehicles. Finally, it will require significantly less maintenance than the *Nimitz*-class arresting gear.

Other new technologies include a new aircraft refueling capability that will improve the refueling rate compared to *Nimitz*-class ships

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[3] A fracture mechanics analysis undertaken by Lakehurst indicated that as much as a 31 percent airframe service life extension may occur as a result of the reduced stress. See Doyle et al. (undated).

and a new heavy under-way replenishment system that will cut in half the time needed to replenish stores from a resupply ship.[4]

Most important, the Navy is likely to consider upgrading the ships' defense systems as new technologies mature. Aircraft carriers' speed and mobility combined with their layered defense systems of aircraft and escort ships have kept them free from attack since World War II. However, the aircraft carrier design needs to keep pace with potential future threats. Global Positioning System (GPS)–guided smart weapons are likely to proliferate among potential adversaries, and a need will likely remain for U.S. carriers to operate in such confined waters as those of the Arabian Gulf and the Adriatic Sea. A premium may thus be placed on defense against smart weapons. Defense against high-speed, GPS-guided missiles will require faster defensive weapons, such as laser guns, and energy dissipating armor systems, such as dynamic armor should the smart weapons get past the lasers. CVN 21 will be in good position to accept these defensive systems. Only half of the electrical power-generation capability on CVN 21 is needed to run currently planned systems, including EMALS. CVN 21 will thus have the power reserves that the *Nimitz* class lacks to run lasers and dynamic armor.

Summary

The new technologies on the CVN 21 carriers will improve their operational capabilities, increase their survivability, and result in smaller crew sizes and lower maintenance costs compared to *Nimitz*-class carriers. Sortie generation rates will increase by more than 15 percent. New systems will allow the launch and recovery of both heavier aircraft and unmanned vehicles and will require less manpower and maintenance. They will also place less stress on airframes, increasing the life of aircraft and reducing aircraft maintenance costs. New structural improvements and advanced forms of armor will pro-

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[4] The new heavy under-way replenishment system must also be installed on the resupply ship.

tect the ship from both torpedoes and missiles. The new propulsion and new electrical distribution systems will enhance battle-damage control and require less maintenance, thus providing more time for operational missions. Eventually, they could allow the ship to defy new threats through upgraded defense systems and energy-absorbing dynamic armor. Combined weight and space reductions will increase munitions, aircraft fuels, and stores capacity while improving the habitability of the ship. The CVN 21–class ships will require 500 to 800 fewer sailors than a *Nimitz*-class ship and the quality of life for those sailors will be improved. Overall, the CVN 21 class is projected to have an 11 to 20 percent reduction in carrier LCC.

APPENDIX B

Shipyard Production Labor Demand by Skill

In Chapter Three, we examined the effects of the build-new options on the workforce at NGNN. In this appendix, we provide information on the rate of change of labor demand, average demand, and variability in demand for each of the individual skills for the reference, 24/72, and 30/72 cases.

Table B.1 lists the maximum rate of change in the demand for workers in each skill. For example, in Figure 3.4 we observed that the rate of change in demand for outfitting workers is 380 workers per year over three years for the reference case, while for the 24/72 plan it was 590 workers per year over three years. Table B.2 lists the mean demand for labor in each skill during the period 2005 to 2025. Table B.3 lists the standard deviation in demand for labor during the period 2005 to 2025.

Of the three options for which data are listed, the 24/72 plan requires the greatest maximum rate of change in labor demand for all workers combined and for all skills except fitting fabrication and engineering. It has the highest mean and standard deviation of labor demand for all workers and for all skills except outfitting and engineering. The reference plan experiences the lowest maximum rate of change in labor demand for all workers combined and the lowest mean and standard deviation of labor demand for all workers. The option with the lowest maximum rate of change and mean for each skill varies with the skill. The reference plan has the lowest standard deviation for all skills except outfitting.

Table B.1
Maximum Rate of Change in Labor Demand

	Change in Number of Workers over Time Indicated		
Skill	**Reference**	**24/72**	**30/72**
Construction support	+271 per year, 2 years	+294 per year, 4 years	+262 per year, 4 years
Electrical	+309 per year, 3 years	+451 per year, 2 years	+430 per year, 2 years
Machinery	+224 per year, 3 years	+288 per year, 3 years	+196 per year, 3 years
Other support	+108 per year, 4 years	+151 per year, 4 years	+148 per year, 3 years
Outfitting	+380 per year, 3 years	+590 per year, 3 years	+494 per year, 3 years
Pipe fitting	+252 per year, 2 years	+270 per year, 3 years	+232 per year, 3 years
Fitting fabrication	+157 per year, 5 years	+240 per year, 5 years	+273 per year, 4 years
Engineering	–161 per year, 4 years	–267 per year, 6 years	–318 per year, 5 years
Welding	+167 per year, 4 years	+250 per year, 5 years	+234 per year, 4 years
All labor	+1,684 per year, 3 years	+2,282 per year, 4 years	+1,953 per year, 4 years

Table B.2
Mean Labor Demand from 2005 to 2025

	Number of Workers		
Skill	**Reference**	**24/72**	**30/72**
Construction support	2,814	3,024	2,844
Electrical	1,134	1,224	1,116
Machinery	1,246	1,286	1,203
Other support	2,425	2,485	2,417
Outfitting	2,423	2,111	2,201
Pipe fitting	1,098	1,217	1,119
Fitting fabrication	1,455	1,938	1,723
Engineering	3,649	3,534	3,368
Welding	1,194	1,576	1,399
All labor	17,438	18,395	17,390

Table B.3
Standard Deviation of Labor Demand from 2005 to 2025

	Number of Workers		
Skill	**Reference**	**24/72**	**30/72**
Construction support	275	405	336
Electrical	288	352	301
Machinery	222	270	235
Other support	142	187	157
Outfitting	615	405	503
Pipe fitting	193	267	221
Fitting fabrication	273	501	392
Engineering	298	583	634
Welding	233	433	338
All labor	1,845	2,856	2,334

APPENDIX C

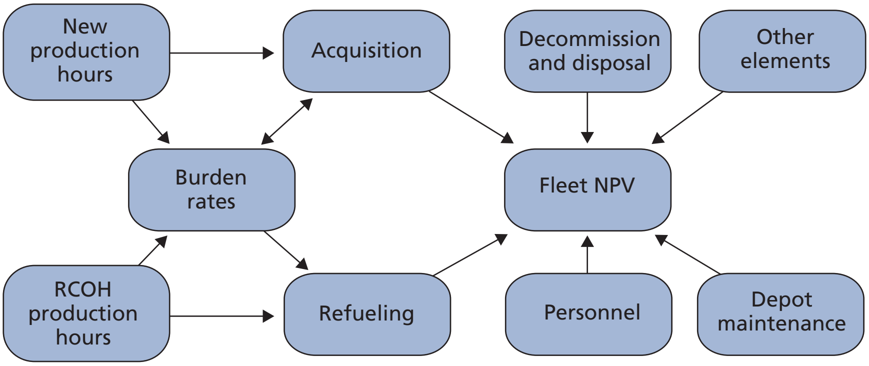
How Life-Cycle Cost Elements Were Estimated

In this appendix, we discuss the methodology responsible for the life-cycle cost elements in Chapter Four (see, e.g., Figure 4.1, reproduced here as Figure C.1 for the reader's convenience).

Acquisition

Acquisition costs are those costs to design, develop, and produce a weapons system. For a carrier, these costs are on the order of several billion dollars. While not the largest portion of the LCC, acquisition

Figure C.1
Influence Diagram for LCC Elements



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costs are very visible to the public and decisionmakers as the purchase of a carrier has a noticeable impact on the defense budget for a given year.

For the purposes of analysis, we split the acquisition cost of a carrier into three broad categories:

- First-ship nonrecurring—These labor costs, mostly engineering costs, are the costs to develop and design the first ship of a particular design.
- Repeat-ship nonrecurring—If the Navy builds a repeat of a certain carrier design, typically improvements and upgrades are incorporated into the repeat ship. Thus, a follow-on ship of the same design will have some nonrecurring engineering, although the costs of that are far less than those for the first ship.
- Recurring—Recurring costs are the costs of producing a ship. They include the costs of production labor, engineering labor, and material and equipment.

To generate a total acquisition cost for a ship, we took several steps to build up a total cost from labor hours and material and equipment prices.[1] Each step in the process is described below.

The first step is to generate year-by-year labor profiles. For each hull, the labor hours (both engineering and production) are spread based on workload profiles provided by NGNN. We assumed a seven-year build period for a carrier because NGNN felt this duration to be most efficient for their current process.

To reflect experience-based gains in efficiency, we use the unit learning curve that represents the production hours per ship as a power function of cumulative production. The equation takes the general form:

$$T(n) = T(1) \times n^{\frac{\ln(slope)}{\ln(2)}} \qquad (1)$$

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[1] As noted in Chapter Three, we used the prevailing NAVSEA 017 estimate for total production labor hours.

The variable *n* is the cumulative number of units produced. *T(n)* is the number of hours for the *n*th unit. *T*(1) is the number of hours for the first unit. The variable *slope* is the improvement rate and represents the quantity by which the number of hours gets multiplied each time the production unit number doubles. For example, a slope of 0.95 implies that the unit hours decrease by 5 percent for each doubling of quantity. So if unit one take 1.0 hours, unit two takes 0.95 hours and unit four takes 0.903 hours.[2] For the reference case, we assumed that learning did not improve for repeat ships. At the high rate of production (delivery of a ship every two years), we assumed a 95 percent unit-learning slope for production labor.

The next step is to determine the direct labor cost for each hull by year. This is simply done by multiplying the number of hours by the appropriate direct wage rate. We used the average 2002 direct labor rates reported in the NGNN Forward-Price Rate Agreement (FPRA) dated February 2002.

Determining the indirect costs is the most complex step in the process of building a total acquisition cost. Indirect costs consist of overhead, general and administrative (G&A) expenses, and other components (e.g., cost of money). Overhead costs, the largest of the indirect costs, are those related to production activities that cannot be charged on a direct basis to a particular product for reasons of either practicality or accounting convention. Overhead includes the costs of fringe benefits, indirect labor, depreciation, building maintenance and insurance, computer services, supplies, travel, and so forth (DAU, 2001). G&A expenses relate more to the company as an entity and may not relate to activity levels at only one plant. These include such general business costs as executive salaries, human resources costs, and the costs of such staff services as legal, accounting, public relations, and financial functions (DoD, 2004). G&A costs are generally incurred and accounted for at a corporate level, whereas overhead is a site-specific cost.

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[2] The insight that hours required to perform manufacturing functions decline at a set rate as the production units successively double was a foundation of formal cost estimation (Asher, 1956).

While these indirect costs are related to and scale with the total direct labor for a site, the relationship is not strictly linear. Indirect costs include both fixed and variable components. As the number of direct labor hours at a site increases, the overhead and G&A rates decrease because the fixed costs are spread over a greater number of hours. To reflect the relationship between direct hours and the indirect cost rates, we use the following formulation,

$$rate_k = {}^{A_k}\!\big/_{TotalHours} + B_k \tag{2}$$

where $rate_k$ is the indirect rate, and A_k and B_k are constants. To determine these constants, we used data from the NGNN FPRA and some supplementary rates supplied by NAVSEA 017.[3] The constants A_k and B_k for both production and engineering labor were determined by fitting these data to equation (2). Therefore year-by-year, we can forecast the indirect labor rates at the shipyard.

The indirect rates for the build-new options will vary from that of the reference case. The increased build-new construction rate will change the fixed component of overhead for the site. As detailed in Chapter Three, some additional and improved facilities are needed at NGNN to support the higher carrier construction rates. A new facility will lead to additional depreciation charges, franchise taxes, and property taxes. For each investment, we calculate the depreciation[4] and facility cost of money and add it to the indirect costs for new carrier construction only (we have ignored tax implications for simplicity).

We do not, however, change the general overhead rates in response to those increased indirect costs. Instead, we assume that the indirect costs due to the facilities additions would solely be charged to the government through user fees. The implication of this assumption is that the indirect rates for other programs, such as the Virginia

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[3] Note that the FPRA does not report separate overhead and G&A rates. Thus, only one equation for production and one equation for engineering were developed.

[4] Assumed to be a 30-year, straight-line schedule.

class submarine program, will not increase as a result of the carrier program changes. The ultimate disposition of such charges would, of course, need to be negotiated between the government and NGNN.

Having the direct labor cost and the indirect rates year by year, we can determine the labor cost for each hull by multiplying the direct cost for a hull for a particular year by the indirect rate for that year. If we sum those costs for all the years a ship is produced, we arrive at the total labor cost for the hull. To this total labor cost, we subsequently add the cost of money and the fee (profit) to arrive at a labor price. Finally, material and equipment costs (including handling fees) are added to the labor price to determine a total acquisition cost (price) for each hull.

The last step in determining the acquisition cost is discounting to an NPV. The total acquisition price for each hull is allocated to specific budget years based on funding profiles from an earlier study.[5] The nonrecurring profile is an average because we have ignored the differences between first-of-a-class and a repeat ship. The profiles we assumed are shown in Figure C.2. Using the 3.2 percent current discount rate from the Office of Management and Budget, we determine the NPV of acquisition cost for the budget.

Depot Maintenance

Depot maintenance activities are the major availabilities for a carrier where the ship is brought to a shipyard (public or private) for an extended period. The overall depot maintenance plan for carriers follows the "Incremental Maintenance Program" (IMP) as outlined in OPNAV Note 4700 for CVN 68 and CVN 77. In that document, the maintenance cycle (intervals and notional man-days) is defined

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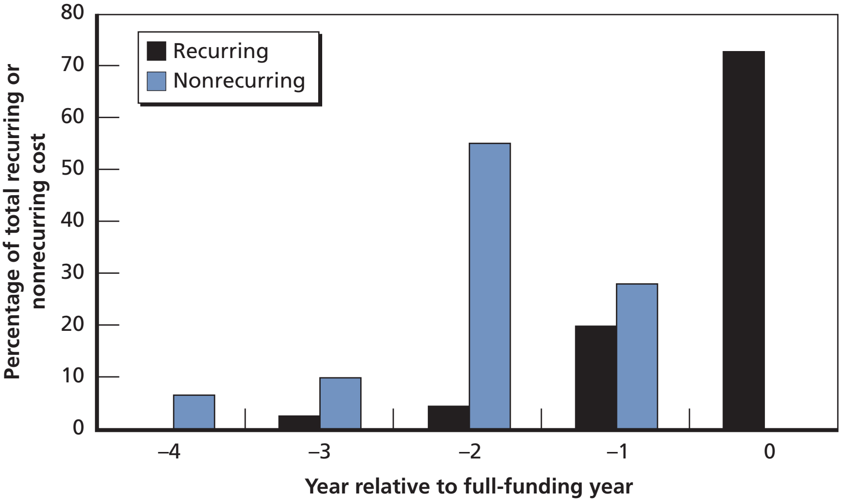
[5] Although carriers are "fully funded" in a given year, some of the recurring and all of the nonrecurring costs are funded through advance procurement in years ahead of the full-funding year. In the figure, the base for the recurring-cost percentages is of course much larger than the base for the nonrecurring-cost percentages. These figures were derived from Excel spreadsheets supporting analyses in Birkler et al. (2002).

Figure C.2
Budget Profiles for Carrier Acquisition, Relative to Year of Full Funding



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for the *Nimitz* class. Using that data as a foundation, NAVSEA 017 and NGNN provided to RAND the labor hours and material and equipment cost for each type of availability. In addition, NAVSEA 017 and NAVSEA 08 provided data on how these maintenance costs are expected to change between the CVN 68 and the CVN 21 classes. These data formed the basis of our depot cost analysis.

For all availabilities except RCOHs, we calculate the cost based on the data from NGNN and NAVSEA 017. We assume a notional "man-day" rate of $550 per person, per day, discounted to an NPV based on the year in which the maintenance event occurs.

As described in an earlier section, we calculate the costs of RCOHs (if done) separately from the other maintenance activities. We develop a cost for an RCOH the same way we develop new production costs. That is, we build up the total cost from the direct labor costs, burden those costs (add overhead and fees), and add profit and the cost of money. The overhead rates are the same as those used for the new construction. There are some minor differences in fees for overhaul work at NGNN that we do take into account.

Personnel

Personnel costs are a recurring cost that the Navy incurs every year a carrier is in the fleet (carriers are always crewed). As a basis for our calculations we used the CVN 74 Ship Manning Document (SMD) as our baseline for the current *Nimitz* class. We aggregated the data by department and by enlisted versus officer. NAVSEA 017 provided fully burdened manpower costs from the Navy's COMET model to determine an overall, annual manpower cost for each sailor by department. Reductions in crew size relative to the 74 SMD were provided for CVN 77 and CVN 21. Some of these reductions were specific to a department, while others were specified as reductions in the overall ship's complement. These calculations allowed us to determine an annual manpower cost specific to each hull. Also, for each class of carrier, we determined an overall, annual manpower cost. As with the other cost elements, the manpower costs were discounted to an NPV.

Other

Similar to personnel costs, the costs for the "Other" cost category are costs that recur. In this category, we placed the LCC elements of miscellaneous, modernization, and unplanned repair. Note that modernization and unplanned repair do not recur on a regular basis. These costs occur at irregular intervals and cannot be predicted easily. For simplification, we spread these costs uniformly over the operational life of the ship.

Disposal

At the end of a service life, a carrier is removed from the fleet and disposed of. The process of disposing of a nuclear carrier is not likely to be an insignificant process (although it has never been done). It entails defueling the ship and placing the reactor in storage, removing and destroying military hardware, removing hazardous materials, and scrapping the remainder of the ship. Costs for defueling and demilitarization were provided by NAVSEA 08 and NAVSEA 017. These costs cannot be cited here. Based on an earlier RAND study of disposal options for ships (Hess et al., 2001), we estimated other disposal costs—e.g., for scrapping—at approximately $115 million.

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