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U.S. Navy Shipyards

An Evaluation of Workload- and Workforce-Management Practices

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Preface

The U.S. Navy's four public shipyards provide depot and other maintenance services to the fleet. Managers at the shipyards operate in a unique environment and have to satisfy many constraints and requirements. The shipyards are required to have the flexibility and capacity to support the operational demands of the war-fighter. At times, unanticipated requirements take priority over regularly scheduled work. This can result in large disruptions to planned schedules, and therefore to disruptions in workload, at the shipyards. At the same time, management decisions are limited by laws and policies that dictate when, where, and by whom maintenance can be performed.

Nevertheless, cost-effective operations and business practices are of utmost importance: Congress, taxpayers, and competing needs for limited resources demand them. The Commander, Naval Sea Systems Command (NAVSEA), asked the RAND Corporation to help identify and evaluate options for managing the ship-depot industrial base. Specifically, NAVSEA asked RAND to evaluate cost-effective workforce-management strategies, alternative workload allocations, and the relevant best practices of other, comparable organizations. This research was conducted over a period of one year, beginning in October 2006. It should be of interest to persons concerned with shipyard management, depot maintenance, and budgeting.

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the Joint Staff, the Unified Combatant Commands, the Department of the Navy, the Marine Corps, the defense agencies, and the defense Intelligence Community.

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Summary

The nearly 300 ships of the U.S. Navy are among the most complex weapon systems operated by the Department of Defense (DoD). The most demanding maintenance performed on these ships is depot-level maintenance, which is performed at shipyards that specialize in the complex repair and upgrade of ship systems, equipment, and infrastructure.

Depot-level maintenance work of Navy ships is split between public and private shipyards. The Navy spends about \$4 billion annually on depot maintenance for its ships. This includes about \$3 billion for work performed at four public shipyards: Norfolk and Portsmouth on the Atlantic, and Puget Sound and Pearl Harbor on the Pacific. These public shipyards employ over 25,000 civilians and will accomplish about 4 million man-days of work in 2008. They are the focus of this book.

Several laws and public policies constrain how the Navy can accomplish depot-level maintenance. Some of these laws and policies dictate that at least half of all Navy maintenance work be performed at a public depot (this is known as the *50/50 rule*), that the shipyards maintain some core maintenance capabilities for all of the existing ship weapon systems, and that depot maintenance be performed in a ship's homeport when possible.

The size of this business, the complexities of managing it, and the need to accomplish work as efficiently as possible led the Commander, NAVSEA, to research the most cost-effective strategy for matching workforce supply and demand, alternative workload allocations that

could improve cost-effectiveness, and what the Navy can learn from other organizations with similar workload and workforce-management challenges.

Matching Shipyard Work Supply and Demand

By some measures, the Navy does a reasonable job of matching workforce supply to workload demand. We compared the Navy's workforce plan to an optimized plan for meeting forecast workload demand and found virtually no difference between the two. In other words, the Navy's workforce staffing plan is a cost-effective strategy for meeting planned workload.

Nevertheless, the Navy's recent *planned* workload demands have not accurately predicted *actual* workload demands. Rather, workload forecasts have consistently underestimated actual demands, particularly in longer-term forecasts that are necessary for developing some of the skills required in shipyard maintenance. Understanding the causes of this underestimation is an important area of future research. Although the causes of this underestimation may not be well understood, the shipyards can and do use a variety of means to compensate for underestimated demand. These are

- **Overtime.** A modest level of overtime can in some cases help shipyard productivity. It can also allow the shipyards to meet schedule objectives. In recent years, however, public shipyards have been using overtime to an extent that diminishes productivity.
- **Temporary labor.** Temporary labor can theoretically help ease peak demands, but it requires the availability of a temporary and otherwise idle labor force. The availability of such a force varies from shipyard to shipyard. On average, temporary labor is not quite as productive as permanent labor.
- **Seasonal labor.** Seasonal labor can be put on a no-pay status for up to six months per year. These workers can then be hired back into the shipyard when work arrives. This allows shipyard managers to increase and decrease the workforce to meet fluctuations

in workload. However, rehiring seasonal employees is contingent upon their availability. On average, the cost of seasonal labor is the same as permanent labor, but productivity is slightly reduced.

- **Labor borrowed from other shipyards.** Shipyards can and do borrow from and loan labor to each other. Such labor, however, is not quite as productive in other shipyards as it is at home. Even if it were, traveling expenses place a high cost premium on its use.

None of the alternatives the Navy might consider to ease workload demands that consistently exceed planned demands is as productive as resident, permanent labor working standard hours (known as *straight time*). An increase in the resident, permanent labor force could help the Navy be more productive and hedge against the costs of workload growth. Table S.1 shows the costs associated with different workforce and workload scenarios. Under current plans (shown in the first row of the table), the Navy will have an average annual available force of 13,800 workers per day and an average demand for 15,485 man-days per day between 2007 and 2013. The shortfall would be met by overtime that averages 13 percent of straight time but peaks at 19 percent. This scenario would cost the Navy \$2.8 billion per year.

The second row of the table shows the overtime and cost implications of a workforce that is not increased to manage a workload that exceeds the estimate by 6 percent. (Note that this 6-percent growth rate is higher than the rate seen in recent years.) In this case, the Navy

Table S.1
Costs of Executing Planned and Increased Workloads

Workforce Increase Above Plan?	Workload Increase Above Plan?	Average Available Force (men per day)	Average Workload (man-days)	Average Overtime	Peak Overtime	Average Annual Cost (FY 2007 \$ billions)
No	No	13,800	15,485	13%	19%	\$2.8
No	Yes	13,800	16,433	20%	28%	\$3.2
Yes	Yes	14,500	16,433	11%	18%	\$3.0
Yes	No	14,500	15,485	9%	17%	\$2.8

has 13,800 workers to accomplish 16,433 man-days of work. Here, the Navy would use overtime that averages 20 percent of straight time and peaks at 28 percent. This second scenario would have an average annual cost of \$3.2 billion.

The third and fourth rows show how increasing the available workforce would hedge against the costs associated with no increase in the workforce. The third row shows increases in both the workforce and the workload. Should the Navy increase its workforce by 5 percent (to 14,500 workers), then workload growth would cost only \$3.0 billion. This is because overtime would average only 11 percent and peak at no more than 18 percent. In this case, the additional 700 permanent workers reduce the average annual overtime from 20 percent to 11 percent.

Perhaps most importantly, insurance against workload growth would cost the Navy virtually nothing. As the fourth row of the table shows, should the shipyard workforce grow above current forecasts but workload demand not materialize, executing the workload with higher workforce levels would still cost the Navy only \$2.8 billion. This is because with more workers, the shipyards could use less overtime to accomplish their current workload.

These results, of course, depend on several assumptions about workload growth, use of overtime, and the productivity of different types of labor. For the highest percentage workload growth evaluated, 16 percent, the cost penalty for not increasing the workforce could be up to \$1.5 billion annually. In this case, the cost of increasing the workforce if there is no work growth, \$200 million per year, is significantly less than the cost of not increasing the workforce if there is work growth. For the highest percentage workload growth evaluated, should the workload growth be minimal, increasing the workforce to meet the highest expected workload growth will result in cost savings of approximately \$100 million per year. Variations in overtime and productivity assumptions do not change these general findings.

Alternative Workload Allocations

Our analyses of how to accomplish shipyard workload most cost-effectively assume a static workload demand (i.e., workload that is fixed based on a certain plan). Theoretically, the Navy could choose to allocate workload differently than it currently does between public and private shipyards or among the four public shipyards.

Shifting workload from the public sector to the private sector may not be realistic for two reasons. First, such a shift may violate federal law requiring that no more than 50 percent of depot maintenance work be performed by the private sector. Second, most of the public shipyard work involves nuclear vessels; qualifying a third private shipyard (beyond the two currently doing such work) to work on such systems would be expensive and politically challenging.

Shifting nonnuclear surface-ship work from the private sector to the public sector would not result in cost savings for the Navy if “green” (i.e., unskilled) labor would have to be hired to accomplish this additional work. If there was readily available skilled labor to perform the work, however, the minimum cost savings estimated could be offset by costs that we were unable to quantify. Potential costs, such as those associated with increases to indirect expenses at private shipyards, contract modifications and associated penalties or fees, reduction in the competition that is assumed to reduce costs and improve quality, productivity adjustments between public- and private-sector shipyards, and investments needed to accomplish surface-combatant work in the public shipyards, could not be estimated but could result in increased cost.

Shifting work among the public shipyards might realize some efficiencies, but a full evaluation of this option would require data that are not currently available. Such a shift would also have to consider the capabilities of each shipyard, how well shifts could accommodate certain policies (such as homeport rules), and, of course, the cost-effectiveness of changes.

Workload-Management Practices in Other Organizations

To identify practices used elsewhere that may be adapted to the public shipyards, we identified four organizations whose workforce-management issues are similar to those of the public shipyards. These organizations are the UK dockyards that support the Royal Navy, European commercial shipbuilders, U.S. Air Force and U.S. Army depots, and the space-shuttle program of the National Aeronautics and Space Administration (NASA). None encounters both the complexity and breadth of work that the U.S. Navy faces in shipyard maintenance, but some individual characteristics of their work approximate those of the Navy.

Common practices that these organizations use to manage workload, some of which are already used by the Navy to some extent and others which would be more difficult to adapt, include

- **Identifying core capabilities and competencies and subcontracting out the others.** Some public shipyards use contractors extensively, but others do not have such local support readily available. Any U.S. Navy subcontracting efforts must stay within core-capability and 50/50 rules.
- **Avoiding excess overtime.** As noted above, the U.S. Navy already relies on what might be considered excessive overtime, and should consider hiring more shipyard workers to boost productivity and reduce costs.
- **Using temporary labor to meet infrequent demands.** As noted above, some U.S. Navy shipyards may not have a sufficient local pool from which to draw such labor.
- **Promoting a multiskilled workforce.** Adopting such a practice would require union approval and could be limited by the need for some workers to develop highly specialized skills in some areas.
- **Smoothing workload demands.** The U.S. Navy's initiatives in this area include a Fleet Availability Scheduling Team charged with keeping shipyard work more level over time and across shipyards.

- **Accepting other work.** The U.S. Navy shipyards have undertaken some outside work, such as work on U.S. Army vehicles.
- **Tracking performance.** Many methods to track performance were pioneered in U.S. Navy shipyards.

Altogether, the U.S. Navy appears to have implemented many of the above strategies when it was relatively easy to do so. Other strategies, such as reducing overtime or using more contracted labor, would take more work to implement.

Conclusions and Recommendations

Our analysis shows that the Navy workforce plan will efficiently execute the Navy's planned workload. We discovered that the Navy uses practices common in other organizations to manage workload variability and uncertainty. Further measures, such as greater levels of subcontracting, could require significant effort to implement.

Nevertheless, given what may be an underestimated future workload, additional measures to decrease overtime levels and hedge against workload growth are worth considering. We found that increasing the number of permanent journeyman by hiring apprentices is a cost-effective strategy. At the least, such measures are necessary to curtail the currently high levels of overtime that the shipyards use to accomplish additional unplanned work. Using more workers and less overtime would cost about the same amount that the Navy currently spends to execute its workload and would provide a hedge against the costs associated with workload inflation or surge requirements.

Beyond increasing the permanent journeyman staff of the shipyards, the Navy could shift more work to the private sector through subcontracts. Although the costs of such a strategy were not evaluated during our study, we did discover that other organizations extensively employ subcontractors to avoid excessive overtime. Such measures may require Congressional action and hence might not be considered feasible in the immediate future.

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Abbreviations

BRAC	Base Realignment and Closure
CFFC	Commander, Fleet Forces Command
CFR	Code of Federal Regulations
CITE	Center of Industrial and Technical Excellence
CMA	continuous maintenance availability
CNO	Chief of Naval Operations
CP	Capability Plan
CSMP	Current Ships Maintenance Project
DoD	U.S. Department of Defense
DLI	direct-labor index
DML	Devonport Management Limited
DPIA	docking planned incremental availability
DSRA/ERP	docking selected restricted availability/extended refit period
EU	European Union
FSL	Fleet Support Limited
FTE	full-time equivalent

FY	fiscal year
GDEB	General Dynamics Electric Boat
IMF	Intermediate Maintenance Facility
JFMM	Joint Fleet Maintenance Manual
MoD	UK Ministry of Defence
MSMO	multi-ship, multi-option
N43	Chief of Naval Operations Fleet Readiness Division
N4B	Assistant Deputy Chief of Naval Operations, Fleet Readiness & Logistics
NASA	National Aeronautics and Space Administration
NAVSEA	Naval Sea Systems Command
NAVSEA 04	Naval Sea Systems Command, Logistics, Maintenance and Industrial Operations
NGSB	Northrop Grumman Ship Building
NNSY	Norfolk Naval Shipyard
NPV	net present value
OPNAV	Office of the Chief of Naval Operations
PHNSY	Pearl Harbor Naval Shipyard
PIA	planned incremental availability
PNSY	Portsmouth Naval Shipyard
POM	Program Objective Memorandum
PSNSY	Puget Sound Naval Shipyard
PB	President's Budget
RCM	reliability-centered maintenance

RCOH	refueling complex overhaul
RIF	reduction in force
RMC	Regional Maintenance Center
SCN	Shipbuilding and Conversion, Navy
SSBN	submersible ship, ballistic missile, nuclear powered
TACOM	Tank and Automotive Command
USC	United States Code
WARR	Workload Allocation and Resource Report

Introduction

Depot Maintenance of Naval Ships Is Big Business

All naval ships require various types and levels of maintenance over their operational lives. Corrective maintenance is needed to repair equipment and systems that have failed. Preventive maintenance consists of periodic servicing to sustain operating equipment and inspections to determine the operating condition of equipment or the structural integrity of the ship. Equipment and systems may require upgrades through modernization programs at various points in a ship's life.

A ship's company can perform some repair and preventive maintenance tasks. Other tasks require special skills, tools, facilities, or an extended period of time to accomplish. These tasks, referred to as *depot-level maintenance*, are typically performed at a shipyard that specializes in the complex repair and upgrade of ship systems, equipment, and structures.

Depot-level ship maintenance costs are significant: It cost nearly \$4.3 billion in 2005.¹ It requires journeyman-level skills as well as facilities and equipment not available at the intermediate level.² Depot work is split between public shipyards specializing in the repair of

¹ Department of the Navy, 2006a. This total excludes depot-level work funded under the Shipbuilding and Conversion, Navy (SCN), accounts. The principal example of SCN-funded depot-level work is the mid-life refueling complex overhauls (RCOHs) of nuclear carriers.

² Journeyman-level skills are those possessed by a journeyman, a fully experienced worker competent in the full range of skills required of his or her trade. Seven or more years experience is typically required to become fully experienced in a trade.

nuclear ships and private shipyards specializing in the repair of non-nuclear vessels.

More formally, depot-level work is defined as

[m]aterial maintenance or repair requiring the overhaul, upgrading, or rebuilding of parts, assemblies, or subassemblies, and the testing and reclamation of equipment as necessary, regardless of the source of funds for the maintenance or repair or the location at which the maintenance or repairs is [sic] performed. The term includes (1) all aspects of software maintenance classified by the Department of Defense as of July 1, 1995, as depot level maintenance and repair, and (2) interim contractor support or contractor logistics support (or any similar contractor support), to the extent that such support is for the performance of services described [above]. The term does not include the procurement of parts for safety modifications [but] does include the installation of parts for that purpose.³

This definition, used primarily for accounting purposes, helps communicate the complex characteristics of depot-level work, but it does not adequately describe the range of work actually performed by shipyards. In addition to those depot-level services described above, the public shipyards perform alteration, refit and restoration, decommissioning of nuclear assets, design services, support services, and other planning functions. The shipyards also provide a number of smaller “miscellaneous” work items, such as voyage (or underway) repairs, oversight of private-sector contracts, component repair of special equipment, and other intermediate-level tasks. Most depot funding goes to the four public shipyards that perform depot-level maintenance: Norfolk Naval Shipyard (NNSY, or Norfolk), Pearl Harbor Naval Shipyard (PHNSY, or Pearl Harbor), Portsmouth Naval Shipyard (PNSY, or Portsmouth), and Puget Sound Naval Shipyard (PSNSY, or Puget Sound). These shipyards, with more than 25,000 total employees, provide the critical capability and capacity to support the Navy’s nuclear fleet. They also have large and specialized facilities needed to

³ 10 USC 2460.

perform certain types of maintenance activities, such as those requiring the docking of large ships.

Much of the remaining depot-level work is performed by a number of private repair firms. For example, BAE Systems Ship Repair provides depot-level repair services to ships based in San Diego, California, and Errol Industries is one of several private repair companies that operate near Norfolk, Virginia. These private-sector firms accomplish almost all of the depot-level work required by surface combatants as well as a large portion of the work required by amphibious ships.

Managing depot-level maintenance at the public shipyards is a challenge. The changing size and composition of the fleet, the development of new classes of ships with uncertain maintenance requirements, and unexpected operational requirements can result in variability and uncertainty in the future workload.

The total number of ships in the Navy, including aircraft carriers and submarines, has decreased by nearly a fourth since the mid-1990s. Removing a single aircraft carrier from the fleet can have a significant impact on a public shipyard because the associated work can represent a large portion of the shipyard's total workload. Further reductions in shipyard workloads can come from changes to maintenance requirements and policies. Longer aircraft-carrier deployment cycles can also result in reduced maintenance demand.

Several laws and policies constrain how the Navy can allocate work among providers and control workforce levels, making management of the public depots more challenging. For example, federal law requires that no more than 50 percent of funds for repair work on military equipment be awarded to private contractors,⁴ that repairs of less than six months' duration be performed at shipyards in the vicinity of a ship's homeport,⁵ and that the Navy maintain certain repair capa-

⁴ According to 10 USC 2466, no more than 50 percent of each military department's annual depot maintenance funding can go toward work contracted to the private sector. U.S. Code also mandates annual reporting to Congress on the depot maintenance funding split between the public and private sectors.

⁵ Within the United States, the Navy has a homeport policy for improving the ship crew's quality of life by minimizing time away from home. The homeport policy instructs that, when possible, a ship's repair and maintenance work of six months or less should be per-

bilities in the public shipyards to meet the readiness and sustainability requirements of the fleet.⁶ (These laws are described in more detail in Appendix A.) Public-shipyard workers are also subject to the rules and constraints that govern the hiring and termination of members of the government workforce. Still other laws prohibit the hiring of workforce in excess of budgeted workload (even if management expects workload to be greater than planned) and require the Navy to seek congressional approval when terminating more than 50 civilian employees at a shipyard at any one time.

Given the large and complex environment that characterizes depot-level maintenance, the Commander, Naval Sea Systems Command (NAVSEA), asked RAND to identify and evaluate options for managing the public shipyards more efficiently. This tasking included identifying effective strategies for managing the public shipyards and lessons the Navy can learn from other organizations. We begin with an overview of the four public shipyards and their workload and of other facilities that supplement their efforts.

Overview of the Four Public Shipyards and Other Repair Facilities

The Navy currently operates four public shipyards. These are

- Norfolk Naval Shipyard in Portsmouth, Virginia
- Pearl Harbor Naval Shipyard and Intermediate Maintenance Facility in Pearl Harbor, Hawaii

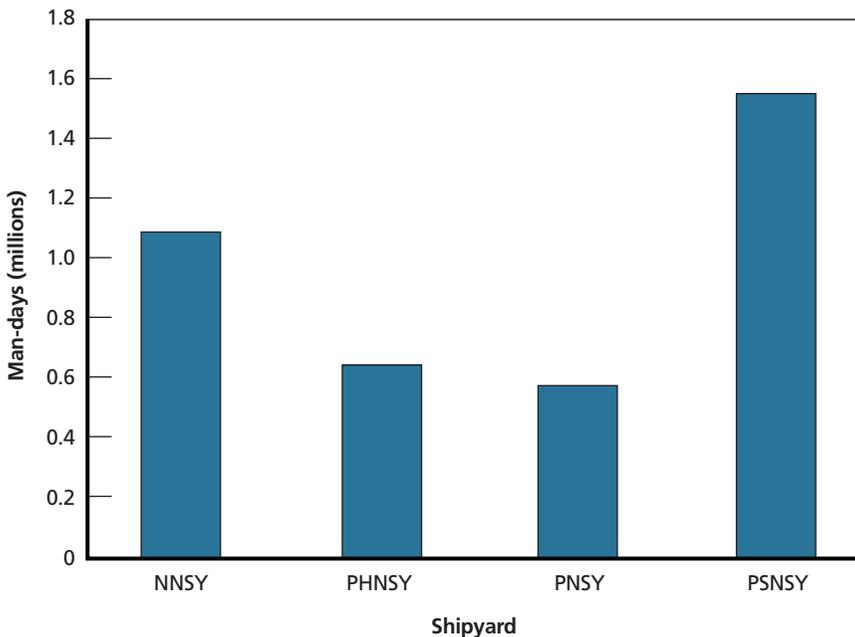
formed at the ship's homeport. For a project estimated to take more than six months, the Navy will solicit proposals for maintenance contracts from private shipyards and ship-repair companies beyond the ship's immediate homeport area as well.

⁶ 10 USC 2460 instructs the Department of Defense (DoD) to maintain a government-owned and operated "core logistics capability." This includes all equipment, facilities, and personnel (who are government employees). In accordance with 10 USC 2464, the Secretary of Defense splits core logistics into two parts. Part One identifies depot maintenance core-capability requirements in direct labor hours and allows for adjustments to avoid redundancy. Part Two identifies the depot maintenance workloads required to cost-effectively support core-capability requirements (in direct labor hours).

- Portsmouth Naval Shipyard in Kittery, Maine
- Puget Sound Naval Shipyard and Intermediate Maintenance Facility in Bremerton, Washington.

Each of these shipyards has a unique organization, operations, and local conditions. Each executes a different amount of workload and employs a different level of workforce. The average annual workload of each shipyard is shown in Figure 1.1. Because each shipyard is relatively close to a major homeport, they are able to perform repairs of longer duration on ships stationed there. Each shipyard also retains critical skills and facilities as required by federal law. We describe each shipyard below.

Figure 1.1
Average Annual Workload, 2007–2013



Norfolk Naval Shipyard

NNSY, shown in Figure 1.2, is the largest public shipyard on the East Coast. It is the only public depot on the East Coast capable of dry docking a nuclear aircraft carrier. The NNSY dry dock is currently only large enough to accommodate CVN 75–class or older carriers. A planned modification will enable it to accommodate the bulbous bow of CVN 76–class and newer carriers, including those of the *Ford* class (CVN 78).

Norfolk currently has the skills and facilities required to support all ship classes. It performs work on aircraft carriers; *Seawolf*-, *Virginia*- and *Los Angeles*-class submarines; large-deck amphibious ships; and surface combatants. It also supports *Ohio*-class nuclear ballistic missile submarines (SSBNs) at Kings Bay, Georgia, and runs a foundry and propeller center and a materials test lab.

Figure 1.2
Norfolk Naval Shipyard



SOURCE: Norfolk Naval Shipyard.

RAND MG751-1.2

NNSY is located next to one of the major fleet concentration areas on the East Coast, including the more than 60 ships homeported in Norfolk, Virginia. It is in the same area as Northrop Grumman Ship Building (Newport News), the Norfolk Shipbuilding and Drydock Company, and the Mid-Atlantic Regional Maintenance Center.⁷ These organizations compete with NNSY for labor, but also provide a pool of ready workers from which the shipyard can draw when necessary.

In 2006, NNSY executed 1.4 million man-days of work and employed more than 7,600 civilians. The September 2006 workload plan for the shipyard shows workload ranging from approximately 0.9 million man-days to 1.3 million man-days each year through 2013.⁸

Pearl Harbor Naval Shipyard and Intermediate Maintenance Facility

PHNSY & IMF, shown in Figure 1.3, holds a strategic position in the Pacific and provides emergency repairs and other services to fleet assets stationed or deployed in the Pacific. The shipyard primarily supports *Los Angeles*-class submarines but also works on *Arleigh Burke*-class destroyers, *Perry*-class frigates, and *Ticonderoga*-class cruisers. It also has the capability to perform work on any surface ship, the SSBN fleet, and the *Seawolf* and *Virginia* classes of submarines. The shipyard has a dock that could accommodate a nuclear aircraft carrier if required, but it is not capable of supporting carriers on a regular maintenance schedule.

PHNSY's location, though strategic, gives it a limited labor pool to draw from. Nevertheless, there is a robust local shipbuilding and repair association. BAE owns and operates a private shipyard. There are 26 ships currently homeported in Pearl Harbor.

In 2006, PHNSY & IMF executed nearly 700,000 man-days of work and employed more than 4,200 civilians. The current planned

⁷ In 2008, NNSY and the Mid-Atlantic Regional Maintenance Center will merge to form the "Norfolk Naval Shipyard and Intermediate Maintenance Facility." An intermediate maintenance facility is abbreviated as "IMF."

⁸ An estimate provided by Naval Sea Systems Command, Logistics, Maintenance and Industrial Operations (NAVSEA 04), on March 11, 2008, reveals an annual workload ranging from 1.0 million man-days to 1.2 million man-days.

Figure 1.3
Pearl Harbor Naval Shipyard and IMF



SOURCE: Pearl Harbor Shipyard and Intermediate Maintenance Facility.

RAND MG751-1.3

annual workload for the shipyard through 2013 ranges from 550,000 man-days to 680,000 thousand man-days.⁹

Portsmouth Naval Shipyard

PNSY, shown in Figure 1.4, provides depot services for *Los Angeles*-class submarines. The shipyard has unique capabilities and technical expertise required for the repair and maintenance of nuclear submarines, and frequently sends skilled personnel to assist in work performed at other sites. The shipyard also provides off-site support for many non-submarine tasks. It is within 160 miles of Groton, Connecticut, the homeport of 18 submarines. DoD recommended the closure of PNSY, but that recommendation was overturned by the 2005 Base Realign-

⁹ An estimate provided by NAVSEA 04 on March 11, 2008, reveals an annual workload ranging from 620,000 man-days to 660,000 man-days.

Figure 1.4
Portsmouth Naval Shipyard



SOURCE: Portsmouth Naval Shipyard.

RAND MG751-1.4

ment and Closure (BRAC) Commission. The near-closure of the shipyard resulted in, among other things, some unanticipated losses in the workforce.

In 2006, Portsmouth executed nearly 700,000 man-days of work and employed nearly 4,000 civilians. The current planned annual workload for the shipyard through 2013 ranges from 400,000 to 640,000 man-days.¹⁰

Puget Sound Naval Shipyard and Intermediate Maintenance Facility
PSNSY & IMF, shown in Figure 1.5, maintains West Coast aircraft carriers in Bremerton, Washington, and San Diego, California. Puget Sound can maintain all current and planned aircraft carriers, *Virginia-*

¹⁰ An estimate provided by NAVSEA 04 on March 11, 2008, reveals an annual workload ranging from 480,000 man-days to 630,000 man-days.

Figure 1.5
Puget Sound Naval Shipyard and IMF



SOURCE: Puget Sound Naval Shipyard and Intermediate Maintenance Facility.

RAND MG751-1.5

class submarines, and surface ships. It is currently the only shipyard that performs nuclear defueling tasks prior to decommissioning ships. It also supports SSBNs whose homeport is in Bangor, Washington, and ships based in Yokosuka, Japan.

Unique among the public shipyards, Puget Sound supports several off-site locations, including Bremerton, Bangor, and Everett in Washington state; San Diego, California; and, starting in 2008, a nuclear aircraft carrier to be homeported in Yokosuka, Japan. The workload at these sites spans a wide range of platforms and capabilities. Bangor is the intermediate-level facility for support of *Ohio*-class nuclear ballistic-missile submarines. Puget Sound workers at Everett perform continuous maintenance for the USS *Abraham Lincoln* (CVN 72) and surface ships stationed with that carrier; other depot-level work is performed in Bremerton. Puget Sound workers use the depot-level facilities in San Diego to perform pier-side maintenance on nuclear

ships stationed there. The shipyard usually supplies 600–800 workers for six-month planned incremental availabilities for aircraft carriers in San Diego, with nonnuclear work, even that aboard nuclear ships, subcontracted to local shipyards. There are currently 43 ships homeported at San Diego, two in Bremerton, 12 at Bangor, and five in Everett.

In 2006, Puget Sound executed nearly 1.8 million man-days of work and employed nearly 10,000 civilians. Current plans call for Puget Sound to perform between 1.3 million man-days and 1.6 million man-days of work annually through 2013.¹¹

Other Facilities

The Navy also performs underway repairs (also called *voyage repairs*) at sites around the world, including Bahrain; Groton, Connecticut; Guam; Jacksonville, Florida; and Yokosuka and Sasebo, Japan. Currently, the four public depots provide a significant amount of specialized skills and manpower to these other sites. Work performed at these other sites is limited by current government regulations and the sites' own infrastructure.

Several private shipyards also support the fleet. Although private facilities are outside the focus of this research, two of these private shipyards—Northrop Grumman Ship Building (NGSB) in Newport News, Virginia, and General Dynamics Electric Boat (GDEB) in Groton, Connecticut—warrant a brief review because of their ability to provide nuclear maintenance, which comprises perhaps the most complex maintenance tasks required by Navy ships. These shipyards can provide skilled labor and additional nuclear capability and capacity to the Navy in times of need.

NGSB in Newport News is the sole builder of nuclear-powered aircraft carriers, one of only two shipyards that build nuclear-powered submarines, and the only facility used to refuel nuclear-powered aircraft carriers. NGSB has two of the four active carrier-sized dry docks in the contiguous United States. One is used primarily for RCOHs and the

¹¹ An estimate provided by NAVSEA 04 on March 11, 2008, reveals an annual workload of at least 1.5 million man-days.

other is used for new construction. NGSB will perform availabilities,¹² continuous maintenance, and inactivation and decommissioning of the USS *Enterprise* (CVN 65). NGSB also performs maintenance on the nuclear submarine fleet.

GDEB built the Navy's first commissioned submarine and its first ballistic-missile submarine. It also built the entire *Ohio* class and the first and several subsequent vessels of the *Seawolf* and *Virginia* classes of submarines. Although GDEB does not regularly perform much fleet maintenance at its shipyard, it has sent nuclear-skilled personnel to the public shipyards to assist with maintenance activities. The shipyard also provides an important technical design capability to the Navy. The shipyard most recently developed a design to convert four SSBNs into cruise-missile, land-attack submarines also capable of supporting the missions of special operations forces. The transformation involved extensive conversion work.¹³

Finally, several intermediate-level maintenance providers comprise a significant part of the organic industrial base. In addition to the two public shipyards performing intermediate maintenance, seven Regional Maintenance Centers (RMCs) provide technical, production, and planning support for intermediate- and depot-level maintenance services. The RMCs manage many of the private-sector contracts that the public shipyards use. Public-shipyard management responsibilities are likely to change as more integration of intermediate-level facilities continues and as production functions are moved from the RMCs to the public shipyards.

¹² An *availability* is the period of time during which a vessel is available to receive a work package comprising repair, alteration, and other required maintenance actions provided by a shipyard or depot provider.

¹³ For more information on the Navy's nuclear-powered cruise-missile submarine program, see Department of the Navy, 2007c.

Management of the Public Shipyards

NAVSEA 04 manages the four public shipyards. It is responsible for managing the NAVSEA resources, processes, and infrastructure associated with ship maintenance and logistics support. It works with the shipyards and the operating commands to develop workload and workforce plans for providing necessary services efficiently and effectively. Specifically, it establishes shipyard workforce-management policies, provides civilian end-strength and overtime guidance to the shipyards, and works with operators to establish maintenance schedules.

Managing the four public shipyards has been challenging. One reason for this is the changing size and composition of the fleet and associated maintenance infrastructure. In the early 1990s, the Navy operated 15 carriers and more than 100 nuclear submarines; it now operates 11 carriers and approximately 75 nuclear submarines. Corresponding reductions in industrial facilities have occurred in response to reductions in the fleet. In the past two decades, civilian employment levels at the public depots have been reduced by over half. Some changes to the force structure have had maintenance implications. For example, the replacement of the *Los Angeles*-class submarines with *Virginia*-class submarines meant the end of refueling tasks for nuclear submarines and therefore of a substantial and steady source of work for the public shipyards. Additionally, new platforms with uncertain maintenance requirements pose planning challenges. Current force-structure plans call for a large number of Littoral Combat Ships whose depot maintenance requirements remain uncertain. Future challenges will also include managing greater amounts of off-site work and accomplishing required maintenance under increasingly tighter budgets.

Managing this changing environment is complicated by the variability and uncertainty of the types and amounts of work that must be accomplished by the public shipyards. The size of availabilities varies from a few thousand man-days to a few hundred thousand man-days, with durations varying from a few weeks to a few years. Allocating and scheduling projects that vary so widely in scope and duration causes “peaks” and “valleys” in the demand for skilled workers, and makes it difficult to keep fairly uniform levels of work in the shipyards.

Table 1.1 provides notional workloads and durations for maintenance availabilities by ship type and maintenance type.

The actual work performed during an availability depends on the material condition of the ship, the size of the modernization package, and the funding available to accomplish the work (a significant factor). The material condition of the ship is often unknown and can only be determined precisely by inspection, which sometimes includes the disassembly of equipment or the opening of sealed spaces. Operational requirements and the availability of facilities also affect notional work-

Table 1.1
Notional Depot-Level Work Packages for Naval Ships

Ship Type/Availability Type	Workload (thousands of man-days)	Duration (months)
Nuclear aircraft carrier		
PIA	150–200	6.0
DPIA	260–360	10.5
Nuclear submarine		
DSRA/ERP	22–80	2.0–8.0
Overhaul	145–200	13.0–16.0
Refuel	300–340	16.0–27.0
Amphibious ship		
Docking	80–140	4.0–6.0
Pier-side	15–25	2.0–3.0
Surface combatant		
Docking	8–50	2.0–12.0
Pier-side	3–8	2.0–4.5

SOURCE: Notional man-days and durations from Department of the Navy, August 2006c.

NOTES: PIA=planned incremental availability; DPIA=docking planned incremental availability; DSRA/ERP=docking selected restricted availability/extended refit period.

load and schedules. Budgets may change during the course of the planning and execution of a work package, leading to changes in workload and workforce plans.

Also making public shipyard management difficult are several laws affecting how the Navy can allocate maintenance work. Workers at the public shipyards are civil-service employees. The level of civilian employment at the shipyards is subject to the rules and constraints of hiring and terminating members of the government workforce. The shipyards are relatively large employers in their areas, so the Navy must consider the political ramifications associated with allocating workload and managing workers. Most shipyard employees are also union members and the Navy must negotiate with unions on work-related issues. Finally, the limited availability of temporary employees and subcontractors makes it difficult to augment the permanent workforce with additional labor resources at some public shipyards.

Objective of the Research

These difficulties prompted the Commander, NAVSEA, to ask RAND to identify and evaluate options for managing the shipyards more efficiently. Specifically, we focused on the following questions:

- Given the current allocation of work between the public and private sectors, is there a cost-effective strategy for matching workforce supply with workload demand?
- Would alternative workload allocations improve cost-effectiveness for the Navy?
- Is there anything the Navy can learn from other organizations that face similar workload- and workforce-management problems?

Research Approach

To answer these questions, we worked closely with NAVSEA 04, the shipyards, and other organizations involved in depot maintenance of the

fleet to fully understand the various processes, issues, and constraints faced by workload- and workforce-management planners. We asked the shipyards about their workforce-management practices through a detailed questionnaire (replicated in Appendix B). We estimated the supply and demand of depot-level resources and established a base case for our evaluations. We then constructed an optimization tool to identify cost-effective workforce-management strategies. The tool estimates the number of workers (by labor type and amount of overtime worked) required to meet workload demands in a cost-effective way. We used the tool to evaluate the cost associated with current planning practices and with various planning options. (Appendix C describes the model in detail.)

We also identified several organizations that face similar problems in managing their workloads and workforces. In interviews with these organizations, we identified their practices for managing more efficiently and investigated the applicability of their practices to the U.S. Navy's public shipyards.

Organization of the Monograph

In Chapter Two, we describe workload demand at the public shipyards, including the differences between planned and actual workloads. In Chapter Three, we identify cost-effective strategies to match workforce supply to workload demand. In Chapter Four, we discuss additional workforce considerations and sensitivity results. In Chapter Five, we evaluate whether alternative workload strategies can improve cost-effectiveness. In Chapter Six, we present the strategies used by other organizations and assess their applicability to the U.S. Navy. Chapter Seven summarizes our findings and recommendations. Several appendices provide more detail about material in this book.

An Evaluation of Planned and Actual Workload Demand

We begin this chapter by discussing the workload plans for public depots and what determines or influences these plans. We then evaluate variability and uncertainty in the workload plans. We observe that recent planned and actual workload demands differ.

Shipyard Workload Plans

Depot workload plans consist of Chief of Naval Operations (CNO) and non-CNO work that is either direct or indirect.¹ CNO availabilities are all the maintenance activities identified in Office of the Chief of Naval Operations (OPNAV) Instruction 4700; they include most maintenance performed during Navy ship availabilities. CNO availabilities also consist of all Fleet and NAVSEA repair, modernization, inspection, and testing requirements for each ship and availability type. They are scheduled in accordance with maintenance requirements, budgets, and operational needs.

Non-CNO workload as defined by NAVSEA Instruction 4850.5C is “all direct labor performed in a shipyard that cannot be charged to a planned CNO availability . . . including emergent restricted availabili-

¹ *Direct work* refers to tasks directly associated with repairing a ship. *Indirect work* refers to the support and other tasks (such as crane operation and planning) required for the organization to do the direct work.

ties of less than 3,000 resource days.”² Non-CNO depot work consists of a number of smaller work packages, such as technical availabilities and continuous maintenance availabilities (CMAs).³ Non-CNO work also includes refit and restoration, design services and other engineering work, work performed by “Tiger Teams” of individuals with specialized skills who work at different sites as needed, Ship Availability Planning workload, specialized component repairs, and other intermediate-level work pushed to the depots. In general, non-CNO work includes scheduled or planned maintenance requiring less manpower, time, or resources than the CNO availabilities. Non-CNO work also includes emergent repairs and other unexpected workloads that can be significant in size and duration. Mostly, the distinction between CNO and non-CNO workload is made for the purposes of financial accounting.

Depot work can also include “overflow” intermediate-level or organizational-level work that the Fleet Maintenance Activity, another intermediate-level provider, or the ship’s crew lacks the time or manpower to perform. In the future, intermediate-level workloads are expected to be reduced or reassigned to depot facilities. Current plans include the elimination of nearly 2,200 billets at the Fleet Maintenance Activities (i.e., at IMFs). Some of the intermediate-level workload previously accomplished by these billets will be accomplished by depot workforces. Other plans include the consolidation, elimination, or reassignment of intermediate-level maintenance for surface ships and carriers. Some of the intermediate-level workload previously accomplished at intermediate-level facilities will now be accomplished at the depots. For example, NNSY is earmarked to absorb some of the production workload associated with the current Mid-Atlantic Regional Maintenance Center. In the future, as the line between depot- and intermediate-level maintenance continues to blur, the question of the validity of the distinction will become more relevant.

² Department of the Navy, 2007a.

³ A technical availability consists of specific work items that do not compromise the ability of a ship to perform its mission and tasks; continuous maintenance work is depot-level maintenance work that is not completed during a scheduled CNO availability. For aircraft carriers, continuous maintenance is now referred to as a *carrier incremental availability*.

Factors Influencing the Demand for Depot-Level Services

The demand for depot-level maintenance is determined or influenced by a number of factors, including force structure (i.e., the number and type of ships in the fleet), maintenance policies and practices, technical maintenance requirements, use of assets, deferred depot- or intermediate-level maintenance, available budgets, and operating schedules. The difficulty of forecasting each of these variables complicates accurately predicting future demand and the size of the infrastructure required to support it. Nevertheless, the current budgeting process requires hard estimates of future requirements. In this section, we review the information available for estimates, including information on force structure and maintenance policies and requirements.

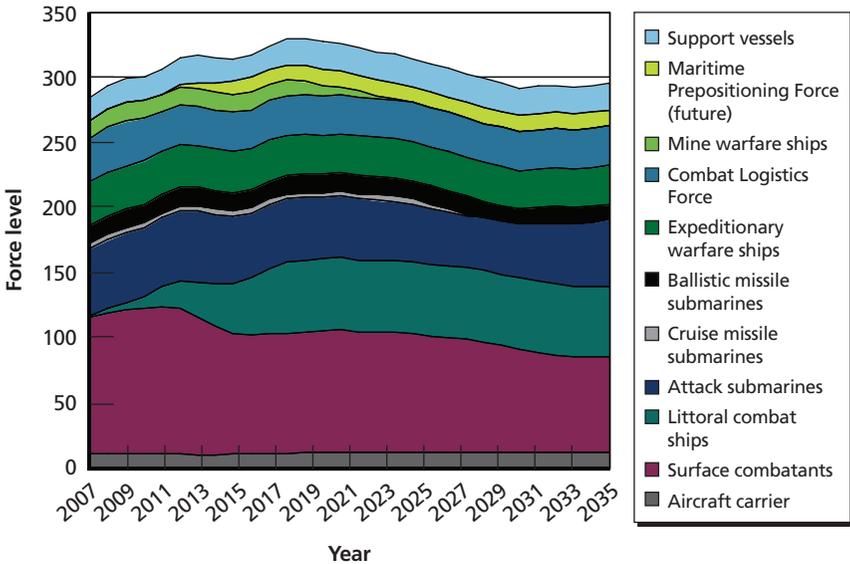
Force Structure

To a large degree, depot-level maintenance requirements are determined by the size and composition of the fleet. Fleet numbers vary with retirements and new acquisitions. Both fleet size and composition will change in coming years, contributing to the challenges depot managers face. Currently, there are ten nuclear-powered and one non-nuclear powered aircraft carriers; approximately 70 attack, four cruise-missile, and 14 ballistic-missile submarines; 100 surface combatants (cruisers, destroyers, frigates, etc.); 30 amphibious ships; and more than 70 additional ships of other types. Current plans indicate that the Navy will increase its number of small ships, such as the Littoral Combat Ship, and introduce the Maritime Prepositioning Force (Future) vessel. *Virginia*-class submarines, as noted, will replace the *Los Angeles* class. The number of attack submarines will fall to 55 in 2013 before decreasing to 40 in 2028. The number of aircraft carriers will fall to ten by 2013 before increasing to 12 by 2019.⁴ Figure 2.1 shows force levels by type of vessel in the Navy's 30-year shipbuilding plan.

This changing mix of assets will affect demand for the maintenance and modernization services provided by the shipyards. For

⁴ Department of the Navy, Director, Warfare Integration and Assessment, OPNAV N8F, 2007.

Figure 2.1
Force Levels by Class of Ship, 2007–2036



SOURCE: Department of the Navy, Director, Warfare Integration and Assessment, OPNAV N8F, 2007.

RAND MG751-2.1

example, the transition from the *Los Angeles*-class to *Virginia*-class submarines will eliminate the need for midlife submarine refuelings that have each required more than 300,000 man-days and 16–27 months to accomplish. Because aircraft-carrier maintenance availabilities also require a relatively large amount of work, ranging from 150,000 man-days to 200,000 man-days and taking six to ten-and-a-half months to accomplish, changes to just one or two carriers in the fleet can have a large impact on shipyard workloads. The mix of aircraft carriers will also affect the maintenance industrial base as older, nonnuclear carriers are retired and replaced with nuclear carriers. The naval shipyards currently maintain nine of the Navy’s 11 aircraft carriers. By 2009, the public shipyards will be maintaining ten nuclear aircraft carriers and by 2019 they will be maintaining 12. This change will result in a significant increase in the amount of nuclear-powered carrier maintenance that the public shipyards will have to perform in future years.

Because of this increase in workload, NGSB in Newport News may play a larger role in helping to support aircraft-carrier maintenance.

Maintenance Policies, Practices and Philosophies

Policies and practices also greatly affect the demand for maintenance. Changes in depot maintenance for aircraft carriers illustrate how policies shape depot-level availabilities and demands. Since 1992, the demand for aircraft-carrier maintenance has been reduced by a third through changes to the frequency with which maintenance is performed and through efforts to identify and accomplish only maintenance that is absolutely required. Specifically, aircraft-carrier maintenance cycles have been extended in the past two decades from 24 months to 32 months.⁵ This has helped the Navy better meet readiness demands, but has also required more work to be accomplished during the depot availability and the carrier incremental availabilities within each cycle.

Since the early 1990s, the movement from time-based maintenance to condition-based maintenance has also played a large role in determining maintenance requirements. Previously, much ship maintenance was time-based. This approach can lead to inappropriate amounts of costly maintenance being performed. Under condition-based maintenance, the condition of the component or system is monitored and maintenance is performed only as needed.⁶

OPNAV Instruction 4700 and the *Joint Fleet Maintenance Manual* (JFMM) describe current maintenance policy. OPNAV Instruction 4700 outlines the duration, maintenance intervals, and workloads associated with a number of maintenance packages. The duration is the length of time that the ship will be at the depot. The interval specifies the number of days that will pass between availabilities. The workload is the estimate of man-days required to perform the availability. The

⁵ Yardley et al., 2008.

⁶ Currently, less than 10 percent of carrier maintenance requirements are time-based; 60 percent are condition-based. The remaining maintenance requirements are determined by other methods.

JFMM outlines much of the detail regarding roles and responsibilities for maintenance.⁷

Maintenance Requirements

Each platform in the force has a technical maintenance requirement, often developed before the ship is commissioned, that serves as a manual for life-cycle service requirements. These technical maintenance requirements are referred to as *preventive maintenance*.

As ships age, are exposed to different elements, and receive different levels of maintenance, still other maintenance may be required. These corrective maintenance items may be discovered through scheduled inspections and evaluations of systems and components. Alternative maintenance needs, also referred to as *modernization* or *alterations*, may require upgrades or adjustments and can include work as complicated as installing new communications equipment or as simple as moving a ladder. These alternative needs are determined by operational needs and budget.

Although technical requirements, maintenance philosophies, and policy determine maintenance needs, planners must also balance operators' maintenance priorities and available budgets. The technical authorities, operators, resource sponsors, and budgeteers work together to determine how much and what type of maintenance will ultimately be performed.

The process of determining maintenance requirements results in notional workload packages of a specified magnitude and duration for each type of ship, and in a number of plans with associated workload estimates. Notional workload values are outlined in OPNAV Instruction 4700 and are used to plan workload at least three years into the future.

Several workload plans result from the requirements process. Each shipyard has a workload plan, referred to as the *Workload Allocation and Resource Report* (WARR). NAVSEA assembles a Capability Plan (CP) for each depot, which specifies the total workload to be accomplished by each shipyard and outlines costs, contracting, and other items. The

⁷ See Department of the Navy, 2007b.

President's Budget (PB) also specifies workload demand for each depot. Because of the iterative nature of this process and other variables affecting requirements, the workload plans are continuously being revised. As we will see, these workload plans also differ in the amount of work they project.

Workload and other requirements are maintained in numerous databases that are sometimes not updated at the same time. Using different databases for planning can therefore lead to different decisions about workforce and other resource requirements. Two data sources available for maintenance-work planning are the Current Ships Maintenance Project (CSMP) and the Fleet Modernization Program Management Information System. Each ship has a CSMP database that is maintained by crew and maintenance providers over multiple inspections and evaluations; the database records preventive and corrective maintenance requirements. The Fleet Modernization Program Management Information System is the primary database for modernization workload reporting and includes data about all required alterations. Planners use these databases to establish and update maintenance requirements. In the future, all of the maintenance-workload data will be contained in the Navy Data Environment, a system still under construction. As this and other information systems continue to be developed, the availability of valid workload data will improve. However, uncertainty regarding the amount and frequency of maintenance required by new classes of ships will not be eliminated.

Other Considerations

Shipyards funding has recently shifted from a working-capital funded system to a mission-funded system.⁸ This transition began in 1997 when PHNSY and its IMF were consolidated. By 2003, Puget Sound was mission-funded; by 2006, Norfolk and Portsmouth were converted to mission funding.

This change has important implications for managing depot-level demands. Under the working-capital system, a shipyard performed work and was then reimbursed for its services. Under mission funding,

⁸ Congressional Budget Office, 2007.

shipyards are funded through Congressional appropriations to accomplish a set amount of work. The demand for depot-level services is constrained by the allocated budget; this constraint drives workforce levels. The shipyards cannot perform more work than is budgeted, but they receive funding even if no work is performed. This system, designed to provide steady funding, provides an incentive to the fleet to keep a steady flow of workload at the shipyards. Under mission funding, the Fleets play a larger role in determining schedules and workload priorities at the public depots, while NAVSEA determines the capacity of the shipyards.

Workload-Demand Forecasts

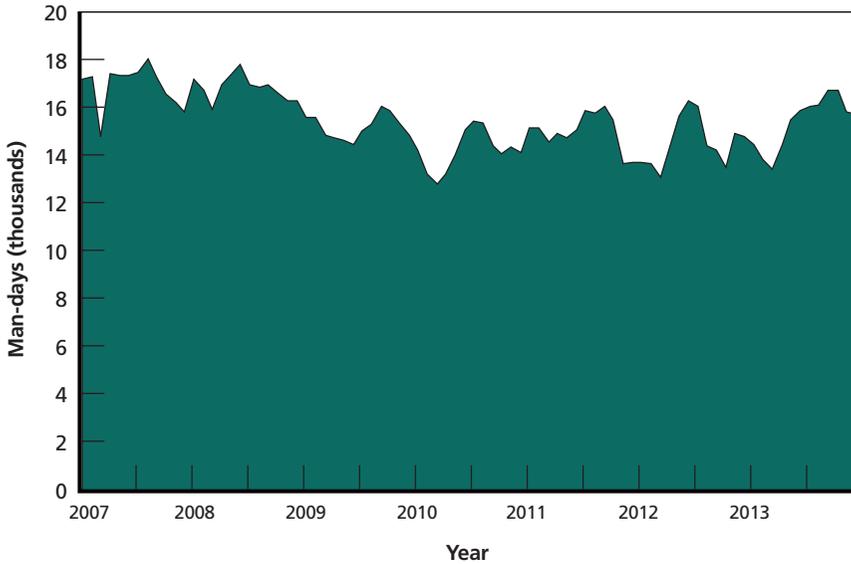
NAVSEA 04, which receives input from the shipyards, maintains workload forecasts for the public depots. These forecasts contain estimates for workload requirements through 15 years into the future. The workload estimates that cover the current year plus two years are updated monthly to reflect work progress and any changes to the workload. As noted above, estimates for work to be accomplished beyond three years are based on notional workload estimates. Estimates for work to be executed within three years are based on assessments of the material condition of the asset. The schedules and assignment of workload to the depots are subject to change.

Figure 2.2 shows the average workload (in man-days per day) to be accomplished each month by the public depots between 2007 and 2013; these data are from the shipyards' September 2006 WARRs.⁹ This workload is expected to vary between 13,000 man-days and 18,000 man-days per day.¹⁰ If no overtime is worked, these figures

⁹ The September WARRs are comprised of Norfolk Naval Shipyard, 2006; Pearl Harbor Naval Shipyard, 2006; Portsmouth Naval Shipyard, 2006; and Puget Sound Naval Shipyard, 2006. We display the workload in man-days per day, rather than man-days per year, to highlight the variability in the workload and to facilitate comparison between the workload and daily employment levels required to accomplish the specified workload.

¹⁰ The Navy uses the term *resources per day* to describe workload. This unit is equal to man-days or (men) per day if no overtime is worked. If overtime is worked, resources per day are

Figure 2.2
Total Depot Shipyard Workload



SOURCE: Data come from Norfolk Naval Shipyard, 2006; Pearl Harbor Naval Shipyard, 2006; Portsmouth Naval Shipyard, 2006; and Puget Sound Naval Shipyard, 2006.

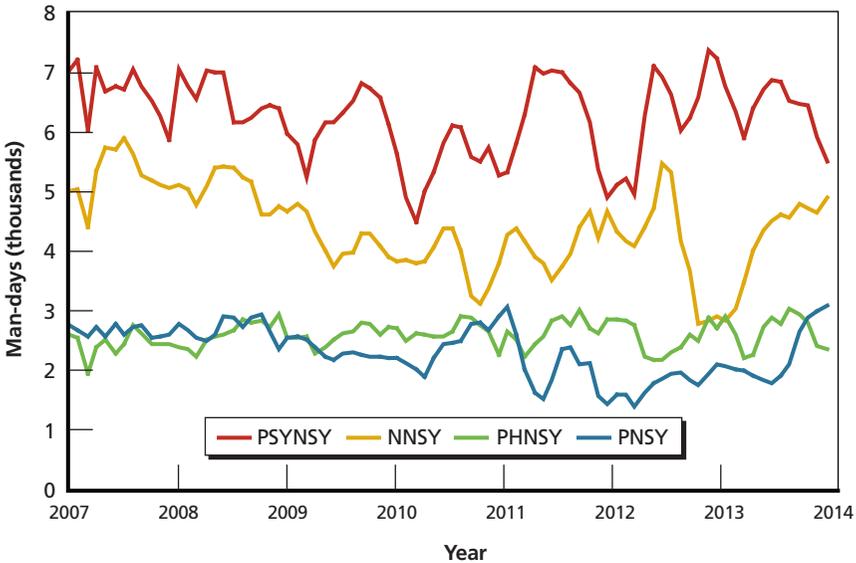
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imply that the shipyards need 13,000–18,000 men per day to accomplish this workload.

Figure 2.3 shows how total workload for each of the four public depots varies between 2007 and 2013. We again show average monthly workload, measured in man-days, to illuminate the variability in the number of workers required from month to month at each shipyard. Puget Sound has the highest workload of the four shipyards in every month shown, with a daily demand of 4,400–7,400 man-days of work. Norfolk has the second-highest workload in nearly every month, requiring 2,700–5,900 man-days of work each day. Pearl Harbor has the third-highest workload in most months shown, requiring

equal to men per day plus overtime worked. The term *men per day* often refers to the workforce, while *resources per day* refers to the workload.

Figure 2.3
Monthly Shipyard Workload at NNSY, PHSNY, PNSY, and PSNSY



SOURCE: Data come from Norfolk Naval Shipyard, 2006; Pearl Harbor Naval Shipyard, 2006; Portsmouth Naval Shipyard, 2006; and Puget Sound Naval Shipyard, 2006.

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1,900–3,100 man-days. Portsmouth has the lowest workload in most months shown, requiring 1,300–3,100 man-days.

Workload forecasts at each shipyard reveal many peaks and valleys. Each shipyard will experience an instance of workload levels changing by 20 percent from one month to the next. These monthly peaks and valleys can represent a significant increase or decrease in work. When comparing the minimum and maximum monthly workload observed from 2007 to 2013 across all shipyards, note that the maximum workload can represent an increase of 65–120 percent of the minimum workload. At Portsmouth and Puget Sound, the minimum and maximum workload occur within two years of one another. More than doubling or halving the workforce in a two-year period poses a significant challenge even under the most optimistic assumptions. In the next chapter, we consider staffing strategies for meeting this vari-

ability. First, we consider sources of variability and uncertainty in these estimates, and their implications.

Variability and Uncertainty in Planned and Actual Demand

Workload plans can differ from actual work accomplished because of misspecification of requirements, poor shipyard performance, budget or schedule changes, or still other variables.¹¹ Workload plans can also differ by source. To assess variations in workload plans, we examined the plans recorded in the 2006 and 2007 PBs (as provided by the Navy Comptroller's Office), the shipyards' POM 08 CPs (as provided by NAVSEA), and historical WARR files dating back to 2001 (as provided by the public shipyards). We first evaluated the WARR data at the aggregate level (i.e., summed across all shipyards for times when all shipyards recorded observations), the shipyard level, and the availability level. We then compared the PB, CP, and WARR data. We found that

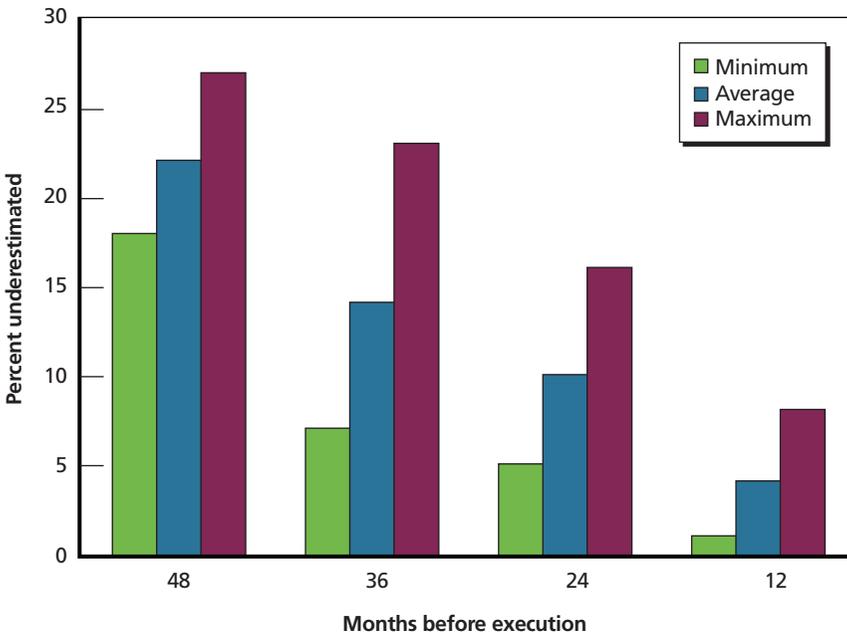
- WARR forecasts underestimate workload actually performed.
- WARR forecasts improve as execution date nears.
- High levels of overtime have been executed to accomplish unplanned work.
- The PB, CP, and WARR workload plans differ.

Evaluating historical WARR data allowed us to quantify the extent to which shipyard-workload forecasts are underestimated. We used the WARR files provided by each shipyard to estimate the deviation between workload forecasts and work actually performed. For each shipyard, we used forecasts made one, two, three, and four years prior to 2003, 2004, 2005, and 2006 to estimate the percentage deviation from the actual workload performed. We then took the average

¹¹ Workload plans should not be confused with planning values. Workload plans consist of the total workload that a shipyard must accomplish; planning values are used to represent the man-days and duration associated with a specific work package.

deviation across the four shipyards to calculate an average annual percent deviation for each of the four years prior to execution. The minimum, average, and maximum deviations are shown in Figure 2.4. The minimum value in the figure represents the smallest average annual percent deviation from actual work performed. The maximum value represents the largest annual average percent deviation. Forecasts made four years in advance of execution underestimated actual workload by 18–27 percent; forecasts made one year in advance underestimated actual workload by only 1–8 percent. Although the accuracy of the estimates improves as execution date nears, the variance in estimates is peculiar in one respect: The range of estimates four years prior to execution is smaller than that observed three and two years prior to execution. Three years before execution is when notional values for availabilities are replaced with assessments of the ships’ material condition.

Figure 2.4
Annual Deviation Between Workload Estimates and Actual Workload by Time Prior to Execution



At this point, variance in the estimates increases. As the execution date nears and estimates are refined, variance decreases.¹²

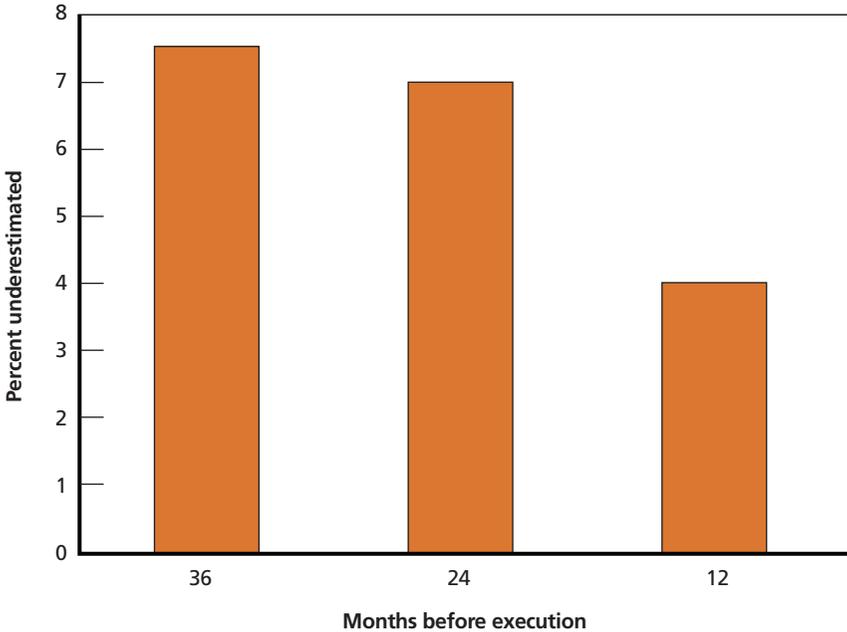
Given the recent transition of shipyard funding to mission funding, we also analyzed variations between workload forecasts and actual workload at PHNSY and PSNSY, the two shipyards that have operated under mission funding for the longest periods of time. We used data from 2003 to 2006, the period during which those two shipyards were mission-funded, hypothesizing that variations between forecast and actual workload in those two shipyards might better represent future variation. Note that because each shipyard is unique, our analysis can only be suggestive. We found that, for these two shipyards, as for all four, forecasts made closer to the time of workload execution are more accurate (see Figure 2.5). Figure 2.4 shows that forecasts of workload three years ahead of execution underestimated workload by 14 percent across all four shipyards; Figure 2.5, however, shows that the WARR underestimated actual workload in the mission-funded shipyards by less than 8 percent.

One result of the difference between planned and actual workload requirements has been the use of levels of overtime far above those originally planned. Figure 2.6 shows programmed versus executed overtime at Norfolk from fiscal year (FY) 2003 to FY 2006. Overtime was budgeted at 12–14 percent of straight time during this period, but monthly overtime executed was 14–32 percent of straight time.

Evaluations of budgeted and actual overtime at other shipyards also reveal that actual overtime exceeds budgeted levels. The average annual overtime worked over the past decade ranged from 18 percent to 29 percent of straight time. This average masks the extremely high levels of overtime observed in some shops, which can exceed 65 percent for an entire year. Such excessive overtime indicates that the planning process is underestimating the demand for maintenance.

¹² Although we had no access to data earlier than 2001, and therefore are relying principally on data generated during a time of military conflict, we found no evidence that the amount of wartime maintenance performed on ships since 2001 accounted for more than 1 percent of the total work performed at each shipyard. Furthermore, individuals we interviewed at each shipyard concurred with our assessment that workload estimates were extremely conservative.

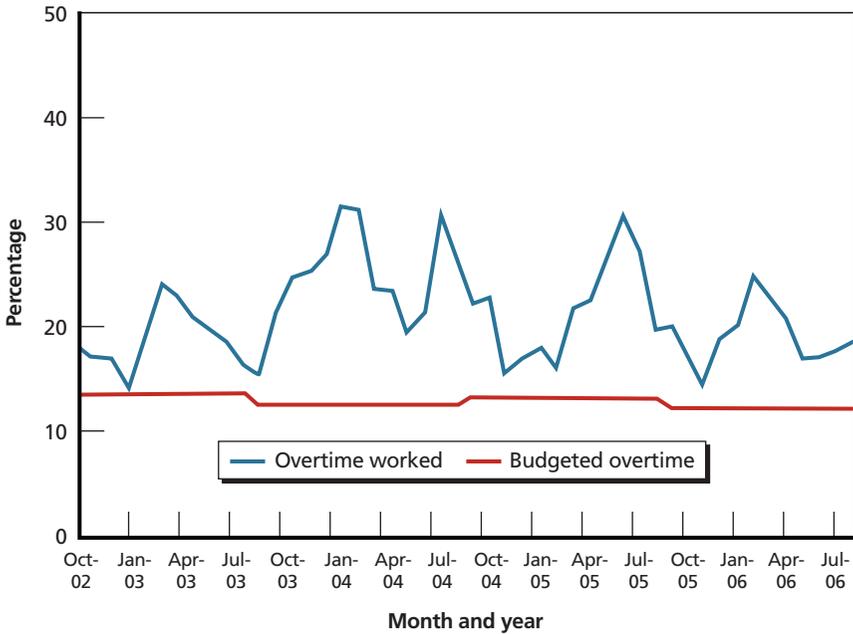
Figure 2.5
Mean WARR Underestimation of Actual Workload at Mission-Funded Shipyards



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This underestimation of workload occurs not only in the WARR but also in other workload plans (e.g., the CP and PB). For long-range plans, these workload forecasts tend to converge. This is largely because, as noted earlier, notional estimates for work more than three years away are the basis of WARR, PB, and shipyard-budget long-term estimates. For near-term work, on the other hand, each estimate uses its own specific basis and therefore the near-term set of estimates demonstrates greater internal variation. The near-term WARR forecast reflects the actual material condition of the ship and variables such as productivity and anticipated new work. The CP reflects actual material condition and budget cuts that ultimately lead to less work than initially identified by the WARR. The PB workload estimates reflect budget tradeoffs between different budget accounts within each program and therefore show still less near-term work than forecast in the WARR or the CP.

Figure 2.6
Historical Percent Overtime Worked and Budgeted at NNSY

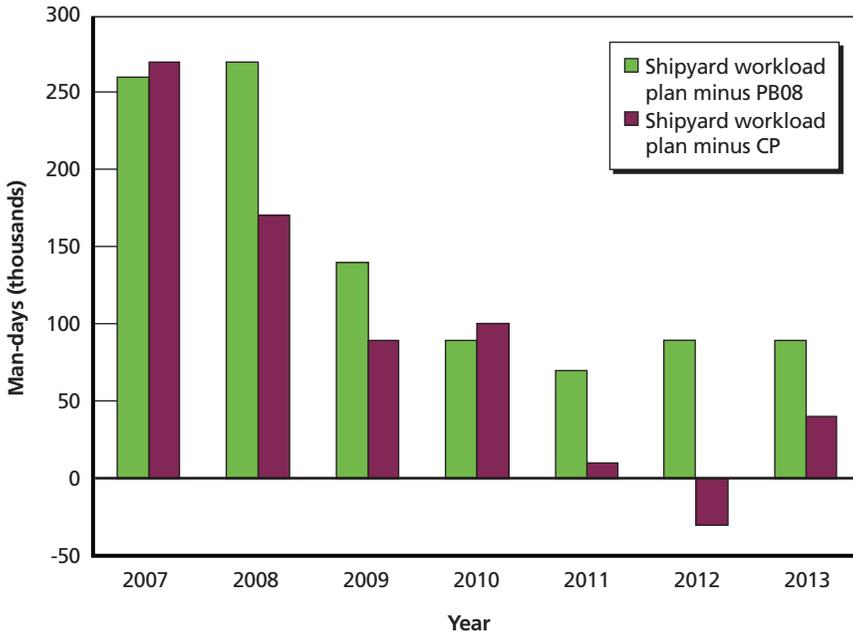


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Figure 2.7 shows how the workload estimates from the shipyards differ from those generated by the CP and PB.

Differences among these plans and their underestimation of future workload have resource-planning and other implications. Workforce development and shaping can take years. The shipyards plan their workforce levels at least 36 months before the start of work. As shown in Figure 2.5, this could result in nearly an 8-percent underestimation of workforce levels. Decisions regarding what skills to develop and how many personnel with these skills will be needed are based on estimates of the workload years ahead. If estimates for future workload are inaccurate, then workforce planning will be misguided.

Figure 2.7
The Difference Between Shipyard and PB Workload Estimates and Between Shipyard and CP Workload Estimates



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Summary

Several variables affect the demand for maintenance, making estimates of future workload challenging. Still, estimates of future workload are required for future workforce and resource planning. These estimates are based on information about the future force structure and on maintenance policy, engineering-based maintenance principles, and continuous monitoring of vessel conditions. We developed estimates of forecast deviation, by year prior to execution, using historical data. We found significant variation between workload plans and actual workload accomplished, indicating a potential problem in the planning process. Workload plans consistently underestimate actual workload. Differences between the forecasts and executed workload increase in longer-term forecasts.

Understanding the causes of bias and associated workload underestimation is an important area for future research. For the most part, shipyards have used high levels of overtime to accomplish this unplanned work. Like all workforce strategies, this use of overtime entails costs. We explore these costs, and how different workforce-planning strategies can affect cost, in the next chapter.

Cost-Effective Workforce Strategies

In the previous chapter, we reviewed pending changes in the composition of the Navy fleet as well as associated changes in forecast workload for the four shipyards individually and combined. In this chapter, we identify cost-effective workforce strategies for using permanent, seasonal, borrowed, and loaned labor—with varying levels of experience and during straight time and overtime—to meet workload demands. As we have already seen, actual workload demands often exceed planned demands, so we evaluate strategies for and implications of planning the workforce for both sets of demands.

We begin by discussing the workforce-planning process at the public depots. We then describe our analytical framework and the Workforce Allocation Tool that we developed to identify cost-effective workforce strategies. We then discuss our evaluation of worker productivity and the relative cost of labor, both important inputs to the tool. Finally, we identify cost-effective workforce strategies for meeting planned workload demands and present the cost implications of actual workload demand exceeding the planned demand. Although the scope of our study limited our evaluations to the aggregate direct workforce at each shipyard, Chapter Four presents some characterizations of the workforce at the shop level, as well as some sensitivity-analysis results and other considerations important for workforce planning.

Workforce Planning at the Public Depots

The Shipyard Workforce and Workforce-Planning Process

Workforce planning is performed by NAVSEA 04 and the shipyards. NAVSEA 04 sets total employment levels and overtime limits for the shipyards. The shipyards then determine the level and mix of skills that will constitute the total workforce and determine how overtime will be executed. The shipyard workforce is organized and managed by shop and trade-skill. There are dozens of shops at each shipyard and the number of trade-skills nearly mirrors the number of shops. The shops are referred to as either *production* or *support* shops. The production shops typically produce a product; this set of shops includes the Welding, Painting and Blasting, Sheet Metal, and Electrical Shops. The trade-skills associated with these shops are the welder, painter, electrician, and electronics trades. The support shops provide support services; this set of shops includes the Quality Assurance (QA) Shop and the Lifting and Handling Shop. The trade-skills associated with the QA Shop include the engineer trade; the crane-operator trade is the primary trade-skill in the Lifting and Handling Shop. At any point in time, the individuals within each shop can be charging their time to a direct, indirect, or leave account. *Direct labor* refers to individuals whose work directly benefits a customer. *Indirect labor* refers to individuals who are carried on an overhead account. Individuals who charge to the leave account are on paid or unpaid leave.

The mix and level of skills required in each shop and trade is based on an expected future workload demand, such as that shown in Figure 2.3. The total workload levels are used to determine full-time equivalent (FTE) levels. The type of work required (including nuclear and nonnuclear work) and the types of platforms involved are used to determine the specific trade-skills and competencies required for future workloads. Shipyard managers and NAVSEA 04 evaluate and address any potential discrepancies between the future requirement and the available workforce. In particular, they can choose to hire new workers into a trade or to borrow labor from another shipyard.

Increasing the number of individuals in a trade by hiring apprentices can take a significant amount of time. The apprentice programs

for the production trades are four-year programs. Upon completing the program, an apprentice needs an additional one to four years to be considered skilled. Trades that require nuclear certification or electronics skills take the longest to develop. The level of difficulty associated with increasing the number of individuals within support shops, such as engineers or technical experts, depends on the availability of university graduates and the health of other industries. Alternatively, if there are too many individuals within one trade at one shipyard, but not enough at another, managers can borrow from or loan labor to other shipyards. The exact mitigation strategy depends on how much planning time is available to address the discrepancy. In addition to planning for future skill requirements, the depots are required to maintain a core capability (further discussed in Appendix A). Core skills and trades must be maintained by the shipyards regardless of demand at any given time.

Currently, the Shipyard Integrated Hiring Plan is the staffing plan for the shipyards. This plan considers expected attrition and estimates the future required workforce and hiring needs of the desired labor pool. The plan is established and revised in two distinct steps. The Hiring Plan is first developed when the budget reflects the official PB employment level. It is then adjusted when the execution plan is built. This process helps ensure that the hiring actions reflect what the budget will support. Nevertheless, as the year progresses and the workload requirements or other variables change, NAVSEA 04 can authorize changes to the workforce plan. Unexpected increases in workload that require critical skills are sometimes difficult to accommodate. Having sufficient planning time is therefore critical to ensuring that the right level and mix of skills is available.

Shipyard managers also face a number of restrictions in workforce planning. These restrictions are discussed in more detail in Appendix A, but the following have the greatest impact on workforce-planning policy:

- The shipyards need approval from Congress to reduce the workforce by more than 50 civilians at any given time. This has led managers to set staff levels below their requirement and to use overtime and nonpermanent labor to overcome the shortfall.

- Shipyards cannot manage by end strength. This means that depot managers can only hire workers for which workload has been budgeted. If they expect workload to be greater than what is in the budget, they cannot hire in preparation for this additional workload.
- Shipyard labor is unionized. This means that there are typically contractual limitations on the tasks an individual can perform outside of a specified job title and shop. This can prevent efficiencies associated with having a multiskilled workforce that can move from task to task as needed.
- The use of subcontracting is constrained by the 50/50 rule that limits the amount of money that the private sector can receive to execute depot maintenance to no more than 50 percent of the total. This means that cost-effective subcontracting is not a viable option whenever it pushes funds to the private sector for repairs that constitute more than 50 percent of the total cost.

When workload plans are established, NAVSEA specifies FTE and overtime levels for the shipyard. The shipyard then determines how to manage personnel resources within these limitations. The shipyard allocates overtime to fit within the specified limit and determines the mix of skills and staffing levels within the shops to fit within the FTE cap. If workload increases, the shipyards must get approval from NAVSEA Headquarters to change the specified FTE and overtime levels. The shipyards each manage their own apprentice programs and workforce training programs required to develop skilled labor. The shipyards therefore maintain a long-term strategic view of future manpower needs, although most “strategic” planning falls to NAVSEA while the shipyards maintain most of the “tactical” responsibilities.

Workforce-Management Strategies for Meeting Variability and Uncertainty

Shipyard managers have developed a number of different types of labor to address variability and uncertainty. These labor types include

- permanent, full-time employees who work year-round
- seasonal, full-time employees who are guaranteed at least six months of work per year but might not work year-round. Seasonal employees maintain benefits when working¹
- borrowed workers, who are usually permanent employees on loan from another public shipyard or from one of the two private nuclear shipyards
- apprentices, who are typically new employees who are enrolled in a training or apprentice program associated with a production trade²
- military, uniformed individuals who provide maintenance services
- contractors, who are brought into the shipyard in any capacity beyond the ones previously described, and whose labor is secured through a contract
- temporary employees, who are similar to contractors but who can be released by the shipyards at any time.

Each of these labor types provides a different capability for the shipyard manager. For example, seasonal employees can be put on no-pay status to help the organization manage short periods of work decline. The apprentice program is used to train and develop the future workforce. Permanent staff help maintain required core capabilities. Borrowed employees can help mitigate worker shortages, particularly in highly specialized skills. Other labor categories not described above, such as helpers, can accomplish tasks that require minimal training.

Uniformed personnel differ from the other types of labor in terms of skill, availability, and how management can employ them. Because of their training and availability, they typically perform intermediate-maintenance tasks that require less skill. Uniformed personnel are not

¹ There are also so-called term seasonal employees, who are hired for more than one year but less than four. They can be released and rehired as needed. They maintain benefits while in active status.

² The apprentices category includes all civilian permanent and seasonal employees who are enrolled in a training or apprentice program. Apprentices are in the production trades and can be permanent or seasonal hires. Trainees are individuals who receive training for an engineering, support, or other nonproduction shop.

subject to the same management constraints as the civilian workforce and can work overtime levels that exceed those approved for the civilian workforce.

Shipyards can also subcontract work using “touch” labor contracts and “other” subcontracts to mitigate labor shortages.³ Touch labor contracts are used to hire specific skills needed to augment a particular shop.⁴ Other subcontracts are used to hire labor teams needed to accomplish a specific task or work package. Multi-ship, multi-option (MSMO) contracts for a specified level of maintenance typically cover a series of availabilities, but are not used to mitigate workload and workforce discrepancies.

Each shipyard manages its workforce differently. Table 3.1 shows the average percentage of the workforce represented by each labor type in FY 2007. Puget Sound and Pearl Harbor, the only shipyards with IMFs, can access a significant number of uniformed personnel available to perform maintenance.⁵ There is significantly more seasonal labor at Puget Sound than at the other shipyards. None of the shipyards appear to use significant amounts of temporary labor, but its use may be underestimated because contracted labor is not recorded in the WARR. The proportion of apprentices varies widely by shipyard. Portsmouth had a higher proportion of apprentices in 2007 because the shipyard, having nearly been closed two years earlier, needed to reestablish its permanent labor force.

Figure 3.1 shows the Navy’s direct labor and workload plan across the four shipyards from 2007 through 2013.⁶ The blue line shows the projected workload, measured in thousands of man-days each year. The

³ We did not evaluate subcontracting because insufficient data were available. For example, we could not access (1) workload estimates excluding subcontracting, (2) workload and workforce data at the trade-skill level, and (3) relevant cost data.

⁴ *Touch labor* refers to subcontracted labor that is used to augment the workforce.

⁵ We did not specifically evaluate “ship’s force” labor, which is separate from permanently stationed uniformed personnel. The ship’s force work package is created and managed separately from the shipyard work package.

⁶ Here we use man-days per year to allow for comparison between budgeted workforce and workload.

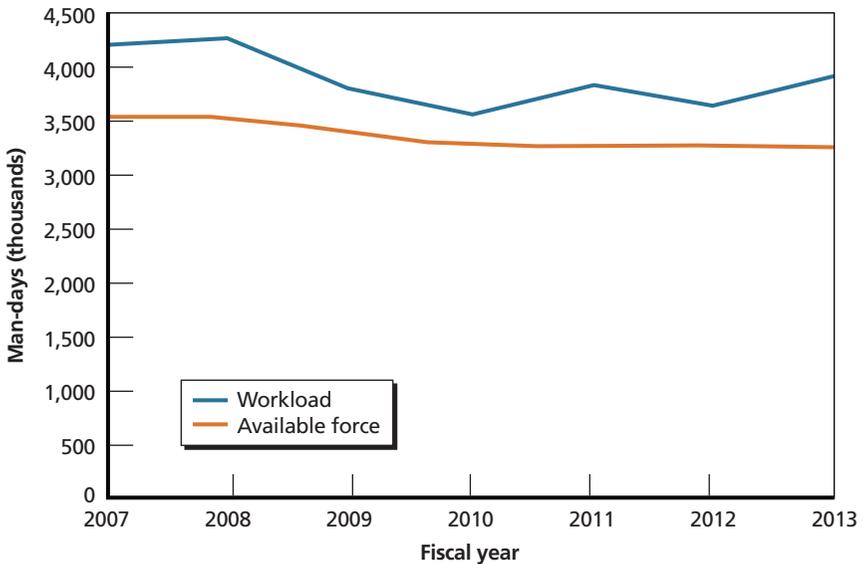
Table 3.1
Average Workforce Composition in FY 2007

Labor Type	NNSY	PHNSY	PNSY	PSNSY
Permanent	90%	72%	77%	78%
Seasonal	1%	3%	1%	9%
Temporary	0%	1%	0%	0%
Apprentice	9%	10%	21%	5%
Military	0%	14%	0%	8%

SOURCE: Data come from Norfolk Naval Shipyard, 2006; Pearl Harbor Naval Shipyard, 2006; Portsmouth Naval Shipyard, 2006; and Puget Sound Naval Shipyard, 2006.

NOTE: Totals may not add due to rounding.

Figure 3.1
Expected Total Workload and Workforce at Public Depots, FY 2007–FY 2013



NOTE: We use man-days per year to allow for comparison between budgeted workforce and workload.

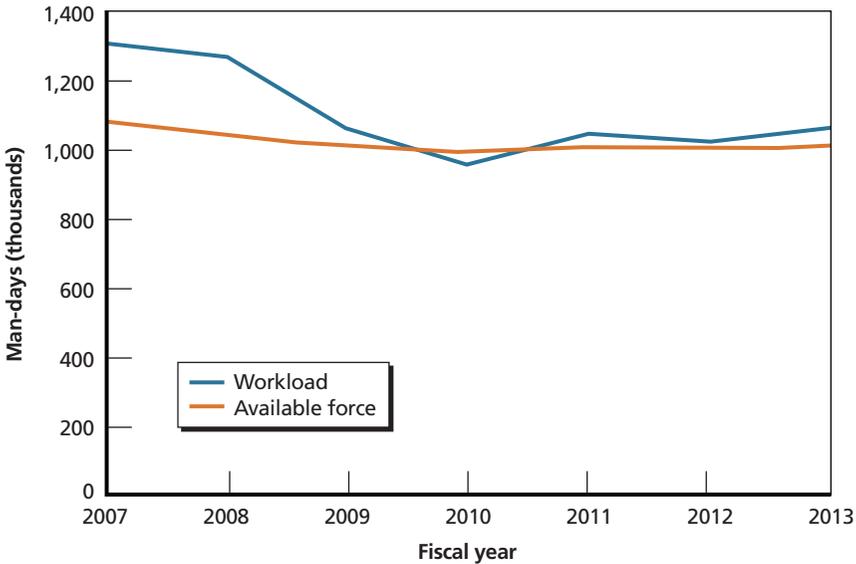
orange line shows the labor (at straight time) that will be available to perform work (calculated as the sum of differing labor types). In every year, the workload anticipated exceeds the available direct workforce. The shipyards are currently planning workload in excess of available labor by at least 9 percent, with this excess approaching 20 percent in some years.

Our evaluations of the workload and workforce plan at each shipyard reveal unique and significant differences in plans across the depots. While some depots have an increasing workload, others have a decreasing one. A recent decision to homeport 60 percent of fleet assets on the West Coast and 40 percent on the East Coast has increased workload at Puget Sound and Pearl Harbor and decreased it at Norfolk and Portsmouth. The unique combination of ships supported by each shipyard can also result in unique variations of workload at each shipyard. For example, because Puget Sound and Norfolk support aircraft carriers, they have greater variations in their workload (particularly as carriers move in and out of the shipyards).

Figure 3.2 shows the workload and corresponding workforce plan for Norfolk. The downward trend in annual workload is the result of a decrease in aircraft-carrier workload caused by the scheduling of availabilities and the reassignment of work from the East Coast to the West Coast. Following this reassignment, the projected workforce will closely match predicted workload. In FY 2007 and FY 2008, overtime, subcontracting, and other mechanisms are required to accomplish excess workload.

Figure 3.3 shows a near-term challenge as workload exceeds the available workforce at Portsmouth. In FY 2007 and FY 2008, the shipyard used overtime or borrowed labor to accomplish excess workload. Subcontracting for nuclear submarine skills was also an option, but is a costly alternative. The annual workload at Portsmouth will then decrease, bringing the workload and workforce levels closer together. In 2011, the workload level falls below the workforce levels. This is largely a result of the completion of refuelings for *Los Angeles*-class submarines, which are a significant portion of the shipyard's workload. Workload levels at the shipyard will recovery slightly when mainte-

Figure 3.2
Expected Total Workload and Workforce at NNSY, FY 2007–FY 2013



NOTE: We use man-days per year to allow for comparison between budgeted workforce and workload.

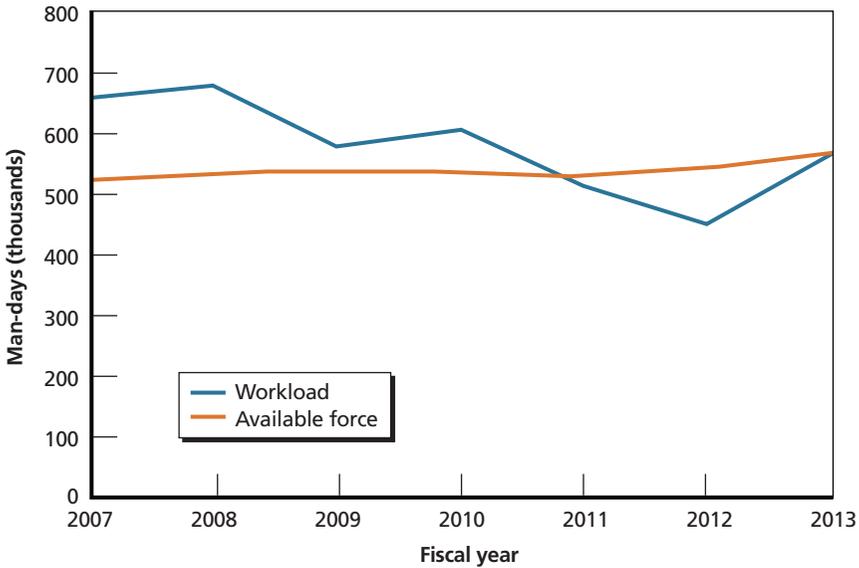
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nance for the *Virginia*-class replacements of the *Los Angeles*-class attack submarines becomes necessary.

At Pearl Harbor, we observe a slight increase in workload (to approximately 650,000 man-days annually) between FY 2007 and FY 2013. At the same time, the available workforce is decreasing, as shown in Figure 3.4. By 2013, the available workforce will be two-thirds of demand, requiring significant use of overtime, subcontracting, and other mechanisms to meet demand. This increase in workload is partly a result of the shift in homeports and the associated shift in work from the East Coast to the West Coast. A corresponding increase in the workforce will be required to execute this work. The workforce could be expanded in a number of ways, including hiring new workers into the apprentice program and reassigning workers between shipyards.

At Puget Sound, there is a clear dip in the workload in FY 2010, as shown by Figure 3.5. This dip is caused by how availabilities are sched-

Figure 3.3
Expected Total Workload and Workforce at PNSY & IMF, FY 2007–FY 2013



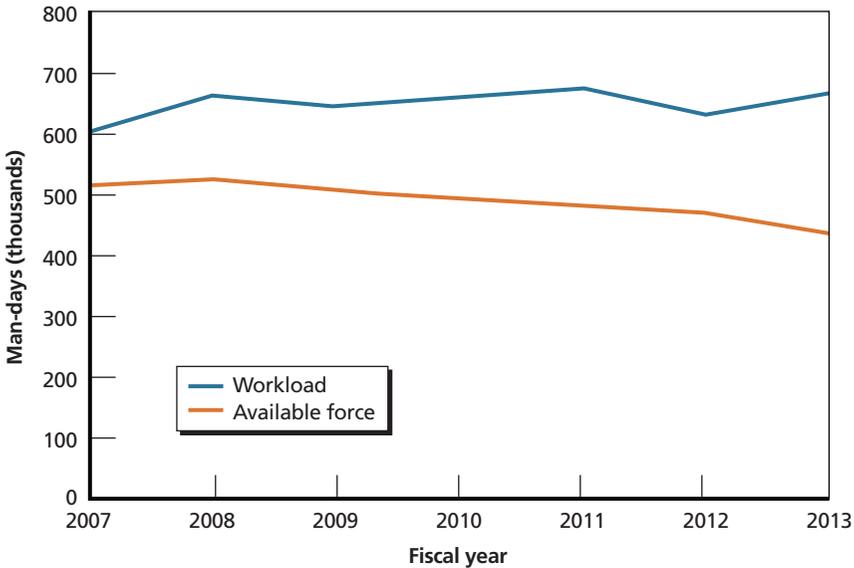
NOTE: We use man-days per year to allow for comparison between budgeted workforce and workload.

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uled, retirements of the *Los Angeles*-class submarines, and the reduced carrier force structure. In all years, annual workload exceeds the available workforce. Workload is expected to increase after FY 2010. Most of this new workload will stem from demands at other locations that Puget Sound supports. When CVN 73 moves to Japan, Puget Sound will perform the carrier's nuclear maintenance overseas. Accomplishing this workload will require subcontracting, hiring additional personnel, or other strategies.

In summary, there will be more work than workforce in the coming years, but the mismatch between workload and available workers varies by year and shipyard, with some shipyards in some years even possibly having excess workers. Establishing cost-effective workforce levels at each shipyard and within each shop or trade will be a challenge for depot managers, who face planning constraints and workload

Figure 3.4
Expected Total Workload and Workforce at PHNSY, FY 2007–FY 2013



NOTE: We use man-days per year to allow for comparison between budgeted workforce and workload.

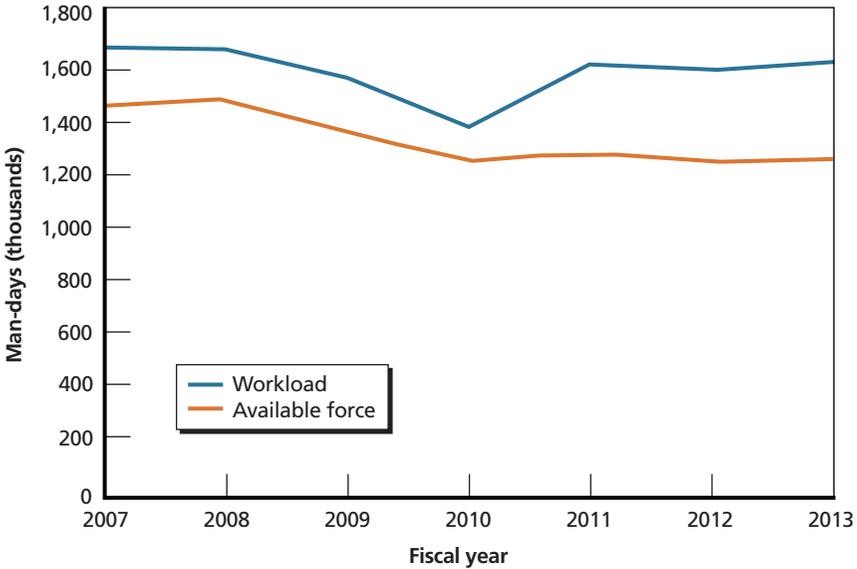
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uncertainty. We turn next to analyses of cost-effective workforce-planning strategies suitable for such an environment.

Analytical Framework and Methodology

We developed a method for estimating how much the U.S. Navy must spend on workload by provider (i.e., by shipyard) and type (e.g., permanent or seasonal) to meet workload demand. Our framework allows us to evaluate the costs of alternative workload allocations, which we evaluate in Chapter Five. Once a workload demand at each shipyard is established, we employ an optimization methodology to estimate a cost-effective workforce-allocation strategy. We first evaluate the Navy's current plan and then compare alternative strategies, including

Figure 3.5
Expected Total Workload and Workforce at PSNSY & IMF, FY 2007–FY 2013



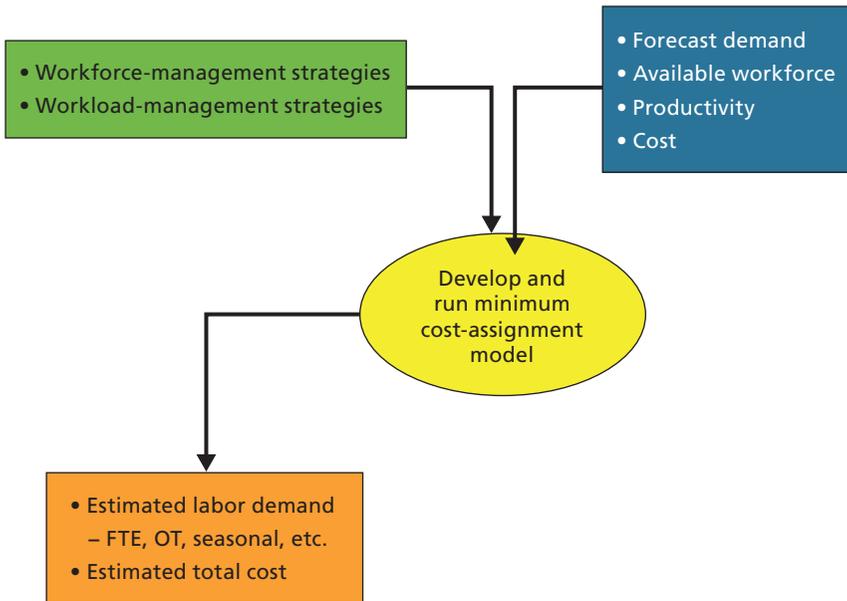
NOTE: We use man-days per year to allow for comparison between budgeted workforce and workload.

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the optimized case, to this base case. To collect the data necessary for this model, we developed a detailed questionnaire for use in interviews with public depot and NAVSEA representatives. (This questionnaire is replicated in Appendix B.)

We also developed an analytical framework, depicted in Figure 3.6, to help us implement this methodology. We first identified the workforce-management strategies (i.e., overtime, borrowed labor, and seasonal labor) to be evaluated. We then entered data on forecast demand, available workforce, productivity, and cost into the Workforce Allocation Tool. The Workforce Allocation Tool produced an estimate of total cost to the Navy (shown in the oval in the middle of the figure) and predicted the level and composition of labor types (shown in the box in the lower left corner). We review the Workforce Allocation Tool and the cost and workload-allocation models in the next several sections.

Figure 3.6
Analytical Framework for Identifying Workforce-Management Strategies



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The Workforce Allocation Tool

The Workforce Allocation Tool allows users to determine the cost of the minimum workforce required to meet workload demands. The mathematical optimization approach we used has been applied in earlier RAND research on the shipbuilding industry.⁷

Previous RAND research that used the Workforce Allocation Tool was primarily concerned with the supply of labor over multiple timeframes in a single shipyard, categorized by experience.⁸ The Workforce Allocation Tool therefore models the direct workforce by type,

⁷ Alkire et al., 2007; Arena, Schank, and Abbott, 2004; Birkler et al., 1998; Schank, Arena, et al., 2007; Schank, Smith, et al., 2005.

⁸ Previous research also typically categorized labor by trade-skill or production shop. The Workforce Allocation Tool is designed to handle labor categorized by production shop, but the scope of the present study limited most of the analysis to the aggregate direct workforce rather than the workforce for individual shops.

experience, shipyard, and period.⁹ For our present study, however, we needed a tool that could estimate the supply of labor for multiple shipyards simultaneously so that we could consider labor that is borrowed and loaned between shipyards. Our optimization variables include the number of direct workers on payroll in each timeframe in each shipyard, categorized by type and experience level. Another variable is the amount of overtime worked by direct workers. Additional optimization constraints correspond to different workforce and workload policies, and include

- upper- and lower-bound constraints on the level of overtime¹⁰
- upper-bound constraints on the percentage increase in the workforce that can be achieved in each timeframe through hiring
- upper-bound constraints on the number of workers in the borrow/loan program per timeframe
- an upper-bound constraint on the ratio of inexperienced workers to experienced workers (also known as *mentor ratios*)
- an upper bound constraint on the number of terminations per timeframe.

These constraints can be varied by labor type and shipyard. The tool also accounts for the average number of direct workers lost through attrition and retirement, and ensures that workforce supply meets workload demand. The tool associates a relative productivity factor for

⁹ Apprentice workers are modeled in our tool as an experience category rather than as a labor type. Temporary and military employees are not represented in our model. Temporary employees are not modeled because they are not widely used in production shops. Military employees are not modeled because (1) they are less available than other labor types, (2) their numbers are few in comparison with other labor types, and (3) there are few management mechanisms available for varying the numbers of military employees in the public shipyards. Touch labor is not represented in our tool because of the complexity of contracting at the shipyards and the limited scope of our study.

¹⁰ Many policy levers are represented by upper- and lower-bound constraints. Such policy levers can be fixed in value by making the upper and lower bounds equal. Otherwise, the bounds can vary within a range, with the final values chosen by the tool. We used both types of settings in our analysis.

workers in each labor type and experience level, and also models the variation in productivity as overtime is introduced.

The tool uses optimization techniques to determine the allocation of the different types of direct labor and of use of overtime to minimize total cost. First, the tool evaluates the wages of direct workers of each type and experience level at each shipyard, per timeframe, for both straight time and overtime. It then estimates indirect costs as a function of the workload demand per timeframe. The indirect costs include fixed and variable costs but exclude hiring fees, travel and per diem for borrowed workers, material costs, and some facility upgrade plans. (These excluded cost factors are discussed later in this chapter.) We then added the costs associated with hiring to the direct- and indirect-labor costs generated by the model. Next, we calculated material costs as a percentage of the total direct-labor costs and added these to the running total. Finally, we summed costs over all shipyards and all timeframes to produce total costs. We used constant-year dollars for our analysis, presenting our results in FY 2007 dollars.

The next section describes the data and the primary sources we used to evaluate workload- and workforce-management strategies in our model.

Data on Workload Demand

As noted in Chapter Two's discussion of expected total workload in future years, we identified several sources of data for workload demand. We used the September 2006 WARR data through FY 2013 as the basis of our evaluations. These data most closely represent the work that will actually be accomplished by each shipyard. These estimates account for shipyard factors, such as productivity and work factors (e.g., the availability of material), that may affect workload at the shipyard. These reports provide start and end dates for individual availabilities, the workload associated with those availabilities, and each shipyard's total workload demand. We also evaluated the shipyard's Program Objective Memorandum (POM)-08 CP and the 2007 and 2008 PBs to investigate workload uncertainty and variability.

Depot-level maintenance workload that is subcontracted to the private sector is not reflected in the WARR estimates for public-depot

demands. Because our research goal is to minimize the costs associated with executing the workload given to the public shipyards, we did not seek this additional workload.

Data on Workforce Characteristics

The Workforce Allocation Tool requires detailed data about a wide range of workforce characteristics. As previously noted, we collected much of this data through a detailed questionnaire that was completed by each of the four public shipyards. The questionnaire included questions about

- **workforce composition**, including the number of direct workers by shop, labor type, experience level, and age
- **workforce growth and reduction**, including the recruitment pool, hiring and growth rates, mentor ratios, attrition, retirement, and reduction-in-force (RIF) programs and options
- **workforce productivity and overtime**, including the relative productivity of workers by type, level of experience, and overtime; and overtime use and policies. As we describe later in more detail, we drew upon external studies of workforce productivity during overtime in addition to the information provided in response to the questionnaire.
- **costs**, including indirect costs and straight and overtime wages for direct workers. These data helped augment other information we gathered about costs.
- **limitations and conditions on the use of borrowed and loaned labor, seasonal labor, and overtime**, including minimum workload requirements for seasonal labor, overtime policies and current practices, and limitations on the use of borrowed and loaned labor.

Data on Cost Factors

We obtained data on cost factors from replies to our questionnaire and from the POM-08 CP we obtained from NAVSEA. The CP provides detailed cost estimates for executing expected maintenance work at each shipyard through 2013.¹¹ We used the CP data to develop a parametric cost model that we applied to our workload estimates. The CP provides

- average man-day rates for direct workers during straight time and overtime
- material cost estimates as a function of direct-labor requirements
- indirect costs
- port rates for some private shipyards.¹²

We augmented the CP data with costs (in man-day rates) by the production shop, labor type, or experience level of direct workers, which we obtained through responses to our questionnaire. We also obtained from NAVSEA separate estimates of port rates for private shipyards and used that data to augment the CP estimates.¹³

To estimate the cost of labor, we drew upon FY 2008 direct-labor index (DLI) estimates from the POM-08 CP, wage-grade information from the U.S. Office of Personnel Management,¹⁴ and travel and per diem estimates from the U.S. General Services Administration.¹⁵ We used these cost factors to evaluate the average cost (direct plus indirect) of a man-day of labor. Figure 3.7 compares the cost of different categories of employees to the cost of a fully experienced permanent

¹¹ See Department of the Navy, 2006b.

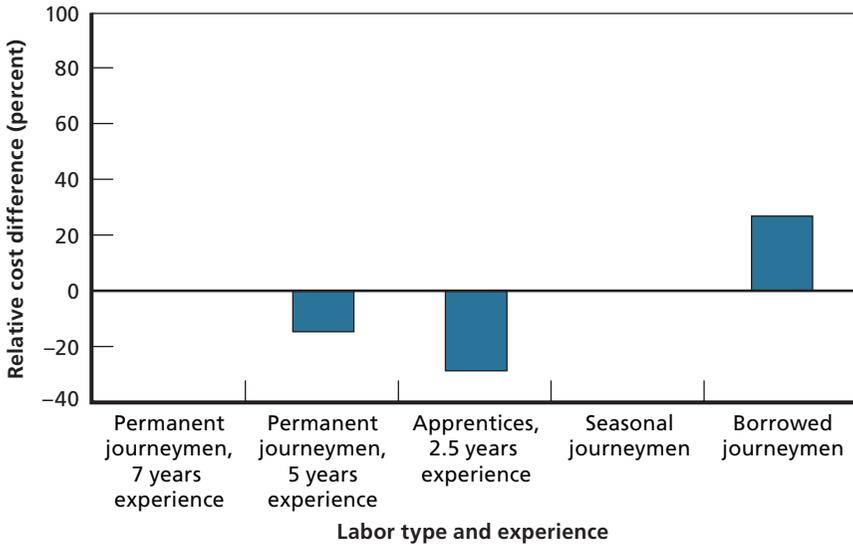
¹² Port rates are NAVSEA estimates of the average daily contractor rate for groups of private shipyards by geographic location. The Navy uses these estimates for planning and budgeting purposes.

¹³ These port-rate data were obtained from Department of the Navy, 2006a.

¹⁴ See U.S. Office of Personnel Management, undateda.

¹⁵ See U.S. General Services Administration, undated.

Figure 3.7
Relative Cost Difference Compared to Permanent Journeymen



NOTE: Shipyard responses to the RAND questionnaire revealed that employees with more than seven years of experience, including apprentice training, are considered fully experienced.

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employee.¹⁶ Specifically, it shows, as a percentage of the cost of the fully experienced permanent labor, the costs of (1) permanent employees with seven years of experience, (2) permanent employees with five years of experience, (3) apprentices with two-and-a-half years of experience, (4) fully experienced seasonal journeymen, and (5) fully experienced borrowed journeymen.

Borrowed journeymen have the highest relative cost because they are paid travel and per diem when working at another site. Seasonal journeymen, who receive the same pay and benefits as permanent staff with comparable experience, have the same cost as permanent employees. Unsurprisingly, employees with less experience have lower relative

¹⁶ Shipyard responses to the questionnaire revealed that employees with more than seven years of experience, including apprentice training, are considered fully experienced.

costs. We next consider how productivity can affect the ultimate cost of labor.

Productivity and the Relative Cost of Labor

There are many ways to define and measure worker productivity. In this book, we define *productivity* as a fraction of productive work over a unit of time. For example, a worker with a productivity of 0.5 completes half as many maintenance tasks in an hour as a worker with a productivity of 1.0.¹⁷ We review productivity data and issues in the next three sections and again in Chapter Four.

Variation in Productivity with the Use of Overtime

We asked shop-level directors, human-resource directors, and other department heads at the four public shipyards to characterize how productivity varies with the use of overtime. We also reviewed literature on the implications of overtime for productivity.¹⁸ We learned that loss of productivity associated with overtime is largely attributable to worker fatigue, but that part is also attributable to ineffective coordination of work and overcommitment of resources.

We also learned that the loss of productivity when overtime is used depends on how overtime is managed and is particularly affected by

- percentage of overtime worked, as defined by overtime hours as a proportion of straight-time hours. (For example, 10-percent overtime in a 40-hour week yields a 44-hour week).
- Spot duration (i.e., the number of weeks that workers remain on overtime).

¹⁷ Although our definition of productivity is the relative fraction of productive work over a unit of time, productivity may be defined in other ways. For example, it may be defined by the breadth of tasks a worker is capable of accomplishing.

¹⁸ Our sources were American Management Systems, 2003; National Electrical Contractors Association, 1989; Department of Army, 1979; Fairman, 2006; Brunies and Emir, 2001; Kerin, 2003; Shepard and Clifton, 2000; Homer, 1985; and Thomas and Raynar, 1994.

The effects of these two variables are not independent. For example, 15-percent overtime for four weeks may not affect productivity as severely as the same level of overtime for 15 weeks. As a result, some managers seek to cycle workers between periods of overtime and straight-time status.

Productivity is not the only concern for managing overtime. Some subject-matter experts suggested that safety concerns become more significant when overtime reaches or exceeds 30–35 percent of straight time even if the spot duration is carefully managed.¹⁹

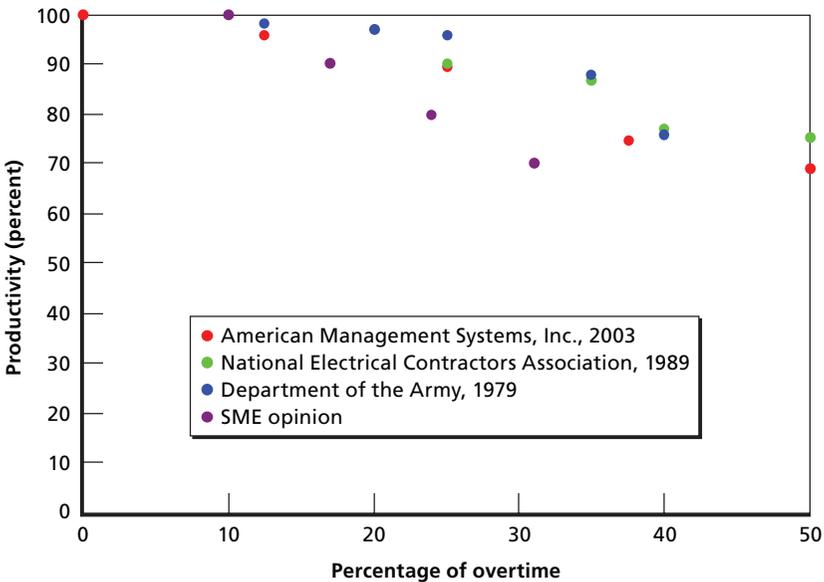
There have been examples of high percentages of overtime and long spot durations in some production shops at the public shipyards. As a result, the four public shipyards have enacted policies to more carefully manage overtime. This is reflected in recent trends. For example, Pearl Harbor implemented a policy in 2002 that prevents individuals from working 13 consecutive days, more than 25-percent overtime during a pay year without approval from the department head, or more than 35-percent overtime during a pay year without shipyard commander approval.²⁰ A subject-matter expert we interviewed (at another shipyard) indicated that current practices typically have workers performing no more than three to five weeks of sustained overtime before returning to straight-time status. This is roughly in alignment with recommendations from a 2003 American Management Systems report. The same expert said that worker productivity does not diminish much when overtime levels of less than 10 percent are used, but that at higher levels of overtime, productivity diminishes roughly 10 percent for every 7-percent increase in overtime. Our analysis of cost-effective workforce strategies therefore assumes an average spot duration of four weeks that is followed by at least one week of straight-time status.

¹⁹ The link between excessive overtime levels and increased on-the-job injuries is cited in Kerin, 2003. Subject-matter experts at naval shipyards cited safety concerns when employees work more than 35-percent overtime. At NNSY, employees who exceed 25-percent overtime in a year are evaluated to prevent safety problems.

²⁰ Commander, Pearl Harbor Naval Shipyard and Intermediate Maintenance Facility, 2002.

We plotted this information along with numerical estimates extracted from three studies.²¹ The horizontal axis of Figure 3.8 gives the percentage of overtime, and the vertical axis gives the average productivity. We do not see a decrease in productivity until overtime exceeds 10 percent. The reduction in productivity observed for every incremental increase in overtime varies by study. We used these data points to derive the marginal productivity rates applied to overtime levels in our tool.²²

Figure 3.8
Average Productivity Versus Percentage of Overtime for Four Weeks of Overtime



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²¹ These studies are American Management Systems, Inc., 2003; National Electrical Contractors Association, 1989; and Department of the Army, 1979.

²² The 2003 American Management Systems study results suggest that workers may actually accomplish a smaller amount of productive work at high levels of sustained overtime than they would if they worked fewer hours. Our tool implements a marginal-productivity model in which workers may accomplish the same amount of—but not less—productive work at high levels of overtime than if they worked fewer hours. In this respect, our model of productivity during overtime is optimistic.

Some shipyard staff observed that overtime can actually increase productivity. For example, there are some tasks that require a significant amount of setup time before productive work can begin. Overtime can be used to increase the number of productive hours of work for each setup.²³ Nevertheless, tasks with significant setup time are relatively uncommon.

Shipyard managers should not focus on finding a single, ideal proportion for overtime. Rather, they should consider a range of overtime that is likely to be effective. The exact overtime level that is most effective in a given situation will depend on conditions at the shipyard, such as the workload, workload variability, and the specific jobs or tasks that must be performed.

The Effect of Worker Type and Experience on Productivity

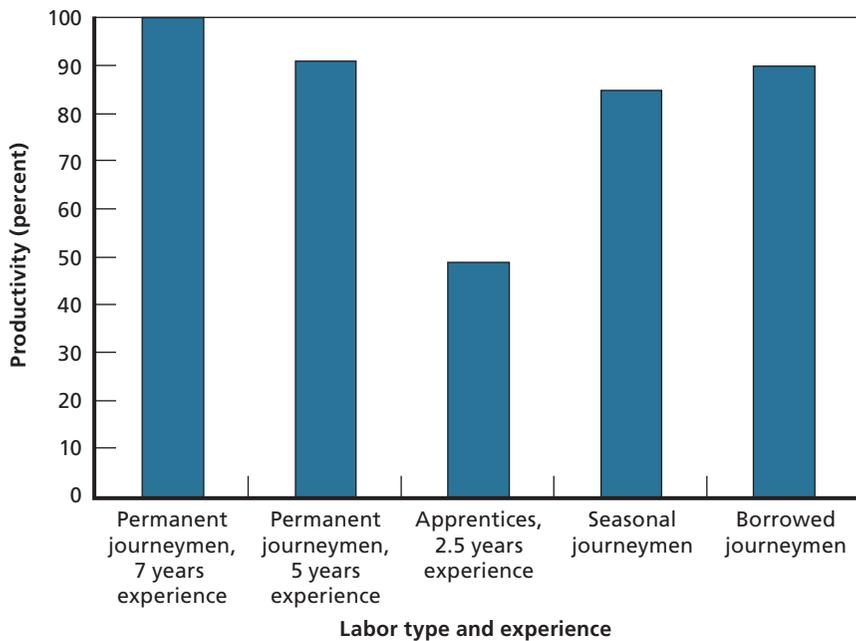
In this section, we consider how productivity varies by worker type and experience level. Our primary sources of information for this evaluation were responses to the shipyard questionnaire and interviews with subject-matter experts during our visits to the shipyards. We learned that in most production shops, it takes about seven years of experience for a worker to become fully productive; we also learned that permanent workers were, on average, as productive or more productive than other labor types. For this reason, we chose permanent workers with seven or more years of experience who are working straight-time hours as our reference case, and associated a productivity of 1.0 with it.²⁴

²³ Consider, for example, a task requiring one hour of setup time each shift before productive work can begin. Workers on straight time work 8-hour shifts, five days a week. Hence, five hours out of every 40 will be spent on nonproductive setup. If workers were to perform 25-percent overtime by working 10-hour shifts five days a week, then the ratio of unproductive setup hours to productive work hours each week would decrease from 5:40 to 5:50. This would result in a productivity increase of about 3 percent, assuming workers did not become fatigued by sustained periods of overtime.

²⁴ We realize that the productivity of *individual* workers will vary. For instance, a young worker with only five years of experience may be more productive than a more senior journeyman because of greater agility and other factors. But we interpret productivity factors as average values for the purposes of costing, rather than interpreting them as predictors of the productivity of individual workers.

For simplicity, we grouped individuals into one of three experience groups. Individuals were categorized as apprentices (i.e., workers who had about two-and-a-half years of experience), workers who had about a year of experience beyond the apprentice program (i.e., a total of about five years of experience), or as fully experienced journeymen (i.e., workers with more than seven years of experience). Each level of experience was assigned an average productivity. We assumed that all new workers are hired as apprentices and that all retirees are journeymen. We collected non-retirement related attrition-rate estimates for workers in each experience category. We asked subject-matter experts at each shipyard to characterize how productivity varies by experience level and worker type. We show the resulting estimates of productivity in Figure 3.9. (Note that, for clarity, we show the productivity of seasonal and borrowed labor types with a journeyman level of experi-

Figure 3.9
Productivity by Worker Type and Experience



ence only. The productivity associated with workers of these labor types with less experience would be lower than the values shown.)

The experience levels of seasonal workers, who may be relatively young workers hired on a trial basis or retired journeymen returning to the workforce, vary greatly; hence, their individual productivity may vary greatly from the average shown in Figure 3.9. Similarly, borrowed workers may vary widely in their productivity, although the average productivity of such journeymen is about 90 percent of that of resident journeymen (as shown in the figure). The lower productivity for borrowed journeymen can result from travel, any additional training and orientation that may be required when the workers come to a new shipyard, and differences in facilities, procedures, and practices they must learn. Although the productivity estimates were provided by experts in the field, they are subject to some debate; we therefore explore the implications of differing estimates and other productivity considerations in Chapter Four.

The productivity factors for overtime, labor type, and experience level are compounded by the Workforce Allocation Tool. For instance, productivity with 20-percent overtime is about 90 percent of the level seen in straight time; permanent workers with five years of experience are about 90 percent as productive as permanent workers with at least seven years of experience; and borrowed journeymen are about 90 percent as productive as resident journeymen. Therefore, a borrowed worker with five years of experience working 20-percent overtime would be about 73 percent ($0.90 \times 0.90 \times 0.90$) as productive as a resident journeyman working straight time. In our model, this average level of productivity applies to all hours worked.

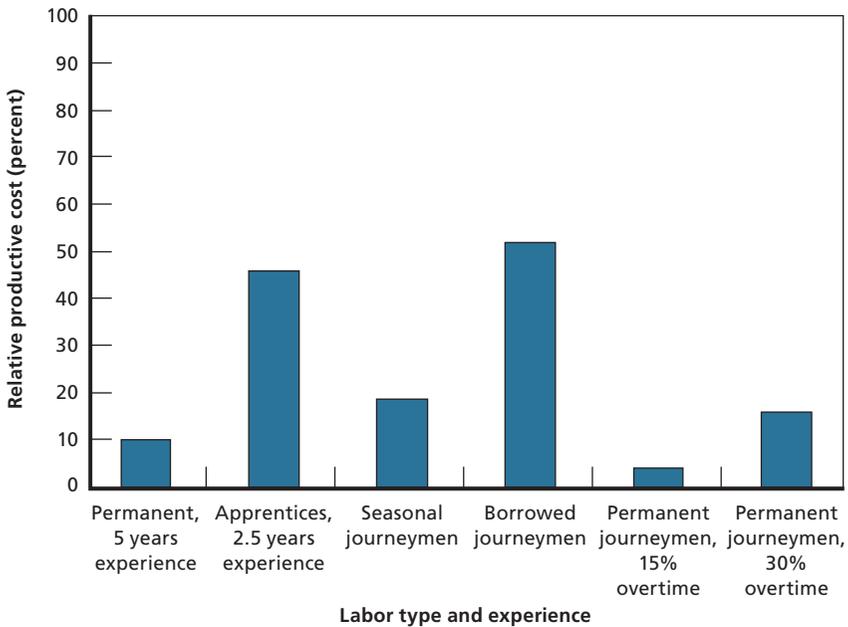
The Relative Productive Cost of Labor

Thus far, we have described the straight-time and overtime costs of different types of labor and have described how productivity can vary between them. When cost and productivity are evaluated together, workforce planning can be improved. We compared the costs of accomplishing productive work using different labor types, varying experience levels, and assumptions about overtime. To do this, we chose permanent journeymen during straight time as a baseline. We

then estimated a relative cost premium for different combinations of labor type, experience level, and overtime. For each combination, we divided the labor cost (see Figure 3.7 for the relative cost differences) by our corresponding estimates of productivity. The results are shown in Figure 3.10.

As the figure shows, there is about a 10-percent cost premium, after adjusting for productivity effects, for using permanent workers with only five years of experience. Although the average wage grade of a less-experienced worker is lower than a journeyman’s, there is a 10-percent cost premium because the less-experienced worker is not as productive as the journeyman. Similarly, apprentices earn lower wages but still carry a cost premium of nearly 50 percent because they are less productive. The wage grade of a seasonal worker is equivalent to that of a permanent worker with the same experience, but seasonal workers are less productive and therefore carry a cost premium of approximately

Figure 3.10
Cost Premium Compared to Permanent Journeymen During Straight Time



20 percent. By far the greatest cost penalty is associated with borrowed labor. As we have discussed, borrowed labor is not as productive as similar resident labor. But the primary drivers of the cost premium for using borrowed labor are the per diem and lodging costs. Note that the cost premiums shown in the first four columns of Figure 3.10 assume productivity and wages during straight time only. For comparison, we also show the cost premiums associated with permanent journeymen at 15- or 30-percent overtime. The cost premiums for these workers result from a combination of higher wage rates (workers earn time-and-a-half during overtime, although additional fringe is not paid) and lower productivity.

The results shown in Figure 3.10 are average values for all four public shipyards and are based on CP-specified DLI values for FY 2008. In reality, costs vary between shipyards and from year to year. The Workforce Allocation Tool evaluates these costs separately for each shipyard and estimates the annual changes in DLI. It also evaluates more combinations of labor types, experience, and overtime levels than are shown in Figure 3.10. For example, the tool can directly estimate the relative cost of a seasonal employee with seven years of experience who works 17-percent overtime.

Nonetheless, Figure 3.10 provides a simple reference for comparing different workforce strategies. For instance, we can see that there is a lower cost premium associated with increasing the permanent workforce by hiring apprentices than there is with using borrowed labor to meet a peak in demand. Of course, borrowed labor does provide an immediate remedy. It takes time to hire and train apprentices, and once the workforce is increased, it is difficult to reduce it when the demand for labor decreases.

We applied the productivity and relative cost data discussed above to the Workforce Allocation Tool. The tool uses this information to calculate minimum-cost workforce strategies to meet specified workload demands. We used these calculations to identify a cost-effective workforce strategy for planned workload demands.

Strategies for Meeting Planned Workload Demands

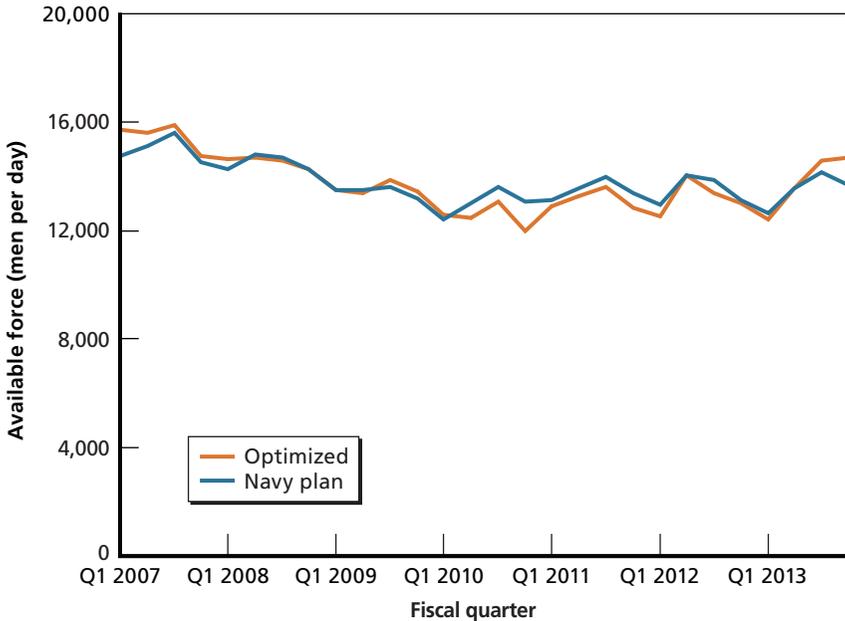
We used our calculations of the relative cost of labor to identify an optimized workforce staffing plan. We compared this plan with the Navy workforce staffing plan specified in the September 2006 WARRs.

For the Navy's workforce staffing plan, we assumed the demand would be met by the available workforce as specified in the WARRs, and that any shortage or surplus in available workforce to meet demand would be mitigated by overtime, borrowed and loaned workers, and seasonal workers. For the optimized staffing plan, we let the Workforce Allocation Tool determine the available workforce levels at each public shipyard in each fiscal year to meet demands at minimum total cost to the Navy. As in the Navy plan, any shortage or surplus in available workforce would be mitigated by overtime, borrowed and loaned workers, or seasonal workers. We assumed that the workforce would decrease only through natural attrition and retirement (i.e., there would be no RIF action) and increase only through hiring and training apprentices. We also considered the time and cost of hiring new labor or using other mechanisms to increase the available workforce.

Figure 3.11 compares the Navy staffing plan with the optimized staffing plan at the total shipyard level. The Navy and optimized staffing plans are nearly identical, with the optimized plan resulting only in a 2.3-percent reduction in total cost. Results for the individual shipyards, not shown here, were similar. The optimized staffing plan's 2.3-percent reduction in cost results from the fact that the available workforce more closely tracks the workload demand during times when workload demand dips below average. Compared to the Navy's plan, the tool predicted that workforce levels could be further reduced (by a small amount) during those periods and then built back up as demand increases following the dip. Given the small cost savings predicted by the tool, and given the uncertain nature of estimates of productivity, we deemed the difference in the two plans to be negligible. In short, we found that the Navy's workforce staffing plan is a cost-effective strategy for meeting planned workload demands.

Although the optimized plan and the Navy plan are nearly identical at the aggregate level, there is one notable difference at the shipyard

Figure 3.11
The Optimized Available Force and the Navy's Plan Are Nearly Identical



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level: the reliance on borrowed labor at Pearl Harbor. The Navy plan calls for an annual average of 150 borrowed workers at Pearl Harbor between FY 2007 and FY 2013, while the optimized plan reduces this annual average to fewer than ten borrowed workers. It accomplishes this reduction by increasing permanent workforce levels at Pearl Harbor and subsequently reducing workforce levels at the yards that would have loaned Pearl Harbor the labor. The optimized workforce plan calls for a drastic reduction in the average number of borrowed workers, but also results in the use of as many as 110 borrowed workers for short durations. The decision to use borrowed workers is often driven by demand for critical skills. We consider influences on the decision to use borrowed workers in the next chapter. The Navy and optimized plans did not differ in their use of seasonal labor or overtime.

Implications of Workload Inflation

As discussed previously, WARRs typically underestimate the workload to be accomplished, although these estimates improve as the execution date nears. As noted earlier, there is some evidence that these underestimations are less severe in near-term estimates at shipyards that are mission funded. However, the cost implications of underestimation, particularly the costs that result from using increased levels of overtime to manage excess work, can still be severe.

To evaluate the potential cost implications of above-the-estimate workload growth, we increased the WARR workload estimates for FY 2007 to FY 2013 and used our tool to estimate the cost of executing the increased workload with the Navy's existing workforce plan. Our reference case is based directly on the WARR estimates for workload and available workforce during this period. Our variants on this case are based on a 4-percent increase to the WARR-estimated workload for FY 2008 and an 8-percent increase for FY 2009–FY 2013. This results in an average annual increase of 6 percent over the seven-year period. We then used the tool to estimate the cost of executing the base case and increased workloads with the Navy's workforce staffing plan. In every case, the tool optimized the use of overtime and borrowed and loaned workers to meet workload demands when the demand exceeded the Navy's plan.

The results of this modeling are summarized in Table 3.2. The data in the first row correspond to the original WARR workload plan. The data in the second row correspond to a scenario in which annual workload is increased by 6 percent. From the first row (or baseline case), we see that the Navy's staffing plan calls for an available force of 13,800 men per day, on average, and we see that the planned workload is 15,485 man-days on average. In the case of increased workload, we see that a 6 percent increase in the workload equals 16,433 man-days on average. From the last column, we see that the cost of executing the planned workload at the public shipyards is about \$2.8 billion per year, but the cost of executing the increased workload is \$3.2 billion per year. This is an increase of about 14 percent. This means that with the Navy's planned staffing levels, a 6-percent increase in workload

Table 3.2
Summary of Cost Implications for Executing Planned and Increased Costs of Executing Planned and Increased Workloads

Workforce Increase Above Plan?	Workload Increase Above Plan?	Average Available Force (men per day)	Average Workload (man-days)	Average Overtime	Peak Overtime	Average Annual Cost (FY 2007 \$ billions)
No	No	13,800	15,485	13%	19%	2.8
No	Yes	13,800	16,433	20%	28%	3.2
Yes	Yes	14,500	16,433	11%	18%	3.0
Yes	No	14,500	15,485	9%	17%	2.8

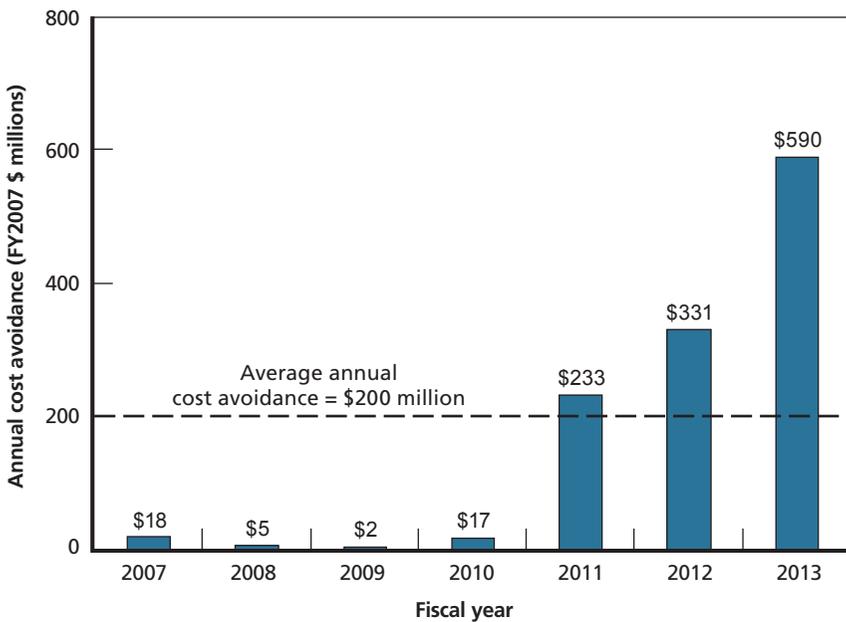
results in a 14-percent increase in cost. The primary reason for the large increase in cost is that the use of overtime must increase substantially to handle the increased workload. The table indicates that, on average, overtime would have to increase from 13 percent to 20 percent; the overtime peak would increase from 19 percent to 28 percent. The lower productivity and higher wages of workers during overtime result in a cost penalty evident in the table.

We also used the tool to (1) generate an optimized staffing plan to accomplish the increased workload and (2) estimate the cost implications of using such a plan if workload inflation does *not* occur. The last two rows in Table 3.2 show the costs that result from an optimal available force of 14,500 men per day. If both the workload and workforce levels increase, the cost of meeting the workload is \$3.0 billion; this is an increase of \$200 million over the total cost shown in the first row. In contrast, the cost of meeting an increased workload with a workforce that does not increase is \$3.2 billion (see the second row). In other words, there is an additional cost of \$200 million for accomplishing 6 percent more work through an increased workforce, but there is a \$400 million additional cost for doing so through greater use of overtime. The last row shows the cost associated with increasing the workforce if workload growth does not materialize. The cost of this scenario

is not measurably different from the cost of the baseline case.²⁵ This is because an increased workforce would allow the Navy to meet workload demands with less overtime. Average use of overtime in this case would decrease from 13 percent to 9 percent; peak overtime use would decrease from 19 percent to 17 percent.

We have seen that increasing the available force halves the annual additional cost of accomplishing 6 percent more work if the actual workload exceeds the planned workload. In this respect, a cost *avoidance* can be realized by increasing available workforce levels. Figure 3.12 shows this savings by year. We estimate that the average annual savings

Figure 3.12
Estimated Annual Cost Avoidance Offered by the Optimized Workforce



RAND MG751-3.12

²⁵ The tool does estimate a very slight increase in cost associated with hiring additional workers, but that cost is (1) small compared to total cost and (2) negligible given the precision of the numbers shown in the table.

from FY2007 to FY 2013 will be approximately \$200 million (in FY 2007 dollars).²⁶

Most of the fiscal benefits associated with reducing overtime would occur after 2010, but several other benefits could be realized more quickly. Increasing the workforce would allow overtime capacity to be used to meet unexpected surge demands. Ensuring that there is a large enough workforce to keep overtime levels down could also reduce workforce burnout and safety problems.

Given the uncertain effect of mission funding on future workload growth, we performed sensitivity analyses for our results on the minimum and maximum historical workload growth observed. We used the minimum and maximum workload growth identified in Figure 2.5 to increase the workload identified in the WARR. We then used our tool to estimate (1) the optimized workforce level to meet the workload growth and (2) the cost of different planning approaches when they are applied to different levels of workload and workforce growth. Table 3.3 summarizes these results.

The first row of Table 3.3 corresponds to the Navy's planned workforce and workload. That is, it shows no growth in the workload or workforce, meaning that the planned and actual workload and

Table 3.3
Costs of Executing Planned and Increased Workloads

Workforce Increase Above Plan?	Workload Increase Above Plan?	Minimum-Growth Case Average Annual Cost (FY 2007 \$ billions)	Average-Growth Case Average Annual Cost (FY 2007 \$ billions)	Maximum-Growth Case Average Annual Cost (FY 2007 \$ billions)
No	No	2.8	2.8	2.8
No	Yes	3.1	3.2	4.7
Yes	Yes	3.0	3.0	3.2
Yes	No	2.8	2.8	2.9

²⁶ The increasing trend in cost avoidance observed might continue beyond 2013, but was not evaluated.

workforce are identical. That is why the costs for minimum, average, and maximum growth are constant. The second row reflects a scenario in which the actual workload exceeds the planned workload but the workforce does not increase. In this scenario's minimum growth case, workload is increased by less than 1,000 man-days each day; in the average-growth case, it is increased by approximately 1,000 man-days each day; and in the maximum growth case, it is increased by more than 1,000 man-days each day. The third row reflects a scenario in which both workload and workforce are increased. In this case, the increase to the workforce is determined by an optimization. The fourth and final row contains the optimized workforce from the third row but an unchanged workload.

As in the case with average workload growth, it is more cost-effective to meet increased workloads through increases in the workforce (rather than through additional overtime). The amount of money that it might cost the Navy to increase the workforce is less than 10 percent of what the Navy might have to pay for not increasing the workforce. In other words, a strategy of increasing the workforce has a much lower cost than a strategy of not increasing the workforce. If the workforce is increased to accomplish a maximum workload growth, but the additional work *does not* materialize, the Navy will pay \$100 million for this labor. However, the annual cost of not increasing the workforce when maximum workload growth does occur is nearly \$1.5 billion. Considering the historical precedence of workload growth, another case is feasible: The workforce is increased to address a maximum workload growth, but only a minimum amount of workload growth is observed. In this scenario, a cost avoidance of nearly \$200 million dollars per year occurs. We observe that hiring additional labor hedges against much higher potential costs if the workload increases by the minimum, average, or maximum amount. As the size of workload growth increases, so does the amount of cost being hedged against. This is because more overtime must be executed to bridge the gap between the available force and workload, which results in increasing costs.

In summary, an examination of the cost effects of minimum and maximum workload growth supports our earlier findings: The Navy

can avoid high cost penalties associated with workload growth by increasing the public-shipyard workforce. We observe only a small or negligible cost penalty for this decision if workload does not increase.

Findings and Recommendations

We have seen that two key variables affect productivity during overtime: percentage use overtime and spot duration. Careful management of both is required to minimize loss of productivity. We assumed that spot durations would be limited to about four weeks; after that time, workers would be required to return to straight time status for at least one week. This assumption roughly matches the recommendations of American Management Systems and appears to be consistent with current shipyard practices. In cases where we allowed our Workforce Allocation Tool to determine cost-effective workforce levels, the tool did not eliminate overtime. That is, when carefully managed, overtime is a useful and cost-effective mechanism for meeting variable workload demands. Overtime is also effective for jobs that require significant setup time. None of our results indicate that eliminating overtime is a cost-effective strategy; in fact, our results suggest that employing average annual overtime of 9–18 percent is cost-effective. Excessive overtime levels or long spot durations can result in large decreases in worker productivity, mostly due to fatigue. High and sustained levels of overtime can also lead to safety concerns.

We have seen that although less-experienced workers earn lower wages than more-experienced journeymen, they are less productive on average; their use results in a cost premium. We have also seen that there is a substantial cost premium associated with using borrowed labor, primarily because of per diem and lodging costs. Nonetheless, borrowed labor may prove more attractive than high levels of overtime, particularly when the overtime results in lost productivity or safety concerns.

We have seen that the Navy's staffing plan is a cost-effective workforce strategy for meeting planned workload demand. The optimized staffing plan and the Navy's staffing plan for anticipated work-

load demand are nearly identical, although our optimized plan would increase the number of permanent workers at Pearl Harbor and reduce that shipyard's reliance on borrowed workers. Furthermore, although the Navy's staffing plan is acceptable for meeting planned workload demand, actual workload demand has often exceeded planned levels. Therefore, there may be a high cost premium (\$200 million) associated with trying to meet continued increased demand with the Navy's current staffing plan. The primary reason for this cost penalty is the high levels of overtime that would be necessary to meet the increased demand under an unchanged workforce plan. If workload growth is even higher than expected, and if the workforce is not increased, the cost of not increasing the workforce could reach \$1.5 billion per year. Increasing the permanent workforce could provide the Navy with a hedge against workload growth at virtually no cost.

Additional Workforce Considerations and Sensitivity Results

The previous chapter described the fiscal and other consequences of current workforce- and workload-planning processes and offered a potential workforce strategy for mitigating cost growth. Shipyard interviewees suggested that we also evaluate several other important considerations that have implications for our analyses. We were able to evaluate some of these considerations during our research, and we discuss them in this chapter.

We first wish to list the elements that warrant future research, but that we could not fully evaluate because of limited data and information. These elements are

- technical- and critical-skill staffing levels
- the impact of off-site work on required staffing levels
- overhead and indirect-workforce levels
- the availability and cost of contractors
- the optimal workforce staffing plan for each shop.

Analyses of technical- and critical-skill staffing levels as well as the impact of off-site work on required staffing levels will be possible when the trade-skill workload and workforce database currently being developed by NAVSEA 04 is implemented. With additional time, funding, and these new data, our Workforce Allocation Tool could be used to estimate the optimal workforce staffing plan for each shop. NAVSEA 04 also wishes to evaluate indirect workload and how this workload is estimated and forecasted. This information will be critical to efforts to

control cost. Gathering data on the availability and cost of contractors will require great effort, but is critical to efforts to control cost. These data are also required for evaluation of cost tradeoffs between contractors and other workforce mechanisms. Any evaluation of contractors must consider specific skills, locations, and contractor overhead rates. Because contractor overhead can vary, it is difficult to forecast a single, fixed contractor rate. Other market variables, such as local demand for a specific trade-skill, can also affect the cost of contractors.

We now turn to the topics recommended for consideration that we were able to address in our study. These are workforce planning at the shop level, limitations to using borrowed and seasonal labor, the implications of off-site work on staffing levels, and the sensitivity of our results to changes in analytical assumptions. We discuss each of these in turn below.

Shop-Level Evaluations

Our discussion of appropriate workforce levels so far has focused on aggregate workforce levels. Yet as many shipyard interviewees emphasized, while a total workforce level may appear optimal for accomplishing a given workload plan, only an evaluation of workload and workforce at the shop level can reveal which skills or trades require more or fewer employees. To evaluate whether staffing levels within each shop require adjustment, we looked at several shop-level characteristics. We were particularly interested in identifying shops with

- highly variable demand
- high peak overtime levels
- high average overtime levels
- recruiting difficulties
- skills that require a long time to acquire and become proficient in
- an above-average attrition rate
- a large proportion of the workforce nearing retirement.

We collected data on these variables through our questionnaire, and only evaluated shops for which we received data. We then evaluated these raw data and information to develop indicators for the variables. These indicators can imply a need for specific workforce-management strategies. For example, excessive overtime, high attrition rates, recruiting difficulties, long skill-development timelines, and a large number of pending retirements all suggest that the shipyard must take action to ensure that desired workforce numbers are maintained. High workload variability requires staffing strategies that allow peak workload demands to be met in a cost-effective manner.

Workload Variability

High workload variability means that matching labor supply to workload demands can be very challenging. In shops where this condition exists, variability may be best addressed through the use of contractors, tiger teams, borrowed and loaned labor, or a multiskilled workforce that can move between shops.

We evaluated the variability of the workload within each shop and compared it to staffing levels. Some shops with highly variable workloads employ a large staff that can manage peaks. Other shops have a small workload but very few workers, and thus are unable to manage even small swings in workload. To measure variation in workload across shops relative to staffing levels, we calculated the standard deviation in shop workload and divided it by the average number of individuals in the shop.¹ Table 4.1 presents the data derived from a sample of shops. The first column lists the shop name, the second column lists the workload standard deviation in men per day, the third column lists the average available force in men per day, and the fourth column lists the ratio of the data in the second column to the data in the third column, expressed as a percentage. We believe that any shop whose ratio of workload variability to average staffing levels exceeds 150 percent has a potential staffing problem. This ratio indicates that the workload variability is well above average levels. Table 4.1 shows two examples of this threshold being exceeded: the Tool Shop and the

¹ This statistic is known as the coefficient of variation.

Table 4.1
Workload Variability Among Several Shipyard Shops

Shop	Workload Standard Deviation (men per day)	Average Available Force (men per day)	Ratio Expressed as a Percentage
Electronics	9	57	16
Electrical	18	95	19
Sheet Metal Workers	7	47	15
Tool Shop	15	3	587
Temporary Services	67	13	502

Temporary Services Shop. In the Electronics, Electrical, and Sheet Metal Shops, the workload variability is less than 20 percent of the available force. In the Temporary Services and Tool Shops, however, the variability significantly exceeds the average staffing level, indicating a considerable challenge in managing workforce and workload.

Temporary Services functions include the initial setup required prior to the start of an availability, such as ensuring that lighting, equipment, power, and water are available. An evaluation of workload variability in the Temporary Services Shop at all four public shipyards revealed that each shop, except the one at Pearl Harbor, experiences a greater-than-average level of variability. All four shipyards' Tool Shops, whose highly cyclical workload demands fluctuate with availability phases, also experience a level of variability that significantly exceeded the available workforce. These Tool Shops and Temporary Services Shops will require additional staffing to meet workload demand. Hiring additional workers or using contractors, tiger teams, or borrowed and loaned labor are all viable options for managing such variability.

Overtime

High overtime levels can also indicate understaffed facilities. Although small amounts of overtime can boost productivity, high amounts (i.e., sustained levels that exceed 15 percent or levels that peak at more than 35 percent for an extended period of time in a single year) may

characterize understaffed shops that should consider adding more permanent staff or using more contractors.

We evaluated monthly peak and average overtime levels from 1997 to 2006 in each shipyard's direct-production shops. We observed that average and peak overtime levels were high at most shipyards and shops. Table 4.2 shows the average and peak overtime levels across all production shops for each shipyard.² Overtime use was relatively low at Puget Sound, where peak overtime in any shop never exceeded 35 percent, but overtime use was relatively high at Portsmouth, where average overtime levels were 40 percent.

Recruiting Challenges

Indicators of recruiting difficulty were identified in the questionnaire and in our interviews with shipyard employees. Recruitment difficulties vary by shop and shipyard. The Electronics Shop, for instance, was difficult to staff at Portsmouth and Puget Sound. No other shop experienced recruiting difficulties at more than one shipyard. Norfolk had the greatest number of shops with recruiting difficulties, especially in the Pipefitter, Outside Machine, Welding, and Electrical Shops. The recruiting difficulty at Norfolk is likely caused by local competition for skilled labor. Portsmouth interviewees also identified the shipfit-

Table 4.2
Average Overtime and Average Peak Overtime Levels per Year at Each Shipyard, 1997–2006

Shipyard	Average Shop Overtime (%)	Average Peak Shop Overtime (%)
NNSY	29	46
PHNSY	23	42
PNSY	40	65
PSNSY	18	24

² Averages shown here are not weighted by the number of individuals in the shop. Hence, they cannot be compared to the averages shown earlier in this book. Small shops with high overtime levels and large shops with low overtime levels are represented in these averages.

ter trade as a trade that is difficult to staff. To mitigate risk, shipyards should consider incentives to increase the available workforce in these particular shops.

Time to Become Productive

Most shop skills take three to seven years (which includes apprentice training) for workers to acquire. Shops requiring longer training time also require longer time to replace lost labor. Increasing the number of individuals in such shops could mitigate the risks associated with loss of skills in these shops. The amount of time it takes for a worker to become fully productive also varies by shipyard. Interviewees at two shipyards indicated that it took more than seven years to develop skilled labor in the Electronics Shop. Considering that this job is also difficult to fill (as noted in the previous section), an increase in the number of Electronics Shop employees is advisable.

Attrition

Higher attrition than evident in nonshipyard local labor markets could indicate staffing problems. If not managed properly, such attrition could cause some shops to become understaffed. In our study, a shop that experiences attrition rates equal to at least 1.5 times the rate of all the other shops in a given shipyard is considered a high-attrition shop. At Portsmouth, the Electronics Shop demonstrated a higher-than-average attrition rate. This is particularly troubling because this shop also (1) requires considerable time to develop skilled personnel and (2) has difficulty recruiting. An increase in the workforce is one approach to keep staffing levels within high-attrition shops, specifically the Electronics Shop, at the desired levels.

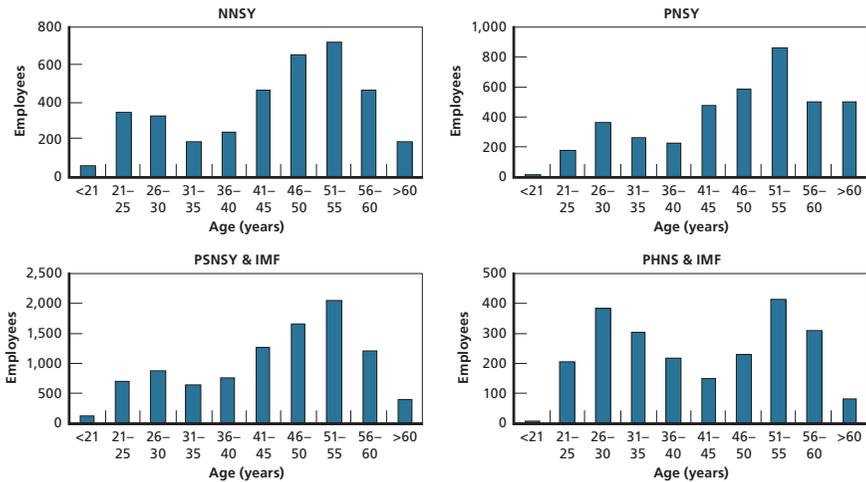
Demographics

The number of individuals within the workforce that are expected to retire in the next five to ten years is significant in some shops. The average retirement age across the shipyards is 58; in our study, therefore, we considered workers of 50 or more years of age likely to retire in the next decade.

Figure 4.1 shows the age distribution of workers at each of the four shipyards. At Portsmouth, nearly 50 percent of the workforce will be eligible for retirement within the next decade. To replace this workforce, Portsmouth must hire nearly 190 employees every year from 2007 to 2014. Norfolk will require 140 new hires annually, Pearl Harbor will require 80, and Puget Sound will require 370. These hiring rates are well within the 20 percent maximum sustainable growth rate that the shipyards can accommodate.³

Some shops' median worker age exceeds 50 years, including the Tool Shop at Norfolk; the Insulating Shop at Pearl Harbor; and the Pipefitter, Inside Machine, and Tool Shops at Portsmouth. To ensure that a sufficient quantity of skilled labor is available to replace the retiring workforce and maintain current employment levels in these shops, shipyard managers must take action to hire workers.

Figure 4.1
Age Demographics at NNSY, PHNSY, PNSY, and PSNSY



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³ Maximum sustainable growth rates were provided by the shipyards and were based on historical data covering the ten-year period between 1997 and 2006.

Shop-Level Summary

An evaluation of all indicators across all shops and shipyards reveals some important trends, as shown in Table 4.3. Demand in the Tool Shop at all shipyards was highly variable, while demand in the Temporary Services Shop was highly variable in most shipyards. Average and peak overtime levels were high at all shipyards. All shipyards experience some recruiting or attrition problems in the Electronics Shop. Other indicators were of interest only in specific shipyards and shops.

Table 4.3
Number of Shipyards Exhibiting Each Indicator

Shop	Highly Variable Demand	Local Demand for Labor Is High/ Recruiting Is Difficult	Time to Acquire a Trade Is More than Six Years	High Attrition	Greater than 50% of the Workforce Is 50 or More Years Old	Average Overtime Exceeds 15%	Peak Overtime Exceeds 35%
Pipefitter	0	1	1	0	1	4	3
Shipfitter	0	1	1	0	0	4	3
Welding	0	1	0	1	0	4	3
Inside Machine	2	0	1	0	1	3	2
Outside Machine	0	1	1	0	0	4	3
Electronics	0	2	2	1	0	2	3
Electrical	1	1	1	1	0	4	3
Sheet Metal	0	0	1	0	0	2	3
Insulating	1	0	0	0	1	4	1
Painting and Blasting	0	0	0	1	0	4	2
Temporary Services	3	0	0	0	0	4	3
Tool	4	0	0	0	2	4	3

We also observed several shipyard-unique trends. Norfolk has difficulty staffing the Pipefitter, Welder, Outside Machine, and Electrical Shops. Pearl Harbor has high attrition in its Electrical Shop, and new workers require a long time to become productive. The Portsmouth Electronics Shop also has high attrition and is difficult to staff. Puget Sound has difficulty staffing the Electronics Shop.

A number of targeted management strategies could help address these challenges. The use of subcontracting or temporary labor may be required to meet variable demands; this in turn will require that a skilled subcontracting or temporary labor pool be available. The development of a common apprentice program shared by the private and public sectors could facilitate the development of a skilled labor force for the public depots. The costs and benefits of such an approach require further evaluation.

A retention or incentive program may be desirable for shops that experience high attrition levels or are difficult to staff. This may be the cheapest approach to staffing problems in shops that experience high attrition and require a long time to develop new workers.

Finally, as the workforce ages and retires, shipyards will need to develop and implement programs for ensuring that the right mix and level of skills are available to execute future work.

The Limitations of Seasonal and Borrowed Labor and the Implications of Off-Site Work

During interviews, shipyard managers commented on the limitations associated with the use of borrowed and seasonal labor and on the implications of off-site work on staffing levels. We discuss each of these issues below.

In our optimization of the workforce, we assumed that borrowed labor would be available when needed. In our shipyard interviews, however, we learned of several obstacles to using borrowed labor. In some cases, shipyards plan to borrow labor but do not receive it. According to one manager, not receiving the promised labor on time (or at all) adversely affects critical-path jobs. Interviewees also noted that there are

restrictions on using borrowed labor once it has arrived. Borrowed labor is subject to the budgets and overtime limitations of the loaning shipyard and cannot be easily moved between projects, particularly if the projects have different funding sources. If these obstacles cannot be eliminated, then our optimization underestimates the amount of resident, permanent labor needed to achieve a cost-effective workforce plan.

One human resources manager told us that seasonal labor is a “permanent solution to a temporary problem.” Because seasonal labor can be laid off for up to but no more than six months, downturns in work that last longer than six months make seasonal labor an unreasonable solution. Temporary labor could be an attractive alternative in such situations, but the workforce needs to be planned accordingly and a substantial temporary labor market must exist.

The public depots support numerous off-site projects, including the maintenance required for a forward-deployed aircraft carrier in Yokosuka, Japan. Although we included estimates for off-site workload in our evaluation of an optimized workforce, we were not able to evaluate the distribution of limited critical skills between projects. Our estimates for the optimized workforce may therefore underestimate the number of workers required across all shipyards. In addition, overseas sites that borrow labor will experience higher costs and lower productivity due to the extensive travel time and costs associated with importing this labor. Given the possible underestimation of the off-site workload, our optimization results should be considered a lower bound for the suggested staffing levels at each site.

The Implications of Productivity Assumptions

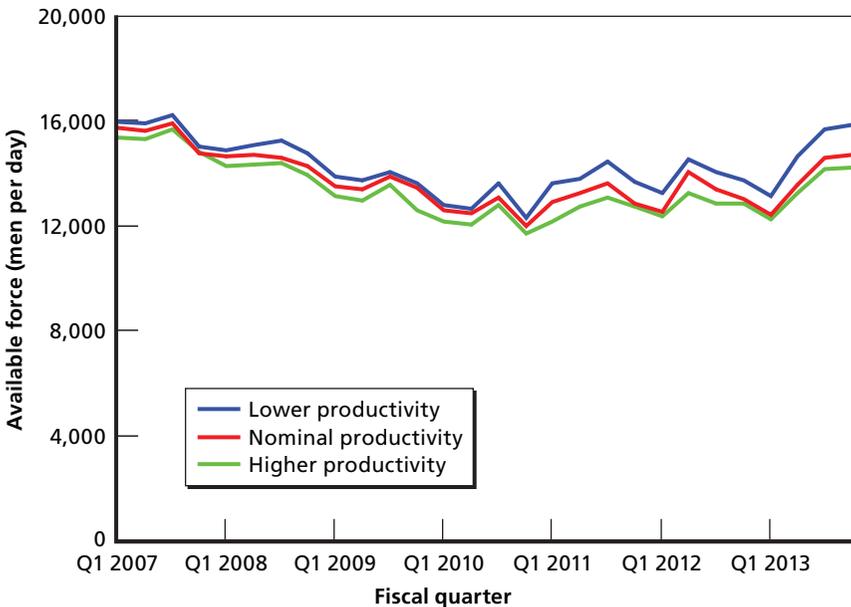
The Sensitivity of Available Workforce and Total Cost to Overtime Productivity

In Chapter Three, we compared the Navy workforce plan with our optimized workforce plan and concluded that the resulting available workforce levels are, given existing workload plans, nearly identical. The key assumption that underlies this finding is our estimate of how productivity varies with levels of overtime use. In this section, we evaluate the

sensitivity of available workforce levels and the total cost of labor to our assumptions about overtime productivity. Specifically, we used previously cited studies to establish productivity penalties of +8 percent and -8 percent of our baseline productivity assumption to account for lower and higher productivity, respectively; used the Workforce Allocation Tool to evaluate an optimized workforce plan; and compared the resulting available workforce levels and estimated costs. The resulting optimized available workforce levels are shown in Figure 4.3.

When the productivity penalty is set at an average of +8 percent of our baseline productivity,⁴ the optimized workforce must increase to offset the lower productivity. More specifically, the optimal workforce level increases by approximately 4 percent and the annual cost increases by approximately 1 percent. Conversely, if the productivity

Figure 4.3
Optimized Available Workforce Levels for Lower, Baseline, and Higher Productivity Penalties



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⁴ I.e., if productivity is 8 percent lower than anticipated in our nominal case.

penalty of overtime work is set at an average of -8 percent of our baseline productivity,⁵ then the optimized workforce can decrease because of the comparatively greater productivity of workers. More specifically, the optimal workforce decreases by approximately 3 percent and the annual cost decreases by approximately 1 percent.

We draw the following conclusions from this sensitivity analysis. First, if the assumptions in Chapter Three underestimate the loss of productivity that results from increased overtime, then the Navy workforce plan may underestimate the number of workers required. If productivity is 8 percent lower than our assumption, then the Navy plan understates the requirement for workforce levels by approximately 4 percent. Conversely, if the assumptions in Chapter Three overestimate the loss of productivity that results from increased overtime, then the Navy workforce plan may overestimate the number of workers required. If productivity is 8 percent higher than our assumption, then the Navy plan overestimates the requirement for workforce levels by an average of 3 percent.

Increased Productivity for Borrowed Workers

In Chapter Three, we saw that there is a 50-percent cost premium for using borrowed journeymen to execute workload. The primary contributions to this cost premium are travel and per diem costs and the slightly lower productivity of borrowed employees.

Although there are few options to reduce travel and per diem costs, there may be options to improve the productivity of borrowed workers. Responses to our questionnaire indicated that borrowed workers are about 90 percent as productive as resident workers. Their lower productivity results from any additional training and orientation that may be required when workers come to a new shipyard and the different facilities, procedures, and practices they must learn.

What if the productivity of borrowed workers could be raised to that of resident workers by standardizing training, facilities, procedures, and practices? Would this reduce the cost premium associated

⁵ I.e., if productivity is 8 percent higher than anticipated in our nominal case.

with using borrowed workers? Would it be cost-effective to use borrowed workers more often?

To address the potential effect of standardized training on the cost premium associated with using borrowed workers, we evaluated that cost premium while assuming that borrowed-worker productivity is equal to that of fully experienced, permanent, resident journeymen. Figure 4.4 shows the results, along with the cost premiums associated with other labor types and skill levels. We see that the cost premium for fully productive borrowed labor decreases to 40 percent.

We used the Workforce Allocation Tool to determine whether it would be cost-effective to use borrowed labor more often if it were as productive as resident labor. Figure 4.5 presents the results of this sensitivity analysis. It shows the cost-optimal amount of borrowed labor the Navy should use across the four public shipyards in each fiscal quarter

Figure 4.4
The Cost Premium Associated with Using Borrowed Workers Instead of Permanent Journeymen (During Straight Time)

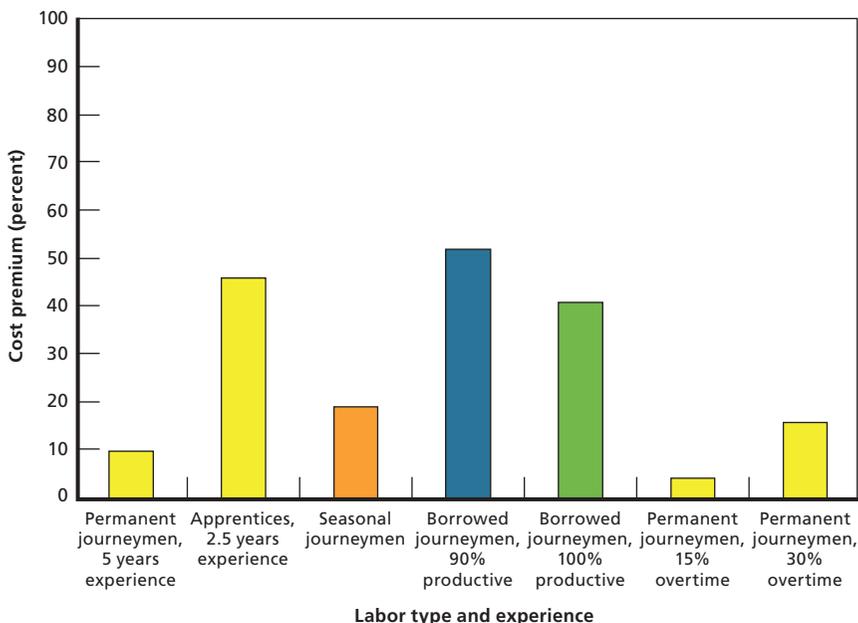
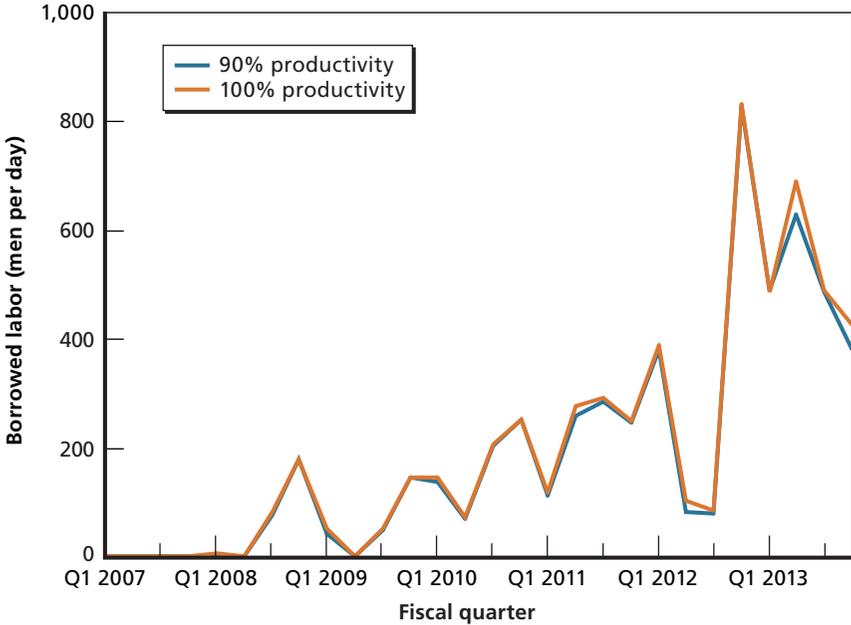


Figure 4.5
Cost-Optimal Levels of Borrowed Labor Assuming 90- and 100-Percent Productivity



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assuming 90- or 100-percent productivity for this labor. It indicates that there is almost no difference in the amount of borrowed labor used in an optimized strategy even if that labor’s productivity matches the productivity of permanent, resident staff.

In summary, although standardizing training and other initiatives to increase the productivity of borrowed labor could reduce the cost premium associated with that labor, borrowed labor’s use in an optimized workforce strategy would remain nearly unchanged because of the remaining travel and per diem costs.

An Evaluation of Alternative Workload Allocation Strategies

In the previous chapters, we explored different workforce-management strategies for a static workload demand. That is, we assumed that workload would remain fixed at the level indicated in a certain plan. What if we were to relax that assumption and explore how different allocations of workload affect cost-effectiveness? That is, what would occur if work were to shift between public and private maintenance providers or among the four public shipyards?

In this chapter, we explore different workload allocations. There are three alternative strategies to reallocate workload, described below.

1. Shift work from the public to the private sector. The rationale for this strategy is that it might result in greater efficiencies or the most cost-effective practices in the private sector, thereby resulting in less-expensive maintenance. The strategy would have to account for workforce-reduction costs, such as increased overhead costs, in the public sector as a result of the shift. A shift from the public sector to the private sector might not be feasible due to the 50/50 rule, regulations requiring public depots to retain core capabilities, and other regulations and laws.

2. Shift work from the private to the public sector. The rationale for this strategy is that public shipyards that are currently underutilized might work more efficiently at higher levels of throughput. This greater efficiency might result from better utilization of the workforce, workers who are more experienced, or lower marginal costs (since fixed indirect costs are paid by more work). One drawback to this strategy

is that modifying existing, long-term contracts with the private sector might result in penalties or fees that would offset any savings. The costs associated with work that stays in the private sector might also rise due to a decrease in the business base (which would result in increased overhead for remaining work). Alternatively, some private-sector firms might go out of business, thereby reducing competition for work (competition is presumed to reduce cost and improve quality). Finally, most private-sector work consists of surface-combatant availabilities. This work is not the major business of the public sector, which generally focuses on nuclear ships and large amphibious ships. Therefore, it is unclear whether moving private-sector work to the public shipyards would actually help the public shipyards sustain key skills or accomplish existing work more efficiently.

3. Shift work between public shipyards. This strategy might be effective for workload mismatches at the shipyards (these occur when, for example, there is a shortage of work in one shipyard and an excess of work at another). It also might be more efficient for the shipyards to specialize in particular work (one could specialize in carrier work, for example, while another could specialize in submarines) and to shift work accordingly. Such specialization, however, may not be compatible with homeport rules. We also have little evidence that specialization can be as efficient during repairs as it is in new construction.

In this chapter, we explore the second allocation strategy: shifting work from the private sector to the public sector. We do not think that the first strategy is realistic because (1) the shift of work to the private sector may violate the 50/50 rule and (2) most public-sector work involves nuclear ships and submarines, and qualifying a private shipyard to work on nuclear systems would be expensive and politically challenging.¹ We did not fully explore the third strategy, but we present a qualitative discussion of this option later in the chapter.

¹ There is one private shipyard that performs nuclear-carrier availabilities. Thus, it might be possible to shift nuclear work to that shipyard. Because discussions with the private sector were precluded in our work, the feasibility of such a work shift remains unknown.

Shift Work from the Private Sector to the Public Sector

The “Naval Shipyard Business Plan” states that the public shipyards would be more efficient if their workload were increased to 4.2 million man-days per year, which is higher than the annual average of 3.7 million man-days observed over the Future Years Defense Program.² This conclusion is drawn from an examination of the *overhead efficiency ratio* (the ratio of direct labor to total labor). The ratio was observed to increase with increasing workload. Thus, on an average per-hour basis, the fraction of indirect hours decreases as workload increases. This reduction in the burden of indirect workload was seen as an increase in efficiency. The plan also notes that if workload were to increase above 4.2 million man-days, then inefficiencies would result from higher levels of overtime and the effects associated with having to hire inexperienced workers to accommodate the work. As we saw in the previous chapter, the overtime levels are already higher than is optimal. Therefore, adding more work to the public-sector shipyards may be even less efficient than believed.

There are two separate approaches to shifting work to the public sector. The first approach is a systemic or long-term increase in shipyard workload. In other words, workload would consistently increase above what is currently planned. Another approach is to use additional work to strategically fill gaps or temporary downturns in demand to keep the workforce active in a short-term shift. We explore these two approaches in the sections that follow.

A Systemic Shift

To evaluate the costs associated with shifting work from the private sector to the public sector, we examine a hypothetical case at Puget Sound. To avoid the complications of other workforce issues related to short-term variability, we hold the workload steady over a number of years. More specifically, we fix the workload at the 2007 level presented in the POM-08 CP. We then compare the costs of this baseline workload to the costs of a workload that increases by a certain number

² Naval Sea Systems Command, 2007.

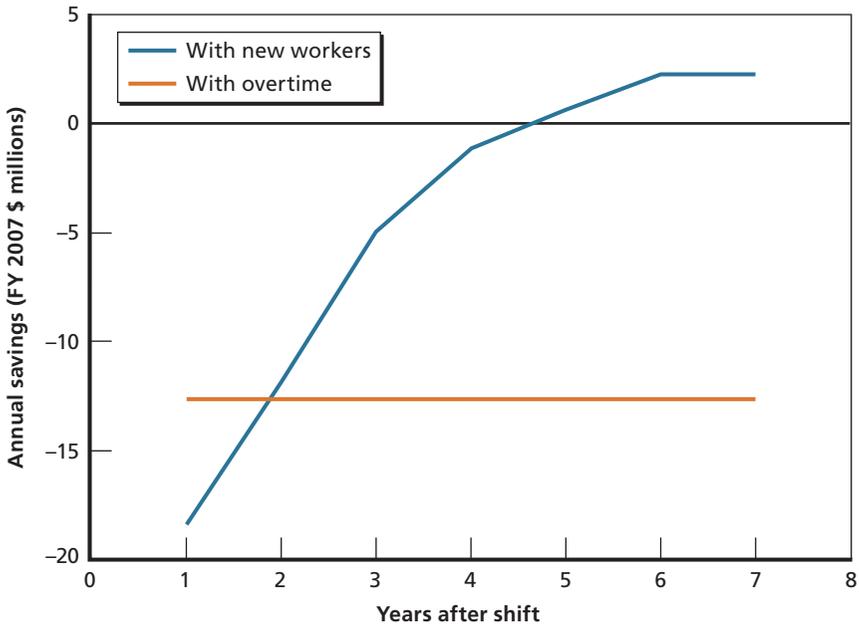
of direct workers in the public sector (and decreases correspondingly in the private sector). The net savings is the cost of the baseline workload plus the cost of the shifted work from the private sector (at the private-sector rates) minus the cost of the increased workload scenario. We use the labor rates, factors, overhead levels, and productivity values provided in previous chapters. The private-sector rates are based on the local average nonnuclear port rate.³

There are two options for accommodating the increased workload in the public sector: hire new workers or use additional overtime. As we observed in Chapter Three, the levels of overtime used by the shipyards are already higher than optimal. Therefore, using increased overtime to accommodate additional work will likely be ineffective. Figure 5.1 shows the annual savings resulting from shifting the demand for 100 workers from the private sector to PSNSY and managing this increased demand through new hires or additional overtime. In the figure, a positive value is a savings in comparison to the baseline plan; a negative number is a net cost. As can be seen, using overtime for the additional workload is not cost-effective at any point. Rather, managing the shifted demand through overtime would cost the Navy nearly \$13 million more each year than it would to keep this workload in the private sector.

Figure 5.1 shows that it takes several years for the Navy to realize the savings that result from hiring new workers to manage a workload shift from the private sector to Puget Sound. In fact, in the first year, it would be less expensive to accommodate the shift using overtime rather than hiring new workers. This is a result of the new worker's lower productivity and the costs associated with hiring and training these workers during the first year. By the third year, however, the annual cost of using new workers to manage the shifted workload would be less than the cost of using overtime. Put another way, it would be less expensive

³ A limitation of this analysis is that we do not know how the port rate is affected by private-sector workload. In other words, we do not have data on how the indirect-cost components of the port rate might increase as work is shifted away to the public sector. However, our analysis can be viewed as an optimistic case for moving work. As we will see, shifting work from the private sector to the public sector is not economically attractive even with these optimistic assumptions.

Figure 5.1
Annual Savings Associated with Using Overtime Instead of New Workers to Manage a 100-Worker Shift in Demand from the Private Sector to PSNSY

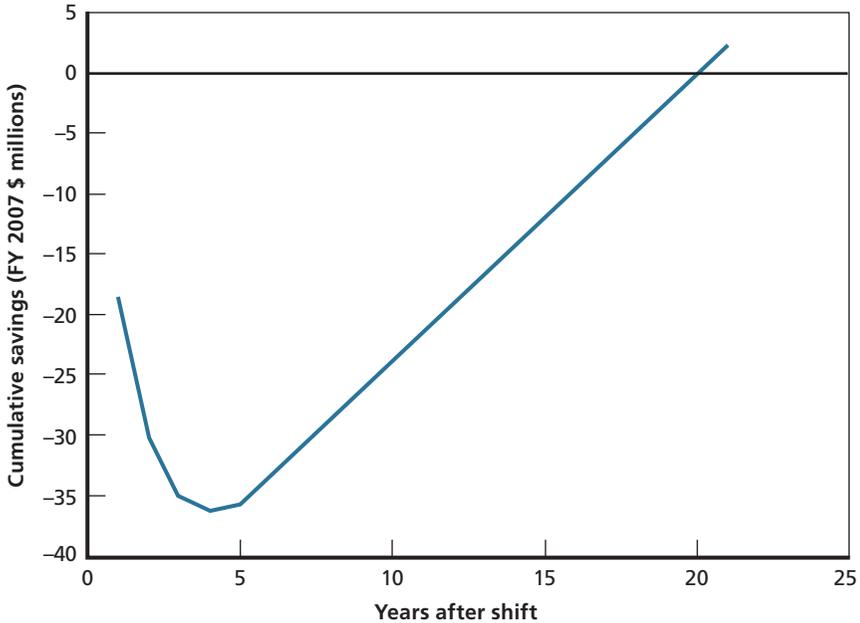


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to use overtime to manage a workload shift of less than two years, but less expensive to hire new workers for a shift that lasts more than two years.

The initial costs (i.e., negative savings) associated with hiring workers to handle a shift of workload from the private sector to Puget Sound mean that the breakeven year (i.e., the year when the cumulative savings total zero), is quite distant. In the cases we examined, in which workload demand for 50–500 workers shifts from the private sector to the public shipyards, the breakeven point is about 20 years away; that is, the Navy would not realize net positive savings from the shift until 20 years after it assumed the additional workload. Figure 5.2 shows the cumulative savings associated with hiring 100 new workers to meet a 100-worker shift in demand from the private sector to Puget Sound. The figure shows, for example, that ten years after the shift, the

Figure 5.2
Cumulative Savings Associated with a Shift of 100 Workers from the Private Sector to PSNSY



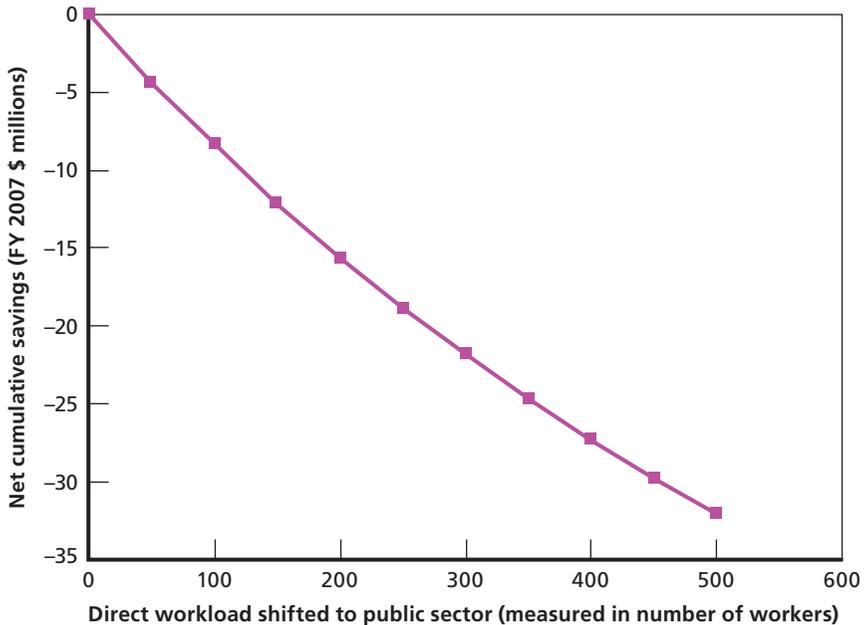
RAND MG751-5.2

net cost to the Navy is approximately \$25 million; that is, ten years after the shift, the Navy would have spent \$25 million more than it would if it simply left the work in the private shipyards.

In fact, this analysis probably overstates the possible savings. According to the Office of Management and Budget, during formal cost-benefit analysis, one should conduct a net present value (NPV) analysis if the time sequence of the cash flows is uneven.⁴ As Figure 5.2 shows, in the example of shifting work to the public sector, there are additional upfront costs, and savings materialize many years later. Figure 5.3 shows the relative NPV of shifting varying workloads from the private sector to the public sector. More specifically, we calculated the NPV of cumulative savings realized 20 years after shifting

⁴ Office of Management and Budget, 1992.

Figure 5.3
NPV of Cumulative Savings 20 Years After Shifting Workload from the Private Sector to PSNSY



RAND MG751-5.3

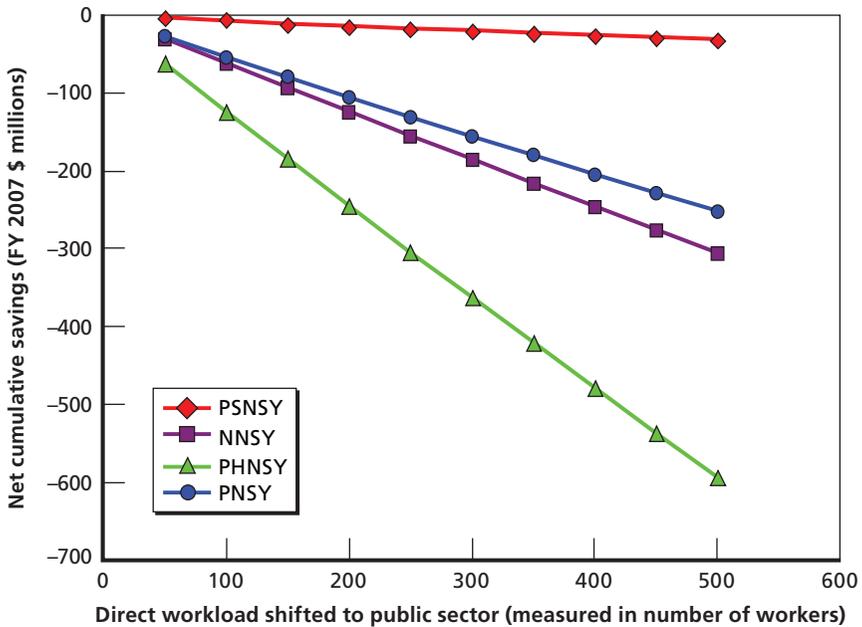
0–500 workers from the private sector to Puget Sound. We applied a discount rate of 3.0 percent per Circular A-94 guidance (20-year, real interest rate) in these calculations.

If no workload is shifted, then the net savings after 20 years is, of course, zero. If 100 workers are shifted, the NPV of cumulative savings after 20 years is \$8.4 million. That is, the Navy will have spent \$8.4 million more over 20 years for shipyard maintenance than it would if it did not to shift workload. Similarly, if 300 workers are shifted, the net cumulative savings after 20 years is \$21.4 million; if 500 workers are shifted, the savings are \$32.1 million. The NPV of shifting workload from the private sector to PSNSY is *never* positive and therefore is economically unattractive, regardless of the amount of work or the timeframe analyzed.

The results for the other shipyards are even more unattractive. As Figure 5.4 shows, none of the other shipyards achieves breakeven within 20 years. After 20 years, for example, the NPV of cumulative savings associated with shifting 500 workers from the private sector to the public sector is \$253 million at Portsmouth, \$307 million at Norfolk, and \$596 million at Pearl Harbor. As at Puget Sound, the costs of shifting private-sector work to these shipyards would never reach a breakeven point, regardless of the workload shifted or the timeframe considered.

We also evaluated how these results would change if each shipyard were able to draw labor from an idle experienced labor pool rather than having to hire additional green labor. In other words, during this analysis, we posit the existence of an experienced workforce that migrates from the private shipyards to the public shipyards. This

Figure 5.4
NPV of Cumulative Savings 20 Years After Shifting Workload from the Private Sector to the Public Shipyards



assumption results in marginal savings at PSNSY (in fact, the amount is small enough to fall well within the uncertainty of these calculations) and even greater expense at the other shipyards.⁵ Therefore, even under optimistic assumptions, we cannot find meaningful savings in a long-term shift of work from the private sector to the public sector.

Short-Term Shift

Occasionally, a depot may have too little work for its workforce; this results in a *workload gap*. If that gap persists for several months or years, finding additional projects or work for the idle workforce would be desirable. In such a situation, it may be beneficial to move private-sector surface-ship work into the public depots.

To identify potential gaps, we evaluated each shipyard's WARR and identified periods when the direct available workforce exceeded the direct workload. As we saw in Chapter Two, the WARR tends to underestimate the workload to be accomplished, so it is important to note that these gaps are likely overstated. In Figure 5.5, green areas represent periods when the available force exceeds the workload; red-shaded areas represent periods when workload exceeds the available force. The green-shaded areas represent opportunities to bring surface-ship work into the depots to fill workload gaps. Although such work might not sustain nuclear skills, it would keep the workforce busy and could save the Navy money. Because the workforce is already paid for, the Navy would have to pay additional money only to cover the material costs associated with the work. If the shifted work were executed in the private sector, then the labor and overhead costs would also have to be paid.

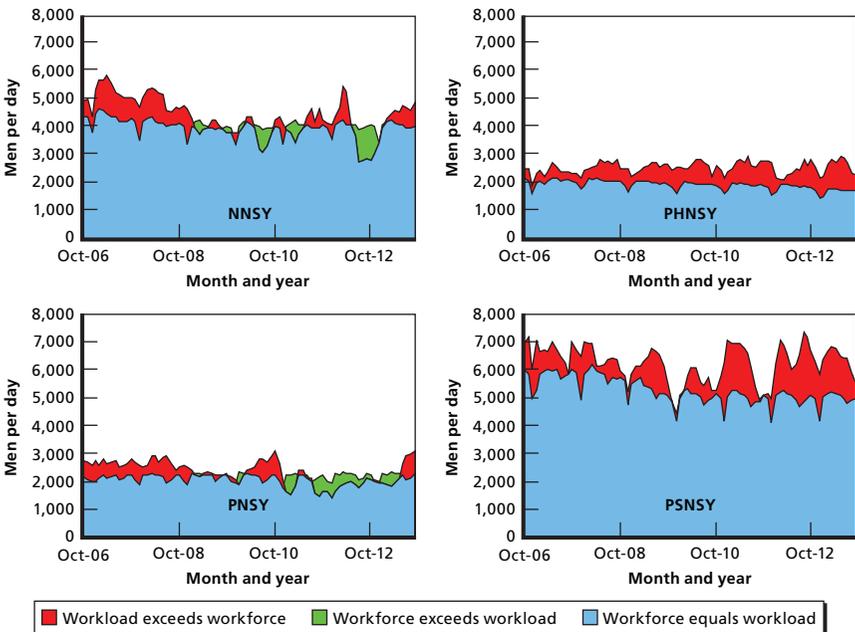
The total workload associated with the green-shaded areas is approximately 380,000 man-days. Our estimate of the cost of an equivalent amount of work in the private sector is based on private-

⁵ Do not confuse this result with our earlier recommendation that the Navy hire more workers to handle its own likely workload in future years. In the previous discussion, we compared the cost of hiring additional workers to using overtime to accommodate additional work with the current workforce. Here, we compare the cost of doing more work in the public sector (with additional public-sector workforce) with the cost of leaving work in the private sector. In this analysis, overtime rates are fixed.

sector port rates. We used the Workforce Allocation Tool described in Chapter Three to estimate the cost of executing the work at the public depots. Our calculations reveal that the cost of doing the work in the public sector is nearly identical to the cost of doing the work in the private sector.

An alternative to using private-sector surface-ship work to fill public shipyard gaps is the borrow-and-loan program. Personnel at the four public depots are treated as a corporate resource that can be shared across sites. Using the WARRs from each shipyard, we identified excess work at Pearl Harbor and Puget Sound. When there is excess workforce at Portsmouth and Norfolk, there is an opportunity to match excess work with excess workers. Although borrowed workers are expensive, the cost of using them in this particular situation would be equivalent to the costs associated with shifting private-sector work to the public depots.

Figure 5.5
Workload and Workforce at the Public Depots



However, there may be nonmonetary reasons to use surface-ship work (rather than borrowed or loaned labor) to fill gaps. For example, the idle workforce may not have the skills required by the borrowing shipyard. Such considerations would have to be evaluated on a case-by-case basis. Overall, our analysis demonstrates that, in general, the cost-benefit of using surface-ship work to fill gaps is small, and the cost-benefit of using surface-ship work rather than borrowing and loaning labor is zero when the workforce exceeds the workload.

Shift Work Between Public Shipyards

NAVSEA and the Commander, Fleet Forces Command (CFFC), work together to assign workload packages to different shipyards. Many factors are considered during the allocation process, but a small number of business rules serve as the main evaluation criteria. While assigning work to shipyards or shifting work among shipyards, the following questions must be considered:

- Does the shipyard have the capacity and capability to execute the work? The public depots provide nuclear repair capabilities while the private sector typically provides nonnuclear repair capabilities.
- Are Navy policies being followed? As noted, maintenance periods of longer than six months must be completed at or near the homeport; maintenance periods of shorter duration can be competed.
- Are statutory regulations (such as the 50/50 rule) being upheld?
- Is the shift cost-effective?

The evaluation of alternative workload also involves estimating the impact on the crew, operations, schedule, class maintenance plan, and modernization.⁶ The extent to which these questions and factors can be answered quantitatively is limited. The Navy is currently developing

⁶ These factors are identified in Department of the Navy, Chief of Naval Operations, 2006.

a workload-allocation tool to help decisionmakers evaluate workload-allocation strategies. A quantitative evaluation of these factors is limited by available data, but is ripe for future research.

Summary

We considered two possible strategies for moving work from the private sector into the public sector. We looked at both long- and short-term shifts of workload, but found no clear cost advantage to moving work. Any shift of work would also have to adhere to statutory requirements, homeport policy, and shipyard-capability constraints. Other workload-allocation strategies, such as shifting work between public shipyards or from public to private shipyards to mitigate costs, would require analysis of questions that were beyond the scope of our study.

An Evaluation of Other Organizations' Workload- and Workforce-Management Practices

Our third research objective was to examine the workload- and workforce-management practices of other organizations to identify practices that could help the Navy manage the public depots. We were interested in organizations that faced similar challenges and constraints in their operations, including (1) variable and uncertain workloads that require a range of skills and (2) workforce-management constraints.

Some military and commercial organizations face variable and uncertain demands. For example, demands at the Defense Logistics Agency have greatly increased with the war in Iraq. Also, commercial shipping companies, such as FedEx and UPS, have variable demands over the course of a year. Workers in these organizations, however, require fewer skills and training than are needed for public-shipyard work. The commercial organizations also do not face the same constraints on managing their workforce as government organizations.

Ultimately, we identified four types of organizations with workforce-management issues similar to those the public shipyards face. These are UK dockyards that support the Royal Navy, European commercial shipbuilders, the U.S. Air Force and U.S. Army depots, and space-shuttle maintenance by the National Aeronautics and Space Administration (NASA). We review each of these organizations below. Although none is a perfect parallel to shipyard maintenance—each varies from the U.S. Navy in terms of scope or complexity of work—all offer some comparative insight into feasible strategies for shipyard workforce-management.

United Kingdom Dockyards

Three dockyards in the UK perform depot-level work for the ships and submarines of the Royal Navy: Devonport Management Limited (DML), Fleet Support Limited (FSL), and Babcock Rosyth. DML is near the Plymouth Naval Base, FSL occupies a portion of the Portsmouth Naval Base, and Rosyth is close to the Clyde Naval Base. In addition to performing depot-level maintenance for the fleet, the dockyards provide engineering and waterfront support as well as some logistics and facilities-management services at the naval bases. They also provide repair services when ships are at homeport; these services are called *fleet time*.

Individually, UK nuclear submarines and surface ships have maintenance workload packages similar to those of U.S. ships. Nevertheless, the Royal Navy fleet is significantly smaller than that of the U.S. Navy, consisting of approximately 12 nuclear submarines and 50 surface ships. Therefore, the total ship maintenance workload in the Royal Navy is much smaller. Also, the UK dockyards are not owned by the government; the former Royal Dockyards were converted to government-owned, contractor-operated status in 1987 and completely privatized in 1997. Thus, the UK dockyards are not subject to the civil-service rules faced by the U.S. public shipyards, although they are subject to UK employment laws regarding the termination of employees. Funding and scheduling also differ, with the UK Ministry of Defence (MoD), rather than the fleet, controlling each of these factors.

Workload-Management Strategies

When the dockyards were privatized, the MoD hoped that competition would help control the costs of depot maintenance. However, a reduction in the size of the Royal Navy coupled with the desire to sustain all three dockyards forced the MoD into a policy of allocating availabilities to each dockyard. The MoD and the three dockyards work together to assign and schedule availabilities to best smooth workload demands across all three dockyards.

Other workload-management strategies in the UK include spreading work more evenly over fleet time and depot visits to help fill gaps

in demand between major depot availabilities. The MoD is shifting to continuous maintenance and increasing the amount of work accomplished during fleet time in an effort to smooth workload. Large work packages are regularly split into smaller, more-frequent work packages in an attempt to avoid large workload peaks and variation. The MoD also works with the dockyards to determine whether a refit can be scheduled slightly earlier or later or whether the duration of a refit can be extended to distribute workload more evenly. To fill gaps in workload, the UK dockyards have been diversifying their product base with non-MoD work, such as building luxury yachts and military land vehicles and repairing train engines and commercial ferries. DML, the only nuclear-certified dockyard—and, therefore, the dockyard that performs all submarine refueling, refit, and decommissioning—is exploring the possibility of working with the commercial nuclear-power industry.

Workforce-Management Strategies

The UK dockyards employ several workforce-management strategies to address the ebbs and flows of workforce demands. The UK dockyards have not found high amounts of overtime to be very effective in meeting peak demands, and therefore try to limit overtime to 20 percent of straight time. European Union (EU) work restrictions on the maximum number of hours in a workweek also help limit overtime. UK dockyard managers agree that a small amount of overtime used over a limited period can increase productivity.

The UK dockyards use nonpermanent workers to augment permanent staff during peak-demand periods. Temporary hires, both blue-collar and white-collar, are procured from an outsourcing agency and are used for specialized tasks or are integrated into a team. The UK dockyards use borrowed and loaned labor to a limited extent, but this is a practice that will likely increase with the upcoming Carrier Vessel Future program and with Babcock's purchase of DML. The dockyards commonly outsource "low-skill" tasks, such as scaffolding, painting, and cleaning.

One of the UK dockyards' strategies for efficiency that is not as widely used in the United States (mostly likely due to union restrictions) is training the workforce to be multiskilled. This permits mem-

bers of any trade to do any type of work, with the exception of a few very specialized skills. A team of workers is expected to be able to go into a ship “zone” and complete all necessary tasks.

The UK uses lean Six Sigma methodologies and other measures of productivity to track its workforce-management strategies and reduce inefficiencies. It also uses earned value management to track progress.

European Commercial Shipbuilders

Commercial shipbuilders face a highly competitive environment in which firms must control costs to win new contracts. Finding it difficult to compete with Asian shipbuilders in the cargo- and tanker-ship market, European commercial shipbuilders specialize in niche markets, such as cruise ships, high-speed ferries, and specialized chemical tankers. Although new construction is different from ship repair, the cyclical demands for workers of different skills is similar in both the commercial shipbuilding and public shipbuilding industries. The competitive nature of the commercial business leads to uncertainty in demands and to fixed delivery schedules (with stiff penalties for late delivery); these factors often cause unanticipated spikes in workload demands.

One trait that European shipbuilders have in common with the U.S. Navy’s public shipyards is tough labor-management constraints. National and EU policies often preclude the termination of employees or provide large monetary payments to workers who are terminated.

Workload-Management Strategies

To remain competitive, European shipbuilders use workload-management strategies that concentrate on core capabilities that attract steady demand for work. Shipbuilders maintain in-house capabilities in structural areas (such as steel fabrication and ship integration) and subcontract out the remaining portion (roughly half) of the man-hours required to build a ship. A robust subcontracting base is available and,

therefore, it is not difficult to augment in-house capabilities with the skilled craftsman of specialized firms.¹

Outsourcing is viewed as a way to simplify organizational structures and reduce the overhead costs associated with facilities and capital equipment. However, reductions in cost are not the primary motivation for outsourcing. European shipbuilders tend to outsource specialized, cyclical work (such as hotel functions), believing that turning such functional areas over to subcontractors increases product quality. To distribute workload more evenly, European shipbuilders divide construction across multiple shipyards. Some European shipbuilders take on military work to smooth workload demands.

Workforce-Management Strategies

As noted, European shipbuilders face stringent national and EU labor policies, making it difficult and costly for them to reduce their permanent workforce when workload demands decrease. Shipbuilders therefore hire only a limited number of new permanent employees. Instead, they supplement their permanent workforce with temporary labor to meet peak demands. If a schedule slips, they bring in temporary labor or subcontractors to get it back on track. Like the UK dockyards, European shipbuilders avoid excessive overtime and promote a multiskilled workforce to increase productivity. They closely monitor productivity at the task level.

The Depots of Other U.S. Military Services

It seems natural to compare workload at U.S. Army and U.S. Air Force depots with workload at U.S. Navy depots or shipyards. Upon further examination, however, we see that the comparison is not particularly apt. Table 6.1 compares the workload and duration of work packages for example platforms in the different services. A typical depot availability for a Navy ship requires tens to hundreds of thousands of *man-days* spread over several months; Air Force and Army availabilities,

¹ Schank, Pung, et al., 2005.

Table 6.1
Work-Package Magnitude and Duration Across the Services

Platform	Workload	Duration
Navy ships	Hundreds of thousands of man-days	6–12 months
Air Force airplanes	Tens of thousands of man-hours	2–3 months
Army combat vehicles	Thousands of man-hours	1–2 months

however, typically involve thousands to tens of thousands of *man-hours* spread over several *weeks*.

Furthermore, the Air Force and the Army typically purchase extra aircraft and vehicles to fill their depot pipelines while maintaining operational inventory levels. As a result, Air Force and Army depots typically have a number of aircraft and vehicles awaiting induction for repair at their depots. These aircraft and vehicles help smooth workload demands. Still, the other services' depots face workforce-management issues similar to those experienced by the Navy. We describe the Army depots below.

U.S. Army Depots

The Anniston Army Depot in Anniston, Alabama, provides depot-level support to the majority of the Army's combat tracked and wheeled vehicles.² Anniston also maintains Army bridges, towed and self-propelled artillery, and small arms. There are approximately 5,800 permanent workers at Anniston and approximately 1,200 additional private-sector partners and tenants at the facility. Prior to the conflict in Iraq and the global war on terrorism, the average annual Anniston workload was approximately 3.2 million man-hours (400,000 man-days). Anniston and other Army depots have seen a large increase in their workload during the Iraq War. Current annual workload at Anniston is approximately 7 million man-hours (875,000 man-days).

² Note that the Bradley Fighting Vehicle is maintained by the Red River Army Depot in Texarkana, Texas.

The Red River Army Depot in Texarkana, Texas, supports the Bradley Fighting Vehicle as well as the Multiple Launch Rocket System and approximately 60 percent of the Army's tactical vehicles (e.g., trucks, high-mobility multipurpose wheeled vehicles [HMMWVs], and heavy expanded mobile tactical trucks [HEMTTs]). It employs approximately 1,500 permanent workers and is currently accomplishing approximately 4 million man-hours (500,000 man-days) of work annually, with 45 percent of the work being done by the permanent staff and the remainder being done by temporary hires or subcontractors.

U.S. Army Depot Workload-Management Strategies

Both Anniston and Red River are leaders in public-private partnerships. This allows the depots to take on private-sector work when their Army depot work does not fully support their workforce. For example, General Dynamics also works on M-1 tanks and builds the Stryker vehicles at Anniston. At times, Anniston employees work alongside General Dynamics employees on those products. Red River has similar agreements with private contractors.

The depots develop budget estimates two years in advance; the budget for FY 2009, for example, is first developed in FY 2007. Supplemental work and funding for the surge in Iraq makes planning difficult because the depots are never sure how much supplemental funding they will receive. Planning for "normal" (i.e., nonsurge) years is more predictable and accurate.

Both depots have made significant progress in reducing work through lean Six Sigma initiatives. These have reduced unit-funded costs and man-hours per unit. Recent initiatives have allowed the depots to accomplish 6.3 million man-hours of programmed work with just 5.9 million actual man-hours. Using lean manufacturing techniques, such as value-stream analysis, the depots are better able to place new permanent or temporary employees in jobs commensurate with their education and experience to maximize productivity. This helps make temporary workers as productive as the permanent workforce in a short period of time.

U.S. Army Depot Workforce-Management Strategies

Both Army depots have increased overtime, contractor support, and temporary hires to meet the increased workload requirements that have resulted from the war in Iraq. Both depots operate at approximately 25 percent overtime, with some shops having an overtime rate of at least 35 percent. Prior to 2003, the depots had an overtime rate of approximately 12 percent. Army depot managers believe that productivity decreases as overtime rates increase.

Both depots normally have permanent staff to cover 80–85 percent of their anticipated workload and they plan to use overtime and subcontractors to cover the remainder. They hire new workers to fill spots vacated by permanent staff. During the war in Iraq, the depots have hired a large number of temporary employees who are given one-year, renewable contracts. They have also outsourced some process work, such as vehicle disassembly and assembly.

The depots use temporary workers with one-year, renewable contracts to fill both skilled and nonskilled positions. The temporary workers in skilled positions normally have a level of proficiency that allows them to blend into the depot workforce without the need for significant training. Depots also use temporary workers with minimal skills as “trade helpers” who support the journeymen or work in an independent job that is compatible with their skill level.

Both depots have had little problem recruiting temporary workers because there is a sufficient pool of available labor in their geographic areas. Higher pay and benefits compared to those offered by local private-sector jobs make work at the Army depots an attractive alternative. The number of applicants for temporary jobs typically exceeds the number of positions available. The depots hire the most-skilled applicants.

During the Iraq War, staying within the 50/50 rule has been difficult for the depots. Funding for depot overhaul of an end item comes from the Tank and Automotive Command (TACOM). The depot reports to TACOM how much work was subcontracted to the private sector. TACOM uses depot inputs to compile a report on the distribution of work between the public and private sectors. In this process,

the primary concern is providing the customer the required end items; staying within the 50/50 constraint is of secondary concern.

The Army depots do not have a borrow-and-loan program for workers. They do send permanent staff to forward locations and military bases to do repair work.

The depots use a workload forecasting system to help plan their workforce.³ Depot managers value the tool, but see some shortcomings in it. One problem is that the tool is only updated weekly. Another is that it requires that direct-sales work be entered manually. Finally, the tool is less helpful when predictions of future budgets are not available.

NASA Space-Shuttle Maintenance

NASA currently operates a fleet of three space shuttles. Although this number of vessels is obviously much smaller than the number of vessels in the Navy fleet, and is just half the number of shuttles NASA once had, these vessels do perhaps rival the most-sophisticated Navy ships in complexity. Each shuttle, though originating from the same design, is unique because of the spiral design used to ensure that it received the latest technology.

NASA managers often compare shuttle maintenance to maintenance required by commercial aircraft. However, they note that whereas commercial aircraft can benefit from reliability-centered maintenance (RCM), in which historical data inform where and when maintenance needs to occur, the orbiter fleet does not produce a large pool of flight data. Because the shuttles do not produce extensive historical data, NASA must perform many more systems tests and inspections between flights (see Table 6.2). In some ways, therefore, shuttle maintenance shares similarities with nuclear-submarine maintenance.

NASA uses two different work philosophies to manage the shuttle-maintenance workload and workforce. The first, *skill-based procedures*, resembles the Navy's management of its ship-maintenance workload

³ General Accounting Office, 1998.

and workforce. Individual workers maintain high-level certifications, with previous knowledge and experience being applicable only if an individual maintains those certifications. A skilled technician is skilled in a specific trade and only does work in that trade; but, he or she is able to do so without detailed instructions.

This contrasts with the second, more-common work philosophy that NASA uses, *rule-based procedures*. Although technicians maintain very high levels of training, rule-based procedures do not require technicians to maintain high-level certifications. Rule-based procedures assume that each technician is a novice and, therefore, that each main-

Table 6.2
Comparability of Maintenance Phases for Commercial Aircraft, Space Shuttles, and Navy Ships

Maintenance	Commercial Aircraft	Space Shuttle	Nuclear Submarine
A-check	Maintenance accomplished at the gate by pilot or flight crew	Maintenance that is part of normal orbiter processing between flights; requires 10,000 man-days and 110 days; A-check and B-check are combined	Maintenance performed by the ship's crew
B-check	In-depth maintenance accomplished at the gate by maintenance personnel	Maintenance that is part of the Orbiter Maintenance Down Period; occurs after every eight flights; involves disassembling parts of the shuttle, wiring checks, structural tests, and some rebuilding; occurs only a few times in a shuttle's life; requires 400 workers, >80,000 workdays, and >10 months; C-check and D-check are combined	Maintenance performed during a CMA
C-check	Maintenance performed during an aircraft's week-long stay in a maintenance depot	Maintenance performed during a pier-side depot availability	Maintenance performed during docking depot availability
D-check	The most complex and time-consuming type of maintenance; includes wiring and avionics work; requires 3–4 weeks		

tenance procedure must be documented in great detail (for example, the procedure for removing a bolt can fill 20 pages). This assumption helps mitigate loss of knowledge between maintenance periods, but still requires the work of skill-based technicians, such as those who stand under engines wearing environmental suits (and who cannot be expected to consult a manual while doing so). NASA notes that novices do not perform critical tasks, although the rule-based procedures are written as if they did.

NASA does not have its own maintenance staff. Rather, the shuttle's prime contractor, the United Space Alliance, hires, pays, and maintains credentials for each technician. NASA engineers oversee the process, ensuring that all work is done according to manuals and meets specifications, approving maintenance tasks as they are completed, and certifying that the shuttle is ready for flight.

Shuttle-maintenance work has been distributed relatively evenly across time. Technicians maintain a "squawk list" of work deferred from previous maintenance that was not critical to the next scheduled mission. Such work is used to maintain level workloads.

NASA closely tracks overtime levels, with maximum levels at 15–20 percent and average levels at 2–3 percent. Technicians who work directly on the orbiter fleet can work no more than

- 60 hours a week
- seven consecutive 8-hour days
- six consecutive 10-hour days
- 240 hours a month
- 2,500 hours a year.

Technicians who reach 2,500 hours in a calendar year are placed on fully paid leave until the beginning of the next year. Work that is particularly complex or demanding may be subject to even more stringent time limits.

NASA maintains a capabilities database of workers and skills for orbiter technicians. Each technician is given five-point ranking based on experience, age, and skills. NASA technicians tend to be older, especially because the workforce has been reduced from 7,200 employees

(prior to the *Challenger* disaster in 1986) to its current level of 4,500. Technicians perform up to 1.2 million man-days of work per year on the shuttles. In contrast to Navy maintenance personnel, space-shuttle technicians have very low levels of unionization; no direct-support personnel for the shuttles belong to unions, but some indirect-support technicians, such as large-machinery operators, belong to the International Association of Machinists.

Findings Relevant to the U.S. Navy

Our analysis of other organizations with workload and workforce issues similar to those the Navy faces identified several practices that could be applicable to shipyard management. In the following sections, we review where and how each of these practices is used and where and how they could be used by the Navy. Many of these practices are already used in some way by the Navy; the Navy would find others difficult to adopt.

Retain Core Capabilities and Competencies, Subcontract Others

It is difficult to manage the workforce associated with tasks that occur periodically, especially given constraints on trimming the workforce when demands decrease. UK dockyards, for example, commonly outsource tasks requiring comparatively fewer skills (e.g., painting), while European commercial shipbuilders outsource specialized cyclical work. U.S. Army depots outsource some processes, such as vehicle disassembly.

Some public shipyards use contractors extensively, but others do not have access to a large local pool of such help. Any efforts to subcontract core capabilities and competencies must abide by core-capability laws and the 50/50 rule.

Avoid Excess Overtime

Excess overtime reduces productivity and can lead to safety problems. Although high levels of overtime are sometimes warranted, hiring addi-

tional permanent staff, subcontractors, or temporary labor is typically a more cost-effective way to satisfy peak demands.

Most of the organizations we examined limit overtime far more stringently than the U.S. Navy public shipyards do. Both the UK dockyards and the European commercial shipbuilders face legal restrictions on overtime, with managers in both industries also seeking to limit overtime to the modest amounts that can sometimes boost productivity. NASA space-shuttle technicians also face limits on overtime that occasionally lead to a worker being placed on leave once the annual limit of individual hours is reached. The U.S. Army depots have used higher levels of overtime during the Iraq War, but prior to that conflict, they used levels below those common in the shipyards.

As noted earlier, hiring more permanent workers at the public shipyards and reducing the amount of overtime used to accomplish workload could be a cost-effective means of improving productivity. Other organizations have similarly found benefits in shifting work from overtime to permanent labor or other workers.

Use Temporary Labor to Meet Infrequent Peak Demands

Like the U.S. Navy, many of the organizations we examined use temporary labor to meet peak demands. The UK dockyards procure temporary workers of differing skills from an outsourcing agency, as do European commercial shipbuilders. The U.S. Army depots hire temporary workers with one-year, renewable contracts, placing these workers in positions that help them blend into the depot workforce without significant training. If they wish to increase their use of temporary labor, the Navy's public shipyards will face some of the same challenges they confront while subcontracting workload; specifically, they may have difficulty finding a sufficient local pool from which to draw such labor.

Promote a Multiskilled Workforce

Many of the organizations we examined use a multiskilled workforce. The UK dockyards use such a force to improve efficiencies, permitting members of any trade to do any type of work (with the exception of a few very specialized skills). European commercial shipbuilders use a

multiskilled workforce to boost productivity. NASA's rule-based maintenance procedures allow technicians to complete multiple tasks.

The public shipyards would face two different sets of obstacles in adopting a multiskilled workforce to promote efficiency. First, such a move would require union approval and an evaluation of pay scales for those qualified to perform more than one task. Second, adoption of a multiskilled workforce could be limited by the need to have some workers develop highly specialized skills in particular areas. It would not make sense, for example, to require a single individual to master two or three highly technical, different skills that all require extensive training to learn.

Smooth Workload Demands

Workload demands can be smoothed through increased interaction with customers to understand the implications of alternative schedules and allocations. This interaction helps decisionmakers smooth workload demands and make the best use of the workforce.

The MoD has worked with UK dockyards to determine whether schedule alterations can help distribute workload more evenly. It has also sought to split work into smaller, more-frequent work packages to smooth workload. U.S. Army depots have used a workload forecasting system (although this system can be problematic). NASA technicians maintain a list of tasks that can be scheduled to smooth workload. This is an area in which the U.S. Navy is pursuing its own initiatives, including a Fleet Availability Scheduling Team for keeping shipyard work more level over time and across each of the four shipyards.

Augment Work

Some of the facilities we examined augment their workload with non-traditional work, including structural work for other military services or commercial organizations. The UK dockyards have diversified their services by building luxury yachts and military land vehicles and repairing train engines and commercial ferries. The U.S. Army depots have pioneered public-private partnerships, working, for example, with General Dynamics employees on M-1 tanks and Stryker vehicles. The

U.S. Navy shipyards have undertaken similar cross-service work, such as that on Army vehicles.

Track Performance

The organizations we studied use several means to track performance at the level of individual tasks. Both the UK dockyards and the European commercial shipbuilders use earned value management to track progress. Many such methods are in use at the U.S. Navy shipyards, which continue to implement lean tracking methods.

Conclusions and Implications

U.S. Navy ship maintenance is a big business, with expenditures reaching nearly \$4 billion annually. Most of these expenditures occur at the four public shipyards, the focus of this book. Ship maintenance is among the most complex tasks DoD undertakes and is unique in its scope and magnitude. By some measures, the Navy does a reasonable job of managing the resources needed to perform this maintenance. When we compared the Navy's workload plan to that of an optimized plan for meeting forecast demand, we found virtually no difference between the two. That is, the total number of permanent employees, planned levels of overtime, and anticipated use of seasonal and borrowed labor in the Navy's workforce staffing plan constitute a cost-effective strategy for meeting planned workload demands.

Nevertheless, our examination of the workload plans at each shipyard revealed some notable differences between the Navy's current staffing plan and our optimization results. The shift of workload from the East Coast to the West Coast has had notable workforce implications. At Pearl Harbor, our optimization suggested that employing less borrowed labor and increasing the number of permanent staff would be more cost-effective. At Puget Sound, new apprentices and new hires would best meet a growing workload. Puget Sound must also support the CVN 73 in Japan and face the associated workforce implications, which include inefficiencies associated with increasing travel time and potentially conflicting demands for critical and limited nuclear skills. Our optimization did not include these considerations and has therefore probably underestimated the total number of permanent staff

required at Puget Sound. At Norfolk and Portsmouth, our optimization suggests that allowing the workforce to follow the workload levels more closely would be more cost-effective.

Qualitative analyses also identified shop-level issues that require attention. The Tool Shop and Temporary Services Shop at nearly all four shipyards experience highly cyclical and variable demands. Shipyards typically meet these demands through labor borrowed from other shipyards or shops or through contractors; these are management approaches used by other organizations to handle workload variability. Some shops, such as the Electronics Shop, experience particular recruiting difficulties and high attrition, and require a long time to develop skilled workers. These problems clearly indicate a need to increase recruiting and retention efforts. More than 50 percent of the workforce in some shops will retire in the next decade, and these workers must be replaced.

Planned workload demands are also not always the same as actual workload demands. In fact, workload forecasts consistently underestimate the eventual demand on the shipyards, although there is some evidence that forecasts at mission-funded shipyards may not underestimate demand as severely as forecasts generated for working capital-funded shipyards. The shipyards use a variety of means to overcome this problem. Indeed, they typically plan to use overtime levels of 12–13 percent to accomplish their workload, but the actual annual average overtime worked can sometimes reach 30 percent. Although levels of overtime close to those planned can be beneficial, the overtime levels actually executed lead to inefficiencies and, potentially, to safety problems.

Other means of accomplishing additional work—such as using temporary or borrowed labor—can be effective, but each is constrained by limitations and entails a cost. First, temporary or borrowed workers are typically not as productive as fully experienced resident journeymen. Second, temporary labor is hard to procure in some markets. Third, the travel expenses of borrowed workers make using them more expensive than using resident journeymen, even under the assumption that the borrowed workers can be just as efficient as the resident workers. Finally, shipyard managers identified challenges to using bor-

rowed labor, such as unmet obligations and restrictions on the use of this labor once it has arrived. These limitations can seriously affect critical-path jobs. Federal policies requiring that at least 50 percent of the ship-maintenance workload remain within the public sector and that the shipyards maintain core logistics capabilities further constrain the Navy's options to meet underestimated workload demands.

The Navy can hedge against the costs of underestimated workload by increasing the permanent staff at the shipyards. We estimated a minimum, average, and maximum workload growth based on historical data and then evaluated the cost of different management strategies in four scenarios:

- maintaining the Navy's current workforce plan while workload remains as planned
- maintaining the current workforce plan while workload grows
- optimizing the workforce while workload grows
- optimizing the workforce (in anticipation of workload growth) while workload remains as planned.

In all cases, the minimum cost strategy is to increase the workforce.

In coming years, the average available Navy shipyard maintenance workforce will total 13,800 workers per day. Current forecasts anticipate a demand for an average of 15,485 workers per day, a shortfall that the Navy will meet primarily through overtime. This strategy will cost the Navy approximately \$2.8 billion per year. If the workload exceeds the forecast amount, perpetuating a trend observed in recent years, meeting it will, of course, require more money. For example, if demand climbs by 6 percent above the forecast demand (i.e., to 16,433 workers per day), meeting that demand with 13,800 workers will cost the Navy \$3.2 billion per year. Yet if the Navy increases its workforce by 5 percent (700 workers), then meeting the greater-than-forecast demand would cost only \$3.0 billion (\$200 million in savings is due to decreased reliance on overtime). In fact, if the Navy increases its workforce but workload does not increase, the lower levels of required overtime would mean maintenance would still cost only an average of \$2.8 billion per year. With lower levels of overtime, the Navy would

realize greater productivity from its shipyard workers and, even with a larger workforce, incur no additional costs. Put another way, if the Navy increases its workforce and workload increases beyond the current forecast, the Navy would realize a savings of \$200 million annually. If workload does not increase, Navy costs even for a larger workforce would not increase. If workload increases by 16 percent annually (an increase not unprecedented historically) but the Navy does not increase its workforce, then it would incur a cost penalty of nearly \$1.5 billion annually. This cost is high compared to the \$200 million the Navy would pay every year for increasing the workforce to meet this demand and then observing no workload growth. However, the \$200 million cost can be avoided if a minimum work growth of only 4 percent is observed. Given the historical precedence of work growth, it is very unlikely that additional costs would be incurred, even if the Navy increased the workforce to meet the maximum potential workload growth.

Another management strategy for reducing cost is reallocation of work. We found that it would not be cost-effective to move nonnuclear surface-ship work currently being performed in the private sector into the public depots, assuming that additional green labor would have to be hired. Even if experienced workers were readily available, we found that such a shift would result only in minimal cost savings. For short-term gap-filling at the public depots, we found that using borrowed labor costs the same as bringing in nonnuclear surface-ship work from the private sector. Such shifts would also have to consider, as our analysis did not, implications for fulfilling homeport policy and the 50/50 rule.

Evaluations of other organizations' practices revealed numerous alternatives to an increased workforce, such as using temporary labor or subcontractors. Practices at other military depots and abroad include significant use of temporary labor and subcontractors. Other practices, such as reverting to a multiskilled workforce, smoothing workload demands, and augmenting product lines with nontraditional work, are also used by other organizations. Despite the limitations the public shipyards face in implementing many of these practices, they have done so to the extent possible.

To summarize, we recommend that the Navy

- Perform workforce-staffing evaluations using critical-skill and other data that may now be available. This will allow more-accurate estimates of workforce requirements to be established, including estimates of requirements that result from off-site work.
- Collect data to allow for evaluations of contractor cost and productivity.
- Continue to improve the workload-planning process to establish a more accurate baseline of actual workload to be performed.
- Reduce the overtime levels worked by hiring apprentices to increase the total number of permanent staff. Focus those increases at the shipyards and shops that need it most.
- Continue to leverage the best practices of other organizations to the extent possible, including the adoption of a multiskilled workforce, strategic subcontracting, and the use of temporary labor.

Depot Laws and Policies Governing Management Options

A number of laws and policies govern and dictate management options and practices at the public depots. An exhaustive list and description of these laws and policies are outside the scope of this book, but below we review the laws and policies most pertinent to our work.

Limitations on Private-Sector Contracting

The 50/50 Rule

According to 10 USC 2466, no more than 50 percent of each military department's annual depot maintenance funding can pay for work contracted to the private sector. U.S. Code also mandates annual reporting to Congress on the depot maintenance funding split between the public and private sectors. According to 10 USC 2460, depot maintenance and repair includes

material maintenance or repair requiring the overhaul, upgrading, or rebuilding of parts, assemblies, or subassemblies, and the testing and reclamation of equipment as necessary, regardless of the source of funds for the maintenance or repair or the location at which the maintenance or repair is performed.¹

¹ 10 USC 2460.

It also includes software maintenance, interim contractor support (i.e., depot maintenance as a part of the acquisition strategy for new systems), and contractor logistics support (a lifetime-support concept). Excluded from the definition of depot maintenance and repair, and thus excluded from the 50/50 restriction, are the “procurement of major modifications or upgrades of weapon systems that are designed to improve program performance and the nuclear refueling of an aircraft carrier.”² Also excluded is the procurement of parts for safety modifications, although the definition does include the installation of such parts.

It is the nature of the work as defined in 10 USC 2460 that governs whether the 50/50 rule applies, regardless of the funding source or where the work is performed. All types of appropriations in addition to designated depot operations and maintenance accounts and work performed at nondepot locations are subject to 50/50 accounting. Touch labor performed in a public shipyard by private-sector contractors is considered private-sector work for 50/50 accounting purposes.

There are a few exemptions from the 50/50 restriction. The Secretary of Defense can issue a waiver for reasons of national security. Furthermore, 10 USC 2474 excludes work performed by contractors as part of a public-private partnership from 50/50 accounting as long as the work is performed at a Center of Industrial and Technical Excellence (CITE) and the contractor leads the project. 10 USC 2474 directs DoD to designate public depots as CITEs for “maintenance and repair, modernization, inactivation, disposal, and emergency repair of Navy ships, systems, and components” and to improve their operations and focus on core competencies.³ CITEs can enter into public-private partnerships that provide depot-level maintenance and repair work involving core competencies. These partnerships aim to maximize use of depots and reduce cost.

² 10 USC 2460.

³ Department of the Navy, 2002.

Core Logistics

10 USC 2464 instructs DoD to maintain a government-owned and operated “core logistics capability.” This includes all equipment, facilities, and personnel (who are government employees). This federal code seeks to ensure that, during a mobilization, national-defense contingency, or other emergency situation, ready and regulated technical expertise and resources are available to respond rapidly and efficiently.

In accordance with 10 USC 2464, the Secretary of Defense splits core logistics into two parts. Part One identifies depot maintenance core-capability requirements in direct labor hours and allows for adjustments to avoid redundancy. Part Two identifies the depot maintenance workloads required to cost-effectively support core-capability requirements (in direct labor hours). These workloads are assigned to facilities to be performed. In Part Two, core-maintaining workloads are subtracted from total public-sector depot maintenance-funded workload. Those workloads thereby identified as not necessary to sustain core-capability requirements are then available for service source-of-repair decisions. Part Two establishes a minimum level of public-sector depot maintenance workloads within each DoD component.⁴ The Secretary of Defense can issue a waiver when the core-identified workload is no longer needed for national-defense reasons.

Requirement for Competition: The \$3 Million Rule

10 USC 2469 dictates that workloads of \$3 million or more (including labor and materials) cannot be moved to the private sector unless (1) merit-based selection among DoD depots and (2) competitive bidding by both the public and private sectors take place. Merit-based selection is not mandatory if the workload is allocated to a CITE.

⁴ Department of Defense, 2007.

Restrictions on Workforce Management

Reduction in Force

A government organization is required to use RIF procedures, outlined in 5 CFR 351, when

an employee is faced with separation or downgrading for a reason such as reorganization, lack of work, shortage of funds, insufficient personnel ceiling, or the exercise of certain reemployment or restoration rights. A furlough of more than 30 calendar days, or of more than 22 discontinuous workdays, is also a RIF action. (A furlough of 30 or fewer calendar days, or of 22 or fewer discontinuous workdays, is an adverse action.)⁵

5 CFR 351 sets forth RIF guidelines. Each organization must establish “competitive areas” in which employees compete for retention. The code specifies that a competitive area “must be defined solely in terms of the agency’s organizational unit(s) and geographical location, and it must include all employees within the competitive area so defined.” Descriptions of all competitive areas must be readily available for review. During a RIF, employees compete for jobs with other employees in the same competitive area and cannot “bump” or “retreat” into a job in another competitive area.⁶

5 CFR 351.403 states that each organization shall establish “competitive levels” that consist of all positions in a competitive area at same grade (or occupational level) and classification series, and similar enough in duties, qualification requirements, pay schedules, and working conditions to allow the organization to reassign an employee in one position without significantly disrupting others at the same level. To be in the same competitive level, jobs have to be in the same job

⁵ See U.S. Office of Personnel Management, undatedb. A furlough is the placement of an employee in a temporary nonduty and nonpay status for more than 30 consecutive calendar days, or more than 22 workdays, if done on a discontinuous basis of less than 1 year.

⁶ For more information about federal RIF processes, including how employees can bump or retreat, see Robbert, Gates, and Elliott, 1997.

series and have the same grade level. Competitive-level determinations are based on each employee's official position, not the employee's personal qualifications. Federal Code states that each organization must establish separate competitive levels according to service, appointment authority, pay schedule, work schedule (e.g., full-time, part-time, or seasonal), and trainee status. In the Naval industrial base, these rules prevent, for example, a production employee from bumping a support employee (engineer) because of tenure.

5 CFR 351.501 provides guidelines for classifying competing employees on a retention register. Employees are grouped

- by tenure group I (career employees not serving a probationary period), group II (career-conditional employees and employees serving a probationary period), or group III (employees serving under indefinite appointments, temporary appointments, term appointments, etc.)
- within each group by veteran preference subgroup AD (preference-eligible employees who have a compensable service-connected disability of 30 percent or more), subgroup A (preference-eligible employees not included in subgroup AD), or subgroup B (non-preference eligible employees)
- within each subgroup by years of service as augmented by credit for performance beginning at the earliest service date (length of service includes all civilian service as a federal employee and all active-duty military service).

5 CFR 351.803 states that when 50 or more employees in a competitive area receive separation notices, the organization is required to provide written notification of the action to

- the State or entity designated by the State to carry out rapid-response activities under Title 1 of the Workforce Investment Act of 1998
- the chief elected official of local government(s) within which these separations occur
- the Office of Personnel and Management.

Each competing employee selected for release from a competitive level is entitled to written notice at least 60 days before the effective date of release. Excluded from these RIF requirements are employees “serving on an intermittent, part-time, on-call, or seasonal basis in a nonpay and nonduty status in accordance with conditions established at the time of appointment.”⁷ Thus, temporary employees at the shipyard do not fall under the RIF regulations.

During our interviews at shipyards, respondents told us that it is possible but very difficult to protect specific skills during a RIF. If an employee’s training in a particular skill area exceeds a certain length of time, managers might be able to retain that employee (who might otherwise be released).

To minimize involuntary separations through RIFs, Voluntary Separation Incentive Payments allow organizations to offer redundant employees (or employees with skills no longer needed) a lump-sum payment up to \$25,000 to voluntarily separate by resignation, optional retirement, or even early retirement. Voluntary Early Retirement Authority permits organizations that are downsizing or restructuring to temporarily lower the age and service requirements for retirement, enabling an increase in the number of voluntary separations by retirement.

Prohibition on Management by End Strength

10 USC 2472 states that civilian employees performing depot-level maintenance and repair work must be managed only on the basis of available workload and funds and not on the basis of other constraints (such as man-years, end strength, maximum number of employees, or full time–equivalent positions). Under mission funding, a more clear interpretation is that shipyards must budget for the workload, not the current workforce. If shipyard managers expect to do more work than is currently budgeted for, because of supplemental funding or otherwise, they cannot hire additional workers in anticipation of such additional funding.

⁷ 5 CFR 351.202.

U.S. Navy Policies

Homeport Policy

Navy guidelines generally require depot work to be performed near a vessel's homeport. 10 USC 7310 restrictions for maintenance apply to

- vessels with a homeport in the United States. A naval vessel with a U.S. homeport cannot be overhauled, repaired, or maintained outside the United States or Guam; voyage repairs are, however, permitted.⁸
- vessels whose current homeport is not in the United States and whose homeport is being changed to a port in the United States. During the 15-month period prior to reassignment, the Secretary of the Navy cannot begin any vessel-maintenance work that is scheduled to last more than six months.
- vessels whose current homeport is in the United States and whose homeport is being changed to a non-U.S. port. During the 15-month period prior to reassignment, the Secretary of the Navy cannot begin any vessel-maintenance work that is scheduled to last more than six months.

Within the United States, the Navy has a homeport policy designed to improve the ship crew's quality of life by minimizing time away from home. The homeport policy instructs that, when possible, ship repair and maintenance work lasting six months or less should be performed at the ship's homeport. For a project estimated to take more than six months, the Navy can solicit proposals for maintenance contracts from private shipyards and ship-repair companies beyond the ship's immediate homeport area.⁹ A ship is considered in violation of personnel-tempo goals when this policy is not followed.

⁸ Voyage repairs are "corrective maintenance of mission- or safety-essential items necessary for a ship to deploy or to continue on its deployment" (Department of the Navy, 2006c).

⁹ General Accounting Office, 1999.

Homeport shift rules determine the boundaries of a particular homeport. In the 1980s, the Secretary of the Navy directed the expansion of three homeport areas—Norfolk, Virginia; New York, New York; and Seattle, Washington—to ensure adequate competition in private-sector ship-repair work. In 1994, the Secretary of the Navy established a new “sequential bid area” policy to abolish the expanded homeport areas and define homeport areas consistently across the Navy. In 1995, the Commander-in-Chief of the Pacific Fleet approved a policy that “homeport clusters shall be established for ports that are within a 75-mile radius and less than 1 1/2 hours one-way travel time using normal modes of travel for the region,” which is the current established rule for the Navy.¹⁰

Man-Day Policy

The man-day policy, which applies to Norfolk Naval Shipyard, establishes workload targets such that work days budgeted for Norfolk Naval Shipyard are guaranteed by the fleet and system commanders and are locked in during the budget process. The intention of this policy is to provide a stable basis for workforce planning. The workforce figures are also set in the budget. To abide by the Navy’s guaranteed man-day policy, Navy officials attempt to match maintenance workload to the shipyard’s workforce because the shipyard’s workforce and related costs have already been committed in the Navy’s budget. Should ship schedules change and a maintenance project be moved from the shipyard, then the shipyard may need to be provided with an equivalent replacement workload.¹¹

Multi-Ship, Multi-Option Contract Small-Business Requirements

MSMO contracts include a requirement to subcontract a certain percentage of the workload to small businesses. CFFC reported that MSMO contracts specify that 50 percent of workload be subcontracted to smaller shipyards. Many managers believe this impedes cost-effectiveness.

¹⁰ General Accounting Office, 1995.

¹¹ General Accounting Office, 1999.

Depot Maintenance Industrial Base Study Questionnaire

Introduction

NAVSEA has asked RAND to assess the U.S. Navy depot maintenance industrial base. Specifically, we are to identify and evaluate workforce and workload management practices that could reduce costs while still meeting fleet requirements. To do this, we need to estimate current and future workload, and the different types of skills and workforce (permanent, seasonal, temporary, contractor, etc.) used to execute this workload. We also need to understand the shipyard's staffing decision process and the policies that constrain the yard's ability to change staffing levels to meet expected workforce demands. This questionnaire asks about the shipyard workforce, and the policies and processes used to manage it.

We will visit your shipyard after we have received your completed form to review the questionnaire to ensure we understand your responses and to give you an opportunity to elaborate. In the interim, please let Jessie Riposo or Brien Alkire of RAND know if you need clarifications on the form.

Thank you for your assistance with this study.

U.S. Navy Contacts

Mike Sydla
NAVSEA 04X

RAND Contacts

Brien Alkire	Jessie Riposo
RAND Corporation	RAND Corporation
1776 Main Street	1200 South Hayes St.
Santa Monica, CA 90407-2138	Arlington, VA 22202-5050

Persons Completing the Form

Name	Title/Company	Phone #	Email address

Instructions:

All questions pertain to direct workers unless specified otherwise. Many questions ask for numerical estimates. If these are not available, or not available in the format we request, we would appreciate any information that will help us understand the issues addressed in the questions. If there is insufficient space to fill out the response, please continue your response in the space provided or on an additional piece of paper and attach. Please assign people and workload to the designated Trade Skills (specified in attachment A) as is done for reporting workload and workforce to NAVSEA 04.

Definitions:

Skill Category: refers to the Electrical, Electronics, Insulating, Paint/Blast, Shipwright, Machining (Inside), Machining (Outside), Pipefitting, Shipfitting, Sheet Metal, Welding skills, Nuclear support, Non Nuclear support skills as specified in the Navsea/Naval Shipyards Trade Skill and Support Section Designator Catalog (September 2002). The 'Other' category refers to all trade and support skills not included in the other specified Skill Categories.

Labor Type: refers to the type of worker used to execute work at the shipyard. We have identified a number of labor types including permanent, seasonal, temporary, contractor, borrows, apprentices and military personnel. We include an 'other' category which we invite you to use to identify any other labor types currently used that we have not specified.

Over Time (OT): refers to the hours worked beyond the specified and allowable hours worked in a week. For example, any hours worked above 40 hours per week for permanent staff.

WORKFORCE COMPOSITION

1. Please provide a list of your shop numbers and names.
2. Please provide the proportion of each trade skill (TS) by shop number.

Shop	Trade Skill										Total
											100%
											100%
											100%

3. Please provide the average number of your company's employees over the FY 2006 for each Shop and Labor Type.

Shop Number	Labor Type						
	Permanent	Seasonal	Temporary	Contractor	Apprentice	Borrows	Other

4. Please provide your current (as of September 30, 2006) workforce age distribution by Skill Category for your permanent workforce.

Trade Skill	<21 yrs old	21 to 25	26 to 30	31 to 35	36 to 40	41 to 45	46 to 50	51 to 55	56 to 60	>60 yrs old

5. Does the age distribution differ significantly by Labor Type?

6. Please provide the current distribution of your workforce by years of experience in the field as of September 30, 2006. If information is only available for years of employment at the public shipyards please specify and provide this data.

Shop	<1 year	1 - 2 years	3-5 years	6 - 10 years	11 - 20 years	21 - 30 years	>30 years

7. Does the experience distribution differ significantly by Labor Type?

8. Please provide the average (over 2002-2006) percentage of total new hires (excluding apprentices) within each experience level and Skill Category.

Trade Skill	<1 year	1 - 2 years	3-5 years	6 - 10 years	11 - 20 years	21 - 30 years	>30 years	Total
								100%
								100%
								100%
								100%
								100%
								100%

WORKFORCE GROWTH AND REDUCTION CONSTRAINTS

9. Please describe your recruitment pool. (e.g. certain vocational schools, other shipyards, grown within the organization, etc.)

10. How does this differ by Labor Type and Shop?

11. Are there particular skills or disciplines that are in high demand or for which recruiting is difficult? What causes the high demand for these skills, or why is it difficult to recruit for them?

12. What constrains your hiring rate for each Labor Type and Shop? (e.g. available recruitment pool, number of mentors, shop space)

13. What is the maximum annual growth rate you have sustained in the past ten years (FY97 to FY06) as a percentage of the total permanent workforce, by shop? (E.g., if there were 100 permanent staff and 50 additional permanent staff were brought into the shipyard to supplement the workforce, the growth rate would be 50%.)

Shop

**Maximum Annual Growth Rate
(Percent)**

14. What is the maximum annual growth rate you could sustain as a percentage of the total workforce, by Labor Type?

Labor Type

**Maximum Annual Growth Rate
(Percent)**

**Permanent
Seasonal
Temporary
Contractor
Apprentice
Uniformed
Borrows
Loans
Other**

15. What is the average mentor/mentoree ratio for new hires to experienced staff? How do these vary by Labor Type, Shop?

16. In the past ten years (1997 to 2006), what has been the maximum percentage of the total workforce represented by seasonal, borrows, temporary, apprentice, uniformed and contractor labor? For how long (in months) did the yard operate at this level of employment?

Percent of Total Workforce Represented by each Labor Type **Duration of time at Max (months)**

**Permanent
Seasonal
Temporary
Contractor
Apprentice
Uniformed
Borrows
Loans
Other**

17. Please provide the average number of annual recruits (from FY2002-FY2006 for new hires excluding the apprentice program and then for the apprentice program only. Please also provide their attrition as a percent of the total number of workers in the Skill Category. For example, if there are 50 new hires and 10 leave (on average, per year) then percent attrition is 20%.

Please specify for voluntary departures only using averages over the past five years.

	New Hires Excluding Apprentice		Apprentice Program Only	
Shop	Annual Average Recruits (2002 to 2006)	Average Annual Percent Attrition (2002 to 2006)	Annual Average Recruits (2002 to 2006)	Average Annual Percent Attrition (2002 to 2006)

18. Please provide an average (calculated over the past five years, 2002-2006) of the percent of the workforce lost, by Shop. For example, if there are 100 people in Shop X, and 10 left, the average % lost would be 10%. Please consider only losses not due to layoff or retirement.

Shop	Average % Lost

19. What constrains your ability to reduce the workforce? How does this vary by Labor Type and Shop?

20. If attrition is not sufficient to reduce the workforce, what types of options are there (Reduction In Force, etc.) and what are the implications of executing these options?

21. At what age do your permanent workers typically retire? Do you expect this to be lower, higher or the same in the future?

WORKFORCE PRODUCTIVITY AND OVERTIME

22. Please indicate the average (over experience levels) relative productivity of the various Labor Types to that of the permanent labor. For example, if seasonal labor is 95% as efficient as permanent labor on average, then enter 95% in the corresponding row and column.

Permanent	Seasonal	Temporary	Contractor	Borrows	Apprentice	Other

23. Does relative productivity between the different types of labor depend upon Shop? If so, please enumerate the relative productivity differences by skill.

24. On average, how many years does it take for a new hire to become fully productive within each Shop?

Shop	Number of years to become Productive

25. What is the relative productivity (to that of a fully production tradesman) by year of the apprentice program? If the program is more than 4 years please specify.

	Year 1	Year 2	Year 3	Year 4
Relative Productivity				

26. In the past ten years (1997 to 2006) what is the maximum (annual average) percentage of overtime that has been worked within each Shop? What is the maximum peak Over Time worked at any point in time and for how long (in months) did the yard operate at this peak level of OT?

Shop	Maximum annual Average % OT	Max Peak OT %	Duration of time at Max Peak (months)

27. What limits or constrains your ability to employ overtime? Do you cap overtime by dollars, hours, or percentage of straight-time hours? If so, how do these caps operate?

28. How does overtime affect the productivity of direct workers? For example, by what proportion does productivity decrease as overtime increases?

29. How does productivity during overtime vary by shop and Labor Type?

Permanent								
Seasonal								
Temporary								
Contractor								
Apprentice								
Uniformed								
Borrows								
Loans								
Other								

36. Please provide the average annual standard mandays per year expected to be worked by an individual for the following Labor Types and years?

Labor Type	2006	2007	2008	2009	2010	2011	2012	2013
	Permanent							
Seasonal								
Temporary								
Contractor								
Apprentice								
Uniformed								
Borrows								
Loans								
Other								

COSTS

Provide all cost data in fiscal year 2006 dollars. We realize that labor costs will vary with worker experience level. We ask that you provide average costs over all experience levels unless otherwise specified.

37. Please provide the direct wage during straight-time in dollars per hour for workers of each type and in each shop for fiscal year 2006, excluding fringe.

Trade Skill	Permanent	Seasonal	Temporary	Contractor	Loans	Other

38. What is the average cost per hour for fringe benefits for each Labor Type that receives fringe benefits?

Labor Type	Dollars/Hour of Fringe Benefits
Permanent	
Seasonal	
Temporary	
Contractor	
Apprentice	
Uniformed	
Loans	
Other	

39. What are the fringe benefits (i.e. insurance, education, pension benefits) included in Q43? If it differs by Labor Type, then please be specific.

40. Please provide the direct wage during overtime (this should include OT premium, for those Labor Types which typically work OT) in dollars per hour for workers of each type and in each Trade Skill Designator for fiscal year 2006.

Trade Skill	Permanent	Seasonal	Temporary	Contractor	Borrows	Other

41. Please provide the labor cost factors that get applied to the direct labor rate as a percentage of the hourly rate in order to calculate a fully burdened rate. Please place an x in the column to which this Factor applies (Over Time and or Straight Time) and indicate if the percent Factor differs for each. If there are other Factors used to establish burdened labor rate, which we did not identify in the table below, please identify and provide corresponding data in the empty space provided below.

Factor Title	Factor Value As % of Hourly Rate	Straight Time	Over Time
Fringe			
Differential			
Bonus			
Leave			
Holiday Pay			
Transportation Incentive Program			

42. Please describe how the factors are used to estimate total hourly cost of a worker.

43. Please apply the factors identified above to the direct rates to provide the fully burdened wage rate during straight-time in dollars per hour for each Labor Type and Skill Category for fiscal year 2006.

Trade Skill	Permanent	Seasonal	Temporary	Loans	Other

44. Please apply the factors identified above to the direct rates to provide the fully burdened wage rate during straight-time in dollars per hour for each Labor Type and Skill Category for fiscal year 2006.

Trade Skill	Permanent	Seasonal	Temporary	Loans	Other

45. Please indicate in the table below how the Civilian Direct Labor Index varies by workload volume.

Percent Change in Business Base	Direct Hours	CIV DLI
50%		
40%		
30%		
20%		
10%		
0%		
-10%		
-20%		
-30%		
-40%		
-50%		

46. What is the expected Overhead Non Labor (OHNL) dollars paid per year in each of the following years?

Labor Type	2006	2007	2008	2009	2010	2011	2012	2013

47. Please provide the average hourly rate paid for contractors in the following Skill Categories.

Trade Skill	Average Hourly Rate

48. What is the average Reduction In Force (RIF) or SIP (Separation Incentive Package) cost for a permanent worker?

49. How do these costs vary by Trade Skill or Labor Type?
50. Please provide the average cost of hiring workers. This cost should not include the cost of new hire time to become productive. It should include cost of relocating, recruiting, and processing the new hire.
51. Please specify how the average cost of hiring workers varies by Trade Skill and Labor Type.
52. What are the average training costs (beyond trainee salary) for a new hire? This should include the cost incurred for providing the trainer, including trainer pay and training materials.
53. Please specify how training costs vary by Trade Skill and Labor Type. For example, do apprentices have different training costs from other new hires?

Use of Borrows, Loans, Contracting, and other Types of Labor

54. For what reasons does your shipyard typically borrow labor? Loan labor?
55. What limits or constrains your ability to borrow or loan labor?
56. Are there specific skills that your yard typically borrows or loans?
57. Is there a particular yard that you typically lend labor to/ borrow from?
58. For what reasons does your shipyard typically hire temporary or seasonal labor?
59. Are there specific skills that your yard typically hires temporarily or seasonally?

60. Are there specific tasks that temporary or seasonal labor perform?
61. How do the skills of the military personnel differ from those of the permanent staff?
62. What tasks are typically performed by military personnel?

Subcontracting and Outsourcing

Note: In the following questions, subcontracting refers to hiring workers of another firm to perform a task at your shipyard. Outsourcing refers to hiring a firm to perform a task outside your shipyard.

63. Under what conditions do you typically subcontract work? For example, is there a seasonal pattern?
64. What types of work or tasks do you typically assign to subcontract work?
65. Please describe commonly-used sources of subcontract labor. Please also specify whether use of subcontract labor varies by Skill Category.
66. What constrains your ability to hire and use subcontract labor?
67. How would you characterize the local subcontracting market? (i.e. there are a number of providers, easy to hire, low/high unemployment for relevant trade skills, etc.)
68. Under what conditions do you typically outsource work? For example, is there a seasonal pattern? Is this a 'last resort' for meeting peak workloads or skill shortages?
69. What types of work or tasks do you typically outsource?
70. Please describe commonly-used outsourcing providers. Please also specify whether use of outsourcing varies by Skill Category.
71. What constrains your ability to use outsourcing?

72. How would you characterize the local outsourcing market?
(i.e. there are a number of providers, easy to hire, low/high unemployment for relevant trade skills, etc.)

Mathematical Details of the Workforce Allocation Tool

In this appendix, we provide mathematical details related to the RAND Workforce Allocation Tool.

Problem Variables

Let n_e denote the number of experience levels, enumerated from $1, \dots, n_e$. Similarly, let n_p denote the number of periods, n_s denote the number of trade-skills, n_t denote the number of labor types, and n_y denote the number of shipyards. Let the variable

$$x_{i_e, i_p, i_s, i_t, i_y}^{(s)}$$

denote the number of workers with experience level i_e , during period i_p , from trade-skill i_s , of labor type i_t , at shipyard i_y , on payroll and working straight time for $i_e = 1, \dots, n_e$; $i_p = 1, \dots, n_p$; $i_s = 1, \dots, n_s$; $i_t = 1, \dots, n_t$; and $i_y = 1, \dots, n_y$. We assume that the variable

$$x_{i_e, i_p, i_s, i_t, i_y}^{(s)}$$

includes workers who were hired during period i_p and excludes workers who were terminated or lost through either attrition or retirement during period i_p . Let

$$x^{(h)}_{i_e, i_p, i_s, i_t, i_y}$$

denote the number of newly hired workers with experience level i_e , during period i_p , from trade-skill i_s , of labor type i_t , at shipyard i_y . We assume that workers hired during period i_p are available to work during period i_p . Let

$$x^{(t)}_{i_e, i_p, i_s, i_t, i_y}$$

denote the number of workers terminated (not lost through attrition or retirement) with experience level i_e , during period i_p , from trade-skill i_s , of labor type i_t , at shipyard i_y . We assume that workers terminated during period i_p are not available to work during period i_p . Let

$$x^{(o)}_{i_e, i_p, i_s, i_t, i_y}$$

denote the amount of overtime, expressed as a number of workers on payroll at experience level i_e , during period i_p , from trade-skill i_s , of labor type i_t , at shipyard i_y . The problem variables are the quantities

$$x^{(s)}_{i_e, i_p, i_s, i_t, i_y}; x^{(h)}_{i_e, i_p, i_s, i_t, i_y}; x^{(t)}_{i_e, i_p, i_s, i_t, i_y}; \text{ and } x^{(o)}_{i_e, i_p, i_s, i_t, i_y}.$$

All variables must be non-negative:

$$\begin{aligned}
 x^{(s)}_{i_e, i_p, i_s, i_t, i_y} &\geq 0, i_e = 1, \dots, n_e; i_p = 1, \dots, n_p; i_s = 1, \dots, n_s; \\
 &\quad i_t = 1, \dots, n_t; i_y = 1, \dots, n_y \\
 x^{(h)}_{i_e, i_p, i_s, i_t, i_y} &\geq 0, i_e = 1, \dots, n_e; i_p = 1, \dots, n_p; i_s = 1, \dots, n_s; \\
 &\quad i_t = 1, \dots, n_t; i_y = 1, \dots, n_y \\
 x^{(t)}_{i_e, i_p, i_s, i_t, i_y} &\geq 0, i_e = 1, \dots, n_e; i_p = 1, \dots, n_p; i_s = 1, \dots, n_s; \\
 &\quad i_t = 1, \dots, n_t; i_y = 1, \dots, n_y \\
 x^{(o)}_{i_e, i_p, i_s, i_t, i_y} &\geq 0, i_e = 1, \dots, n_e; i_p = 1, \dots, n_p; i_s = 1, \dots, n_s; \\
 &\quad i_t = 1, \dots, n_t; i_y = 1, \dots, n_y.
 \end{aligned} \tag{C.1}$$

Problem Constraints

Borrowed and Loaned Labor

Labor can be loaned and borrowed between shipyards. Assume without loss of generality that labor type 1 corresponds to loaned labor, and labor type n_t corresponds to borrowed labor.¹ The number of borrowed workers must equal the number of loaned workers:

$$\begin{aligned}
 \sum_{i_y=1}^{n_y} x^{(s)}_{i_e, i_p, i_s, n_t, i_y} - x^{(s)}_{i_e, i_p, i_s, 1, i_y} &= 0, i_e = 1, \dots, n_e; \\
 &\quad i_p = 1, \dots, n_p; i_s = 1, \dots, n_s \\
 \sum_{i_y=1}^{n_y} x^{(o)}_{i_e, i_p, i_s, n_t, i_y} - x^{(o)}_{i_e, i_p, i_s, 1, i_y} &= 0, i_e = 1, \dots, n_e; \\
 &\quad i_p = 1, \dots, n_p; i_s = 1, \dots, n_s.
 \end{aligned} \tag{C.2}$$

¹ We assume that borrowed and loaned workers are permanent workers who have the same characteristics as permanent workers.

Upper and Lower Bounds on Workforce Levels

We may wish to impose lower and upper bounds on the total number of straight-time workers over all experience levels during each period, for each trade-skill, for each type, and at each shipyard. Let

$$L_{i_s, i_t, i_y}^{(w)}$$

and

$$U_{i_s, i_t, i_y}^{(w)}$$

denote the lower and upper bound, respectively. We can impose these bounds with the following constraint:

$$L_{i_s, i_t, i_y}^{(w)} \leq \sum_{i_e=1}^{n_e} x_{i_e, i_p, i_s, i_t, i_y}^{(s)} \leq U_{i_s, i_t, i_y}^{(w)}, i_p = 1, \dots, n_p; \\ i_s = 1, \dots, n_s; i_t = 1, \dots, n_t; i_y = 1, \dots, n_y. \quad (\text{C.3})$$

Upper and Lower Bounds on Use of Overtime

Let

$$L_{i_y}^{(o)}$$

and

$$U_{i_y}^{(o)}$$

with

$$0 \leq L_{i_y}^{(o)} \leq U_{i_y}^{(o)}$$

denote lower and upper bounds on the amount of overtime per worker at shipyard i_y expressed as a fraction of the straight-time workload, respectively. We can express upper and lower bound constraints on overtime as

$$\begin{aligned} x_{i_e, i_p, i_s, i_t, i_y}^{(s)} L_{i_y}^{(o)} &\leq x_{i_e, i_p, i_s, i_t, i_y}^{(o)} \leq U_{i_y}^{(o)} x_{i_e, i_p, i_s, i_t, i_y}^{(s)}, \\ i_e &= 1, \dots, n_e; i_p = 1, \dots, n_p; i_s = 1, \dots, n_s; i_t = 1, \dots, n_t; \\ i_y &= 1, \dots, n_y. \end{aligned} \tag{C.4}$$

Ensuring that Labor Supply Meets or Exceeds Labor Demand

Let

$$T_{i_e, i_s, i_t, i_y}^{(s)} \in [0, 1]$$

denote the average relative throughput of workers with experience level i_e , from trade-skill i_s , of labor type i_t , at shipyard i_y , during straight-time hours. Similarly, let

$$T^{(o)}_{i_e, i_s, i_t, i_y} \in [0, 1]$$

denote the average relative throughput of workers during overtime.

$$T^{(s)}_{i_e, i_s, i_t, i_y}$$

and

$$T^{(o)}_{i_e, i_s, i_t, i_y}$$

are model parameters. Let

$$d_{i_p, i_s, i_y}$$

denote the demand for labor, expressed as the number of workers on payroll with throughput equal to 1, during period i_p , with trade-skill i_s , at shipyard i_y . The values in

$$d_{i_p, i_s, i_y}$$

come from the Workload Allocation Model. The constraint that the workforce labor supply meets or exceeds labor demand can be expressed as

$$\sum_{i_e=1}^{n_e} \sum_{i_t=2}^{n_t} T^{(s)}_{i_e, i_s, i_t, i_y} x^{(s)}_{i_e, i_p, i_s, i_t, i_y} + T^{(o)}_{i_e, i_s, i_t, i_y} x^{(o)}_{i_e, i_p, i_s, i_t, i_y} \geq d_{i_p, i_s, i_y}, i_p = 1, \dots, n_p; i_s = 1, \dots, n_s; i_y = 1, \dots, n_y. \tag{C.5}$$

Observe that, as intended, loaned labor does not contribute a supply of labor to meet demand for labor within a shipyard, although borrowed labor does.

Attrition, Retirement, Advancement in Experience, Hiring, and Termination

Let

$$a_{i_e, i_s, i_t, i_y}$$

denote the average attrition rate as a fraction of workers lost with experience level i_e , in trade-skill i_s , of labor type i_t , at shipyard i_y , per period. Let

$$r_{i_e, i_s, i_t, i_y}$$

denote the average retirement rate as a fraction of workers lost with experience level i_e , in trade-skill i_s , of labor type i_t , at shipyard i_y , per period. Let

$$s_{i_e}$$

denote the fraction of workers with experience level i_e that will advance to experience level $i_e + 1$ in the next period. Let $i_t = 2$ denote the index for permanent workers, excluding borrowed and loaned labor. The supply of permanent (including loaned) labor per period varies with attrition, retirement, advancement in experience, hiring, and termination in all but the highest experience level according to the following expression:

$$\begin{aligned}
 & \sum_{i_t=1}^2 x^{(s)}_{i_e+1, i_p+1, i_s, i_t, i_y} \\
 &= \sum_{i_t=1}^2 \left(\left(1 - a_{i_e, i_s, i_t, i_y} \right) \left(1 - r_{i_e, i_s, i_t, i_y} \right) s_{i_e} x^{(s)}_{i_e, i_p, i_s, i_t, i_y} \right. \\
 &+ \left. \left(1 - a_{i_e+1, i_s, i_t, i_y} \right) \left(1 - r_{i_e+1, i_s, i_t, i_y} \right) \left(1 - s_{i_e+1} \right) x^{(s)}_{i_e+1, i_p, i_s, i_t, i_y} \right. \\
 &+ \left. x^{(h)}_{i_e+1, i_p+1, i_s, i_t, i_y} - x^{(t)}_{i_e+1, i_p+1, i_s, i_t, i_y} \right), \\
 & i_e = 1, \dots, n_e - 2; i_p = 1, \dots, n_p - 1; i_s = 1, \dots, n_s; i_y = 1, \dots, n_y. \quad (C.6)
 \end{aligned}$$

Note that workers at the highest experience level of n_e do not advance further in experience. Therefore, the supply of permanent labor per period varies according to the following expression:

$$\begin{aligned}
 & \sum_{i_t=1}^2 x^{(s)}_{n_e, i_p+1, i_s, i_t, i_y} \\
 &= \sum_{i_t=1}^2 \left(\left(1 - a_{n_e, i_s, i_t, i_y} \right) \left(1 - r_{n_e, i_s, i_t, i_y} \right) x^{(s)}_{n_e, i_p, i_s, i_t, i_y} \right. \\
 &+ \left. \left(1 - a_{n_e-1, i_s, i_t, i_y} \right) \left(1 - r_{n_e-1, i_s, i_t, i_y} \right) s_{n_e-1} x^{(s)}_{n_e-1, i_p, i_s, i_t, i_y} \right. \\
 &+ \left. x^{(h)}_{n_e, i_p+1, i_s, i_t, i_y} - x^{(t)}_{n_e, i_p+1, i_s, i_t, i_y} \right), \\
 & i_p = 1, \dots, n_p - 1; i_s = 1, \dots, n_s; i_y = 1, \dots, n_y. \quad (C.7)
 \end{aligned}$$

The supply of seasonal and temporary labor types also vary with attrition, retirement, hiring, termination, and advancement. Let J denote the set of labor type indices for seasonal and temporary workers:

$$\begin{aligned}
 & x_{i_e+1, i_p+1, i_s, i_t, i_y}^{(s)} \\
 &= \left(\left(1 - a_{i_e, i_s, i_t, i_y} \right) \left(1 - r_{i_e, i_s, i_t, i_y} \right) s_{i_e} x_{i_e, i_p, i_s, i_t, i_y}^{(s)} \right. \\
 &+ \left. \left(1 - a_{i_e+1, i_s, i_t, i_y} \right) \left(1 - r_{i_e+1, i_s, i_t, i_y} \right) \left(1 - s_{i_e+1} \right) x_{i_e+1, i_p, i_s, i_t, i_y}^{(s)} \right. \\
 &+ \left. x_{i_e+1, i_p+1, i_s, i_t, i_y}^{(h)} - x_{i_e+1, i_p+1, i_s, i_t, i_y}^{(t)} \right), \\
 & i_e = 1, \dots, n_e - 2; i_p = 1, \dots, n_p - 1; i_s = 1, \dots, n_s; i_t \in J; \\
 & i_y = 1, \dots, n_y.
 \end{aligned} \tag{C.8}$$

For workers at the highest experience level, we have

$$\begin{aligned}
 & x_{n_e, i_p+1, i_s, i_t, i_y}^{(s)} \\
 &= \left(\left(1 - a_{n_e, i_s, i_t, i_y} \right) \left(1 - r_{n_e, i_s, i_t, i_y} \right) x_{n_e, i_p, i_s, i_t, i_y}^{(s)} \right. \\
 &+ \left. \left(1 - a_{n_e-1, i_s, i_t, i_y} \right) \left(1 - r_{n_e-1, i_s, i_t, i_y} \right) s_{n_e-1} x_{n_e-1, i_p, i_s, i_t, i_y}^{(s)} \right. \\
 &+ \left. x_{n_e, i_p+1, i_s, i_t, i_y}^{(h)} - x_{n_e, i_p+1, i_s, i_t, i_y}^{(t)} \right), \\
 & i_p = 1, \dots, n_p - 1; i_s = 1, \dots, n_s; i_t \in J; i_y = 1, \dots, n_y.
 \end{aligned} \tag{C.9}$$

Let

$$U_{i_t, i_y}^{(t)}$$

denote an upper bound on the number of workers of type i_t at shipyard i_y that can be terminated per period. We can represent the upper bound constraint with the following formula:

$$\sum_{i_e=1}^{n_e} \sum_{i_s=1}^{n_s} x^{(t)}_{i_e, i_p, i_s, i_t, i_y} \leq U^{(t)}_{i_t, i_y}, i_p = 1, \dots, n_p; i_t = 1, \dots, n_t; i_y = 1, \dots, n_y. \tag{C.10}$$

Let

$$U^{(h)}_{i_e, i_s, i_t, i_y}$$

denote an upper bound on the percentage increase that could be achieved through hiring per period for workers of experience level i_e , of labor type i_t , in trade-skill i_s , at shipyard i_y . We can represent the upper bound constraint with the following formula:

$$\begin{aligned} x^{(h)}_{i_e, i_p, i_s, i_t, i_y} &\leq U^{(h)}_{i_e, i_s, i_t, i_y} x^{(s)}_{i_e, i_p, i_s, i_t, i_y}, \\ i_e &= 1, \dots, n_e; i_p = 1, \dots, n_p; i_s = 1, \dots, n_s; i_t = 1, \dots, n_t; \\ i_y &= 1, \dots, n_y. \end{aligned} \tag{C.11}$$

Mentor Ratios

We assume that there must be at least one worker of the highest experience level n_e for every

$$L^{(m)}_{i_s, i_t, i_y}$$

workers of lower experience levels trade-skill i_s , of labor type i_t , at shipyard i_y , for each period. That is,

$$\begin{aligned} \sum_{i_e=1}^{n_e-1} x^{(s)}_{i_e, i_p, i_s, i_t, i_y} &\leq L^{(m)}_{i_s, i_t, i_y} x^{(s)}_{n_e, i_p, i_s, i_t, i_y}, \\ i_p &= 1, \dots, n_p; i_s = 1, \dots, n_s; i_t = 1, \dots, n_t; i_y = 1, \dots, n_y. \end{aligned} \tag{C.12}$$

Cost Objective

Let

$$c^{(s)}_{i_e, i_s, i_t, i_y}$$

denote the average direct wage per period during straight time for workers of experience level i_e , of labor type i_t , trade-skill i_s , at shipyard i_y . Similarly, let

$$c^{(o)}_{i_e, i_s, i_t, i_y}$$

denote the average direct wage per period during overtime. Let

$$c^{(h)}_{i_e, i_s, i_t, i_y}$$

denote the cost of hiring a worker, and let

$$c^{(t)}_{i_e, i_s, i_t, i_y}$$

denote the cost of terminating a worker (termination does not include retirement or attrition) of experience level i_e , of labor type i_t , trade-skill i_s , at shipyard i_y . Let

$$c^{(l)}_{i_y}$$

denote the average per diem of a loaned worker per period at shipyard i_y . Let

$$b_{i_p, i_y}$$

denote the burden rate during period i_p at shipyard i_y . The burden-rate parameter

$$b_{i_p, i_y}$$

is used to evaluate the fixed and variable indirect costs minus material, hiring, and termination costs. It will vary inversely with business volume. We use labor demand as a proxy for business volume, and relate burden rate to labor demand by

$$b_{i_p, i_y} = \frac{v_{i_y}^{(1)}}{\sum_{i_s=1}^{n_s} d_{i_p, i_s, i_y}} + v_{i_y}^{(2)}, i_p = 1, \dots, n_p; i_y = 1, \dots, n_y,$$

where the parameters

$$v_{i_y}^{(1)}$$

and

$$v_{i_y}^{(2)}$$

are estimated using a least-squares fit to estimates of burden-rate sensitivity to volume for each shipyard. Let

$$m_{i_y}$$

denote the material cost per direct labor dollar cost factor for shipyard i_y . These parameters are estimated from historical cost data for each shipyard. Total cost to the Navy, including fully burdened wages and material costs, is then estimated as

$$\begin{aligned}
 & \sum_{i_e=1}^{n_e} \sum_{i_p=1}^{n_p} \sum_{i_s=1}^{n_s} \sum_{i_t=2}^{n_t} \sum_{i_y=1}^{n_y} \\
 & \left(\left(1 + m_{i_y} \right) \left(1 + b_{i_p, i_y} \right) \left(c_{i_e, i_s, i_t, i_y}^{(s)} x_{i_e, i_p, i_s, i_t, i_y}^{(s)} \right. \right. \\
 & \left. \left. + c_{i_e, i_s, i_t, i_y}^{(o)} x_{i_e, i_p, i_s, i_t, i_y}^{(o)} \right) + c_{i_e, i_s, i_t, i_y}^{(h)} x_{i_e, i_p, i_s, i_t, i_y}^{(h)} \right. \\
 & \left. + c_{i_e, i_s, i_t, i_y}^{(t)} x_{i_e, i_p, i_s, i_t, i_y}^{(t)} + c_{i_y}^{(l)} x_{i_e, i_p, i_s, 1, i_y}^{(s)} \right).
 \end{aligned}$$

Problem Formulation

The Workforce Allocation Tool estimates the minimum-cost workforce allocation to meet workload demands by minimizing (C.13), subject to the constraints (C.1), (C.2), (C.3), (C.4), (C.5), (C.6), (C.7), (C.8), (C.9), (C.10), (C.11), and (C.12). This is a large-scale linear programming problem.

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