

Optimal Manning and Technological Change

Martha E. Koopman • Heidi L. W. Golding

DISTRIBUTION STATEMENT A
Approved for Public Release
Distribution Unlimited

20000717 162

Center for Naval Analyses

4401 Ford Avenue • Alexandria, Virginia 22302-1498

DMC QUALITY INSPECTED 4

REPORT DOCUMENTATION PAGE

Form Approved
OPM No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources gathering and maintaining the data needed and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22302-4302, and to the Office of Information and Regulatory Affairs, Office of Management and Budget, Washington, DC 20503.

1. AGENCY USE ONLY (Leave Blank)	2. REPORT DATE Jul 1999	3. REPORT TYPE AND DATES COVERED Final
4. TITLE AND SUBTITLE Optimal Manning and Technological Change	5. FUNDING NUMBERS N00014-96-D-0001 PE - 65154N PR - R0148	
6. AUTHOR(S) ME Koopman, HLW Golding	7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Center for Naval Analyses 4401 Ford Avenue Alexandria, Virginia 22302-1498	
8. PERFORMING ORGANIZATION REPORT NUMBER CRM 99-59	9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Director, Total Force Programming, Manpower & IRM Division (N12)	
10. SPONSORING/MONITORING AGENCY REPORT NUMBER	11. SUPPLEMENTARY NOTES	
12a. DISTRIBUTION AVAILABILITY STATEMENT Distributions of this report are limited. For further requests for this document must be referred to the sponsor.	12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words) The Assistant Deputy Chief of Naval Operations, Manpower and Personnel, requested CNA examine the implications of technological change for Navy manpower. This paper addresses the changes that are likely to occur in the type of sailor the Navy needs as a result of new ship and aircraft maintenance and the changes likely to occur in the civilian population. It also examines how Navy workforce management policies may have to change due to these changes in technology, required skills, and civilian labor markets. The paper concludes that technological advances will most likely require a more skilled workforce. In particular, the Navy will need sailors who understand the general principles in their area of expertise, are technically literate, and have strong problem-solving, decision-making, and communication skills.		
14. SUBJECT TERMS Civilian personnel, education, force structures, manpower utilization, military force levels, modernization, national defense, naval personnel, policies, quality, skills technology, 21st century		15. NUMBER OF PAGES 98
16. PRICE CODE		17. LIMITATION OF ABSTRACT SAR
18. SECURITY CLASSIFICATION OF REPORT Unclassified	19. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	20. SECURITY CLASSIFICATION OF ABSTRACT Unclassified

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
299-01

Contents

Summary	1
Changes in technology and skills	1
21st century platforms	1
Two questions	2
21st century crews	2
Changes in civilian education and workforce	3
Changes in workforce policies	4
Conclusion and recommendations	5
Background	7
Changes in technology and skills	9
21st century Navy platforms	9
Smart Ship Project	10
LPD 17.	12
DD 21	13
Future carriers	22
Different platforms have different emphasis	25
Future aircraft.	25
Questions about technology and manning	27
Will skill levels rise or fall?	28
Are there limits to automating warfighting?.	29
21st century crews	29
Acquisition reform	30
Ship of the future	31
Optimized manning lessons learned.	33
Technology initiatives	34
Common themes	38
Future sailor's resume	39
Changes in civilian education and workforce	41
Overall youth population	41
High school graduate market	44

Number of high school graduates	44
Academic progress of high school graduates	45
Trends in educational attainment.	54
Fewer people stop education at high school	55
College enrollments	55
Technical degrees.	58
Government programs to increase technical expertise	58
Wage premium for higher education	61
Other changes in the American workforce	63
Changes in workforce policies	65
Career structure	65
Legacy workforce structure: the manpower pyramid	65
Future workforce structure.	67
Are future force structures executable?	69
Recruiting.	70
Training.	72
Generalist vs. specialist	72
Training technology	73
Loss of apprenticeships.	74
Navy training process	74
Skill vs. rank	75
Compensation strategy.	76
Skill-based pay.	77
Retirement pay	78
Summary	79
Conclusion and recommendations	81
References	83
List of figures	89
Distribution list	91

Summary

In the 21st century, the traditional ways of manning Navy ships, submarines, and squadrons will change. Two compelling sets of forces will be at work. First, technological advances and budget pressures are combining to produce a new generation of platforms and systems with significantly reduced manning. Second, the civilian population and labor force are changing.

Recognizing that these forces may require fundamental changes in how the Navy recruits, trains, retains, and promotes personnel, the Assistant Deputy Chief of Naval Operations, Manpower and Personnel (N1B) requested that CNA examine the implications of technological change for Navy manpower. In this paper, we address the following issues:

- What changes are likely to occur in the type of sailor the Navy needs as a result of new ship and aircraft acquisitions?
- What changes are likely to occur in the civilian population and labor force?
- Given the type of sailor needed and the changes in the civilian sector, what changes will be needed in personnel policies, such as recruiting, training, retention, promotion, and compensation?

Changes in technology and skills

21st century platforms

Between now and 2020, the Navy plans to introduce new platforms, equipment, and systems—some with profound changes in technology and manning. We surveyed the new platforms and also some technology initiatives that cut across platforms. The programs we examined include Smart Ship, LPD 17, DD 21, CVN 77, CVX and the Joint Strike Fighter. Research programs and technology initiatives we examined include the Ship Systems Automation (SSA) study, Multi-Modal Watch

Station (MMWS), Integrated Command Environment (ICE), intelligent automated sensors, agent-based systems, condition-based maintenance, and advanced embedded training. We also considered the implications of acquisition reform for future manning.

We collected information through interviews, participation in working groups, and a literature review that included material from internet sites. We talked with scientists, human factors engineers, manpower, personnel and training (MPT) experts, and Navy officers from systems commands, program offices, research organizations, Naval Warfare Centers, contractors, resource sponsors, and MPT offices.

Two questions

Two general questions regarding technological advance and manning that emerged were whether skill levels would rise or fall and the extent to which warfighting could be automated. We conclude:

- As technology gets more advanced, the workforce tends to become more skilled rather than less skilled. In part, new skill requirements depend on the quality of human-machine interfaces (HMI), which in turn depends on today's R&D efforts.
- Combat situations are inherently chaotic—their complexity and uncertainty defy automation with current technology. The risk, then, of automating routine tasks is that the crew may be cut so deeply that there won't be enough people to cover complex combat evolutions. Alternatively, enough people may be retained, but they will lack the experience gained by performing routine tasks during peacetime. Any manning reduction initiatives for warfighting ships must address this problem.

21st century crews

The effect of technology on manpower requirements will differ across platforms. Nevertheless, some common themes emerge across the new platforms, systems, and acquisition programs:

- Automation of routine tasks and information processing, including more collaboration between human and machine in which the human adds context and makes complex decisions

- Reduction of maintenance and watchstanding requirements
- Movement of workload from operational units to the shore because of new information technology
- Use of more commercial off-the-shelf (COTS) technology
- Change in makeup of future crews from specialists to generalists.

In almost all areas, including combat systems, command and control, engineering, maintenance, material handling, and hotel functions, automation will have progressed to the point where humans are overseeing complex, automated systems—providing context, coaching, and making decisions.

Given these trends, we see a growing requirement for a future sailor who is a skilled technician. The Navy will still need unskilled labor to perform tasks that can't be automated, and it will still need supervisors and military leaders. But an increasing proportion of the Navy's enlisted force will be sailors whose job descriptions include the following:

- Apply general principles in technical fields.
- Define problems, establish facts, and make decisions.
- Communicate technical problems and solutions.

Changes in civilian education and workforce

At the same time that technological advances are changing workforce requirements, we will see significant changes in civilian education and labor markets. In particular:

- The youth population will reverse a long-term decline and begin to grow, as will the number of high-school graduates.
- Contrary to conventional wisdom, today's high school graduates are as intelligent and as well prepared academically as were students of the past and students in other countries:
 - After adjusting for larger populations taking college entrance exams, there is no evidence of declining SAT scores over time.

- Standardized tests indicate that more students are getting top- to middle-level scores in science and math performance.
- High school students are taking more science and math courses and all students are getting more exposure to computers.
- More high school graduates will go on to postsecondary school: in 1967, 50 percent of high-school graduates stopped their education at high school; by 1996, only 33 percent stopped.
- Substantial numbers of students are graduating from less-than-4-year civilian institutions in technical fields that are relevant to the Navy's needs.
- Government initiatives should further improve students' preparation to join an increasingly technical workforce.
- Workers with more technical education command higher earnings.

The evidence suggests that the Navy will have access to a larger recruiting pool if it includes 1- to 2-year postsecondary school graduates. These high school and postsecondary school graduates will be increasingly well prepared and technically literate. On the other hand, the competition for highly skilled workers will be stiff, so the Navy should expect to pay more for these recruits.

Changes in workforce policies

Changes in technology and required skills along with simultaneous changes in civilian labor markets imply that the Navy will have to make fundamental changes in the way it manages its workforce. We examined how Navy workforce management policies may have to change. Our findings include:

- Manpower requirements will no longer be pyramids. Automation of routine tasks will lower junior paygrade requirements while the increasing proportion of skilled technicians will require more middle paygrade requirements.

- Allowing skilled technicians to have full careers without moving into supervisory ranks will require changes to up-or-out policies and increases in pay not tied to increased rank.
- More recruits will come from postsecondary institutions. Accomplishing this will require higher compensation, either through lateral entry or pay increases not tied to rank.
- Future sailors will increasingly be generalists, rather than specialists, and will require relatively more education rather than Navy-specific training.
- Better embedded training will mean that more training can be done in operational units. This may require additional training personnel.
- Because operational units will have fewer apprentice level requirements, the Navy must develop methods to supply the knowledge and experience formerly acquired during apprenticeship tours.
- Average manpower costs will increase because the Navy's workforce includes a higher proportion of skilled technical workers.
- A skill-based pay system may be needed to set compensation levels that will attract and retain workers with high-paying civilian alternatives.
- Retirement incentives should be changed to retain skilled technical workers during their most productive years.

Conclusion and recommendations

Technological advance will most likely require a more skilled workforce. Some familiar skills will be less needed as the Navy automates routine tasks and information processing, as maintenance workloads and watchstanding requirements decrease, and as workload moves from operational units to the infrastructure. New skills will be required as automation progresses to the point where humans are overseeing complex, automated systems. In particular, the Navy will need sailors who understand the general principles in their area of

expertise, are technically literate, and have strong problem-solving, decision-making, and communication skills.

In the future Navy, manpower requirements will no longer be pyramids but will have reduced junior paygrade requirements and increased middle paygrade requirements. A number of factors point to the need for a clearer distinction between skill and rank; in particular, skill-based pay structures may be required. More enlisted recruits will have some postsecondary education because skill requirements will be general rather than Navy-specific, more COTS technology will be used, and more civilian institutions will offer relevant programs of study. Training will change to include more embedded training and methods to provide knowledge formerly acquired during apprenticeship tours. Average manpower costs will increase as the Navy's workforce includes a higher proportion of skilled technical workers.

Background

In the 21st century, two compelling sets of forces will be operating to change traditional ways that the Navy has manned its ships, submarines, and squadrons. First, technological advances and budget pressures are combining to produce a new generation of platforms and systems with significantly reduced manning. Second, the civilian population and labor force are changing in ways that will alter the effectiveness of traditional methods of recruiting, training, compensating, and retaining sailors.¹

The Assistant Deputy Chief of Naval Operations, Manpower and Personnel (N1B) requested that CNA examine the implications of technological change for Navy manpower. Specifically, many new ships and systems will be introduced in the next 20 to 30 years: from Smart Ship to LPD 17 and SC 21 in Surface Warfare, and from the CVX to the Common Support Aircraft (CSA) and Joint Strike Fighter (JSF) in Aviation. These new platforms incorporate advanced technologies that will significantly change manpower requirements. Among the possible impacts are reduced manning, higher skill requirements, rating consolidations, and moving some administrative, support, and maintenance functions to shore activities. The potential changes in requirements are so broad that they may require fundamental changes in how the Navy recruits, trains, retains, and promotes personnel.

In the Optimal Manning study, we addressed the following issues:

- What changes in the type of sailor the Navy needs are most likely to occur as a result of new ships and aircraft being acquired over the next 20 to 30 years?

1. A recent CNA paper [1] has taken a broader look at demographic and technological changes as well as changes in society, ways of doing business, and military concepts and missions. Some of the conclusions reached regarding how manpower and personnel policy may be affected are similar to those reached in this paper.

- What changes in the civilian population and labor force are likely to occur that will affect Navy workforce policies?
- Given the type of sailor needed and the changes in the civilian sector, what changes will be needed in personnel policies, such as recruiting, training, retention, promotion, and compensation?
- How much might it cost to set compensation so that the Navy can recruit and retain the future sailor?

In this paper, we examine likely future trends in naval technology and in civilian labor forces. We then consider how the combination of these two forces is likely to affect Navy manpower and personnel practices. This paper focuses on changes in career structure, recruiting, and training. We also discuss tying pay to skill rather than rank. A companion paper looks more closely at how future sailors will have to be compensated [2].

Changes in technology and skills

Our first task was to learn how future technologies will affect Navy platforms and what type of crew will be needed to operate the future platforms. There is considerable uncertainty about this issue because many of the systems are still in the initial design phases. Some initial designs even depend on technology that doesn't yet exist, so the funding and success of research and development (R&D) programs is an issue. Nevertheless, given the extent of the changes that may be necessary, it's important that manpower planners have as much advance notice as possible. Therefore, we gathered all available information about what platforms and technologies will be in the future Navy, and what kind of sailor will be needed.

We collected information through interviews, attending meetings of teams working on future systems, and a literature review that included material from internet sites. We talked with people from systems commands' program offices, research "think tanks," Naval Warfare Centers, contractors, resource sponsors, and manpower, personnel and training (MPT) offices. The range of people we talked to included scientists, human factors engineers, MPT experts, and Navy officers.

21st century Navy platforms

Between now and 2020 the Navy is planning to introduce new platforms, equipment, and systems, some with profound changes in technology and manning. Table 1 lists some of the major new platforms and initiatives. This section provides a summary of some of the major acquisition programs, focusing on technological changes that will affect manpower requirements.

Table 1. New platforms

Community	Platform	Number of ships	In the fleet	Delivery schedule
Surface Warfare				
	Smart Ship		Ongoing	
	LPD 17	12	2002	One per year
	DD 21	32	2008	Three per year
Aviation				
	CVN 77	1	2008	
	CVX		2013	One every five years
	Smart Squadron		Ongoing	
	F/A-18 E/F		2001	Existing aircraft replaced by 2008
	JSF		2008	

Smart Ship Project

The Smart Ship Project was stimulated by the report of the Naval Research Advisory Committee (NRAC) panel on reduced manning [3]. The report concluded that culture and tradition, rather than lack of technology, represented the major obstacle to reduced manning aboard Navy ships. As a result, the Chief of Naval Operations (CNO) asked the Commander, Naval Surface Force, U.S. Atlantic Fleet (COMNAVSURFLANT) to undertake a demonstration project on an operational ship to find ways to reduce workload and manpower requirements while maintaining readiness and safety. USS *Yorktown* (CG 48) was chosen as the first "Smart Ship."

The Smart Ship Project did find some effective ways to reduce manning. Some involved adopting existing technologies, whereas others were primarily organizational changes. The project assessment concluded that workload reductions could be achieved in three areas:

- *Policy and procedure.* The core/flex, or "flex to action" initiative reorganized the watch bill so that only core functions are manned 24 hours per day. Other functions are manned by a flex team that is called up only when needed. Routine

maintenance is moved to the day shift, and maintenance functions are moved out of watchstation manning.

- *Technology.* Navigation, machinery control, equipment condition monitoring, and information management functions were automated.
- *Maintenance methods.* Use of reliability-centered maintenance methods reduced the scheduled preventive maintenance workload by about 15 percent.

All the initiatives combined to reduce the weekly workload by over 9,000 hours, or about 30 percent. Translated into manpower requirements, the reduction was 44 enlisted personnel and 4 officers, or about a 12-percent reduction from the initial manning of 410.

A review of optimized manning case studies cited Smart Ship as an example of successful reengineering [4]. One element that was mentioned as contributing to the manpower reductions was improved situation assessment through the use of networked PCs, remote sensors of the status of engineering and damage control components, and the HYDRA wireless hand-held radio. Other important features of the Smart Ship effort were an iterative approach to adopting innovations that emphasized working through early failures and the increased size of the training department to support the innovations.

The Navy has begun extending the Smart Ship program; backfits are being planned for all existing CG 47 and DDG 51 Aegis ships at the rate of four per year. In addition, the new ships of the DDG 51 class will be delivered with Smart Ship improvements. At this rate, all the Aegis ships should have Smart Ship manning by roughly 2010.

In other communities, some of the innovations have been applied to USS *Rushmore*—the Smart Gator. Other amphibious and Combat Logistics Force (CLF) ships may be included as the program expands and additional funding is made available.

Efforts are under way on the aviation side, through the Smart Squadron and carrier programs.² CVN 73, USS *George Washington*, has been

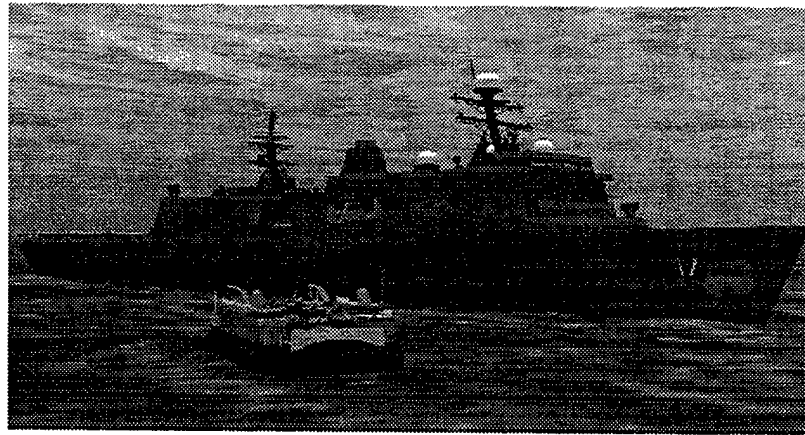
2. The web site is www.hq.navy.mil/airwarfare/smart_squadron.

designated as the first Smart Carrier. In addition, the final carrier of the Nimitz class (CVN 77, scheduled for commissioning in 2008) will incorporate new technologies that include and go beyond some of the Smart Ship initiatives [5].

LPD 17

The LPD 17, Amphibious Transport Dock, program is a planned 12-ship procurement that will replace several classes of aging amphibious ships (including the LHA, LPD 4, LSD 36, and LST 1179). It is the first major ship design program initiated under the revised DoD acquisition regulations. The lead ship, USS *San Antonio*, is scheduled to be delivered by the Full Service Contractor, Avondale Industries, in 2002 (see figure 1). Current designs call for a crew of 382 and capability to carry 705 embarked troops.³

Figure 1. Design sketch of LPD 17^a



a. Source: Internet web site, lpd17.nswc.navy.mil/lpd17.

3. General information on the LPD 17 is available at www.avondale.com/projects.htm and lpd17.nswc.navy.mil/lpd17/index.html. Information on manning was drawn from the "Design for Ownership, LPD 17 Manning Conference II, 5-6 Feb 1998, Final Report," at lpd17.nswc.navy.mil/reladocs/mannconf/manconfii.htm.

The overall philosophy toward reduced manning in the LPD 17 program has been to optimize manning in a way that will “do no harm.” While recognizing the need for reduced life-cycle costs, the program office stressed the importance of full operational readiness and the need to validate reductions before removing manning. Given this, the overall manning reduction goal for the LPD 17 is 20 percent. The baseline manning estimate established during the Cost and Operational Effectiveness Analysis (COEA) was 450. This had been reduced to 382 in the Preliminary Ship Manning Document (PSMD), with a further goal of getting to 360 for the 20-percent reduction.

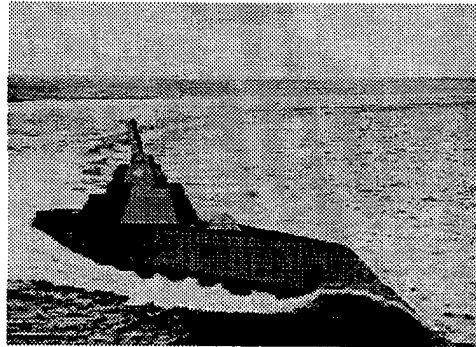
The techniques being used to reduce LPD 17 manning include some of the “work smart, not hard” techniques of the Smart Ship Program, as well as additional innovations. The manning reduction initiatives include: core/flex watchstation manning, reliability-centered maintenance, advanced communications and display technologies, and data storage and management innovations.

DD 21

The DD 21 is the first of the new ship classes to be acquired under the Surface Combatant of the 21st Century (SC 21) program.⁴ Thirty-two ships are planned for the DD 21 class, with the lead ship to be delivered in 2008. The DD 21 program has an explicit goal of reducing ship manning to 95, including the helicopter detachment.⁵ This is a 75-percent reduction from the 440-person crew of a baseline reference ship. Figure 2 shows one conception for the DD 21 hull design.

-
4. Information on the SC 21 and DD 21 programs was obtained through interviews with personnel from the program office, resource sponsor, R&D centers, contractors, and from the following Internet web sites: <http://sc21.crane.navy.mil/>, <https://ganymede.dv.synetics.com/Projects/pms-500/MHSIPNB.nsf> and <http://www.manningaffordability.com/S&tweb/index.htm>.
 5. A Key Performance Parameter (KPP) of the acquisition program sets a manning objective of 95 and threshold of 150 assigned shipboard personnel.

Figure 2. Possible hull design for DD 21^a



a. Source: Internet web site, <http://sc21.crane.navy.mil>, file atds.pdf.

Human Systems Integration (HSI)

An important feature of the DD 21 program is the emphasis on HSI early in the design process to reduce crew size without affecting capability. The DD 21 program office in the Naval Sea Systems Command (NAVSEA) has a branch devoted to Manning and Human Systems Integration (M/HSI). HSI is the systems engineering discipline that integrates people with hardware, software, information, the environment, and internal and external organizations. The advantage of HSI is that systems are designed from the beginning to take human capabilities and limitations into account, as well as the best human and machine allocation, and the costs of automation versus labor costs.

One technique of HSI is the Top Down Functional Analysis (TDFA) [6, 7, 8]. Crew requirements start at zero under TDFA. The process to define requirements starts with operational requirements and uses them to define detailed functions, then assigns the functions to humans or automation. In addition, human systems engineers design human-machine interfaces that are as efficient as possible and systems that ensure required levels of shipboard human performance, workload, reliability, and safety can be sustained. Another advantage of TDFA is that functions are allocated between human and machine at a high level rather than with ship systems defined by traditional acquisition structures. The result is more integration, coordination, and more efficient use of crew across narrow functions.

The organizational structure that NAVSEA is using to support HSI is the M/HSI Integrated Product Team (IPT). IPTs are a means for industry and government to collaborate in the design process. The M/HSI IPT has four working groups: Personnel, Policy, Training, and Human Systems. The Personnel IPT's mission is to:

- Provide guidance and assess industry proposals for:
 - Crew deployment
 - Crew management
 - Crew composition and structure
- Anticipate necessary changes to personnel system and infrastructure and facilitate acceptance.

Sources of reduced manning

Features of the DD 21 that are intended to reduce manning include [9]:

- Automation
- Minimization of maintenance and administrative functions
- Sensors for damage control
- Embedded training
- User-friendly Human-Machine Interfaces (HMIs)
- Corrosion minimizing materials and preservatives.

In general, the approach to manning the DD 21 will be to automate wherever practical without sacrificing capability, using the most advanced technology available. The result will be automation of many simple skills, with a probable increase in the average skill level of the remaining sailors.

Maintenance will be reduced by several means. First, improved reliability and reduced maintenance will be engineered into all systems and components. Advanced materials, coatings, and preservatives will reduce cleaning, corrosion control, and painting requirements. Automation will replace human labor whenever possible. Remote

sensors will take the place of maintenance watchstanders. Advanced sensors used for condition-based maintenance will be able to predict imminent failures so that maintenance is done only when absolutely necessary. Some maintenance will be moved ashore through the use of redundant systems or swapping out subcomponents. Finally, new information technology will be exploited so that experts can be located ashore and consulted when needed.

The use of remote sensors and "core/flex" watchstanding bills, such as those demonstrated in the Smart Ship program, will reduce watchstanding. The cleaning and structural maintenance workload will decrease by using robotics, automation, and better materials, paints, coatings, and tools.

Damage control is another manpower-intensive area that requires reductions to reach the 95-person crew. Methods to reduce damage control manning include dividing the ship into compartments, using remote sensors and automated damage control systems (e.g., halon gas, automated dewatering), engineering in improved survivability, lighter weight hoses, and robotics or automated strength multipliers.

In the administration and support areas, the workload associated with routine tasks will also decrease by taking advantage of interactive databases, automated tellers, paperless ship technology, "heat and eat" meals, vending machines, automatic dishwashers and laundry, and hygienic toilets.

Another important element of reduced manning is transferring work to the shore infrastructure. Two ways to achieve this transfer are by means of redundant systems, which allow delay of repairs until back in port, and by using information technology to link ship to shore (or other ships) and relying on remote experts.

Features of technology

Reaching the manning goals will require development or improvement of certain key technologies. These technologies are part of the military's current R&D program, either through DARPA, ONR, NAVSEA, or other sponsors. Later in this paper, we examine some of

the technology initiatives that affect more than one ship class. Programs that should have the largest manpower impacts are:

- Advanced computing: single open architecture so that any console can be configured to perform any ship function
- Multi-Modal Watch Station (MMWS)
- Advanced sensors, both for condition-based maintenance and for processing sonar and other signals
- Integrated digital communications: one network to carry computer, voice, and visual data with a reliable, broadband link to other ships and to shore
- Embedded training.

With these technological advances, the DD 21 will be an integrated, interoperable platform whose crew is made up of operators and decision makers, rather than data integrators and maintenance technicians. The total ship computing architecture will take advantage of information and knowledge technologies so that it is capable of disseminating information to widely dispersed and dissimilar units.

The old model for information processing used humans to receive, verify, process, correlate, and prioritize data and to determine its relevance to the situation. More advanced information systems will integrate and filter information, resolve ambiguities, and determine the relevance. Humans will oversee this process, get knowledge rather than data from the machines, and use it to make decisions. In many areas, the crew will rely on intelligent systems and agents to process sensory data, display the data in an understandable way, recommend and execute actions, autonomously control system components, and assess workload and distribute it across automated and human agents.

Because tasks normally accomplished by less experienced, less knowledgeable crewmembers are targeted to be automated, the remaining crew may be, on average, either quite knowledgeable or quite senior, or both.

Is a crew of 95 possible?

Important concerns remain regarding the ability to reduce manning to 95. In particular, manning for special evolutions and for crises that include multiple engagements could be a problem. Special evolutions that may have high manpower demands include damage control, replenishment, helicopter operations, boarding and salvage of other ships, and small boat operations. Of special concern is a crisis situation, such as hitting a mine, that would stress a small crew because many functions would have to be performed simultaneously.

Another major reservation regarding the 95-person crew is whether all the necessary technological innovations will be available in time. A previous CNA analysis placed the technological innovations needed to support reduced manning into three risk categories [10]:

- *Low.* Technology exists today or is being tested in the Smart Ship program and will incur minimal to no R&D or implementation cost.
- *Moderate.* Technology may be available but has not been validated or may incur moderate R&D or implementation cost.
- *High.* Technology does not exist or will involve high R&D and implementation costs.

The analysts included the following technologies in the high-risk category:

- Artificial intelligence systems interfaces
- Automated correlation and deconfliction of track identification data
- Common consoles
- Voice recognition
- On-line liquid analysis
- Advanced fire-retardant bulkheads
- Automated ship control for underway replenishment

- Mechanical mobile firefighting station for helicopter operations
- Corrective maintenance with remote support
- Self-cleaning systems
- Predictive human performance modeling for embedded training
- Ship-to-shore connectivity needed to move all administrative functions ashore.

The authors concluded that, if all high-risk technologies are implemented, and some cultural and institutional barriers are overcome, a crew of 99 (not including the helicopter detachment) may be feasible. They argue that a more realistic appraisal of what technologies may be operational by 2008 would require a 170-person crew (again, not including the helicopter detachment). The authors also state that cultural issues form another large impediment to crew reduction.

The Ship Systems Automation (SSA) study also looked at the state of the art in reduced manning technology and what remains to be done [8]. Although the authors have similar opinions regarding the largest remaining challenges, they have a more optimistic assessment of the feasibility of a 95-person crew. They consider the most important technology needs, considering both the need for additional research and the payoff in reducing manning, to be:

- Hands-off communication
- Mechanical assistance for operators
- Data representation
- Intelligent Systems Interface
- Mobile robotics
- Voice recognition
- Cross-rate training.

DD 21 manpower reductions in perspective

Even though the proposed DD 21 manpower reductions are dramatic, this program alone won't have a major impact on total Navy manpower requirements. Figures 3 and 4 illustrate this by examining the role of

Figure 3. Numbers of surface combatants, 2000-2020

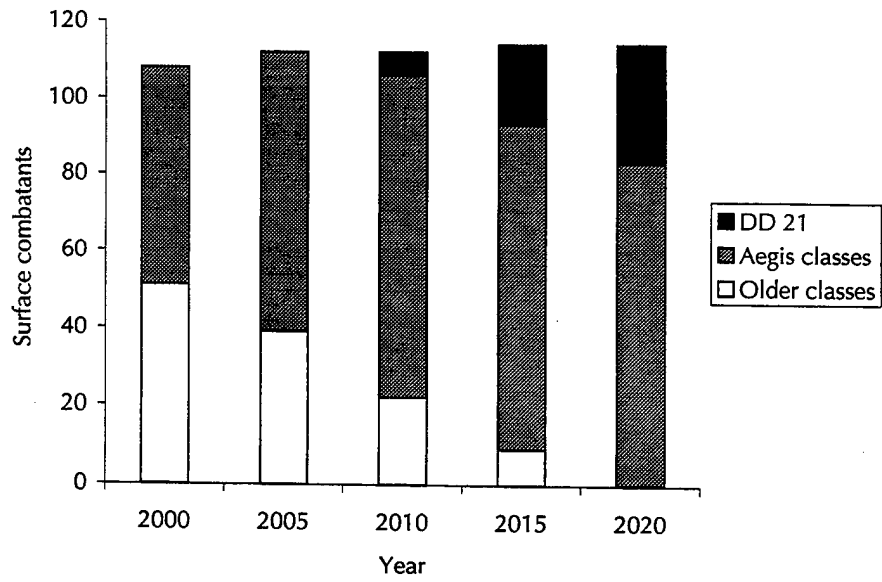
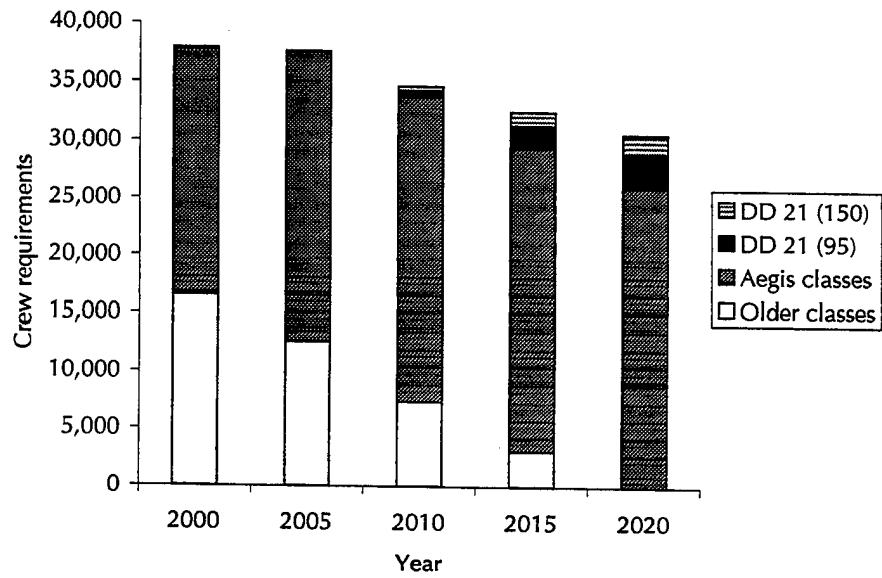


Figure 4. Manpower requirements for surface combatants, 2000-2020^a



a. Because surface combatants would make up only 40 percent of all surface ship manning in 2020, if DD 21 crews were 10 to 15 percent of surface combatant manning, they would be only 4 to 5 percent of all surface ship manning.

DD 21 within the surface combatant force—noting that surface combatants account for less than half of surface ship manning.⁶ Figure 3 shows the approximate number of surface combatants planned for 2000 to 2020 by type of ship. In 2000, there will be 20 ships in the DDG 51 class and 27 in the CG 47 class, for a total of 57 Aegis class surface combatants. The remaining 51 ships in 2000 are from older classes of cruisers, destroyers, and frigates. Between 2000 and 2010, the number of Aegis class ships increases to 84, replacing some of the older ships. Starting in 2008, ships of the DD 21 class begin to arrive and replace more of the older ships. Even as late as 2015, however, some ships from these older classes will remain in the Navy. By 2020, the DD 21 will make up 27 percent of the surface combatants, with the remainder being Aegis destroyers and cruisers.

Figure 4 translates the number of ships in figure 3 into approximate manpower requirements. For the older ships, the crew size per ship is assumed to remain constant, so that the falling crew requirements reflect ship retirements. For the Aegis cruisers and destroyers, we assume that Smart Ship changes that reduce manning by 15 percent phase in gradually from 2000 to 2010. Two assumptions are made regarding the DD 21 manning—that crew size reaches the goal of 95 or, alternatively, that crew size remains at the threshold level of 150.

If all surface ships, rather than just cruisers and destroyers, are taken into account, DD 21's share in manning becomes even smaller. Analysts in N81 forecast that, by 2020, about 40 percent of all ship billets will be on cruisers and destroyers, with the remaining 60 percent on carriers, amphibious ships, and mine warfare ships. If DD 21 accounts for 10 to 15 percent of surface combatant manning, it accounts for only 4 to 5 percent of total surface ship manning. DD 21's manning

6. Using 1997 requirements, total manning for all surface ships was about 127,000, of which 27 percent were on carriers, 29 percent were on CLF ships, 19 percent were on amphibious ships, and 25 percent were on cruisers, destroyers, and frigates. Based on forecasts by analysts in N81, by 2020 total manning for surface ships will be 73,000, of which 25,000 (34 percent) will be on carriers, 16,000 (22 percent) on amphibious ships, 2,000 (3 percent) on mine warfare ships, and 30,000 (41 percent) on cruisers and destroyers. By this time, all CLF ships will have been transferred to the Military Sealift Command. Of the 30,000 billets on cruisers and destroyers, only 3,000 will be on DD 21 ships (assuming a crew size of 95).

share also depends on what assumptions are made about manning reductions on other ship classes. We assumed fairly modest manning reductions of around 15 percent for most ship classes, which is roughly consistent with the Smart Ship reductions. If more aggressive manning reduction initiatives were pursued on other ships, DD 21's share of total ship manning would increase.

Future carriers

Innovations in carrier manning are proceeding along two paths: procurement of the tenth and final Nimitz class carrier, CVN 77; and design of the carrier of the future, CVX.⁷ CVN 77 is scheduled for commissioning in 2008. She will be a transition ship, retaining the Nimitz class hull and propulsion system, but including new technologies from ongoing R&D programs and some manning reduction initiatives. The CVX program, with the first ship to be delivered in 2013, will include more substantial changes.

CVN 77

CVN 77 will include design features and organizational changes that are expected to reduce total ownership costs by as much as 15 percent. These features may also be backfitted to existing CVNs once they are tested and evaluated. Some of the innovations being considered that have substantial manpower impacts include the following:

- *Integrated Information System.* This system would capitalize on advances in commercial industry to support the transfer and integration of voice, video and data information between audio, video, and computer systems.
- *Multifunctional embedded antennas.* Reduction of the number of antenna systems should reduce maintenance manpower requirements.

7. Material in this section is drawn from interviews with personnel in Team CVX, the CVX AOA, and N86 and from information on the CVX web site at www.navsea.navy.mil/cvx/pubcvx.html and articles in the Jan-Feb 1997 issue of *Naval Aviation*, available at www.history.navy.mil/nan/1997/index.html.

- *Alternative energy catapults.* Electromagnetic or liquid propellant catapults would provide increased reliability and reduced manning requirements compared to current steam-driven catapults.
- *Advanced systems for flight operations management.* This family of information management and decision aids will facilitate mission planning, aircraft control, and aircraft/pilot information upload and download. These systems should improve operations and result in a significant manning reduction.

CVX

The carrier to be delivered in 2013, CVN 78, is considered the first CVX. This carrier will have a new propulsion plant, a big jump in information technology, and innovations in material handling. CVN 79, due in 2018, will be the first completely redesigned carrier including a new hull.

The mission statement for the CVX explains that “the platform should be automated to a sufficient degree to realize significant manpower reductions in engineering, damage control, combat systems, ship support, and Condition III watchstanding requirements.”⁸ A particular point of emphasis is the need to reduce preventive maintenance requirements by using self-analysis features as well as materials and preservatives that minimize corrosion.

The goal for CVN 78 is a 20-percent reduction in total ownership cost and a 20- to 30-percent reduction in manning. The percentage manning reduction goal is comparable to the LPD 17 and considerably less than the DD 21 goal because of the traditional, evolutionary approach used by CVN 78 and LPD 17. On the other hand, because of the large absolute size of the carrier, a 20-percent reduction translates into about 500 fewer people in the ship’s company, so the potential impact on total sea manning requirements is substantial. Furthermore, there is some discussion of whether more dramatic manning reductions, on the order of 50 percent, might be possible.

The following manning reductions are likely:

8. Source: www.navsea.navy.mil/cvx/cvxmns.html.

- Damage control manning requirements—because of automated battle damage management and improved electrical distribution systems
- Command-and-control manning requirements—as a result of advanced information technology, displays and decision aids, as well as common architecture
- Maintenance workload—through greater reliability, improved materials, and condition-assessment technology coupled with condition-based maintenance.

Other areas in which manning reductions are expected include:

- Handling of aircraft on the flight deck
- Material handling, including ammunition, fuel, and food supplies
- Hotel functions, such as messing, berthing, and laundry.

The changes in information technology and command-and-control areas are similar to those discussed for the DD 21. As in the DD 21, the new technologies allow manning to be reduced, but still call for a “person in the loop to gather and process information and to react to unexpected circumstances” [11].

Reduced manning for material handling is much more important on a carrier or logistics ship than on surface combatants. In this area, significant changes are expected in how material is physically moved around in the ship and in how the supply system is administered. As a result, the existing Storekeeper (SK) rating with its emphasis on administration, paperwork, and physical labor will be replaced by sailors who maintain automated inventory and material handling systems.

Innovations are also being pursued in the hotel functions, which are of special importance on large ships that deploy. The future carrier will be a cashless ship with an automated ships store or vending machines. Food service will be much different, although the exact changes are still in the R&D stages. Perhaps there will be more reliance on cruise-ship techniques in which meals are cooked and flash frozen on shore, then reheated on demand at sea. Serving meals will also be different, with greater dispersion in eating times and more

self-service. Automation and manning reductions will also be sought in laundry, dishwashing, and waste disposal functions.

Different platforms have different emphasis

Many of the same technological advances will be used on most future platforms, but they will have relatively greater or smaller impacts on manning depending on the type of ship. For example:

- Automation of information processing will affect all platforms, but the tactical information processing will be especially important for surface combatants, battle groups, and tactical squadrons. That is, because of a higher proportion of billets on surface combatants in command and control, changes in this area will be relatively more important.
- Automation of material handling will be especially important for carriers and CLF ships because of a greater proportion of manpower requirements that relate to this function.
- Automation of hotel functions will affect all ships, but it will be especially important for carriers and other large ships that deploy.

Future aircraft

F/A-18 E/F

The F/A-18 E/F is scheduled to replace the primary tactical aircraft (F-14, A-6, and older F/A-18 series) starting in 2001. All F-14s would be replaced by 2008. The Preliminary Squadron Manning Document (PSQMD) for the F/A-18 E/F shows small overall reductions from previous F/A-18 squadrons, accompanied by a slight increase in the percentage of requirements in the top six paygrades.

The F/A-18 E/F is consistent with two general trends in future aviation manning:

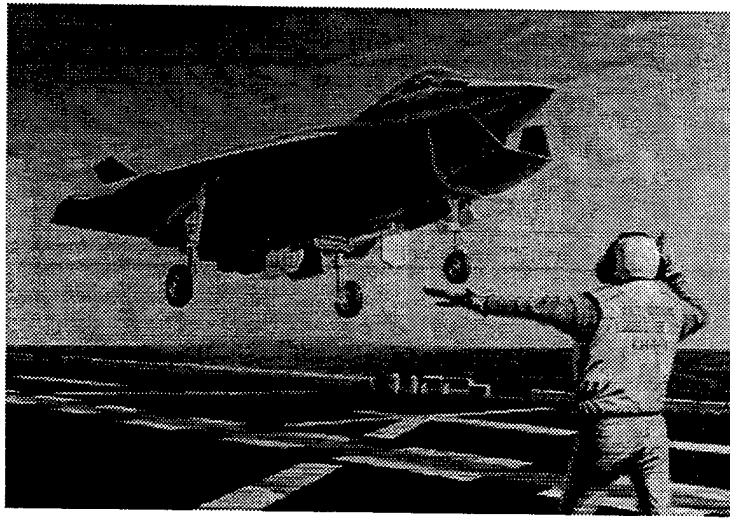
- Continuation of past trends to use "swap-out" design that moves organizational-level maintenance requirements up to intermediate or depot level.

- Use of common airframes and systems to as great an extent as possible. This reduces the complexity of rating and Navy Enlisted Classification (NEC) requirements.

Joint Strike Fighter (JSF)

The JSF is being developed for the U.S. Air Force, Navy, and Marine Corps and the United Kingdom Royal Navy.⁹ The JSF will replace several types of fighter aircraft, including the F-16 and the F/A-18 C/D. The total joint-service acquisition program has a goal of delivering the first operational aircraft in 2008 with a total of 3,000 aircraft planned. The U.S. Navy has identified a requirement for 300 strike fighters to complement the F/A-18 E/F. Figure 5 shows an artist's representation of the JSF for carrier operations.

Figure 5. The Joint Strike Fighter (JSF) on a carrier^a



a. Source: Internet web site, <http://www.jast.mil>.

9. Information on the JSF was taken from the JSF website at <http://www.jast.mil> and from an industry website at www.naval-technology/projects/jsf/index.html.

Although many design issues remain unresolved, some general themes in how manpower requirements will change are consistent with other future systems:

- Increased reliability and advanced condition-based maintenance systems for aircraft and weapon systems will reduce organizational-level support requirements.
- Advanced information technology, displays, decision aids, and embedded training will change the skills needed by operators and maintainers.

Some of the R&D efforts and new systems needed for the JSF include:

- Virtual reality for maintenance training
- Interactive Electronic Technical Manuals and maintenance information databases linked to personal digital assistants for deployable training
- Embedded training with distributed simulation
- Enhanced sensors and prognostic/diagnostic software (neural nets or intelligent agents).

Common Support Aircraft (CSA)

The CSA program is in the very early stages of defining the Navy's need for a new generation of support aircraft. Although it is too early to say much about the manpower needs of the CSA, it is conforming to the general trend of reducing the number of airframes by developing one airframe for all Navy support aircraft. Reduced complexity should allow considerable streamlining of manpower requirements and training infrastructure.

Questions about technology and manning

Several questions commonly arise in discussions of how technological advances will affect crew requirements for ships and squadrons. The first is whether advances will result in a higher or lower skill mix. The second involves how far automation should be pushed for ships whose fundamental mission is warfighting.

Will skill levels rise or fall?

Some tasks lend themselves to automation, while others do not. At the lower end of the skill spectrum, there are some physical labor jobs that are difficult to automate because of the nature of the work. One example would be some underway replenishment evolutions where the crew has to react to changing physical conditions. At the higher end of the spectrum, you need humans involved in combat information processing to provide context and to make decisions. Some decision-making shouldn't be relinquished to automation, such as command, interpreting Rules of Engagement, and weapon release.

With some people remaining on both the high and low ends of the skill spectrum, it may not be immediately obvious whether average skill requirements will increase or decrease. In part, remaining skill requirements depend on the quality of the human-machine interfaces (HMI). Poorer interfaces may require very sophisticated users, while the best interfaces reduce the demands on the operators. The success of future HMI depends, in turn, on how much is devoted to R&D today. More R&D expenditure today could reduce skill requirements tomorrow.

There has been a considerable amount of research on the relationship between technological advance and workforce skill levels. The general conclusion reached by these studies is that as technology gets more advanced the workforce becomes more rather than less skilled. Particular findings include the fact that wages range from 5 to 20 percent higher on average for firms using advanced technologies [12, 13, 14]. Other studies find an increase in both average education and the proportion of high-skilled occupations within firms using advanced technologies [12, 15, 16, 17]. Reference [12], for example, finds that, after adopting advanced technology, about 10 percent more workers had postsecondary schooling, and another 10 percent more were employed in higher skilled occupations. However, despite the overall findings of increased skill levels, some individual occupations have become less skilled, including some clerical and manufacturing jobs [15, 18].

In any event, trends in both information systems and maintenance indicate that, in the future, operator/decision-makers will replace

specialized maintenance technicians. Crewmembers will be needed to take knowledge that the machines have processed and turn it into decisions. On the other hand, with added redundancy and reliability, there may be less need for the crew to know how the machines work and be able to maintain and repair them while deployed.

Are there limits to automating warfighting?

In general, the more routine a task is, the more easily it can be automated. Unexpected events, on the other hand, require adaptations that are difficult to automate. This is the paradox of applying automation to warfighting. With complex problems that require many agents to interact, introducing uncertainty soon increases the number of possibilities to the point that traditional software architectures become too cumbersome. There is some promise that adaptive, intelligent agents can be developed to the point that complex, uncertain problems can be automated. This technology is far from mature, however.

The problem with automating warfighting is that combat situations are inherently chaotic—their complexity and uncertainty defies automation with current technology. In this case, automating the routine tasks that can be automated involves a risk. There are two possible negative outcomes. One is that, with the routine tasks automated, the crew will be cut to the point that there will not be enough people to cover the complex evolutions that arise during combat. The second is that enough people will be retained, but they will have poor combat skills because they lack the experience gained by performing routine tasks during peacetime.

The implications of reduced manning for warfighting capability are potentially serious. Any manning reduction efforts on warfighting ships must address this problem.

21st century crews

In this subsection, we will synthesize the features of the new platforms discussed at the beginning of this section to discover general principles regarding what 21st century crews will look like. First, we will look at some general issues, such as the implications of acquisition reform

for future systems. Also, we'll examine some research programs and technology initiatives that cut across platforms. Then, we'll identify common themes and use them to develop a resume for the future sailor.

Acquisition reform

Two features of acquisition reform have especially important implications for design and manning:

- More of the design work is done by industry, rather than having industry work from detailed specifications provided by Navy engineers.
- One contractor or integrator, known as the Full Service Contractor (FSC), is responsible for all aspects of design, including component systems, logistics, manning, and training.

Under the new acquisition guidelines, the FSC is responsible for designing and proposing training, maintenance, and manning plans which are then validated and approved by the Navy. The buyer and the contractors work together throughout the design process in Integrated Product Teams (IPTs). This differs from the old acquisition process in which the military drew up detailed design specifications, including logistic and support plans. The idea behind this change is that industry will have more leeway to adopt innovations that reduce costs while maintaining capability. Likely consequences are military systems, work organizations, and training and maintenance plans that are closer to those used in commercial industry.

In particular, future systems are expected to rely much more heavily on commercial-off-the-shelf (COTS) equipment. This should be a direct result of letting industry design and innovate so as to reduce costs. With more COTS technology, the skills that military personnel need will be more similar to skills of civilian personnel. This means that the military may be able to make increased use of private-sector training and education. It also means that the military will be in more direct competition with industry for its workforce.

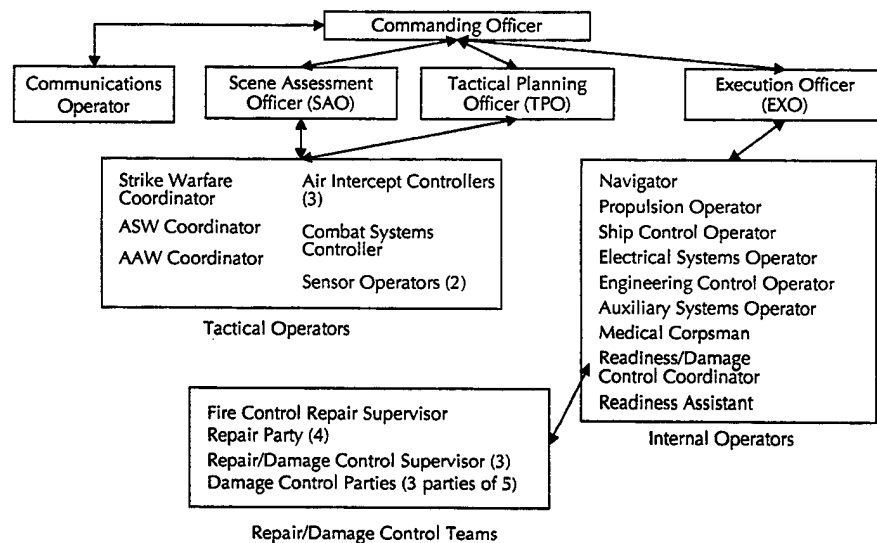
Another consequence of the "industry proposes, Navy approves" system is that the Navy won't have detailed manpower requirements

until later in the acquisition process. Because changes to Navy accession and training plans are driven by changes in manpower requirements, this could pose a problem under the traditional ways of doing business. The Navy will, therefore, have to be more flexible in anticipating likely future changes before detailed changes to manpower requirements are in place.

Ship of the future

Ship Systems Automation (SSA) is a Defense Advanced Research Projects Agency (DARPA) program that has studied both submarine and surface ships to envision a fully automated, minimum-crew platform.¹⁰ Reference [8] describes a Concept of Operations (CONOPS) for a fully automated surface combatant, including possible crew configurations and descriptions of necessary technologies. Figure 6 shows a proposed condition I watch organization from the SSA operational manning concept.

Figure 6. Conceptual condition I watch organization for SSA ship



10. SSA is the descendant of the earlier Autonomic Ship and Submarine Operational Automation System (SOAS) DARPA programs.

To illustrate the manning concepts for the SSA, consider the scene assessment function. Scene assessment is done by the SAO, three coordinators, and six console operators. For this to be possible, all sensor processing for radar, sonar, and visual systems must be done automatically. In addition, correlating signals across sensors and drawing conclusions regarding the combined state must be done automatically. Because some signals will contain spurious information and ambiguities that can't be resolved by the system, the system will have to characterize these data and assist the operators in arriving at the correct tactical picture. That is, the system must be able to identify areas where uncertainty exists, direct the operator's attention to them, allow the operator to understand them, and then accept instructions from the operator. Another requirement for such a reduced crew would be workload sharing: each sensor resource would be generic and able to switch from one warfare area to another as the workload changes. Similar automated information processing and decision aid systems will assist the Tactical Planning Officer (TPO), the Execution Officer (EXO), and their staffs.

Another example of how the SSA project envisions the ship of the future is given in the engineering section. The Engineering Control Operator will have highly automated propulsion, steering, and auxiliary systems. All equipment will have automated startup, shutdown, and reconfiguration that can be controlled remotely. All major valves and equipment will be configured for remote control and will include reasoning systems to evaluate system health and status, evaluate potential operating modes, and automatically control subsystems. Machinery and systems will be monitored by remote sensors to assess their condition and readiness. In case of failure, the advanced reasoning systems will be able to evaluate alternative lineups and recommend optimal configurations to the operator.

The SSA that results from the TDFA has the following features:

- Intelligent systems interfaces, including graphical displays that are multifunctional and multitasking
- A high level of automation in communications, ship control, ships log, lookout, and engineering

- Generic sensor resources and universally adaptable consoles
- Advanced information processing (i.e., reasoning systems that process data into knowledge)
- Embedded, distributed sensors to monitor equipment and system performance
- Dependability, redundancy, automatic reconfiguration, and graceful degradation
- Increased generalization of human skills
- Remote expert assistance.

Optimized manning lessons learned

In another study, analysts looked at successful and unsuccessful optimized manning initiatives in a variety of military and civilian contexts [4]. They examined 20 case studies that included the Smart Ship program, the British Royal Navy, General Motors, and examples in the nuclear power, petrochemical, and health care industries. They compiled the following lessons learned:

- Smaller workforces have less time for on-the-job training and so must find other ways to train.
- Risks of reduced work forces are highest when there are multiple modes of operation because there are fewer people to handle unusual situations. Multiple scenarios and all possible conditions should be considered in determining optimal manning.
- Areas that best support staffing reductions include:
 - Tools to build and maintain situation awareness, that is, better tools for maintaining, updating, and communicating the big picture
 - Technology for using remote specialists (e.g., telemedicine)
 - Central monitoring systems so that fewer, centralized humans can monitor a larger area.
- Reduced manning often requires cross-training, or personnel with more generalized skills.

Technology initiatives

To meet the reduced manning goals for future Navy platforms, significant progress must be made in several technology areas. To this end, a number of DOD organizations are funding various technology initiatives. This subsection summarizes some of the initiatives that have especially significant implications for future manning.

Automating situational awareness and tactical information processing requires good sensors; software that transforms the raw, sensory data into knowledge; and software and displays that communicate the knowledge effectively to human operators and decision-makers. One broad area of research covers all these elements of automated information processing. Within this are a few notable projects.

Multi-Modal Watch Station (MMWS)

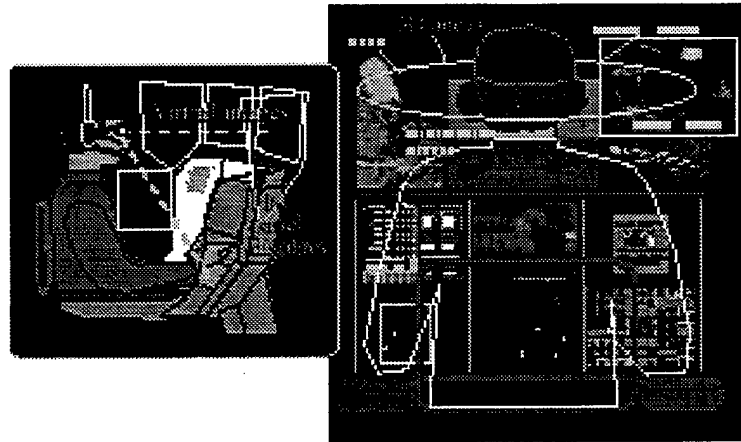
ONR has established the SC-21 Manning Affordability Initiative, a research team that integrates the efforts of ONR and the SC-21 program [19]. The team's agenda includes research on the MMWS, an advanced workstation that seeks to reduce manning requirements by using advanced displays and embedded intelligence. An MMWS includes visual and auditory displays, controls, firmware, multi-modal (e.g. audio, visual, sensory) human-computer interface (HCI) software, decision aids, information management tools, and a work space (see figure 7). Desirable features that may be designed into the MMWS are three-dimensional audio, hands-free input, voice recognition, and lightweight wearable displays.

One element of an MMWS may be dynamic function allocation (DFA) [20]. In a complex automated environment, it may be best to redistribute tasks among human and automated components in different ways at different times depending on workloads, capabilities, fatigue, failure, or other factors. One area of research is how human (or automated) agents can make the best decisions about DFA in an operational setting.

To design a good MMWS, human systems engineers need to understand how human cognitive processing works. Human cognition models are not mature, and development will require more R&D

money [21]. Further, the best MMWS would include models of distributed and team information processing, which are a high-risk R&D element.

Figure 7. MMWS concept^a



a. Source: Internet web site, <http://sc21.crane.navy.mil>, file atds.pdf.

The MMWS would integrate control of multiple systems through one console. For example, one console would combine the Tomahawk Launch Controller, Engagement Planner, and Harpoon Operator, which are currently three consoles and three software packages. With an MMWS, the future surface warrior would sit in a single watchstation and oversee mission planning, execution, monitoring, and engagement of a family of weapons using multiple sensor systems.

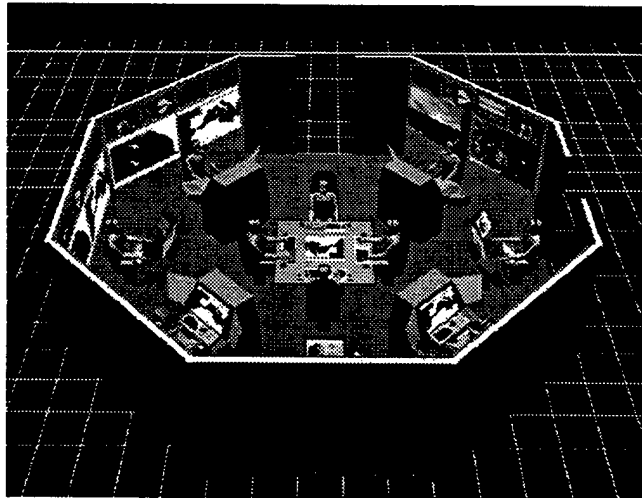
Advanced information management would direct users to important information at the right time, monitor what the user is doing and adapt the information displays accordingly, and provide intelligent task aids. Performance monitoring capabilities would include measuring eye movements, keystrokes, and speech communications. These could then be compared to an expert model to identify where a trainee made mistakes. In nonoperational modes, training scenarios could be loaded, making the MMWS a training platform [22].

Integrated Command Environment (ICE)

On the ship of the future, the MMWSs would sit in an ICE. The ICE is envisioned as being radically different from today's Combat Information Center (CIC). The main difference is that it would include all areas of command, control, and communications. Each watchstation would be multifunctional and all ship data would be part of an integrated computer system. Figure 8 shows one of many possibilities for the design of an ICE.

An ICE must have a computer architecture that reduces both delay and uncertainty to facilitate intelligent decision-making. Data from different sensor systems should be integrated, processed, and communicated through a human-machine interface (HMI) so that the decision-maker can operate effectively in a minimally manned command center. Many of the features of the ICE also appear in DARPA's Command Post of the Future [23].

Figure 8. One possible ICE design^a



a. Source: Internet web site, <http://sc21.crane.navy.mil/>, file ice.ppt.

Reference [21] describes the workforce in the ICE as follows:

Operators will be provided with multiple candidate solutions (via automated decision aids) from which to choose a response to a problem. In the absence of information, uncertainty measures and multi-hypothesis reasoning techniques will provide the operator with alternative interpretations of the tactical domain, with each alternative characterized by measures of likelihood. Conversely, in a data-rich environment, automation will provide the user with a means to sort out and interpret information that might otherwise be overwhelming.

Intelligent sensors/adaptive agents

One way to imagine intelligent sensors is to envision a mobile agent walking around a ship's engineering spaces. This agent uses its sensors to gather data, then processes the data to arrive at a "belief" about the space's condition. It may then translate this belief into a desire to have further information, or an intent to take some corrective action.

Intelligent sensors can be contrasted to a traditional, close-ended architecture in which the information to be gathered is precisely defined and reported in prespecified ways [24]. A system based on intelligent sensors and adaptive agents could provide the following advantages:

- Real-time decision support
- Performance monitoring and assessment of human operators, to be used for training or for dynamic function reallocation
- Automated associates or digital assistants that would perform tasks and interact with human operators in an intelligent and cooperative manner
- Embedded intelligent training
- Cooperation and collaboration support (i.e., checking that all work gets done and that there are no redundant efforts)
- Knowledge management and transfer.

Control of Agent-Based Systems (COABS)

Automated collecting and processing of information can be accomplished in two ways. In the first, referred to as finite state models or object-oriented processing, programmers try to identify and model all possible interactions. In complex situations with many agents and uncertain environments, the number of possible interactions can become so large that finite state models aren't possible. The second, newer, type of information processing uses computers that can learn and rewrite their own code; this is referred to as intelligent agent or adaptive agent technology.

With adaptive agents, the human operators become, in effect, coaches. The crew must constantly monitor the software's development, correcting mistakes and controlling its actions. The DARPA COABS program is researching the feasibility of using adaptive agents in military applications and designing effective control strategies for agent-based systems.

Accelerated Capabilities Initiative

This ONR project focuses on Condition-Based Maintenance (CBM) and advanced embedded training. The CBM program involves oil analysis, machinery diagnostics and prognostics, and corrosion prevention or protection [10].

The Advanced Embedded Training Advanced Technology Demonstration (ATD) is investigating ways of using human information management and advanced training technology to deliver training as part of a system. In tactical systems, this would involve switching to a non-operational mode and running training scenarios while intelligent agents evaluate responses in real time and provide feedback. The best embedded trainers could even generate training plans and scenarios that address the operators' weak points.

Common themes

Across all the new platforms, systems, and acquisition programs, some common themes emerge:

- Routine tasks and as much information processing as possible will be automated. Requirements for human labor will diminish and will involve more collaboration between human and machine where the human adds context to information processing and makes complex decisions.
- Maintenance requirements in operational units will abate through increased reliability, remote sensors, condition-based maintenance, automation, interactive technical manuals, and access to remote experts.
- Watchstanding requirements will decrease through technology and organizational changes.
- New information technology and other methods of accomplishing tasks remotely will result in workload moving from operational units to the shore.
- Cost considerations and new acquisition policies will increase the use of COTS technology.
- Increased commonality of systems will reduce the complexity of manpower requirements and support the development of generalists rather than specialists. The outcomes may include a reduction in NECs, combining various maintenance ratings, combining various operator ratings, or even combining maintenance and operator ratings.

Future sailor's resume

In summary, future Navy platforms will have lower requirements for routine labor because there will be fewer maintenance and watchstanding tasks, less need for general, unskilled labor, and less need for detailed knowledge of specific systems.¹¹ On the other hand, there will be greater needs for people with broad knowledge of their areas of expertise and strong problem-solving, decision-making, and communications skills.

11. This assumes that adequate investment is made in using human-centered design in future Navy platforms.

In almost all areas—including combat systems, command and control, engineering, maintenance, material handling, and hotel functions—automation will have progressed to the point where humans are overseeing complex, automated systems, providing context, coaching, and making decisions. This job will require someone who knows the general principles of his or her field, such as electrical or mechanical engineering, acoustics, or information technology. This crewmember will be a decision-maker rather than a maintenance technician. More occupations will have direct civilian counterparts.

There will still be some need for unskilled labor to perform tasks that can't be automated. The need for supervisors and military leaders will still exist, although the need for people who supervise large crews of unskilled or semiskilled laborers will diminish. An increasing proportion of the crew, however, will be what we can think of as skilled technical workers. This type of future sailor will need to be able to think critically and reach general conclusions. They will spend much of their time collaborating with machines: monitoring, verifying, validating, and correcting the automated systems. They will have to be technically literate so that they can read diagrams and displays. They will also have to have good communication skills to interact both with other crew members and with the sophisticated human-machine interfaces.

Elements of the future enlisted sailor's resume, then, would include the following:

- Apply general principles in technical fields
- Define problems, establish facts, and make decisions
- Communicate technical problems and solutions.

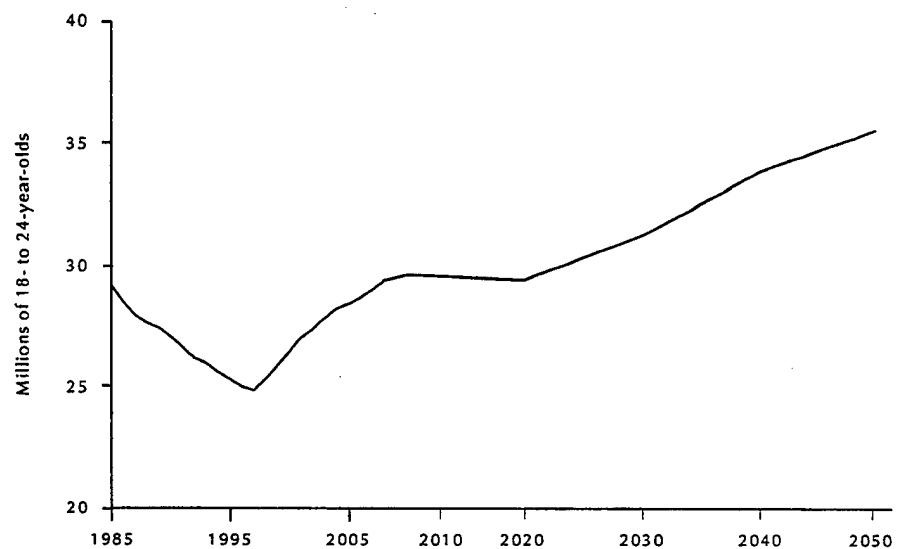
Changes in civilian education and workforce

The previous section examined how technological advances and budgetary pressures may change the manpower requirements of ships, submarines and squadrons. Significant changes in civilian education and labor markets will be occurring at the same time. This section examines trends in the civilian sector that could have important consequences for how the Navy recruits, trains, compensates, and retains sailors in the 21st century.

Overall youth population

Because the Navy recruits young people and promotes them from within, the size of the youth population is an important determinant of the recruiting climate. Figure 9 shows the population of 18- to 24-year-olds historically back to 1985 and projected out to 2050.

Figure 9. Population of 18- to 24-year-olds^a



a. Data for 1985 to 2008 are from [25] and for 2020 to 2050 are from [26].

The population in the 18-24 age group has been steadily declining from its peak in the early 1980s of 30 million. The lowest point was reached between 1995 and 1998, with a population of about 25 million. Much of the recent history of recruiting, then, has occurred in an environment of declining youth population and a strong civilian economy. Even long-term trends, however, are subject to reversal. As the children of baby-boomers begin to graduate from high school, and as immigration increases the youth population, the 18-24 population will begin to grow once more, reaching 30 million by 2010 and 36 million by 2050.

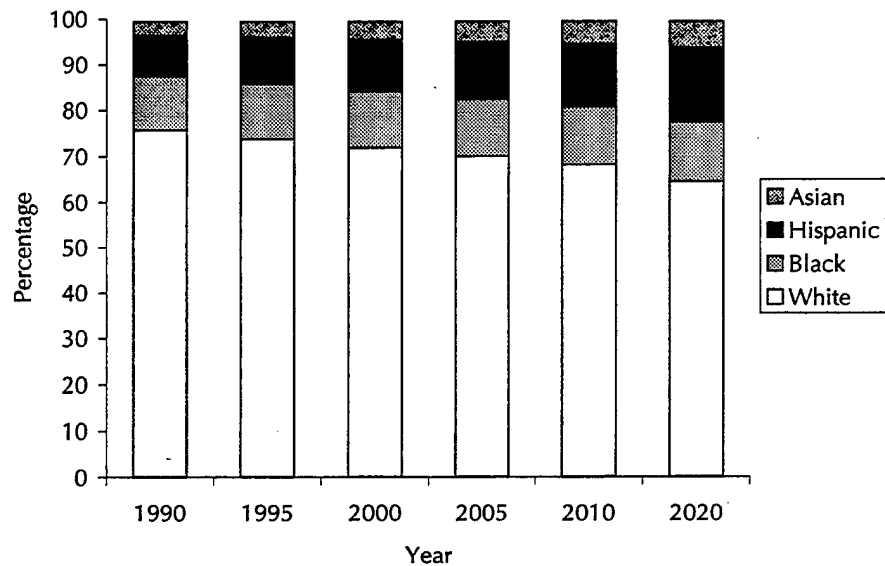
One factor that contributes to the increasing youth population is immigration. If immigration law does not change, one projection is that immigration will cause the U.S. population to grow by 70 million between 1990 and 2040—25 million immigrants and their 45 million children. This would mean that immigration would account for almost two-thirds of net population growth [27].

One implication of immigration trends is that the Navy's efforts to attract and retain a diverse workforce will continue to be important. While white non-Hispanics will continue to be the majority population, the size of that majority has been decreasing and will continue to decrease. In the 1980s, the share of white non-Hispanics in the total American population fell from 80 to 76 percent. Figure 10 shows that, using moderate immigration projections, the Census Bureau predicts that white non-Hispanics will fall to 64 percent of the population by 2020 [26].¹² Between 1990 and 2020, the share of black non-Hispanics

12. The Census Bureau projections are built from the 1990 Census using fertility rates, life-expectancy rates, and immigration rates that vary by age, sex, race, and ethnicity. The variable that introduces the most uncertainty into the projections is immigration. Different projections are made for low, middle, and high forecasts of net immigration. We use the middle series, which assumes net immigration of 820,000 per year based on the 1990 immigration law changes and current knowledge of emigration and undocumented migration. The higher and lower series reflect different assumptions about legal changes and changes in immigration behavior. In the Census data, people of Hispanic origin can be of any race. In the race/ethnicity breakdowns, people of Hispanic origin are identified first, then non-Hispanics are divided into the racial categories of White, Black, American Indian, and Asian and Pacific Islander.

in total population is projected to increase from 12 to 13 percent, Asians from 3 to 6 percent, and people of Hispanic origin from 9 to 16 percent.

Figure 10. Population shares by race and Hispanic origin, 1990 to 2020^a



a. Source: [25], table I.

Note: American Indians, who make up less than 1 percent of the population, were omitted from the chart.

Workforce 2020 translates population growth into labor force growth and corrects a common misinterpretation of the *Workforce 2000* report [28]. In particular, they note that, although there will be more women and minorities in the workforce of 2020, the pace of change is gradual rather than dramatic. Not only will white non-Hispanics continue to be the majority of the workforce (68 percent), they will also be the majority of new entrants to the workforce (66 percent).

Although the overall youth population begins to increase after 1998, there will continue to be factors that make it difficult to recruit these youth into the Navy. These factors include:

- About 18 percent of youth don't graduate from high school.

- About 67 percent of high school graduates go on to get some college.
- Even among high school graduates, some youth are not qualified to join the Navy because of aptitude or medical, moral, and legal problems.
- The propensity to enlist in any service is low, and the Navy has among the lowest.

These factors make recruiting more difficult, but we have no reason to believe that any of the factors will change in the future in a way that would make recruiting even more difficult.¹³ If the Navy continues to attract roughly the same share of the youth population, the increasing youth population should help recruiting.

High school graduate market

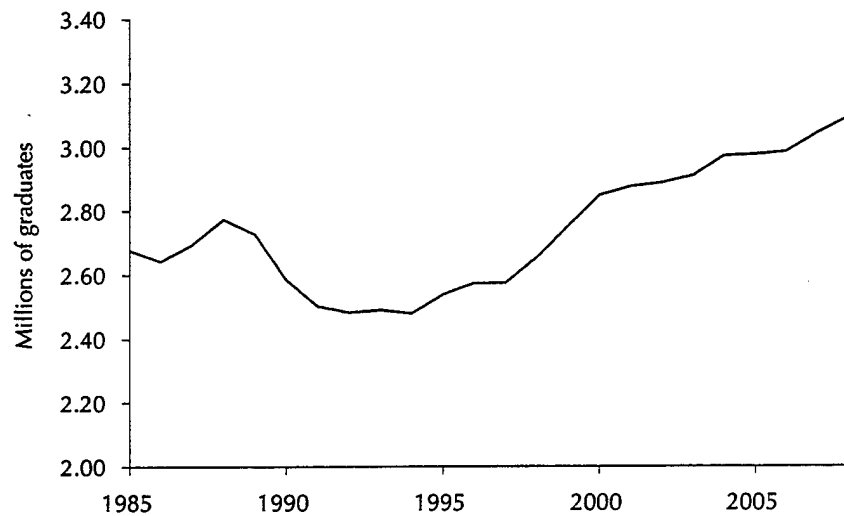
The traditional market the Navy taps for enlisted recruits is high school graduates. In recent years, enlisted recruits have included very few people who didn't graduate from high school and even fewer people with postsecondary education. Thus, we can refine our predictions of how the Navy's recruiting environment might change by moving from the total 18- to 24-year-old population to the subset of this population that graduates from high school. We will then consider how the qualifications of high school graduates have been changing over time.

Number of high school graduates

The National Center for Education Statistics (NCES) produces forecasts of elementary, secondary, and higher education enrollments and graduates for ten years into the future. Figure 11 shows their projections of high school graduates out to 2008, along with historical data on high school graduates. The projections depend mostly on Census Bureau forecasts of the 18-year-old population but also take into account estimated graduation rates for sub-populations and expected policies affecting graduation requirements [29].

13. Subsequent sections consider whether the percentages graduating from high school and going on to college are likely to change in the future.

Figure 11. Annual high school graduates projected through 2008^a



a. Source: [28], table 26.

Similar to trends in youth population, the number of high school graduates fell from a high of 2.8 million in the 1980s to 2.5 million in the mid-1990s. After 1995, the numbers begin to rise again, reaching 3.1 million in 2008. This represents a 22-percent increase in the number of high school graduates between 1995 and 2008.

Although increases in the number of high school graduates should improve the recruiting environment, the availability of these graduates to the Navy is restricted by college enrollments, a low propensity to enlist, and lack of qualifications.

Academic progress of high school graduates

Some high school graduates don't qualify for the Navy because of legal problems or because their test scores are too low. There is also a question of whether high schools are giving students the education they need to succeed in the Navy's technical training. This question will become even more important in the future as the Navy begins to require more technically proficient sailors. In this subsection, we examine existing evidence regarding the academic preparation of high school graduates.

A nation at risk?

Conventional wisdom has it that American students are bad and getting worse all the time. Here we review the debate regarding academic progress and present some evidence that runs counter to the conventional wisdom. Although some experts disagree about the statistical evidence, the consensus is that students today are no worse, and in some respects are better, than in the past and that they fare pretty well in international comparisons.

Negative perceptions regarding public schools became widespread with the publication of the National Commission on Excellence in Education's 1983 report, *A Nation At Risk* [30]. This report painted a dire picture of U.S. public schools that is often used by the proponents of a national school voucher system. To substantiate the arguments made in this report, the Bush administration in 1990 requested that the Strategic Studies Center at the Sandia National Laboratory undertake a comprehensive review of the effectiveness of K-12 education in the United States.

To the surprise of many K-12 critics, the Sandia study reported steady or slightly improving trends over time [31] on nearly every popular measure of the status of education. They examined dropout rates, standardized test scores, higher education enrollment, education spending, international comparisons, educator status, and workforce skills. One warning that was sounded was that schools must improve the performance of disadvantaged minority and urban students and confront immigration.

Or a manufactured crisis?

The more optimistic assessment of the Sandia Report is reinforced by David Berliner and Bruce Biddle in *The Manufactured Crisis* [32]. This book argues that today's students are as intelligent and as well prepared by their K-12 educations as were students of the past and students in other countries. In reference [33], the authors write that:

throughout most of the Reagan and Bush years, the White House led an unprecedented and energetic attack on America's public schools, making extravagant and false claims about the supposed failures of those schools, and arguing

that those claims were backed by "evidence."...Since the attack was well organized and was led by such powerful persons—and since its charges were shortly to be echoed in other broadsides by leading industrialists and media pundits—its false claims have been accepted by many, many Americans.

Berliner and Biddle then present evidence to contradict the major myths, including evidence that SAT scores have not declined, achievement test scores have been steady or improving, and U.S. students do fairly well in international comparisons.

Of course, there are two sides to every argument, and Lawrence Stedman has written articles criticizing both the Sandia Report and *The Manufactured Crisis* [34, 35]. Stedman argues that the data were mishandled and that, handled properly, there is evidence of declines in SAT scores and of poor international performance. Even here, though, Stedman asserts that "U.S. performance in the international arena is not as dismal as school critics have asserted." He further argues that, although National Assessment of Educational Progress (NAEP) scores in math and science have been stable or rising, the absolute level of achievement on the tests has been too low for decades.

Berliner and Biddle answered Stedman's criticisms and reassert their claims that almost all available statistical evidence shows that U.S. students have been holding their own or improving over time and that they do fairly well in international comparisons [33]. Their views are strongly upheld by Gerald Bracey, who has written widely arguing against the conventional wisdom that American students are poorly prepared by their K-12 schools and can't hold their own against students of former times or from other countries [36, 37]. He argues that most international comparisons are favorable to U.S. students and that gaps between Japanese and American students in science and math have been exaggerated.

How about declining SAT scores?

Most of the debate regarding the performance of U.S. public schools revolves around careful interpretation and use of statistical data. A good example is the case of declining SAT scores. Almost every year,

the release of average SAT test results is accompanied by extensive media coverage of declines in test scores over time. What isn't pointed out, though, is the substantial change over time in the sample of people who take the SAT. If one adjusts for changes in the composition of students taking the test, the evidence of decline disappears.

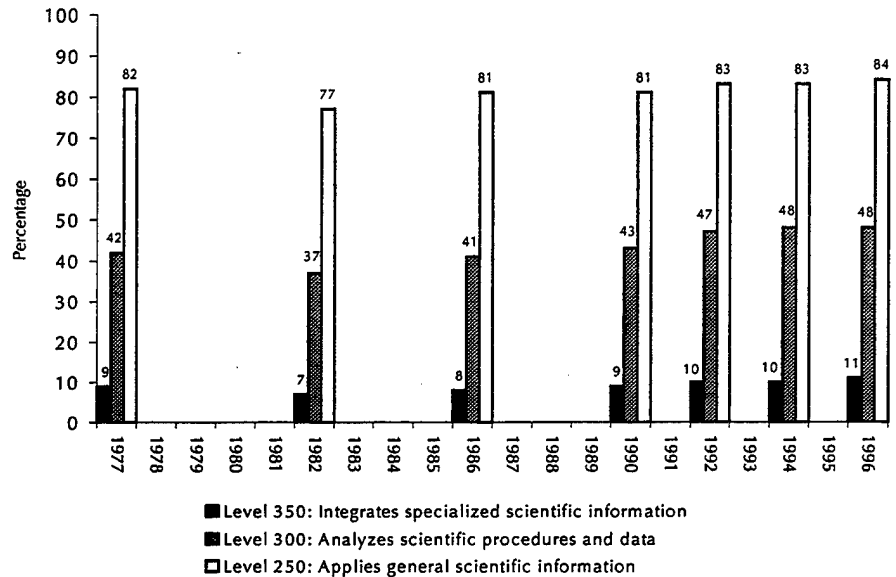
Comparisons from state to state in raw average SAT scores are also misleading because of large differences in the percentage of students taking the test. In states (or in past times) where a low percentage of students take SAT tests, average scores tend to be high because the test-taking population includes a high proportion of high-achieving students. As more and more students take the tests, the test-taking population expands beyond the highest achieving students and average test scores fall.

Several studies have examined differences in SAT scores over time and among states, adjusting for differences in the test-taking population. The control variables used have included race, ethnicity, sex, family income, family size, parents' educational level, first language used, class rank, and urbanization. The studies all conclude that characteristics of the test-taking populations explain a great deal of the variation in average test scores. In particular, conclusions regarding lower college entrance exam scores over time fail to take into account that more students now take the tests as college education becomes an option for more than an elite minority [38, 39, 40].

Evidence: trends in NAEP scores

The NCES National Assessment of Educational Progress (NAEP) has tested nationally representative samples of students aged 9, 13, and 17 in science, mathematics, and reading periodically since the early 1970s [41]. Figure 12 shows the results of the science test for 17-year-olds—generally high school seniors. Knowledge and skills in science are scored on a scale of 150, 200, 250, 300, and 350, and the figure shows the percentage of students who scored at or above the highest three levels.

Figure 12. Percentage of 17-year-old students at or above science performance levels^a



a. Source: [40], table 1.1.

What level of scores will the future Navy require? Based on the definitions given by NCES [41], we estimate that most level 350 scorers will be college bound, but those scoring somewhere between 250 and 300 will meet Navy qualifications:

Level 250: Applies General Scientific Information. Students at this level can interpret data from simple tables and make inferences about the outcomes of experimental procedures.

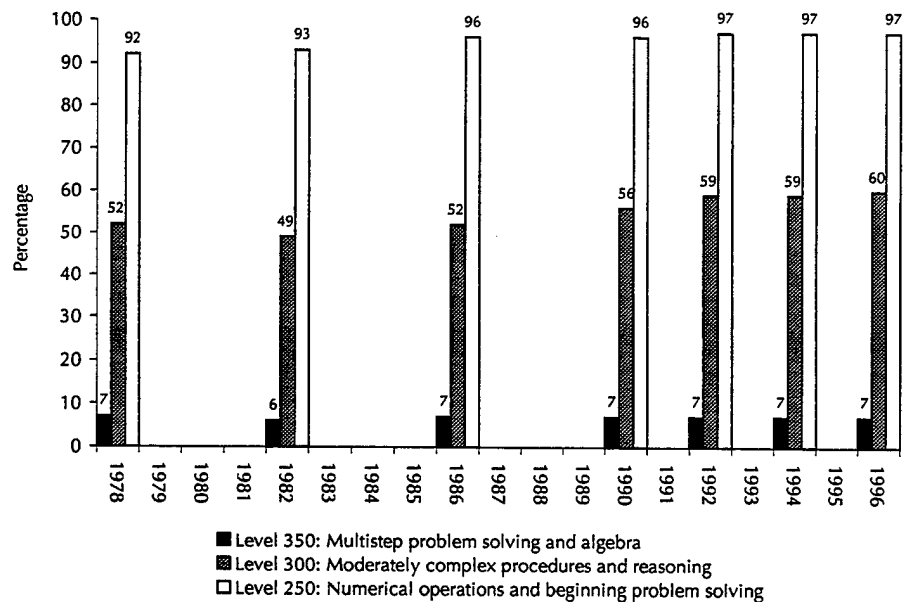
Level 300: Analyzes Scientific Procedures and Data. Students at this level can evaluate the appropriateness of the design of an experiment. They have more detailed scientific knowledge and the skill to apply their knowledge in interpreting information from text and graphs.

Both level 250 and 300 scores have shown an increasing trend over time, a favorable indicator of the availability of high school graduates who meet the Navy's requirements for technical proficiency.

Figure 13 shows a similar trend in mathematics performance. In mathematics, almost all high school seniors are at or above the 250 level. Perhaps a better level for future sailors is 300:

Level 300: Moderately Complex Procedures and Reasoning:
 Students at this level are developing an understanding of number systems....They can find averages, make decisions based on information drawn from graphs, and use logical reasoning to solve problems.

Figure 13. Percentage of 17-year-old students at or above math performance levels^a



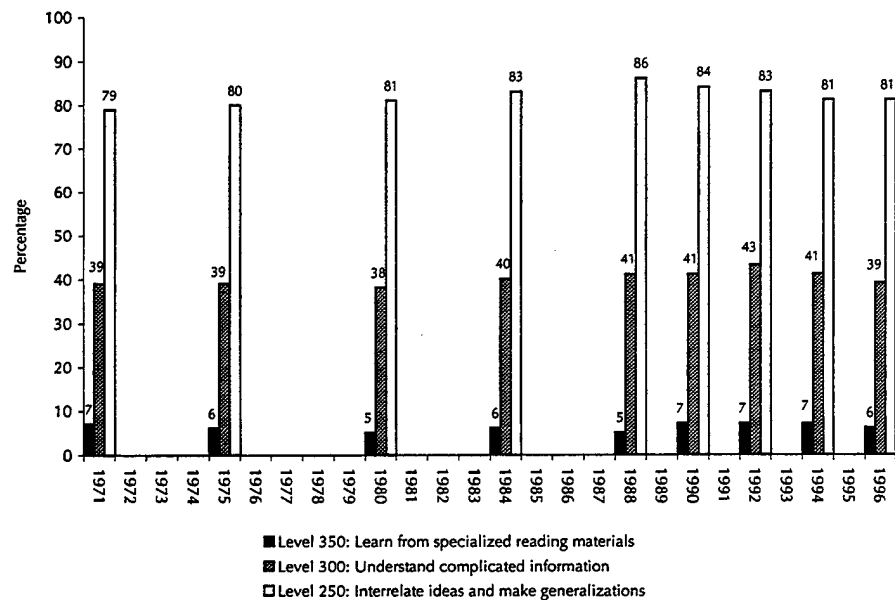
a. Source: [41], table 3.1.

The upward trend at level 300 in math is even more pronounced than the upward trends in science. There is strong evidence that there was improvement between the 1980s and 1990s in math performance by 17-year-old students at a level consistent with Navy enlisted requirements.

The last area of NAEP testing is reading, shown in figure 14. We have argued that the future sailor will need strong communication skills to

interact with both the machines and the rest of the reduced crew. Unfortunately, unlike math and science, high school seniors' reading levels haven't shown much evidence of improvement at the top three scores. In fact, after modest gains in the late 1980s, scores have declined again in the 1990s. On the other hand, there is general agreement among educators that the baseline reading skills were somewhat higher than baseline math and science skills.

Figure 14. Percentage of 17-year-old students at or above reading performance levels^a

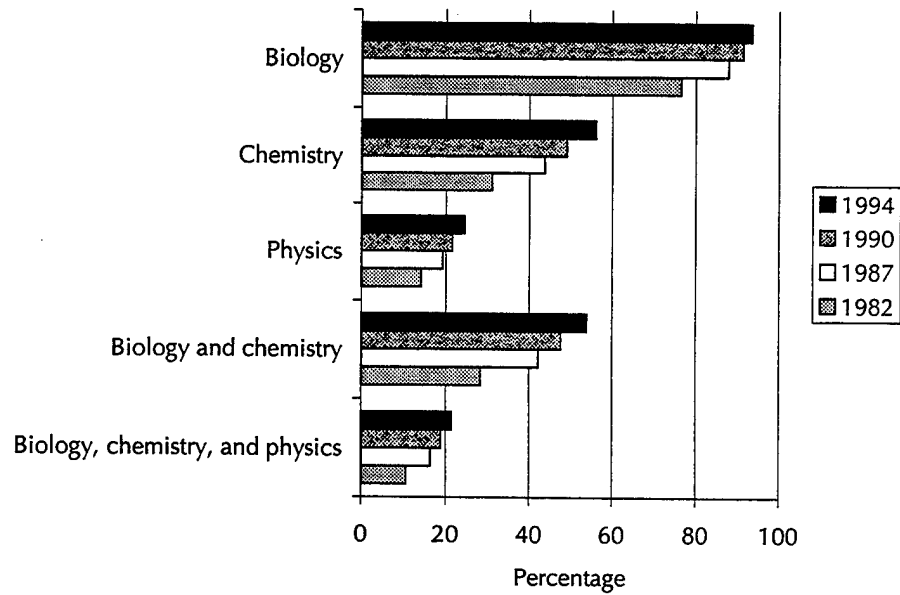


a. Source: [40], table 5.1.

Evidence: high school courses and computer use

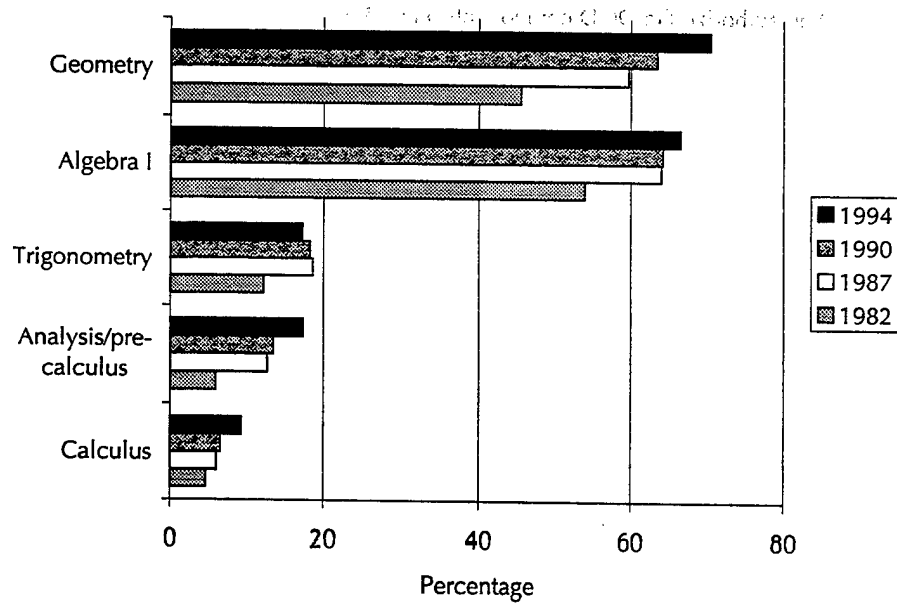
The NCES annual report, *Condition of Education*, provides a number of indicators of the condition of the U.S. educational system [42]. One indicator that may speak to the future technical preparedness of students is the type of courses that are being taken. Recent initiatives have sought to increase the number of science and math courses required to graduate from high school or to enter college. Figures 15 and 16 show evidence that these initiatives have been successful in increasing the amount of science and math being taken.

Figure 15. Percentage of students taking selected science courses, 1982-1994^a



a. NCES, *Condition of Education 97*, table 24-2.

Figure 16. Percent of students taking selected math courses, 1982-1994^a

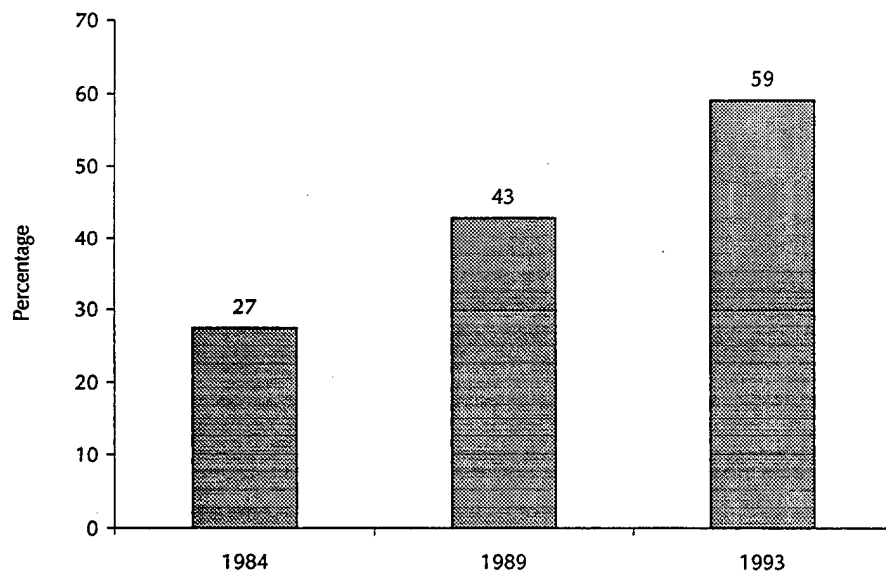


a. NCES, *Condition of Education 97*, table 24-2.

Figure 15 shows the percentage of high school students who took biology, chemistry, physics, or multiple science courses from 1982 to 1994. All of these courses were taken by increasing numbers of students. In particular, the number of students taking both biology and chemistry increased from under 30 percent to almost 55 percent. Figure 16 shows the percentage of students who took geometry, algebra, trigonometry, and calculus courses. Again, math preparation has been increasing from 1982 to 1994.

A final note involves exposure to technology through the use of computers in schools. Figure 17 shows that the percentage of students who used computers while at school more than doubled between 1984 and 1993 (including all students from prekindergarten through graduate school). This trend is expected to continue until computer use in schools is all but universal. Home use of computers is also increasing.

Figure 17. Percentage of students using computers at school^a



a. Source: NCES 98-015, *Digest of Educational Statistics*, 1997, table 422.

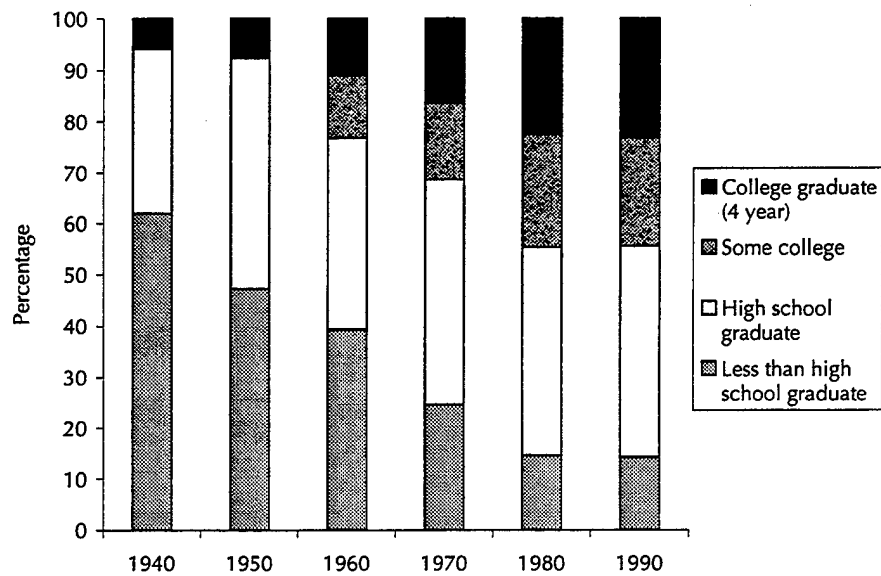
We believe that, contrary to conventional wisdom, both aptitude and achievement levels of high school graduates have remained steady or improved in recent years. With the new initiatives to increase preparedness of students for the future workforce that will be discussed below, we also believe that there will be more improvements in the future. The Navy, then, will have access to a larger pool of high school graduates who will be increasingly technologically literate. On the down side, however, the Navy will also face increased competition for these high-tech workers, both from other employers and from post-secondary schools. We examine the issue of high school graduates going on for further education in the next subsection.

Trends in educational attainment

The previous subsections documented the growing numbers of high school graduates and their improving academic performance. The other side of this equation for Navy enlisted recruiting, though, is how many of the high school graduates will go on to some form of postsecondary education. Traditionally, most enlisted recruits have had no more than a high school education. There have been some attempts to recruit more community college graduates, but so far they have not been extensive [43]. Thus, using current practices, high school graduates who go on to postsecondary schools are not part of the Navy enlisted recruiting pool.

Figure 18 shows long-term trends in educational attainment from 1940 to 1990. The major trend from 1940 to 1980 was the large drop in the percentage of people who didn't complete high school: this fell from 62 percent in 1940 to 15 percent in 1980. The percentage of people with only a high-school diploma doesn't increase very much, however, because from 1960 to 1980 there was also an increasing trend of people going on to college. Thus, by 1990, high school drop-outs made up 14 percent of the population, 41 percent had high school diplomas, 21 percent had completed some college, and 23 percent were 4-year college graduates.

Figure 18. Shifts in educational attainment over last half-century^a



a. Source: [44].

Note: The "some college" category was not tracked before 1960.

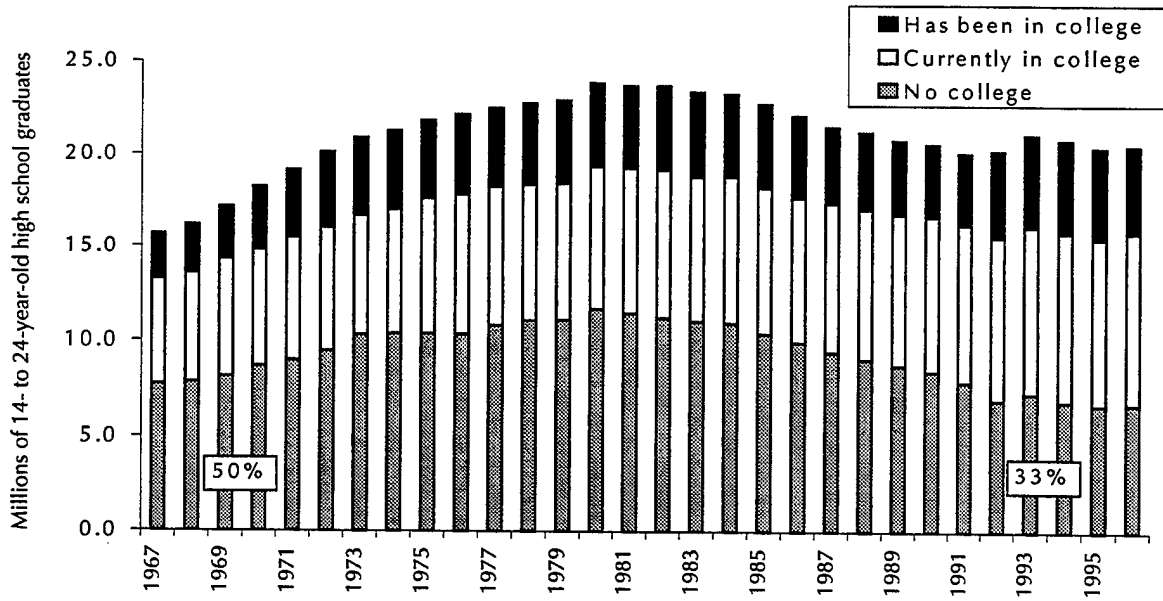
Fewer people stop education at high school

Figure 19 examines trends in educational attainment in more detail for 1967 to 1996. This figure shows the percentage of 14- to 24-year-old high-school graduates by whether they were currently in college, had been in college, or had never been in college. Although 50 percent of the 1967 high school graduate pool had not been in college, only 33 percent of the 1996 pool had not. By relying on only high school graduates with no plans for postsecondary education, then, the Navy is targeting a shrinking proportion of the youth population.

College enrollments

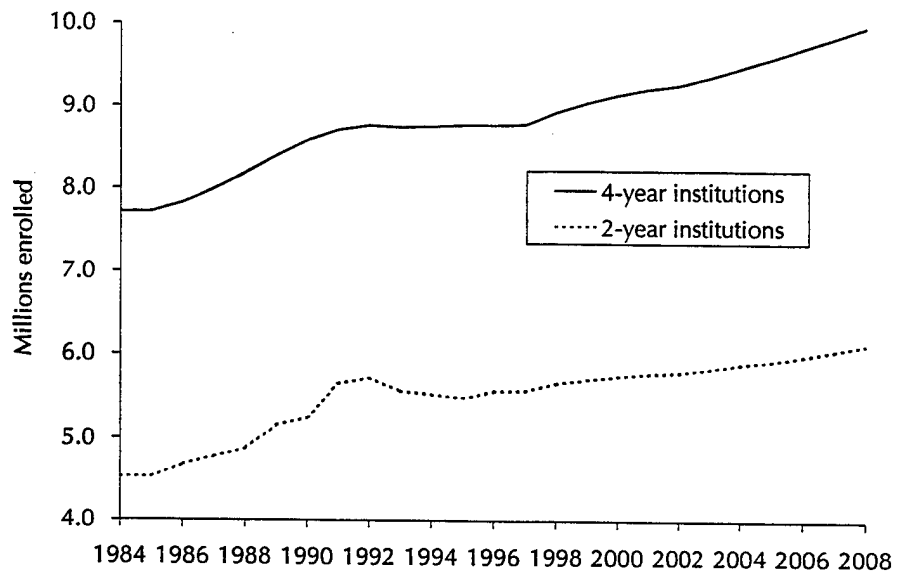
Next, we look at projections of how many high school graduates will go on to either 2- or 4-year postsecondary schools. Figure 20 shows total enrollments at institutions of higher learning (this includes colleges, universities, community colleges, private 2-year colleges, and vocational and technical schools). Enrollments at both 2- and 4-year schools are expected to increase, but it isn't clear from this figure whether the rates of increase are higher or lower than rates of increase for youth population and high school graduates.

Figure 19. Fewer people stop education at high school, 1967-1996^a



a. Source: [44].

Figure 20. Enrollment in 2- and 4-year institutions of higher learning^a

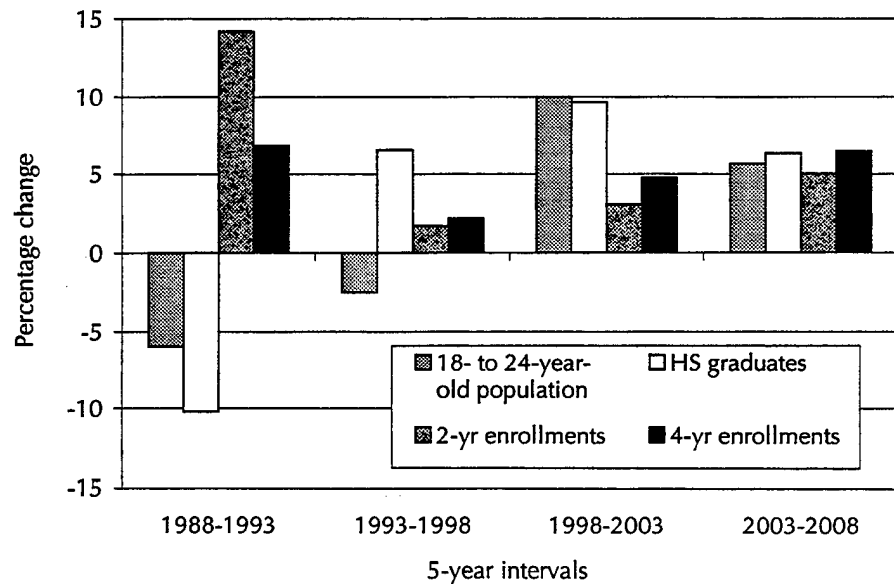


a. Source: [29], table 11.

Note: the numbers are actual fall enrollments through 1997 and projections of fall enrollments after 1998.

Figure 21 compares the rates of change over 5-year intervals for 18- to 24-year-olds, high school graduates, and enrollment in 2- and 4-year postsecondary schools. For 1988 to 1993, both youth populations and high school graduates were falling, but college enrollments were rising. This was the period in which high school graduates with no college plans became increasingly rare. Notice that the increase in 2-year enrollments was especially large. For 1993 to 1998, the number of high school graduates actually increased more rapidly than either 2- or 4-year enrollments. This is also expected to be the case for 1998 to 2003. In the last period, 2003 to 2008, all rates of growth are comparable. This figure implies that, although the relative availability of people stopping their education at high school fell during the late 1980s and early 1990s, this trend is not expected to continue.

Figure 21. Comparison of rates of change



Our conclusion, then, is that the Navy should recognize that changes in the recent past have narrowed the high school graduate market, but it shouldn't have to contend with significantly more narrowing in the future. One qualification to this conclusion is that new tax laws and scholarship programs are decreasing the cost of attending

college, especially for 2-year or shorter programs. It isn't clear to what extent the NCES projections take these cost changes into account, so they may understate increases in postsecondary enrollments.¹⁴

Technical degrees

A final consideration is to what extent civilian postsecondary institutions are providing the kind of education and training that the Navy will need in the 21st century. The existence of relevant programs may provide some assurance that qualified recruits will be available. We decided that the relevant programs are 2-year or shorter technical degrees and certificates. These could be technical majors at community colleges, or vocational certificates in technical occupations.

Figure 22 shows how many awards (degrees or certificates) below the Bachelor's level were awarded in technical fields in 1995. Some fields, such as precision production trades, rely on certificate programs as much as or more than Associate degrees. Other fields, such as engineering-related technologies, rely more heavily on the Associate Degree. In all, there were about 180,000 awards in the listed technical fields in 1995. This represents a significant amount of civilian resources devoted to postsecondary education in technical fields.

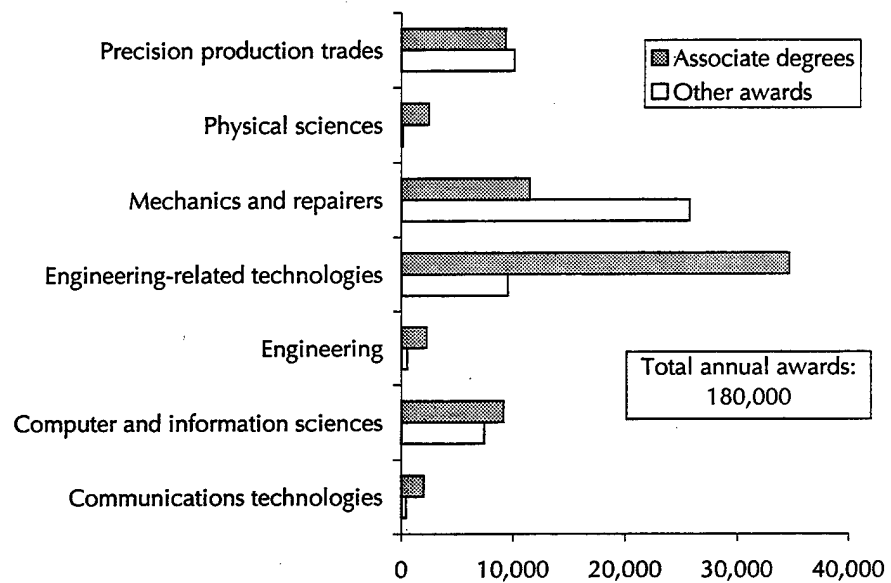
Government programs to increase technical expertise

We have already discussed the perception that U.S. public education has been failing. In addition, there has been significant attention paid to a "skills gap," or a discrepancy between the skills that American workers possess and what will be needed as technology continues to advance. In 1987, the *Workforce 2000* report warned that, if the American economy were to prosper, "the educational standards that have been established in the nation's schools must be raised dramatically.

14. Higher education enrollment rates were predicted using the Census Bureau's middle series population projections. Age-specific enrollment rates were estimated using an econometric model that included such variables as real disposable income per capita, unemployment rates, and proxies for relative earnings by educational attainment. No mention was made of scholarship and tax law changes [29].

Put simply, students must go to school longer, study more, and pass more difficult tests covering more advanced subject matter” [45].

Figure 22. Awards below Bachelor’s degree in technical fields, 1994-1995



Although such concerns may have been overstated, they are nevertheless legitimate. It is important for schools to prepare young people for the demands of increasingly technical work. Moreover, this concern is not unique to the Navy; it is economy wide. For this reason, a number of federal policy initiatives have been enacted to improve the education and skills of American youth, especially their preparation to join a technical workforce.

Government policies have included tax credits for life-span educational expenses, the Hope Scholarship program for students attending 2-year colleges, and the Goals 2000—Educate America Act. A major part of the new educational policy is the Tech Prep program. Previous CNA research has examined the Tech Prep program and how the Navy can take advantage of this initiative [46].

The purpose of the Goals 2000 legislation is to prepare students so that they meet employers' needs for a more technically trained workforce. Among the initiatives are high school graduation requirements with more emphasis on science and math. But there is also a conviction that more and more employees will need education beyond high school. In fact, the White House goal is to make 14 years of education—at least 2 years of college—the standard for all Americans.

To reach the 14-year standard, the legislation promotes the integration of school- and work-based learning. In the schools, more technical material would be taught, more instructional material would be drawn from the workplace, and there would be more career exploration and counseling. In the workplace, employers would be encouraged to provide active learning environments. And to ensure coordination, the Act calls for public/private partnerships among businesses and elementary, secondary, and postsecondary schools, students, and parents.

The Tech Prep program provides a mechanism for secondary and postsecondary schools and employers to put together school and work experience packages that will produce technically competent employees. The programs include the last 2 years of high school and a 2-year Associate degree or certificate program, with businesses providing workplace opportunities. With assistance from CNA, the Navy has recently entered into its first Tech Prep partnership.

The Tech Prep program is one specific way that the Navy can take advantage of economy-wide efforts to improve workforce technical skills. In general, we believe that the sailor of the future will often need the equivalent of an Associate degree. Traditionally, the Navy has recruited high school graduates and provided its own advanced training. This may not continue to be the most efficient way to do business in a world that has more and more civilian opportunities to pursue technical postsecondary training. Other options that the Navy will have to consider are outsourcing its training to civilian institutions, or hiring more pretrained personnel from the community college and vocational/technical school markets.

Previous CNA research has already made a strong argument for making more use of civilian postsecondary education and training

[47]. These arguments can only become stronger as Navy technology continues to advance, more COTS technology is used, and relevant civilian educational opportunities proliferate.

Wage premium for higher education

We have argued that the future sailor will need more education and that there will be more opportunities to acquire relevant education and training in the civilian sector. A related concern, though, is how much the Navy will have to pay to hire people with more technical education.

There is a positive correlation between workers' earnings and their level of education. Moreover, this educational premium increased rather dramatically during the 1980s. Figure 23 shows the ratio of earnings for men with different levels of education relative to high school graduates.¹⁵ In the 1970s, men with at least a Bachelor's degree earned about 20 percent more than high school graduates—but this had increased to 50 to 60 percent more by 1990. Men who attended some college, but didn't get a Bachelor's degree (including Associate degree holders) earned very little more than high school graduates in the 1970s, but their relative earnings grew during the early 1980s until they earned 10 to 15 percent more. At the other extreme, high school dropouts' earnings fell relative to high school graduates.

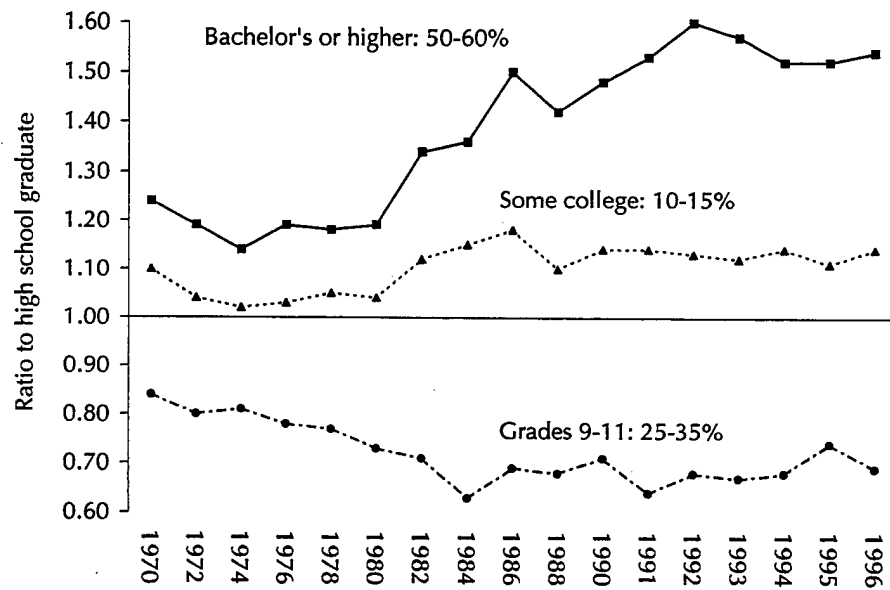
Why do more highly educated workers earn more? One possibility is that more education causes higher earnings by increasing workers' productivity. Another possibility is that both more education and higher earnings are caused by some underlying factor, such as higher intelligence or better work habits.

The implication of the educational premiums for the Navy is that, first, officer pay should be higher than enlisted pay, and that difference should have increased during the 1980s. If it did not, then either

15. The figure shows male earnings only so that gender, another important correlate of earnings, is held constant. Similar educational premiums are observed for women. The educational premiums persist in statistical studies that hold other attributes constant, such as race, region of country, and parents' socio-economic status. See [48].

officer pay didn't keep pace with increases in what the average college graduate earned, or enlisted pay more than kept pace with what the average high school graduate earned. Second, if the Navy wants to recruit more people with Associate degrees or some postsecondary education, it will have to pay them more than it pays its enlisted force of mostly high school graduates.

Figure 23. Ratio of earnings relative to high school graduate for men age 25 to 34^a

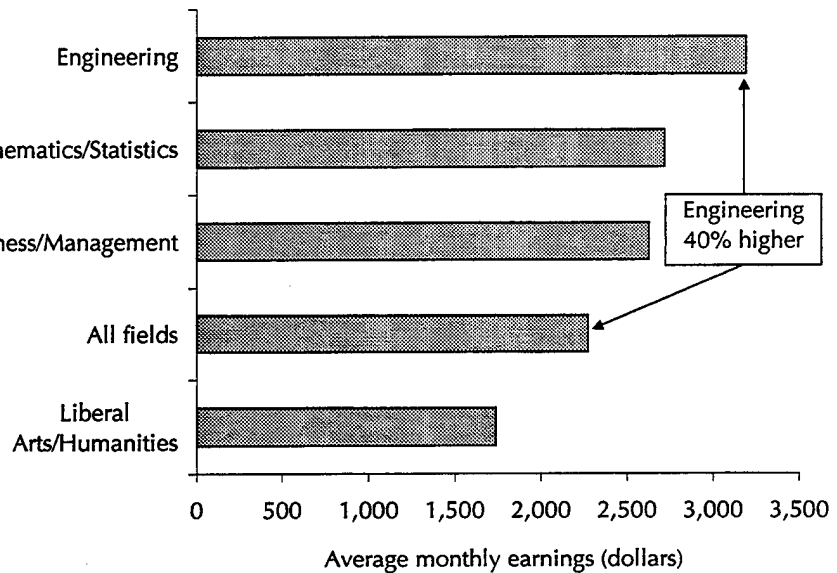


a. Source: [42], Indicator 32.

Differences in average earnings by educational level conceal substantial differences in earnings for people with the same level of education. One important source of earnings variation is the field of study in college. Figure 24 shows average monthly earnings by field of study for selected fields. This figure illustrates the premium that people with technical backgrounds earn. Although the 40-percent premium for engineering degrees applies to college graduates, there is presumably some premium for technical education below the Bachelor's level. The other paper from the Optimal Manning study gives more precise estimates of the premiums that the Navy should expect to pay

enlisted people who have had some technical postsecondary education [2].

Figure 24. Wage premiums by field of Bachelor's degree^a



a. Source: Census Bureau, *Current Population Reports*, P70-51, Dec 95
Note: the data used are for spring 1993 graduates.

Other changes in the American workforce

The Workforce 2020 study examined many forces shaping the American economy in the future and drew the following implications for the American workforce [28]:

- Pay will increasingly be linked to performance.
- Workers will change jobs more often.
- Swiftly developing technologies will increase the demand for highly skilled and well-educated workers.

Employment in some types of jobs is expected to increase at the expense of other types of jobs. The Bureau of Labor Statistics (BLS) predicts the following trends for the year 2005 [49]:

- White-collar jobs will grow more rapidly than blue-collar jobs, but overall differences between 1994's job mix and the mix in 2005 will not be great. The conventional wisdom that technological change will lead to the disappearance of blue-collar and low-skilled white-collar jobs does not appear true by 2005, although it will be increasingly true further on.
- Out of the 25 fastest growing occupations between 1994 and 2005, 8 are in technical fields.
- Many of the fastest shrinking occupations represent jobs that are being lost because information technology is enabling machines to substitute for human labor. Examples are computer operators, machine tool-cutting operators, and bank tellers.

Workforce 2020 took the analysis of growing and shrinking occupations one step further by trying to estimate how the skills needed by workers would change [28]. It matched the BLS employment projections with measures of the educational levels needed for each detailed occupation. By every measure of educational requirements, that is, language, mathematics, and reasoning, the analysis showed that the growing occupations require substantially higher skills than the shrinking occupations. The Workforce 2020 conclusion is that efforts to improve the education and skill levels of American workers must continue.

Changes in workforce policies

Changes in technology and required skills and simultaneous changes in civilian labor markets imply that the Navy may have to make fundamental changes in the way it manages its workforce. The legacy military workforce structure includes high demand for strength and vigor at the lower paygrades, tapering down to small requirements for senior leadership. As we have seen, future workforce needs will increasingly stress long-term technical competency. Along with the skilled technicians, there will still be some, although much reduced, demand for unskilled labor and, of course, still a need for senior leaders. This section discusses how Navy workforce management policies may have to change to accommodate these new structures.

The areas of personnel policy that require reexamination include:

- Career structure
- Recruiting
- Training
- Compensation.

Career structure

Legacy workforce structure: the manpower pyramid

Throughout the All-Volunteer Force (AVF) the services have used a promote-from-within labor force in which career paths and pay schedules are designed primarily for generalists who progress gradually from entry-level to leadership positions. In the traditional manpower pyramid, high junior paygrade requirements are driven by the need for strength and vigor to operate older military technologies. Requirements for senior leaders then drive up-or-out policies that

curtail careers of officers and enlisted personnel who are not selected for promotion to the next level of responsibility.

The pay system that accompanies the manpower pyramid is based on pay tables. Pay tables tie pay increases to promotions and longevity, with the same table being used for all enlisted personnel, regardless of their occupation. There are some discretionary pays, such as enlistment bonuses, Selective Reenlistment Bonuses (SRBs), sea pay, and submarine pay, but discretionary pays are a small percentage of total pay. Some ratings also achieve higher average pay through more rapid advancements.¹⁶

The pyramid structure has already seen significant changes. Relatively more junior billets were cut during the drawdown, and newer systems with richer paygrade structures were introduced. Another study of future manpower challenges for Chief of Naval Personnel compared total force billet requirements in 1988 and 1998 [51]. It found that the 1988 pyramid had a broad base of junior billets, lower relative cost per billet, more selectivity for advancement, and less critical retention requirements. By 1998, the billet structure was much more senior, with more billets in the top six paygrades than current funding allows. Other changes were a higher cost per billet and more rapid advancement with associated lower selectivity and less experience in the mid-grade petty officer ranks.

The traditional pyramid force structure seems to work less well in fields that employ more technical specialists. Civilian opportunities are often better for technical specialists, so that higher pay is needed to attract people and to keep the best people from leaving the military. Enlistment bonuses, SRBs, other special pays, and more rapid advancements have been used to increase compensation in some specialties, but there have still been recurring recruiting and retention shortfalls. At times, existing compensation tools haven't been flexible enough to remedy shortfalls, or have worked but at relatively high costs.

16. Reference [1] examines compensation systems in more detail, including existing differences in pay among ratings. A previous study calculated average base and special pays by rating, paygrade, and length of service [50].

Another feature of the traditional pyramid that is not adapted to technical workers is the up-or-out policy. In technical fields, it's sometimes best to keep a person working for a long time at more or less the same level in the organization. Longer careers allow more time to recoup investments in costly training and are often feasible because technical skills may not decline as rapidly with age as strength and vigor requirements. Current up-or-out policies may force technical workers out at a point where they still have valuable skills. Alternatively, workers may be promoted to supervisory ranks who would be better used back on the line.

Traditional manpower pyramids, then, are already changing and are not necessarily well suited to technical occupations. In the future Navy, with its even more technical workforce, existing problems can only get worse.

Future workforce structure

Given the manpower pyramid changes that have already occurred and what we know about trends in future requirements, how is the future force structure likely to look? Too little is known about the precise requirements of future platforms to be sure, but we can draw some general conclusions by breaking future manpower requirements into three components:

- *Laborers*: There will be a remaining, although much reduced, need for unskilled labor to perform "strength and vigor" tasks that can't be automated.
- *Skilled technicians*: These sailors of the future (discussed at the beginning of this paper) will be needed in almost every field, including command and control, engineering, material handling, and hotel functions.
- *Senior leaders*: There will also be a need for experienced personnel with knowledge of Navy operations, procedures, and personnel to supervise and motivate their crews and to make important decisions.

Figure 25 is a hypothetical example of what the requirements for the three types of personnel might look like. At the lower paygrades,

there are requirements for laborers that might be met by people who mostly serve one term and leave. Skilled technicians would generally have to be brought in at higher paygrades to provide them with compensation that meets their civilian alternatives. This assumes that pay will continue to be tied to rank; a subsequent section considers the possibility of skill-based pay. The skilled technicians would then mostly stay in the middle ranks, rather than being forced out or promoted into supervisory ranks. Finally, senior leaders would continue to develop by promotion within the Navy, either in a specific “management” track, or by selection out of the laborer and skilled technician pools.

Figure 25. Future requirements driven by different needs

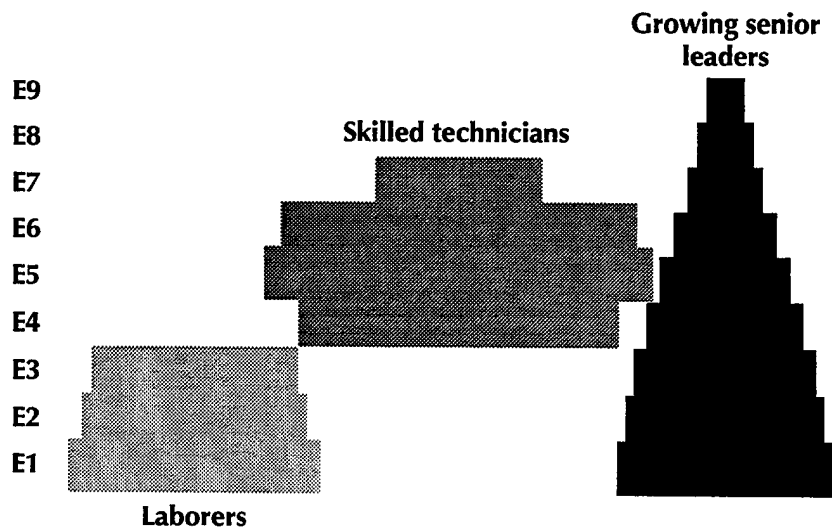
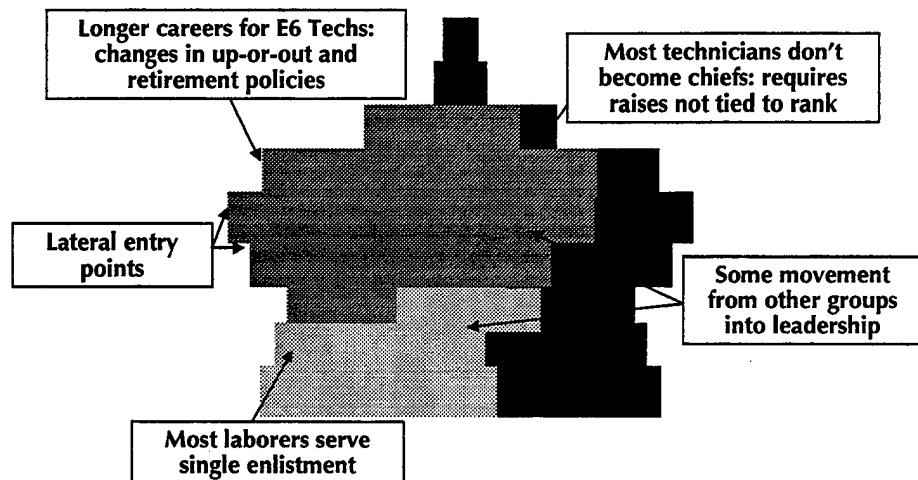


Figure 26 shows how the three sets of requirements might combine to form a total force workforce structure. This is merely meant to be illustrative, the exact force structure depends on systems that haven't yet been designed and on policy variables that have yet to be determined. Some likely features of the future workforce, however, can be identified:

- At the lower paygrades, a pool of laborers, many of whom serve only a single term

- Lateral entry into higher ranks or higher pay structures for skilled technicians with high-paying civilian employment opportunities
- Longer careers for skilled technicians without being promoted into supervisory ranks
 - Changes in up-or-out policies to allow longer mid-grade careers
 - Increases in compensation not tied to rank so that experienced technical workers don't leave the Navy
- Development of senior leaders by progression through the ranks, some being selected out of the laborer and skilled technician workforces.

Figure 26. The end of the manpower pyramid?



Are future force structures executable?

Future force structures with considerably richer paygrade structures are not executable given current recruiting and career management policies and reasonable assumptions about retention rates. Reference [51] shows that even the 1998 billet structure presents serious

problems: it requires more rapid advancement than is currently allowed and produces shortfalls at paygrades E4 and E9.

As platforms are introduced that make the paygrade structure even richer than the 1998 level, execution problems become more critical. After modifying 1998 requirements to reflect changes from the Smart Ship program, the F/A-18 E/F, shore billet outsourcing initiatives, and the future carrier program, the authors define a potential 2010 grade structure. The 2010 structure has 78 percent of requirements in the top six paygrades—much more than current funding allows. Furthermore, the structure couldn't be executed without unreasonably high retention rates or persistent inventory shortfalls at E4, E5, and E6. If the structure could be executed, a significantly higher programming rate per sailor would have to be used.

Recruiting

In the traditional enlisted recruiting model, high school graduates are recruited based on a heavy appeal to the job training and experience provided by the military. While this model has generally been successful, recent recruiting problems, trends in educational attainment, and the resume of the future sailor all suggest that a new approach may be required to expand the recruiting market.

In spite of rapid growth in recent years in the proportion of high school graduates pursuing less than 4-year degrees, none of the services has aggressively pursued the market for these students.¹⁷ The "some college" market offers a number of advantages in addition to its size:

- Students with some postsecondary education are high quality as measured by either test scores or attrition behavior while in the service.

17. This market is often equated to the community college market, but that term is too narrow. Other significant sources of technically qualified recruits are private 2-year colleges and both public and private vocational and technical schools.

- Less than 4-year postsecondary schools also have relatively large proportions of minority students.
- Graduates already possess technical skills that recruits would otherwise have to learn in the military.

Community colleges and vocational/technical schools teach material (e.g., basic electronics and computer networking) that is quite similar to what the Navy teaches in initial and specialized skill training. In fact, some Navy schools receive academic accreditation from the same professional groups that accredit 2-year programs.

We believe that the Navy will have to expand enlisted recruiting to include more graduates of less than 4-year postsecondary institutions. There is a strong argument for doing so now, and future trends will reinforce these arguments. A greater proportion of sailors will require advanced technical education, the type of education or training needed will become more general, and there will be more civilian institutions providing relevant training.

To fully exploit the potential of postsecondary school recruits, the Navy needs to address four issues. First, it must develop an effective method of recruiting at postsecondary schools. Traditionally, enlisted Navy recruiters have not worked the 2-year postsecondary school market, so strategies for accessing this market need to be developed and incorporated in the training material.

Perhaps the biggest component of the recruiting problem is how to put together a compensation package that will attract community college graduates in technical fields. One way to increase compensation is to allow lateral entry at higher paygrades, but the higher rank may not be appropriate. Another option would be to use existing bonuses and special pays, but these may not be sufficiently flexible. A final option (discussed later in this section) is to create a skill-based pay system.

Second, recruiting, training, and assignment processes that are built on the assumption that recruits are unskilled high school graduates will have to be reexamined. Current Navy recruiting focuses on selling Navy service and training opportunities and plays down discussions of particular career fields. With pretrained personnel, the Navy

may have to move closer to the civilian hiring model in which people are recruited for a particular job or type of job in a specific location.

Third, better methods of assessing the skills of pretrained recruits must be developed. Without this, the Navy cannot take full advantage of civilian training and may force recruits to duplicate training received in a civilian school. Also, more flexibility will be needed in the training and assignment system so that recruits with varying levels of skills can receive the additional training they need for the job they will have.

Fourth, the Navy may have to develop partnerships with 2-year schools to ensure that courses of study and training equipment are appropriate. The newly created Tech Prep partnerships provide a model.

Training

Generalist vs. specialist

Future sailors will be generalists rather than specialists. They will need to know the theory underlying their fields, be technically literate, and be skilled analytical thinkers, decision-makers, and communicators. They may need to be cross-trained in several different areas. They will have less need for specific training tied to operating and maintaining one piece of equipment. All of these factors imply that future sailors will need more education and less training.

The services do much more of their own training than large civilian employers or other branches of the government. One reason for this has been that the military has had its own technology and practices, so that civilian training was not relevant. Two major trends may change the uniqueness of military training requirements, however. First, reduced manning, increased commonality of systems and subsystems, and technologies that require a "person-on-the-loop" all point toward a workforce with more generalists and fewer specialists. Second, as the military adopts more COTS technology, its workspaces will increasingly resemble those of businesses.

The need for education rather than training and the decreasing uniqueness of Navy training requirements both mean that the case for in-house training will be weakened in the future. Two alternatives to in-house training are outsourcing and hiring already trained workers. The savings from a reduced training infrastructure will, of course, have to be weighed against risks that the Navy won't be able to recruit enough pretrained personnel, that military acculturation won't be sufficient, and that the training won't fit Navy requirements as well.

Training technology

Current acquisition programs are moving as much as possible toward simulation-based training in operational units, also called embedded training. Embedded training is seen as a more effective way to train warfighters in a dynamic environment and, at the same time, a way to economize on the Navy training infrastructure. Engineers are also attempting to reduce training needs by developing intuitive interfaces and intelligent job aids.

Systems are being designed with integrated training modes, simulation, and interactive HCI to support both individual and team training. Advanced embedded trainers include performance diagnostics so that weak areas can be identified and intensive remedial training provided. Electronic manuals are being integrated into designs, and advanced learning methodologies are being exploited so the right training is delivered at the right time in the most accessible format [22].

One advantage of embedded training is that it reduces the need for schoolhouse training and thus lowers infrastructure costs. With reduced manning, however, there will be less time available for training, fewer personnel to oversee training, and a greater need for all personnel to arrive fully trained. The move toward embedded training must take these constraints into account. In fact, the Smart Ship Project found that additional training personnel had to be added to support reduced manning requirements.

Other advances in training technology will also be needed. For sailors to arrive at operational units fully trained, much greater use must be

made of shore-based modeling and simulation, interactive video, and virtual reality training.

Loss of apprenticeships

As automation replaces routine labor, many of the apprentice-level jobs in the Navy may disappear. This raises the question of where sailors will acquire the skills they now learn during their apprenticeship. Technical skills, such as engineering, network administration, and computer proficiency, can be acquired during an expanded postsecondary education. Some skills and knowledge, however, are specific to the Navy and can't be learned in a community college. Examples include tactical decision-making, Navy practices and procedures, and how to work in an effective Navy team [8].

The problem is that the future platforms require supervisors who arrive fully trained so that they can monitor the lower- and mid-level automated processes. Because there is less need for entry-level personnel in operational units, however, some other means must be used to provide learning environments so that less experienced personnel can acquire the experience they need to become fully trained supervisors.

If the apprentice stage of training largely disappears, the Navy will have to create other ways of developing Navy-specific skills. Possible methods are formal training in tactical decision-making, more and better simulators, and better use of shore tours to develop operational skills. One mechanism for accomplishing the latter is to assign people to readiness centers during their shore tours. There, they would continue to work and train on the systems they'll use in their operational tours. Another implication of this issue is that the training for entry-level personnel must be funded.

Navy training process

There is some feeling that the process to create and modify Navy training courses must become more dynamic as the rate of technological change accelerates. Under current practices, occupational standards for ratings or NECs drive the Navy training system. When a new system is introduced, new occupational standards must be drawn up,

then new curricula can be developed based on the standards. The process can be quite lengthy and time consuming.

On the DD 21, there may be a need for one "super" electronics technician who could operate and do minimal operational-level maintenance on many different types of equipment. One rating with more general skills may replace people with maintenance specializations in several ratings and many NECs would also be eliminated. The current training development process, geared toward training for narrow specialties, would not necessarily be the best method of developing training courses for generalists who arrive with significant technical education.

A related concern is that under acquisition reform detailed manpower requirements won't be available until later in the design process. There may not be enough time left to use traditional training development processes.

Skill vs. rank

In our discussion of career structures, recruiting, and training for the future Navy, it becomes clear that we must distinguish between skill and rank. Future platforms will require more highly skilled sailors, but not necessarily more sailors with higher rank. In putting together notional requirements for future platforms, it is tempting to make the paygrade structure richer, but this is not necessarily what should be done.

More highly skilled sailors have more technical skills and probably some postsecondary education. As we have seen, future sailors will have to know the underlying principles in their areas of expertise, be technically literate, and have strong problem-solving, decision-making, and communication skills. Because such skills will also be in high demand in the civilian sector, the future sailor will have to be well compensated.

Many of the future sailors' skills are general in nature, rather than particular to the Navy. This has two implications. First, general skills can be acquired through civilian education rather than through

Navy-specific training. Second, someone could be highly skilled in this sense and know nothing about the Navy.

Rank, on the other hand, is tied to acquiring Navy-specific knowledge and experience. With rank comes command authority, and the only way to get that should be by proving one's ability to make the kinds of decisions that go with that authority.

Separating skill and rank in military organizations will not be easy. The two concepts are closely enmeshed because, in the past, most skills needed in military units could only be acquired through military-specific training and experience. Even paying people in different occupations differently to reflect civilian market conditions is controversial. Some argue that the morale needed to fight together effectively could be undermined by differences in pay.

With technological change altering the set of skills that sailors need, and with the proliferation of civilian technical postsecondary school training, however, it may become essential to make a sharper distinction between skill and rank. In particular, a skill- rather than rank-based compensation system could alleviate some of the problems with recruiting highly skilled people and creating force structures that aren't executable because of rich paygrade structures.

Compensation strategy

All of the changes discussed in career structure, recruiting, and training have corresponding implications for compensation. The compensation challenge in the future will be to attract and retain a highly skilled, but not necessarily high ranking, workforce. The compensation system will also have to encourage sailors to acquire and maintain needed skills and to fill critical billets.

The first implication of a workforce with a higher proportion of skilled technical workers is that average pay rates will have to increase. The sailor of the future may require compensation at least 13 to 25 percent higher on average than today's sailor [2]. Any calculations regarding savings from reduced manning should allow for inevitable increases in manpower programming rates.

A major hindrance to meeting the future compensation challenge may be the military pay system that ties pay to rank. Some future sailors will have to be highly paid because otherwise they won't sign up or will leave for attractive civilian opportunities. One way to increase the pay of skilled technicians is to give them higher rank, but that causes problems. First, the resulting richer paygrade force structures may not be executable. Second, higher rank implies greater command authority, which may not be appropriate. Bringing in a community college graduate with no Navy experience at paygrade E5 might solve the compensation problem, but it creates problems in career management and leadership.

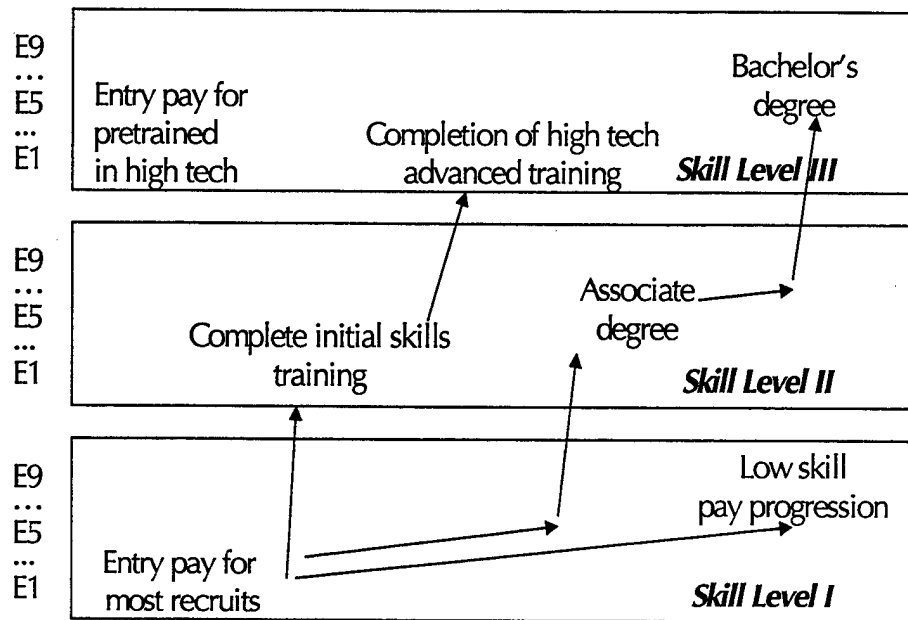
Another way to compensate skilled technicians would be to use bonuses and special pays. The drawback of this solution is that it would require pushing SRBs and special pays to unprecedented levels and even then wouldn't be the lowest cost way to construct an attractive compensation package [2].

Skill-based pay

A more innovative approach would be to adopt a skill-based pay system. Skill- and performance-based pay systems are becoming increasingly common in the civilian world because they allow the employer to set pay to reflect market conditions and productivity, creating the right incentives to attract and retain the best workers. Figure 27 shows a hypothetical skill-based pay scheme for the Navy.

This system has three skill levels, corresponding to high school graduates in low-skill occupations, semiskilled sailors who have completed some training, and sailors with 2-year degrees working in technical fields. Entire careers could be completed within one skill level, or movements could be made to higher skill levels. For example, a new high school graduate recruited as a General Detail (GENDET) sailor would enter as an E1 in Skill Level I. He or she could then progress to higher paygrades in a low-skill occupation, or opt for additional training. Perhaps after an initial sea tour the sailor would choose to take initial skill training, provided either by the Navy or by a civilian institution. After training is complete, the sailor would move up to the Skill Level II pay table at the appropriate rank.

Figure 27. Skill-based pay



On the other hand, someone who entered the Navy with a 2-year post-secondary award in a relevant technical field would start at paygrade E1 in the Skill Level III pay table. They might spend their entire career in their technical enlisted field, or decide to go on for a 4-year degree and become an officer.

If the services will be recruiting personnel with greatly different skill and education levels (e.g., a GENDET who is not a high school graduate vs. a dental technician with an Associate degree), compensation systems must recognize these differences so that individuals can be recruited and retained in necessary numbers.

Retirement pay

The current military retirement system was also designed for an earlier era when most sailors and soldiers had used up their strength and vigor at a relatively young age. The optimal retirement age for skilled technical workers is likely to be later for at least two reasons. First, the jobs are not as physically demanding, and workers can maintain peak

productivity over a longer period. Second, more time is needed to recoup investments in expensive training.

Under the current system, people who pass a certain number of years of service have a strong incentive to stay to the 20-year point. After that point, the incentives change dramatically. Rather than these arbitrary decision points, a more flexible system would allow the Navy to tailor vesting points and contribution levels so that incentives matched optimal career lengths.

Summary

Technological change, coupled with changes in civilian labor markets, will have the following implications for Navy personnel policy:

- Manpower requirements will no longer be pyramids.
 - Routine tasks will increasingly be automated, lowering junior paygrade requirements.
 - Skilled technicians will make up an increasing proportion of the force, requiring either more middle paygrade requirements or a skill-based pay system.
 - Allowing full careers without moving into supervisory ranks will require changes to up-or-out policies and increases in pay not tied to increased rank.
- Recruiting
 - Increased use will be made of recruits from less than 4-year institutions.
 - Accomplishing this will require higher compensation, either through lateral entry or pay increases not tied to rank.
- Training
 - Future sailors will increasingly be generalists rather than specialists and will require education rather than Navy-specific training.

- Technological advances will mean better embedded training so that more training can be done in operational units. With reduced manning, however, this may require additional training personnel.
- The loss of apprenticeship tours will require different means of acquiring Navy-specific skills and different methods of funding this training.
- To accommodate greater generalization, rapidly changing technology, and new acquisition processes, major changes may be necessary in the Navy's training development process.
- Skill vs. rank: New manpower requirements may necessitate a clearer distinction between skill and rank in setting recruiting, training, and compensation policies.
- Compensation
 - Average manpower costs will increase as the Navy's workforce includes a higher proportion of skilled technical workers.
 - Existing pay systems don't support the need to set compensation levels in order to attract and retain workers with high-paying civilian alternatives.
 - A skill-based pay system, or some other method of separating pay from rank, should be considered.
 - Retirement incentives should be changed to retain skilled technical workers during their most productive years.

Conclusion and recommendations

Over the next 20 to 30 years, profound changes will take place in military technology and the skills needed to operate it, as well as in the civilian population and labor force. We have analyzed how the type of sailor the Navy needs is likely to change as a result of new ship and aircraft acquisitions. We have also analyzed changes in the civilian population and labor force that may affect Navy workforce policies. Combining these two analyses, we then looked at implications for changes that may be needed in Navy personnel policies, such as career management, recruiting, training, and compensation.

An early conclusion was that technological advances will probably require a more skilled, rather than less skilled, workforce. Also, the Navy must use care in automating warfighting because routine peacetime tasks can be automated more easily than inherently chaotic and complex combat evolutions.

The types of skills needed by the Navy enlisted force will change markedly. Some familiar skills will be needed less as the Navy automates routine tasks and information processing, as maintenance workloads and watchstanding requirements decrease, and as workload moves from operational units to the infrastructure.

Sailors will need new, or different, skills to support collaboration between human and machine, introduction of more COTS technology, and the development of generalists rather than specialists. In almost all areas, including combat systems, command and control, engineering, maintenance, material handling, and hotel functions, automation will have progressed to the point where humans are overseeing complex, automated systems—providing context, coaching, and making decisions.¹⁸

18. One area that is intrinsically more difficult to automate is Damage Control. Unpredictable manual requirements, the need to address multiple contingencies, and a scarcity of commercial applications all limit the likelihood that technology will greatly reduce Damage Control manning requirements. Because Damage Control manning is a significant part of shipboard manpower requirements, this is an important limitation.

Given these trends, we see a growing requirement for a future sailor who is a skilled technician. These future sailors will understand the general principles in their areas of expertise, will be technically literate, and will have strong problem-solving, decision-making, and communication skills.

Changes in civilian education and workforces suggest that the Navy will have access to a larger recruiting pool if it expands its market to include 1- to 2-year postsecondary school graduates. These high school and postsecondary school graduates will be increasingly well prepared and technically literate. On the other hand, there will be stiff competition for highly skilled workers, so that the Navy should expect to pay more for these recruits.

Finally, we conclude that future manpower requirements will no longer be pyramids but will have reduced junior paygrade requirements and increased middle paygrade requirements. A number of factors point to the need for a clearer distinction between skill and rank; in particular, skill-based pay structures may be required. More enlisted recruits will have some postsecondary education because skill requirements will be general rather than Navy-specific, more COTS technology will be used, and more civilian institutions will offer relevant programs of study. Training will change to include more embedded training and methods to provide the knowledge formerly acquired during apprenticeship tours. Average manpower costs will increase as the Navy's workforce includes a higher proportion of skilled technical workers.

References

- [1] Donald J. Cymrot, Paul W. Mayberry, and Michael Mara. *Revolution in Personnel Affairs: Rethinking the Military Personnel System for the 21st Century*, Nov 1998 (CNA Research Memorandum 99-168)
- [2] Heidi L.W. Golding, Jeremy Arkes, and Martha E. Koopman. *Compensating the Sailor of the Future*, forthcoming (CNA Research Memorandum 99-58)
- [3] Commander, Naval Surface Force, U.S. Atlantic Fleet, ltr 3980 Ser N6/1687, "Smart Ship Project Assessment," 19 Sep 1997
- [4] Laura G. Militello et al. *Optimized Manning Case Studies*, Oct 1998 (SC-21 Manning Affordability Initiative White Paper, prepared by Klein Associates, Inc., N61339-97-C-006) (<http://www.manningaffordability.com/S&tweb/index.htm>)
- [5] RADM H. T. Rittenour and CAPT Mark O'Hare. "On Track to Tomorrow's Carrier." *Naval Aviation News*, Jan-Feb 1997
- [6] J. Robert Bost, Jennifer A. B. McKneely, and Trish Hamburger. "Surface Combatants of the Future—Reduced Crew Warships," Oct 1998 (paper presented at Human Factors and Ergonomics Society's Annual Meeting) (<http://www.manningaffordability.com/S&tweb/index.htm>)
- [7] RADM Joseph A. Carnevale and CAPT Thomas Bush. "Optimizing Manning on DD 21," Jun 1998 (paper presented at the Warship '98 International Symposium, Royal Society of Arts, London, England) (<http://www.manningaffordability.com/S&tweb/index.htm>)
- [8] John P. Jackson and Wade Taylor. *Ship Systems Automation Concept of Operations (SSA CONOPS), Revision 4*, Jul 1996 (Johns Hopkins University Applied Physics Laboratory, STD-R-2486)

- [9] Office of the Chief of Naval Operations, ltr 5000 Ser N86/6U654826, "SC-21 Manpower Goals," 10 Dec 96
- [10] Peter A. Gumataotao, CDR, USN, and Donald W. Mennecke, LCDR, USN. *SC-21 Manning Reduction Initiatives*, May 1997 (CNA Annotated Briefing 97-37)
- [11] David A. Perin. "Setting a Course for the 21st Century Carrier Force," *Naval Aviation News*, Jan-Feb 1997
- [12] Mark Doms, Timothy Dunne, and Kenneth Troske. "Workers, Wages, and Technology," *Quarterly Journal of Economics* CXII, 1997
- [13] Timothy Dunne and James Schmitz, Jr. "Wages, Employment Structure and Employer-Size Wage Premia: Their Relationship to Advanced-Technology Usage at U.S. Manufacturing Establishments," *Economica* LXII, 1995
- [14] Ann P. Bartel and Nachum Sicherman. "Technological Change and Wages: An Interindustry Analysis," *Journal of Political Economy* 107, 1999
- [15] Peter Capelli. "Are Skill Requirements Rising? Evidence from Production and Clerical Jobs," *Industrial and Labor Relations Review* 46, 1993
- [16] Loek F. M. Groot and Andries de Grip. "Technological Change and Skill Formation in the Bank Sector," *Economics of Education Review* 10, 1991
- [17] Eli Berman, John Bound, and Zvi Griliches. "Changes in the Structure of Wages in the 1980s: An Evaluation of Alternative Explanations," *Quarterly Journal of Economics* CIX, 1994
- [18] Jeffrey H. Keefe. "Technological Change and Employment: the Case of the Numerical Control," *Industrial and Labor Relations Review* 44, 1991
- [19] Internet web site: <http://www.manningaffordability.com/S&tweb/index.htm>

- [20] Gwendolyn Campbell et al. *Dynamic Function Allocation in the SC-21 Manning Initiative Program*, Apr 1997 (SC-21 Manning Affordability Initiative White Paper, Naval Air Warfare Center Training Systems Division) (<http://www.manningaffordability.com/S&tweb/index.htm>)
- [21] Janis A. Cannon-Bowers et al. "Achieving Affordability Through Human Systems Integration," Apr 1997 (paper presented at third annual Naval Aviation Systems Engineering Supportability Symposium) (<http://www.manningaffordability.com/S&tweb/index.htm>)
- [22] Gwendolyn E. Campbell, Janice A. Cannon-Bowers, and Joe Villalonga. *Achieving Training Effectiveness and System Affordability Through the Application of Human Performance Modeling*, 1997 (SC-21 Manning Affordability Initiative White Paper, Naval Air Warfare Center Training Systems Division) (<http://www.manningaffordability.com/S&tweb/index.htm>)
- [23] Internet web site: <http://www-code44.spawar.navy.mil/cpof/index.html>
- [24] Wayne Zachary et al. *Application of Human Modeling Technology to the Design, Operation, and Evaluation of Complex Systems*, 1998 (CHI Systems Technical Memo, 980727.9705) (<http://www.manningaffordability.com/S&tweb/index.htm>)
- [25] U.S. Department of Commerce, Bureau of the Census, *U.S. Population Estimates, by Age, Sex, Race, and Hispanic Origin: 1980 to 1991*, Feb 1993 (Current Population Reports, P25-1095)
- [26] U.S. Department of Commerce, Bureau of the Census, *Population Projections of the United States by Age, Sex, Race, and Hispanic Origin: 1995 to 2050*, Feb 1996 (Current Population Reports, P25-1130)
- [27] Michael Fix and Jeffrey S. Passell. *Immigration and Immigrants: Setting the Record Straight*. Washington, DC: Urban Institute, 1994

- [28] Richard W. Judy and Carol D'Amico. *Workforce 2020: Work and Workers in the 21st Century*. Indianapolis, IN: Hudson Institute, 1997
- [29] U.S. Department of Education, National Center for Educational Statistics, *Projections of Education Statistics to 2008*, 1998 (NCES 98-016) (nces01.ed.gov/pubs98/pj2008/)
- [30] National Commission of Excellence in Education, *A Nation at Risk: The Imperative for Education Reform*, Apr 1993 (<http://www.ed.gov/pubs/NatAtRisk/>)
- [31] Robert M. Huelskamp. "Perspectives on Education in America," *Phi Delta Kappan* 74, May 1993
- [32] David C. Berliner and Bruce J. Biddle. *The Manufactured Crisis*. New York: Addison Wesley, 1995
- [33] David C. Berliner and Bruce J. Biddle. "Making Molehills Out of Molehills: Reply to Lawrence Stedman's Review of *The Manufactured Crisis*," *Education Policy Analysis Archives* 4, Feb 26, 1996 (<http://olam.ed.asu.edu/epaa/v4n3.html>)
- [34] Lawrence C. Stedman. "The Sandia Report and U.S. Achievement: An Assessment," *Journal of Educational Research*, Jan-Feb 1994: 133-146
- [35] Lawrence C. Stedman. "The Achievement Crisis Is Real: A Review of *The Manufactured Crisis*," *Education Policy Analysis Archives* 4, Jan 23, 1996 (<http://olam.ed.asu.edu/epaa/v4n1.html>)
- [36] Gerald W. Bracey. "The Bracey Report on the Condition of Public Education," *Phi Beta Kappan*, October 1991, 1992, 1993, 1994, 1995, 1996, 1997
- [37] Gerald W. Bracey. "Are U.S. Students Behind?" *The American Prospect* 37, Mar-Apr 1998: 64-70 (<http://epn.org/prospect/37/37bracfs.html>)

- [38] Brian Powell and Lala Carr Steelman. "Bewitched, Bothered, and Bewildering: The Use and Misuse of State SAT and ACT Scores," *Harvard Educational Review*, Spring 1996: 27-59
- [39] F. Howard Nelson and Jewell C. Gould. "Teachers' Unions and Excellence in Education: Comment," *Journal of Labor Research* 9, Fall 1988: 379-387
- [40] Amy E. Graham and Thomas A. Husted. "Understanding State Variations in SAT Scores," *Economics of Education Review* 12, 1993: 197-202
- [41] U.S. Department of Education, National Center for Education Statistics, *NAEP 1996 Trends in Academic Progress*, 1997 (NCES 97-985)
- [42] U.S. Department of Education, National Center for Education Statistics, *The Condition of Education 1998*, 1998 (NCES 98-013) (<http://nces.ed.gov/pubs98/condition98/index.html>)
- [43] Peggy A. Golfin. *A Summary of Navy Recruiting Efforts in Community Colleges in FY 1997*, Mar 1998 (CNA Research Memorandum 97-139)
- [44] U.S. Department of Commerce, Bureau of the Census, *Educational Attainment in the United States*, Mar 1997 (Current Population Reports, P20-505) (<http://www.census.gov/population/socdemo/educ-attn.html>)
- [45] William B. Johnston. *Workforce 2000: Work and Workers for the 21st Century*. Indianapolis, IN: Hudson Institute, 1987
- [46] Peggy A. Golfin. *Partnerships With Community Colleges: Vehicles To Benefit Navy Training and Recruiting*, Mar 1998 (CNA Research Memorandum 97-144)
- [47] Peggy A. Golfin, John D. White, and Lisa A. Curtin, CDR, USN. *A Role for Community Colleges in Navy Training*, Mar 1998 (CNA Research Memorandum 97-97)

- [48] John Pencavel. "Higher Education, Productivity and Earnings: A Review," *Journal of Economic Education* 22, 1991
- [49] George T. Silvestri. "Occupational Employment to 2005," *Monthly Labor Review*, Nov 1995: 60-84
- [50] Joyce S. McMahon. *Pay Distributions for Enlisted Communities*, Dec 1992 (CNA Research Memorandum 92-83)
- [51] Al Rouse. "Future Manpower Challenges," Jan 1999 (briefing prepared by Naval Personnel Research and Development Center for N12)

List of figures

Figure 1. Design sketch of LPD 17	12
Figure 2. Possible hull design for DD 21	14
Figure 3. Numbers of surface combatants, 2000-2020	20
Figure 4. Manpower requirements for surface combatants, 2000-2020	20
Figure 5. The Joint Strike Fighter (JSF) on a carrier.	26
Figure 6. Conceptual condition I watch organization for SSA ship	31
Figure 7. MMWS concept	35
Figure 8. One possible ICE design	36
Figure 9. Population of 18- to 24-year-olds	41
Figure 10. Population shares by race and Hispanic origin, 1990 to 2020	43
Figure 11. Annual high school graduates projected through 2008	45
Figure 12. Percentage of 17-year-old students at or above science performance levels	49
Figure 13. Percentage of 17-year-old students at or above math performance levels	50
Figure 14. Percentage of 17-year-old students at or above reading performance levels.	51

Figure 15. Percentage of students taking selected science courses, 1982-1994.	52
Figure 16. Percent of students taking selected math courses, 1982-1994	52
Figure 17. Percentage of students using computers at school	53
Figure 18. Shifts in educational attainment over last half-century	55
Figure 19. Fewer people stop education at high school, 1967-1996	56
Figure 20. Enrollment in 2- and 4-year institutions of higher learning	56
Figure 21. Comparison of rates of change	57
Figure 22. Awards below Bachelor's degree in technical fields, 1994-1995.	59
Figure 23. Ratio of earnings relative to high school graduate for men age 25 to 34	62
Figure 24. Wage premiums by field of Bachelor's degree.	63
Figure 25. Future requirements driven by different needs	68
Figure 26. The end of the manpower pyramid?	69
Figure 27. Skill-based pay	78

Distribution list

Research Memorandum 99-59

SNDL

21A1	CINCLANTFLT NORFOLK VA	N120
	Attn: N1	N120C
21A2	CINCPACFLT PEARL HARBOR HI	N122
	Attn: N1	N122B
24A1	COMNAVAIRLANT	N122C
	Attn: N1	N122C1
24A2	COMNAVAIRPAC SAN DIEGO CA	N122C2
	Attn: N1	N122E
24D2	COMNAVSURFPAC	N125
	Attn: N1	N125D
24D2	COMNAVSURFLANT	N13
	Attn: N1	N130
A1H	DASN - M&RA WASHINGTON DC	N131
A1H	ASSTSECNAV - M&RA WASHINGTON DC	N13B
A1H	PDASN - M&RA	N13D
A1H	OPDASN - M&RA	N13T
	Attn: LCDR THOMLISON	N132
	Attn: CDR GRUENDL	N132C
A5	BUPERS	N132D
	Attn: PERS-1	N4
	Attn: PERS-4	N4B
	Attn: PERS-40	N46
	Attn: PERS-45	N7
	Attn: PERS-6	N7B
FF38	USNA ANNAPOLIS	N73
FF42	NAVPGSCOL MONTEREY CA	N8
FF44	NAVWARCOL NEWPORT RI	N80
FJA10	NAVMAC	N81
FJA13	NAVPERSRANDCEN SAN DIEGO CA	N801
FJB1	COMNAVCRUITCOM WASHINGTON DC	N801D
	Attn: 00	N813
	Attn: 00B	N869
	Attn: 00P	N879
FT1	CNET	N889
	Attn: ETE	
	Attn: OTE	

OPNAV

N00D
N1
N10
N1B
N12
N12B