Balancing Officer Community Manpower through Decentralization: Granular Programming Revisited

Amanda Kraus, Jared Huff, and Elliot Lee

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Dr. Molly F. McIntosh
Defense Workforce Analyses Team
Resource Analysis Division

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Abstract

This study addresses inventory-billet imbalances in the Navy's officer corps. It uses a game-theoretic model to explore whether these imbalances can be resolved using substitution-based granular programming rates in the billet authorization process. The results show that, within the model's stylized framework, substitution-based granular rates can be set to substantially reduce inventory-billet imbalances, thus indicating that granular programming has the potential to work in practice. Parts of the analysis, however, also highlight that any effort to use granular programming to resolve imbalances must include adopting complementary policies and practices. In particular, billet authorizations must be allowed to deviate from manpower requirements, and the relevant information technology systems must be adapted to accommodate granular rates.

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Executive Summary

Issues

One of the persistent challenges facing Navy leadership is a disconnect between the paygrade structure of authorized officer billets and that of officer personnel inventories. Fundamentally, this is a disconnect between the demand for and supply of officers with different experience levels. In Navy terminology, this disconnect is referred to as an imbalance between authorized billets (BA) and personnel inventories (INV).

These imbalances impose substantial costs on the Navy. Some of these costs are hard costs that can be measured in dollar terms. In particular, when there is excess INV, the Navy pays for more officers than it needs. Other costs are soft costs that cannot be directly measured in dollar terms. These can include low productivity due to low morale, reduced readiness due to unfinished work or low retention, and negative impacts on community health.

A solution that was tried from 2006 to 2013 was the use of paygrade-specific, granular programming rates in the billet authorization process. Granular programming was seen as a way to not only resolve INV-BA imbalances but also introduce market-based and organizational efficiencies into the system. In this paper, we revisit granular programming because it still holds promise for solving this long-standing problem.

Analytical approach

To address the study issues, the study team used a multi-step approach. First, we used personnel and billet data to define, describe, and analyze the INV-BA imbalances of current concern. Then, we reviewed the extant literature on the manpower and personnel management systems, focusing on features that cause the INV-BA imbalances and on previously suggested solutions. Based on our assessment of the proposed solutions, we chose to revisit granular programming using a paper exercise. Specifically, we developed a game-theoretic model to explore whether our proposed approach to granular programming could resolve INV-BA imbalances.

Step-by-step takeaways

Supply-demand imbalances in the Navy's officer corps

The primary imbalance of current concern is excess supply (also known as officer overexecution, or OOE) in the junior grades (JGs) of the Surface Warfare (SW) and Submarine (SUB) communities. Although excess demand exists for the control grades (CGs) of these communities, it is mainly in the healthy range when the flexibility of non-discrete billet allocation is taken into account. The exception here is the SUB community, which doesn't have enough CG inventory to fill its discrete CG BA.

Two factors contribute to INV-BA imbalances and make managing them a persistent challenge. First, some community management practices can increase the likelihood that imbalances will occur. For the SW and SUB communities, planning accessions to meet work requirements that occur after most members complete their minimum service requirements contributes to the JG OOE they are experiencing. And, for the unrestricted line as a whole, the lateral transfer system drives a wedge between community requirements and accessions. Second, the manpower and personnel management systems allow for independent changes in BA and INV. This study focused on the latter.

Manpower versus personnel management

Although the Navy's manpower and personnel management processes are intended to function as two parts of one integrated system, they have several fundamental differences that make keeping INV-BA imbalances in the healthy range a constant challenge. In general, the issue is that decentralized manpower and personnel decision-makers have different priorities and constraints. Given this characterization of the problem, we focused on one of four previously proposed or attempted solutions: granular programming.

Granular programming to minimize supply-demand imbalances

Economic theory identifies costs and benefits associated with decentralization. On the benefits side, decentralized decision-makers often have better information about how work can be done most efficiently in their parts of the organization. On the cost side, what is locally best may not be best for the organization as a whole. When such costs arise, pricing solutions can be used to align the interests of decentralized decision-makers across an organization. Thus, in the Navy context, granular programming is a theoretically sound way to align the competing priorities of manpower and personnel.

There are, however, multiple ways to set granular programming rates. In the Navy's closed personnel system, cost-based rates—rates based on either average or marginal personnel costs—are either infeasibly difficult to calculate or unlikely to resolve INV-BA imbalances, or both. Thus, we proposed using what we call a substitution-based approach that is explicitly designed for the purpose at hand.

Granular programming: A substitution-based approach to setting rates

The results of the paper exercise showed that, within its stylized framework, substitution-based granular rates can be set to substantially reduce, if not eliminate, INV-BA imbalances. This means that granular programming has the potential to work in practice.

In particular, the calculated rates have two important features: Like the cost-based granular rates that were actually used, they are increasing with paygrade. Unlike those rates, however, they do not increase linearly with paygrade. Combined, these features suggest that cost-based granular rates would be better than using one rate for all paygrades, but such rates aren't likely to be sufficiently targeted to eliminate either specific or very large imbalances.

Other aspects of the paper exercise highlight the complementary policies that need to be in place for substitution-based granular programming to be effective. First, the game's structure assumes that a centralized Navy authority can both set paygrade-specific prices and impose binding budget constraints for Navy Budget Submitting Offices (BSOs).

Second, BSOs must be able to respond to changes in relative billet prices. They must not only understand their activities' production processes well enough to make output-maximizing trade-offs among billets of different paygrades, but also have the authority to buy billets in those optimizing combinations. The game's results reinforce this point. For granular programming to eliminate, or substantially reduce, INV-BA imbalances, BSOs must be able to request billet structures that deviate from the limits set by requirements. This conclusion holds regardless of whether the rates are based on substitution patterns or costs.

Finally, the estimated productivity coefficients used in the game are not likely to reflect actual substitution patterns. In actual practice, if granular programming were in place long enough, this problem could be addressed by directly estimating substitution patterns based on BSOs' real responses to changes in paygrade-specific rates. This would, however, require that BSOs can not only change their billet structures but also rearrange the underlying work to maximize readiness.

Path forward

The paper exercise was based on a very stylized representation of the billet authorization process. As such, it may have more value as the first steps on a path forward than as a ready solution. In particular, given the complexity of the entire Manpower, Personnel, Education & Training (MPT&E) system, more research could help to reveal the potential for unintended effects and additional complementary practices. We offer two possible approaches.

The first approach is to expand the game-theoretic model to capture some of the additional complexities of the MPT&E system. For example, given that INV-BA imbalances vary across communities, the model could easily be adapted to solve INV-BA imbalances for individual designators rather than designator groups. A more complicated extension would be to allow BSOs to substitute across designators as well as paygrades. Another option is to solve for a multi-year solution that would both capture the effects of a given year's pricing system on future inventories and allow the players in the game to learn from each previous round to make better decisions in the next round. This type of extension would require making assumptions about how inventory flows through the system from year to year.

The second approach is to actually re-implement granular programming using cost-based rates to collect data on actual substitution patterns. To accompany this approach, it would be valuable to study how, and to what extent, Navy activities actually redistribute work across paygrades. Do they simply do their own versions of billet roll-downs or do they fundamentally reorganize their work processes?

Whichever approach is taken, the most important thing to remember is that any effort to use granular programming to resolve INV-BA imbalances must include adopting the required complementary policies and practices. In particular, BA must be allowed to deviate from requirements and the relevant information technology systems must be adapted to accommodate granular rates.

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Abbreviations

AVN	Aviation
BA	Billets Authorized
BSO	Budget Submitting Office
CG	Control Grade
DH	Department Head
DIVO	Division Officer
INV	Inventory
JG	Junior Grade
MPN	Military Personnel, Navy
MPT&E	Manpower, Personnel, Training & Education
MRD	Manpower Requirements Determination
MSR	Minimum Service Requirement
NAVFAC	Naval Facilities Engineering Command
NFO	Naval Flight Officer
OBF	Officer Billet File
OCM	Officer Community Management
OOE	Officer Overexecution
OPINS	Officer Personnel Information System
OUE	Officer Underexecution
RL	Restricted Line
RS	Reporting Senior
SUB	Submarine
SW	Surface Warfare
TFMMS	Total Force Manpower Management System
TYCOM	Type Commander
URL	Unrestricted Line
YCS	Years of Commissioned Service

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Introduction

Issues

One of the persistent challenges facing Navy leadership is a disconnect between the paygrade structure of authorized officer billets and that of officer personnel inventories. Fundamentally, this is a disconnect between the demand for and supply of officers with different experience levels. In Navy terminology, this disconnect is referred to as an imbalance between authorized billets (BA) and personnel inventories (INV).

This disconnect in terms of demand and supply outcomes is caused by a fundamental disconnect in the underlying processes that generate them. Specifically, authorized officer billets are determined within the broad process of manpower management, while officer inventories are determined within the separate process of personnel management. The separateness of the two systems is by design because they are governed by different Navy, Department of Defense (DOD), and congressional rules and policies.

A solution that was tried from 2006 to 2013 was the use of paygrade-specific, granular programming rates in the billet authorization process. Granular programming was seen as a way to not only resolve INV-BA imbalances but also introduce market-based and organizational efficiencies into the system.

In this paper, we revisit granular programming from a theoretical perspective and also using a pseudo-empirical approach. Specifically, we use a game-theoretic model to calculate programming rates that could resolve one year's observed imbalances and compare them to the granular programming rates that were actually used.

Why address imbalances?

Given the persistent, systemic nature of the Navy's INV-BA imbalances, why is it important to address them? There is one reason: they have costs.

In a 2003 study [1], researchers from the RAND Corporation identified two types of costs associated with INV-BA imbalances—hard costs and soft costs.

Hard costs are costs that can be measured in dollar terms. When there is excess INV, the Navy pays for more officers than it needs. When there are INV shortages, the Navy gets savings. In the Navy's closed personnel system, excesses of one type of officer typically mean shortages of another. The net cost of imbalances depends on which effect dominates. For example, excess junior inventory may be offset by shortages of senior inventory. Since senior officers are more expensive than junior officers, junior excesses have to be large to outweigh senior shortages. Costs also differ across communities, depending on the costs of training pipelines. So excesses and shortages in different communities have different impacts on the Navy's bottom line.

Soft costs are costs that cannot be directly measured in dollar terms. They include low productivity due to low morale and reduced readiness due to unfinished work or low retention. For example, INV shortages that result in gapped billets mean that work either doesn't get done or is performed by officers who are also doing other jobs. The former reduces readiness; the latter can put stress on the force. And imbalances of either type mean that officers may be assigned to billets for which they have either too much experience—thus decreasing morale—or too little experience—thus reducing productivity.

An additional cost of INV-BA imbalances is their negative effects on community health. These effects are related to, and interact with, both hard and soft costs. In 2009, the Navy's officer community managers summarized all these costs in the following way:

> These shortages and surpluses [of inventory] drive real problems in the form of unstable promotion rates, unexecutable retention goals with ballooning incentives, unreasonable training pipeline capacity delays, and unbudgeted distribution solutions (e.g., double stuffs, quad 9's, out of designator fills, and unfilled training quotas). [2][1]

Based on these costs, this is a problem that is worth finally solving.

Why revisit granular programming?

Given that granular programming was attempted and ostensibly deemed ineffective relative to its cost of implementation, why do we revisit it in this paper? We have two reasons. First, granular programming is a market-based, decentralized solution to the problem; indeed, it is likely that any market-based, decentralized solution to INV-BA

[1] Also quoted in a formal CNA research memorandum, reference [3].

imbalances would resemble granular programming. Not only are market-based initiatives and decentralization popular topics among Navy leadership, but they also have promising theoretical properties. As such, it is possible that the idea of granular programming could be revisited in the future even if the current appetite for re-implementation is minimal.

Second, previous discussions of granular programming have proposed using rates that are based on personnel costs. There are, however, features of the Navy's closed personnel system that, in addition to making the appropriate costs quite difficult to calculate, make them unlikely to eliminate INV-BA imbalances. We offer an initial solution to this problem.

Organization of the report

This report is divided into four main sections. The first section defines, describes, and analyzes the INV-BA imbalances of current concern. The billet and personnel data used for the analysis cover 1986 through 2015 and come from the September files of CNA's extracts of the following Navy databases:

- The Officer Billet File (OBF) for billet data from 1986 through 2000
- The Total Force Manpower Management System (TFMMS) for billet data from 2001 through 2015
- The Officer Personnel Information System (OPINS) for personnel data from 1986 through 2015.

The second section reviews the extant literature on the manpower and personnel management systems, focusing on features of the systems that cause the INV-BA imbalances and previously suggested solutions to this persistent problem.

In the third section, we propose revisiting granular programming but using a substitution-based, rather than cost-based, approach to setting the rates.

In the fourth section, we use a game-theoretic model to explore the feasibility of the proposed approach and compare the properties of substitution-based and cost-based rates.

The report ends with a summary of the discussion and the conclusions we draw from it.

Supply-Demand Imbalances in the Navy's Officer Corps

The demand for Navy officers in any given fiscal year (FY) is expressed by officer BA. These are funded billets that represent the jobs that must be filled by Navy officers to meet the Navy and joint-service missions. They are defined in terms of skill categories (i.e., designators) and experience levels (i.e., paygrades). The supply of Navy officers is summarized by the officer INV, which is defined according to the same skill categories and experience levels as BA.[2]

The job of the officer management system is not only to fill all the billets and employ all the officers but also to make the best skill/experience matches possible, all within binding fiscal and legal constraints. Imbalances occur when officer supply does not equal officer demand, either in aggregate, or by skill or experience group. Thus, imbalances can be in terms of quantity or quality, or both.

The standard measure of balance (or imbalance) is the ratio of INV to BA: INV/BA. Based on this metric,

- A value of 1 indicates that supply equals demand, and the system is perfectly balanced.
- Values greater than 1 indicate that supply exceeds demand. This is called officer overexecution (OOE).
- Values less than 1 indicate that supply falls short of demand. This can be called officer underexecution (OUE).

Given the dynamic nature of the system and the multiple constraints placed on it, it is not expected to achieve perfect balance all the time. Therefore, planners define a healthy range of within ±5 percent [3].

[2] Additional descriptive details for both billets and officers include the following: Navy Officer Billet Classifications, which describe general occupational duties; subspecialty codes, which identify postgraduate education (or equivalent training and/or experience) in various fields and disciplines; and Additional Qualification Designations, which identify additional qualifications and skills not included in the other code structures.

Supply-demand imbalances are tracked in the aggregate, by community, and by paygrade. In this section, we describe historical the imbalances as well as those that that are of current concern to Navy leadership.

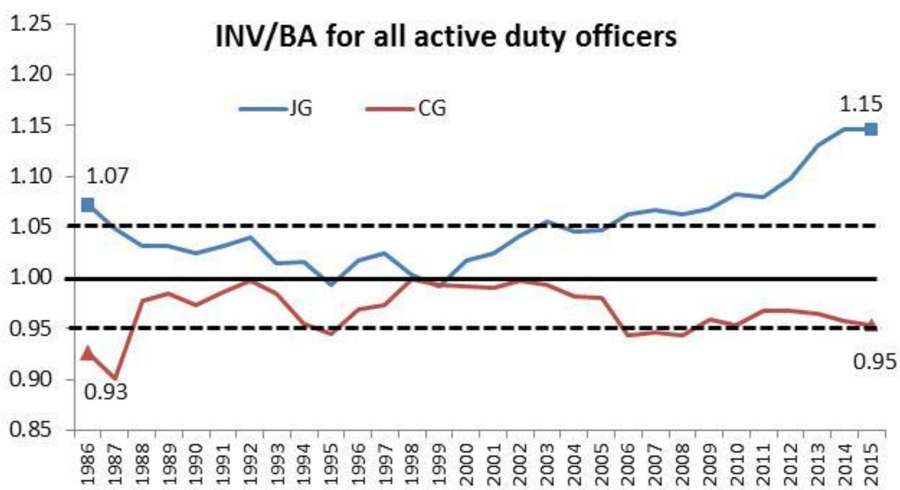
To give the historical perspective, we start with imbalances for all active-duty Navy officers from 1986 to 2015. Then, to better understand the Navy-wide look and to highlight the current imbalances, we narrow the timeframe to 2001 to 2015 and disaggregate the data to look at specific groups of officers. The first level of disaggregation is by the three main designator groups of the Navy's officer corps: the unrestricted line (URL), the restricted line (RL), and the Staff Corps. The second level of disaggregation is by the three main designators within the URL: surface warfare (SW), submarine (SUB), and aviation (AVN).

For all groups, we look at imbalances in two sets of paygrades: the junior grades (JGs) of O1 through O3 (ensign through lieutenant) and the control grades (CGs) of O4 through O6 (lieutenant commander through captain).

Navy-wide imbalances

Figure 1 shows the JG and CG INV/BA ratios for all active-duty Navy officers from September 1986 through September 2015, the most recent year for which data were available.

Figure 1. INV/BA ratios for all active-duty officers, September 1986 through September 2015



The data show that, over the past 20 years, the control grades have maintained a fairly healthy balance: although the CG INV/BA ratios have been consistently less than 1, they have mostly stayed within the -5-percent range. In contrast, although a healthy balance was maintained for the junior grades for most of the 1990s, the JG INV/BA ratio has increased fairly steadily since September 1999; in 2006, it went outside the +5-percent healthy range. By September 2015, the ratio stood at 1.15.

Thus, the data show that maintaining a healthy supply-demand balance is a persistent challenge and that JG OOE has become a problem in the past decade. The persistence reflects the difficulty of getting the supply-demand balance exactly right within the constraints of the system. Disaggregating the data helps us understand the recent increase in JG OOE, and it reveals additional areas of potential concern.

Imbalances by designator group

Description

Starting with the first level of disaggregation, Figure 2, Figure 3, and Figure 4 show the INV/BA ratios for the URL (including non-discrete 1000/1050 billets[3]), the RL, and the Staff Corps, respectively. The data for each community group tell a unique story.

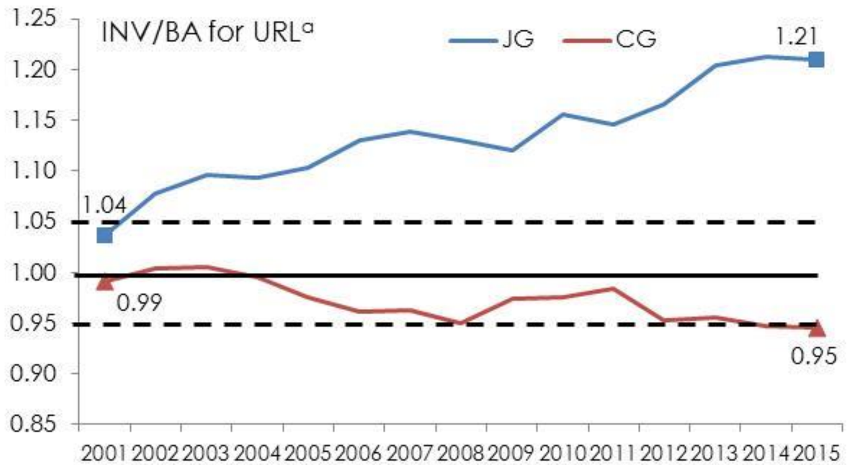
The URL has been overexecuted in the junior grades for the whole period, with the URL JG INV/BA ratio steadily increasing from 1.04 in 2001 to 1.21 in 2015. The URL has been slightly underexecuted in the control grades for the whole period, and the URL CG INV/BA ratio has decreased from 0.99 to 0.95, just within the healthy range.

The RL has been both underexecuted and overexecuted in the junior grades during the time period, with an average JG INV/BA ratio of 0.99. It was, however, overexecuted in these grades from 2013 through 2015. The RL has been underexecuted in the control grades throughout the period, and only entered the healthy range in 2010.

[3] Billets coded with community-specific designators are called discrete billets. They represent community-specific requirements and work. Non-discrete billets, in contrast, represent requirements that can be filled (i.e., work that can be performed) by officers from multiple communities. These data include two types of non-discrete billets:

- 1000-coded billets, which can be filled by any appropriately skilled and experienced URL officer or Special Duty Officer
- 1050-coded billets, which can be filled by any URL officer who is qualified in any one of the warfare specialties and has achieved the rank of lieutenant or higher.

Figure 2. INV/BA ratios for all active-duty URL officers, September 2001 through September 2015[a]



[a] BA data include both URL discrete-coded billets and 1000- and 1050-coded (i.e., non-discrete) billets.

Figure 3. INV/BA ratios for all active-duty RL officers, September 2001 through September 2015

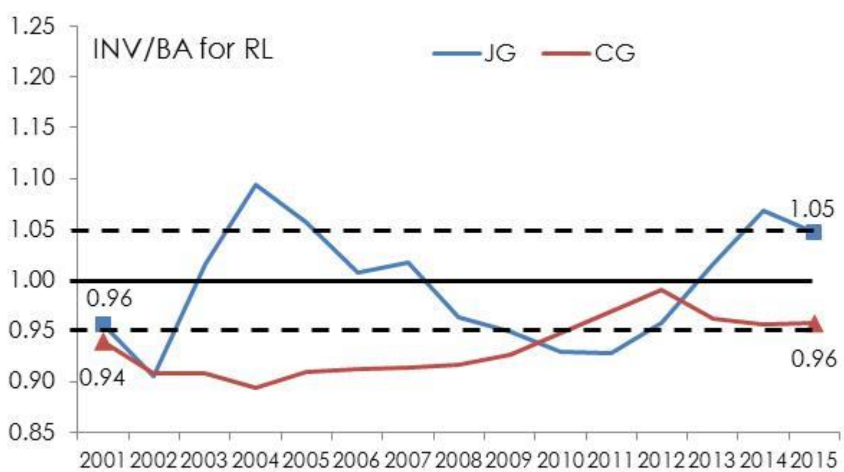
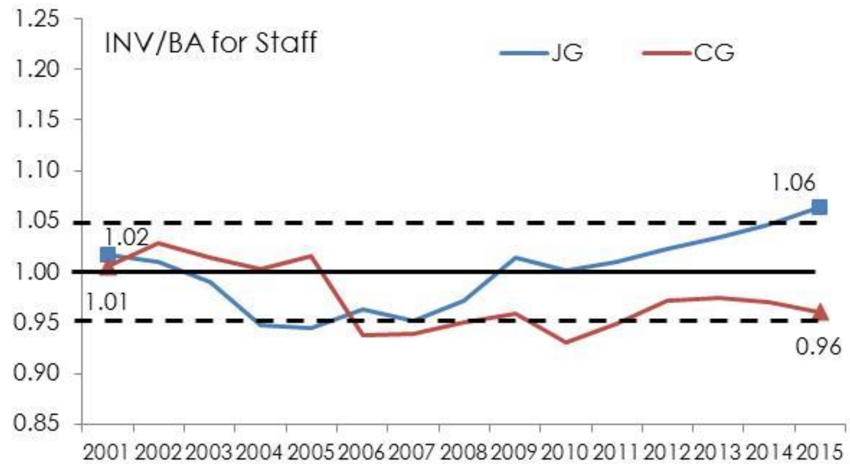


Figure 4. INV/BA ratios for all active-duty Staff Corps officers, September 2001 through September 2015



The Staff Corps started the period being slightly overexecuted in the junior grades (with a JG INV/BA ratio of 1.02), was underexecuted between 2003 and 2008 (with a minimum JG INV/BA ratio of 0.95), and then became overexecuted in the latter part of the data period. From 2008 to 2014, it was in the healthy range, but it went just outside the range (1.06) in 2015. In the control grades, the Staff Corps was barely overexecuted from 2001 to 2005 (with the CG INV/BA ratio ranging between 1.0 and 1.02) and then was unhealthily underexecuted from 2006 to 2010. Since 2010, the Staff Corps has remained underexecuted in the control grades, but the imbalance has been in the healthy range.

Insights from cross-group comparisons

Comparing the INV/BA ratios across designator groups, three points stand out. First, the URL results look similar to the total results because it is the largest group.

Second, JG OOE is more extreme for the URL than for the other groups. Indeed, JG OOE is mainly a URL issue. This is primarily because of differences in community management models across the three groups.

Third, although JG OOE is concentrated in the URL, the challenge of maintaining a healthy supply-demand balance that was visible in the aggregate data is also clear at the designator-group level. For all three designator groups and for both paygrade groups, the INV/BA ratios were constantly changing over the period and were never strictly equal to 1. This is because the underlying paygrade structures of INV and BA were also changing constantly, but were doing so separately (i.e., not always in the same directions or at the same rate) within the separate manpower and personnel management processes.

We discuss each of these observations in turn.

The dominance of the URL

Table 1 shows the distribution of total, JG, and CG BA and INV across designator groups based on the averages for the period. The URL is the largest group, making up just over half of total BA and INV. The URL has an even larger majority of JG BA and INV and, concomitantly, a relatively smaller share of CG BA and INV. Thus, URL imbalances are the primary drivers of the aggregate imbalances, especially for the junior grades.

Table 1. Designator groups' shares of total, JG, and CG BA and INV based on averages from September 2001 through September 2015

Designator group	Average share of BA			Average share of INV		
	Total	JG	CG	Total	JG	CG
URL[a]	51.8	57.9	44.1	54.1	61.0	44.3
RL	13.0	10.0	16.8	12.1	9.2	16.3
Staff	35.2	32.1	39.1	33.8	29.8	39.4
Total	100.0	100.0	100.0	100.0	100.0	100.0

[a] The URL BA data include both URL discrete-coded billets and 1000- and 1050-coded (i.e., non-discrete) billets.

Differences in community management models

Table 2 shows the paygrade structures of total, JG, and CG BA and INV for each designator group. The data show that, compared with the RL and Staff Corps, a much larger portion of URL BA (INV) is JG billets (officers)—an average of 63 (66) percent for the URL versus 43 (44) percent for the RL and 52 (48) percent for the Staff Corps. As a result, the JG/CG ratios are also different across the three groups—about 1.7 (1.96) for the URL versus 0.75 (0.80) for the RL and 1.05 (1.07) for the Staff Corps. Note that the paygrade distributions of BA and INV reflect the same broad patterns for each community group; however, given JG OOE, the differences between BA and INV are larger for the URL than for the RL and Staff Corps.

The group-specific paygrade distributions of both BA and INV reflect fundamental differences in how the communities in the three designator groups are managed within the closed officer management system. The URL communities grow officers from O1 to O6, and most of their accessions are direct accessions, with virtually all entering as O1s. Within this construct, URL JG billets provide on-the-job training in community-specific warfare skills, enabling junior officers (JOs) to achieve warfare qualification. These billets also provide early leadership experience.

Table 2. Paygrade structures of total, JG, and CG BA and INV for each designator group based on averages from September 2001 through September 2015

	BA			INV		
Grade(s)	**URL[a]**	**RL**	**Staff**	**URL***	**RL**	**Staff**
O1	15.6	5.7	6.4	17.7	7.3	7.1
O2	15.9	7.3	8.1	15.9	9.6	8.2
O3	31.0	29.8	36.6	32.5	27.5	36.4
O4	18.5	29.1	25.4	16.2	27.4	24.2
O5	13.0	19.7	14.9	12.1	19.6	15.3
O6	5.9	8.3	8.6	5.5	8.6	8.8
Total	100.0	100.0	100.0	100.0	100.0	100.0
JG	62.6	42.9	51.1	66.1	44.4	51.8
CG	37.4	57.1	48.9	33.9	55.6	48.2
JG/CG	1.68	0.75	1.05	1.96	0.80	1.07

a. The URL BA data include both URL discrete-coded billets and 1000- and 1050-coded (i.e., non-discrete) billets.

RL communities, in contrast, build primarily from URL transfers. Some of these transfers are training attrites (mainly from the SUB and AVN communities), but most are lateral transfers who join their RL communities after becoming warfare qualified (mainly from the SW community). The logic behind the RL community-management model is two pronged. First, providing transfer opportunities for both training attrites and warfare-qualified officers allows the Navy to keep high-quality officers it might otherwise lose. Second, building from lateral transfers provides warfare experience in these support communities, which is expected to make these officers more effective in their supporting roles.

The Staff Corps communities use a mix of these two approaches, getting some transfers, but mostly building from direct accessions. Many of the Staff Corps' direct accessions, however, are granted constructive credit and access as O2s or O3s rather than O1s. Thus, the JG share of total Staff Corps billets is in between that of the other two groups.[4]

So, on one level, these community-specific management practices make JG OOE more likely and more problematic in the URL simply because they mean that the URL has

[4] See [4] and [5] for more details on lateral transfer patterns by supplier and receiver communities.

more JG BA and INV than do the RL and Staff Corps. On another level, however, they also contribute to JG OOE because of the practices they incentivize. Reference [4] explains it this way:

> On one hand, to accommodate the flow of lateral transfers, the URL communities may access and train more officers than necessary to meet their own requirements. On the other hand, anticipating lateral transfers from the URL, the RL and selected staff communities may underaccess to their true requirement. This approach results in excess junior officers in training in some URL communities…. [4]

Underlying changes in the paygrade structures of INV and BA

Table 3 shows the underlying, independent changes in JG and CG BA and INV for each designator group and in total.

Table 3. Changes in JG and CG BA and INV from September 2001 to September 2015, by designator group

	JG changes		CG changes	
Designator group	**BA**	**INV**	**BA**	**INV**
URL[a]	-1,827	660	-814	-1,209
RL	949	1,160	1,032	1,034
Staff	-947	-588	-29	-375
Total	-1,825	1,232	189	-550

[a] The URL BA data include both URL discrete-coded billets and 1000- and 1050-coded (i.e., non-discrete) billets.

The data show that the proximate cause of the increase in URL JG OOE was a decrease in URL JG BA, combined with an increase in URL JG INV. At the same time, although changes in URL CG BA and INV were in the same direction (i.e., down), URL CG OUE increased because the decrease in URL CG INV was nearly 1.5 times greater than the decrease in URL CG BA. This same pattern of change explains the increase in Staff Corps CG OUE: Staff Corps CG INV decreased faster than Staff Corps CG BA. Changes in the other imbalances can be explained by making similar comparisons. Of note is the fact that the case in which changes in BA and INV were essentially the same—RL CG—is the exception rather than the rule.

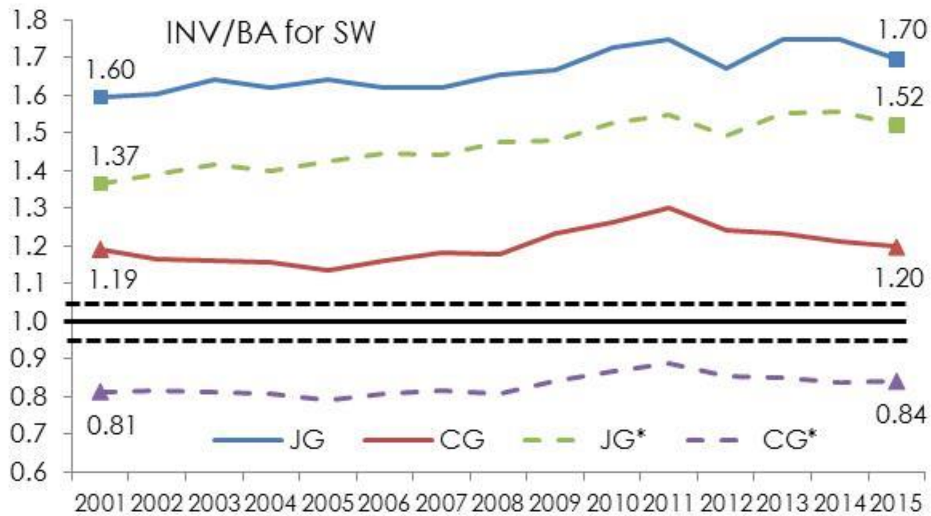
The literature review in the next section will describe the differences in the manpower and personnel management processes that allow BA and INV to move in opposite directions.

Imbalances by designator within the URL

Description

Having shown that the most severe imbalance is JG OOE in the URL, we now focus on designators within the URL. The JG and CG INV/BA ratios for the SW, SUB, and AVN communities are shown in Figure 5, Figure 6, and Figure 7, respectively. For each community, there are two sets of JG and CG ratios—one corresponding to the community's discrete BA and one corresponding to the community's discrete BA plus its share of non-discrete BA. Specifically, unless otherwise noted, non-discrete billets are allocated to each URL community in the following way: 40 percent to AVN and SWO, and 20 percent to SUB.[5] The data show the following.

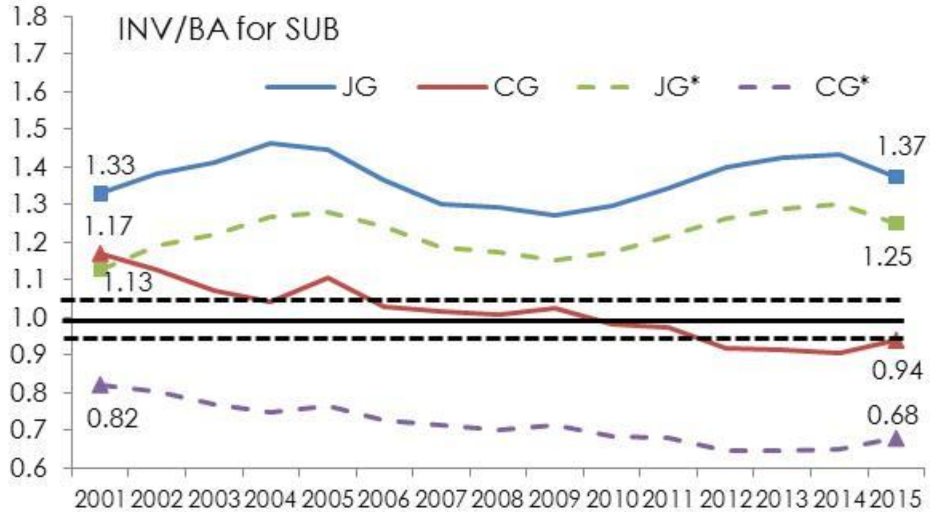
Figure 5. INV/BA ratios for all active-duty surface warfare officers, September 2001 through September 2015[a]



[a] JG and CG indicate ratios for discrete BA, while JG* and CG* indicate ratios for discrete and non-discrete BA.

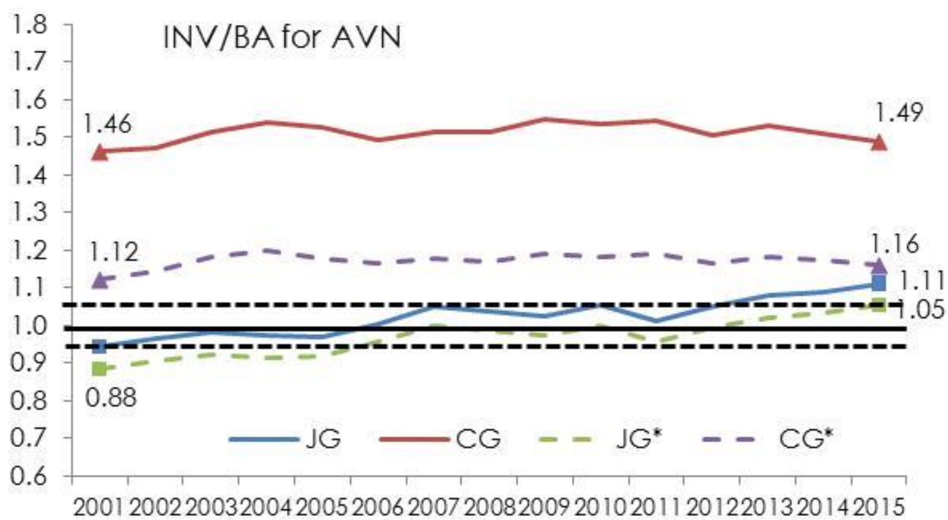
[5] This is the allocation guidance used for community management purposes. Actual allocations vary substantially (see [6]).

Figure 6. INV/BA ratios for all active-duty submarine officers, September 2001 through September 2015[a]



[a] JG and CG indicate ratios for discrete BA, while JG* and CG* indicate ratios for discrete and non-discrete BA.

Figure 7. INV/BA ratios for all active-duty aviators, September 2001 through September 2015[a]



[a] JG and CG indicate ratios for discrete BA, while JG* and CG* indicate ratios for discrete and non-discrete BA.

JG OOE in the URL is mainly due to JG OOE in the SW and SUB communities. For both, JG OOE is far out of the healthy range, and this holds even when the non-discrete billets are included in the billet base. The problem is most pronounced for SW. In contrast, for most of the period, AVN experienced JG OUE; only since 2006 has AVN been overexecuted in the junior grades. Thus, although URL JG OOE is mainly a SW and SUB issue, AVN has contributed to the increase over the period.

In the control grades, OUE is also an SW and SUB issue. In this case, however, the imbalance is more acute for the SUB community. In particular, since 2010, SUB has not had enough CG inventory to fill its discrete CG billets, though its CG INV/BA ratio has remained mostly in the healthy range. SW, in contrast, has consistently had more than enough inventory to fill its discrete billets, and it is only underexecuted in the control grades when its share of non-discrete billets is included in its billet base. AVN, once again, has the opposite pattern: it is overexecuted in the control grades when its share of non-discrete billets is included, as well as when it is not.

Insights from cross-group comparisons

There are two important factors to consider when looking at these figures. The first is the role of non-discrete billets and the second is two within-URL differences in community management practices—different accession planning targets combined with different minimum service requirements (MSRs).

The role of non-discrete billets

The allocation of non-discrete billets to each community is, by definition, flexible. This means, in particular, that SW and SUB CG OUE and AVN CG OOE can be simultaneously mitigated by allocating a larger share of non-discrete billets to AVN and smaller shares to SW and SUB. This has, in fact, been done, as documented in [6]. Thus, the CG INV/BA ratio for the URL overall (shown in Figure 2) may be a better indicator of community health than the community-specific ratios (shown in Figure 5, Figure 6, and Figure 7). This does not, however, help with the SUB community's inventory shortfall relative to its discrete billets.

Differences in MSRs and accession planning targets

The AVN community has a much longer MSR than do the SW and SUB communities—7 to 11 years for AVN compared with 4 years for SW and 5 years for SUB.[6] This

[6] The MSR for pilots is 8 years after completing the undergraduate portion of the initial aviation training pipeline (i.e., when they earn their wings). Since it can take up to 2 years to earn wings, completion of a typical MSR for pilots may occur from 9 to 11 years of commissioned service (YCS). The MSR for naval flight officers (NFOs) is 6 years after winging,

means that, once training attrition has occurred, AVN JG retention is higher and JG INV is, consequently, more predictable.

This difference in MSRs alone is not, however, what makes JG OOE more likely and more persistent in the SW and SUB communities. Rather, it is the difference in MSRs combined with differences in accession planning targets. Specifically, the SW and SUB communities plan accessions to meet their requirements for department head (DH) billets, which officers fill at approximately 8 years of commissioned service (YCS 8). This means that SW and SUB are planning to meet requirements that occur well after most community members have completed their MSRs. And given SW and SUB post-MSR retention, the numbers of SW and SUB accessions needed to fill these requirements typically exceed the O1 and O2 BA, resulting in OOE. In other words, for SW and SUB, O1, O2, and most O3 INV is there to ensure enough senior O3s to fill the DH requirement, rather than to fill the O1, O2, and junior O3 workloads.

In contrast, the AVN community plans to meet its requirement for division officer (DIVO) tours, which occur at approximately YCS 5, several years before most AVN members complete their MSRs. This means that there is less risk associated with the accession plan and that the number of AVN accessions more closely matches O1 BA. These differences can be summarized by comparing the O1 INV/BA ratios across communities: 1.55 for SW, 1.17 for SUB, and 1.04 for AVN.

Summary

The primary imbalance of current concern is JG OOE in the SW and SUB communities because their JG INV/BA ratios have gone increasingly out of the healthy range. The main reason for this is that SW and SUB bring in accessions not to fill junior work requirements, but to fill work requirements for senior O3s. The problem has become worse over time because, while URL JG INV has increased, URL JG BA has decreased.

Although OUE exists for the control grades, it is mainly in the healthy range when the flexibility of non-discrete billet allocation is taken into account. The exception here is the SUB community for which CG INV/discrete BA decreased from 1.13 to 0.94. This means that filling any non-discrete BA with SUB INV will take it out of the healthy range.

More generally, the discussion of why these imbalances exist and change over time highlighted the systemic nature of this management challenge. Two things stood out.

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which may happen anywhere from around 9 to 18 months after commissioning. Thus, the typical NFO MSR occurs around YCS 7 to YCS 9. (See [7] and 10 U.S. Code § 653.)

First, some community management practices can increase the likelihood that imbalances will occur. For the SW and SUB communities, planning accessions to meet post-MSR work requirements contributes to the JG OOE they are experiencing. And, for the URL as a whole, the lateral transfer system drives a wedge between community requirements and accessions. Second, the personnel and manpower management systems allow for independent changes in the supply of and demand for officers. This cause of INV-BA imbalances is the focus of this study, so we explore it in more detail in the next section on past work addressing INV-BA imbalances.

Literature Review

Managing supply-demand imbalances in the officer corps is a persistent, systemic challenge that has been addressed many times in the past. A large body of research describes and assesses the underlying manpower and personnel management processes. Here we draw on all these studies to address three questions:

- What features of the two management processes contribute to supply-demand imbalances?
- What solutions have been proposed?
- How might these solutions be pursued?

Manpower management versus personnel management

The organization that manages both the demand for and supply of Navy officers (as well as enlisted personnel) is called Manpower, Personnel, Training & Education (MPT&E), reflecting the four processes that work together to ensure that the Navy has the right quantity and quality of personnel to achieve its mission. Here, we are interested in two of these processes: manpower management, which determines the demand for Navy officers, and personnel management, which governs the supply of Navy officers.[7] These processes are intended to work together, as parts of one integrated system. In practice, however, they tend to function separately, so they not only can, but indeed are likely to, generate the imbalances described in the previous section. The Navy's primary document for manpower policies and procedures acknowledges this explicitly in the following statement regarding the limitations of funded billets:

[7] Reference [8] describes the overall MPT&E organization and its processes, while [9], [10], and [11] focus on manpower management, and [12], [1], [13], and [14] focus on personnel management.

> Funded billets do not guarantee a precise match of personnel. Statutory, fiscal, and inventory limitations may individually or collectively cause mismatches between funded billets and the actual inventory. In addition, funded billets are regularly updated to incorporate changes resulting from the budgeting and congressional processes and other emergent priorities. [9]

This acknowledgment alludes to some of the systemic factors that can drive a wedge between INV and BA. To provide explanatory detail, we identify six such factors, characterizing each as a fundamental difference between manpower management and personnel management.

Different goals

The first factor is that the goals of manpower management and personnel management are fundamentally different. The Navy's total force manpower management policies and procedures, laid out in [9], state that manpower management in the Navy is "a comprehensive methodical process" for:

- Determining manpower requirements, which constitute an unconstrained estimate of the manpower needed to achieve the desired mission capability and are used to inform budget decisions
- Manpower programming, which prioritizes manpower requirements based on mission requirements, available funding, and personnel executability, and provides the funding to turn requirements into actual authorizations
- Billet authorization, which translates authorizations into a demand signal for the personnel, training, and education processes

Thus, manpower management is mission focused. It both defines and funds the work that must be done (i.e., the jobs that must be filled) by Navy officers to ensure that individual commands can execute their portions of not only the Navy's mission, but also the joint mission.

Personnel management, in contrast, is about recruiting, developing, and retaining officers to fill the required jobs. According to United States House of Representatives (quoted in [15]), the personnel management system, known as DOPMA, that governs all military officers was designed to achieve three primary goals deemed important by the U.S. Congress.[8] Specifically, the system is intended to allow each service to:

- Meet requirements for officers in various grades at ages and levels of experience conducive to effective performance
- Provide career opportunities that would attract and retain the number of officers of high caliber needed
- Provide reasonably consistent career opportunities [relative to the other services]. [14]

Certainly these personnel management goals were adopted to support mission accomplishment, but the rules the DOPMA system imposed, and the management structures that grew from those rules, have meant that successful personnel management exists independent of achieving the mission. The remaining factors relate to these rules and structures.

Different determinants

Officer BA, in total and by paygrade and skill, reflect both the underlying requirements they're intended to support and annual budget constraints. According to [9], "Manpower requirements identify the type and level of strength needed to perform the Navy's work and deliver the OPNAV-approved specified capability." Consistent with the mission focus of manpower management, all manpower requirements determination (MRD) processes start with the approved Navy mission and ignore funding considerations to ensure that requirements reflect what is needed to accomplish the mission regardless of cost.

Funding considerations are introduced via manpower programming and manpower authorization. Specifically, programming decisions determine aggregate authorizations and reflect leadership's assessment of "alternative ways to achieve the objectives established by the President and the Secretary of Defense" based on "balancing near term readiness, sustainability, and force structure requirements with long term modernization needs to ensure warfighting capability today and in the future" [9]. The manpower authorization process, in turn, allocates total

[8] The legal framework for managing military officers was initially passed in 1980 via the Defense Officer Personnel Management Act, or DOPMA. As currently used, however, the name *DOPMA* typically refers to the larger collection of not only laws but also policies and practices that govern active duty officer management. See reference [12].

authorizations to Navy commands based on their individual mission-driven requirements.

Although total officer INV is primarily driven by aggregate manpower authorizations (see the discussion of constraints that immediately follows), the grade structure of officer INV is determined by DOPMA rules that create a personnel pyramid. As described in [12], the officer personnel pyramid is mainly the result of legal guidance on how officer total inventory may be distributed across paygrades. In particular, the grade table provided in section 523 of Title 10 specifies, for any given officer endstrength, the maximum number of Navy officers who may serve in grades O4 through O6. This is why they are called the control grades.

In addition, the pyramids defined by the grade table are supported by the closed nature of the DOPMA system. With few exceptions, new officers enter the system at low grades, and positions in higher grades are filled by internal competitive promotion. At the same time, exit from the system is strictly controlled at the lower grades based on MSRs. This closedness means that the shape of the pyramid, especially the size of the base, is largely driven by post-MSR retention behavior.

Given these differences in underlying determinants, there are only a few things that link the paygrade structure of BA to the paygrade structure of INV. At the most basic level, the hierarchical nature of military organizations suggests that officer work will be arranged according to rank, typically with more junior officers and fewer senior officers. More directly, Navy policy [9] says that requirements and authorizations should be assessed in terms of their potential impacts on community health and personnel executability. Such assessments are, however, done at the review stage of each manpower process; they do not constitute the primary basis for either requirements or authorizations.

More important, the different determinants of BA and INV change continually over time and there is nothing to guarantee that these changes will be in the same or mutually supporting directions. Consider the drivers of change for BA. First are changes in underlying requirements. Requirements change with changes in the number and types of activities (e.g., changes in the force structure or organizational change), as well as with changes in requirements at a given activity, which may occur because of technological innovations that change staffing standards or changes in organizational structures that may redistribute or eliminate functions and tasks. Second, even if requirements don't change, changes in funding levels will change BA via their effect on how much of the requirement is funded.

In contrast, within the DOPMA system, the main drivers of changes in INV are changes in entry-level accessions and in retention behavior due to changes in external factors, such as civilian labor market conditions. Personnel policies (e.g., retention incentives and force shaping) can counter the effects of such changes, but only at the margin.

Different constraints

For each FY, both BA and INV are funded through the application of the congressionally mandated officer endstrength and the associated military personnel, Navy (MPN) budget.

For BA, endstrength is the total number of requirements that can be authorized based on approved budgets. BA cannot exceed endstrength. For the purposes of manpower management, endstrength and MPN dollars are allocated at the activity level, and manpower managers are tasked with translating fiscally unconstrained requirements into authorized billets in a way that will maximize each activity's warfare or support capability within the budget constraint.

For INV, endstrength is the maximum number of personnel that can be on active duty at the end of the FY. For the purposes of personnel management, endstrength is expressed as Officer Programmed Authorizations (OPA). OPA is defined by designator and paygrade, and personnel managers must ensure that INV matches OPA in each category.

Both sets of managers must also meet additional, but different, constraints. Manpower managers must ensure that the "quality" of BA mirrors the quality of requirements, where quality is defined in terms of skill, grade, and experience. Personnel managers, for their part, must meet constraints defined by DOPMA to manage the flow of officers through the rank structure. The constraints that are most difficult to meet while simultaneously meeting the OPA constraints are those related to promotion timing (i.e., flow point) and opportunity.

Different decision-makers

As head of the MPT&E organization, the Deputy Chief of Naval Operations (Manpower, Personnel, Training and Education) (N1) has broad policy authority over both manpower and personnel management.

When it comes to manpower management, however, it is organizations outside MPT&E that have primary decision-making authority over how many and which billets to fund and authorize. Manpower programming is governed by the Deputy Chief of Naval Operations for Integration of Capabilities and Resources (N8) and directed by resource sponsors (RSs).[9] Specifically, RSs choose "the amount of mission

[9] Per reference [9], an RS is an "office responsible for an identifiable aggregation of resources which constitute inputs to warfare and supporting tasks. The span of responsibility includes interrelated programs or parts of programs located in several mission areas." Reference [16]

or workload to fund, while maximizing their value stream within fiscal constraints" [9]. The RS decisions, in turn, are based on input from budget submitting offices (BSOs, also known as claimants), which, in coordination with Type Commanders (TYCOMs), specify which requirements they would like to authorize by skill and paygrade. The "bottom-up" submissions developed by BSOs are reconciled with the "top-down" constraints imposed by RSs to generate a list of authorized billets.[10]

MPT&E does have primary decision-making authority and responsibility for personnel management. It is responsible for managing officer inventories so they meet all the constraints, both in aggregate and for each community. Activities in this arena relate to all aspects of community management: strength planning, accession planning and recruiting, promotion planning and implementation, compensation, and training and education. Key organizations are Military Personnel Plans and Policy (N13) and the Officer Community Management (OCM) Division of the Bureau of Naval Personnel (BUPERS-31).

Different efficiency criteria

For manpower management, efficiency guidance is given at the MRD stage. In [9], broad guidance for all MRD processes is that manpower requirements must reflect the minimum quantity and quality "required for peacetime and wartime to effectively and efficiently accomplish the activity's mission."

There does not appear to be any guidance regarding potential trade-offs between officer quantity and quality, either in terms of costs or productivity. In particular, even when budget constraints are introduced in the programming process, the Navy has generally charged only one programming rate for all officer billets (typically the average MPN for all Navy officers), despite the fact that the costs of filling billets vary significantly by both paygrade and skill.

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identifies the following resource sponsors: DCNO MPT&E (N1), Joint (N1J), Information Dominance (N2/N6), Fleet Readiness and Logistics (N4), Warfare Information (N9I), Expeditionary Warfare (N95), Surface Warfare (N96), Undersea Warfare (N97), Air Warfare (N98), and Secretariat Review Board (BSO 12).

[10] MPT&E organizations do play important roles in manpower management. Specifically, the Navy Manpower Analysis Center (NAVMAC) develops and documents manpower requirements for all Navy fleet activities, while the Office of the Chief of Naval Operations, Total Force Manpower, Training and Education Requirements (N12) approves both the methodologies used in MRD processes and the inputs on which they are based. N12 is also responsible for enforcing manpower management rules designed to maintain an executable billet base, in compliance with fiscal controls and legal constraints.

There has, however, been a move toward ship design and manning and staffing concepts based on the idea that smaller, more experienced crews and workforces will produce the same amount of capability with greater efficiency. (See references [11, 17-18].) In this context, more experienced means more senior.

For personnel management, efficiency concerns focus on how to achieve community-specific personnel pyramids at the lowest cost. Efforts to increase efficiency within the current DOPMA system have focused mainly on the design and implementation of retention and separation incentives. There is also, however, a significant literature arguing that the system is inherently inefficient because it does not allow inventory to change flexibly in response to changes in missions and requirements. (See references [12, 18-19].)

Different degrees of responsiveness to change

Changes in BA are directly under Navy control and can be implemented immediately when funding or other drivers change. INV, in contrast, changes much more slowly and is primarily incentivized rather than done by decree. Here, it is DOPMA rules related to entry into and exit from the closed system that make the difference.

For entry, with only a few exceptions, Navy officers enter at the most junior rank (ensign or O1); there is very little lateral entry.[11] This means that the primary way to increase officer inventories is via larger accession missions, which increases the number of junior officers only. The system can't automatically add officers at higher ranks if authorizations for them increase; they must be grown from within by increasing promotion rates or by incentivizing higher retention among officers already in the system.

For exit, officers must complete their MSRs before leaving. The Navy can, however, separate officers for a variety of performance-related reasons up to YCS 6.[12] The opposite holds after YCS 6. Beyond this point, officers can resign their commissions

[11] Exceptions are officers who get constructive credit for civilian education or experience. The communities that consistently grant substantial constructive credit are the Medical, Dental, Chaplain, and Judge Advocate General's Corps.

[12] According to Navy policy, up to YCS 6, officers are considered "probationary." When probationary officers cannot complete their initial training requirements, fail to qualify in the warfare area to which they are originally assigned, or become unviable in their initial communities for specific reasons, they can be reviewed by a Probationary Officer Continuation and Redesignation (POCR) board to determine whether they should continue in the Navy in another community or leave the Navy and finish their contract obligation in the Reserves. (See the POCR Board Business Rules available on the Bureau of Naval Personnel website: http://www.public.navy.mil/bupers-npc/officer/communitymanagers/Pages/default.aspx.)

and leave the Navy at the end of any tour, but the Navy only has two main ways to separate officers who don't choose to leave. The first is to induce them to resign by offering separation incentives, and the second is by not selecting them for promotion on two consecutive tries.

Combined, these features of the system mean that it takes a long time for inventories to change, and the effects of any change are felt for a long time as unusually large or small cohorts move through the system. Reference [1] summed it up as follows: "Authorizations change instantaneously on paper; the inventory of people changes slowly over long periods."

Previously proposed solutions

Following from each of the main causes of supply-demand imbalances, researchers have also identified associated potential solutions. Here, we summarize four categories of solutions.

Make personnel management more flexible

Given that the separateness of the manpower and personnel management processes is, to a large degree, the result of the rules and structures imposed by the DOPMA system, a natural solution is to make personnel management more flexible by relaxing some of the DOPMA constraints. Specifically, a 2003 report by Thie et al. made the following recommendation:

> Manage communities individually, flexibly employing such tools as longer careers and broader promotion zones as needed to align inventory and authorizations. This would require the Navy to seek legislative relief from DOPMA. [1]

In the absence of DOPMA reform, [12] recommended using as much of the flexibility in the current system as allowed, even if it means setting aside Navy tradition and cultural practices.

Use information about community health as an input into manpower management

Recognizing that manpower management is done mainly by organizations outside of MPT&E, in 2009, the OCMs in BUPERS-31 recommended that community health assessments be formally incorporated into the programming process. In particular, the goal was to provide information that would help to prioritize the funding of billets that could actually be filled, and to ensure that changes to the billet base to optimize local missions would not result in the degradation of the overall health of the officer force.

To support this recommendation, BUPERS-31 developed "a common structure and language of vital signs to evaluate proposed billet changes in the context of officer community health" [2]. Specifically, it developed a community health matrix designed to provide RSs, BSOs, and TYCOMs with a clear understanding of the relative risks of specific billet changes to several community health areas, including not only the INV-BA balance, but also career progression, promotion opportunity, and promotion flow point.

Use "granular" programming rates to make manpower management more fiscally informed

Other researchers have focused on the lack of well-developed efficiency criteria for manpower management, and have recommended making manpower management more fiscally informed to induce the organizations that buy billets to make the same trade-offs between cheaper junior officers and more expensive senior officers that the personnel system forces the Navy to make.[13]

MRD processes are based on industrial engineering models that use one activity-specific set of inputs (e.g., mission-related workloads, staffing standards, and availability factors) to generate one activity-specific set of requirements. Notably, the model inputs do not include the costs of different types of manpower and, therefore, do not allow for efficiency-enhancing trade-offs to be made if relative costs change.

Costs are considered in the manpower programming and authorization processes, but even here the exercise mainly boils down to imposing top-level budget constraints, rather than making cost-saving or productivity-enhancing trade-offs among junior and senior officers (or officers with different skill sets). Two features of the system reflect this priority. First, the traditional approach in both processes has been to charge only one programming rate for all officer billets, typically the average MPN amount for all Navy officers. Second, the policy stipulating that authorizations must equal requirements in terms of quality strictly limits manpower managers' ability to make cost-based adjustments to the structure of BA.

Thus, the solution that has been proposed is to make programming rates more granular by manpower type, especially by paygrade. Researchers who recommend

[13] See [10], [11], and [20].

this solution also note, however, that two complementary practices are required: manpower managers must face binding budget constraints and have the flexibility to make trade-offs across paygrades within the limits defined by the grade table.

Just buy extra billets

Finally, although not specifically proposed by research, another approach to solving INV-BA imbalances, specifically JG OOE, is to simply buy the billets to reduce or eliminate the discrepancy. In fact, this appears to be the solution adopted by the SW community. According to [21], January 2015 TFMMS data indicated that, from 2016 to 2020, O1, O2, and O3 SW BA were planned to increase by about 5, 24, and 8 percent, respectively.

Pursuing proposed solutions

To develop the approach for this research, we considered each set of proposed solutions.

We started by eliminating the first solution—making the personnel system more flexible—because it is beyond the Navy's power to do alone. We do note, however, that recent changes to the military retirement system may make DOPMA reform more likely and more beneficial.[14] We also reiterate the recommendation from [12] that, until DOPMA reform occurs, the Navy should work harder to use more of the flexibility the system does offer.

Next, we eliminated the fourth solution—just buying billets to eliminate OOE. This approach is unsatisfactory for a variety of reasons. First, while it does solve the simple accounting problem associated with OOE, it does not solve the more important problem of having no underlying work for junior officers to do and, thus it does not increase efficiency or save costs. Second, it may create other distortions in the system by lowering the quality of BA as a demand signal. Finally, it is not a general solution to INV-BA imbalances: it only addresses OOE; it cannot be applied to OUE.

We also eliminated the second solution. We saw this solution as simply a tweak to the existing system, which already calls for manpower managers to consider

[14] We refer to the new "blended retirement system" that was adopted based on recommendations of the Military Compensation and Retirement Modernization Commission. See [12] for a discussion of the relationship between DOPMA and the retirement system.

community health and executability in the programming and authorization processes, and gives personnel managers the responsibility to review proposed changes to the billet structure. In making their recommendation, the OCMs implicitly assumed that manpower managers create unexecutable billet structures because they lack the information to do otherwise. While this may be true in part, it is more likely that they are responding to other pressures, such as increasing joint requirements (which are more senior) and external pressures to decrease costs by adopting labor-saving technology that ends up being biased toward more experience.[15] Thus, while the information included in the community health matrix is likely to be valuable, it is unlikely to change behavior on its own.

This left the proposal to make manpower management more fiscally informed by introducing granular programming rates. This solution is the most appealing from an economic efficiency point of view. It is also the approach that is most likely to bridge the identified disconnects between manpower and personnel management because it should be possible to design granular programming rates that align some of the competing pressures related to the different priorities of the different decision-makers.

In response to similar arguments, as well as tightening budget constraints and the external pressures that have been noted, the Navy implemented granular programming from FY06 to FY13.[16] It was dropped because of technical and institutional implementation difficulties before it could have observable effects. Specifically, software used for programming exercises did not allow for entering paygrade-specific rates. Given current efforts to update the information technology systems used for manpower and personnel management, it is likely that these technical problems will eventually be resolved.

Based on these assessments of each solution, we opted to revisit granular programming. Specifically, we follow the recommendation in [20] to perform a "paper exercise" to explore whether the advantages of a granular programming approach could be realized if granular rates can be effectively set and the right complementary policies and practices are adopted to overcome institutional barriers.

[15] See references [1, 11-12, 17-18].

[16] These fiscal years correspond to programming BA for 2008 to 201.

Summary

Although the Navy's manpower and personnel management processes are intended to function as two parts of one integrated system, they have at least six fundamental differences that make keeping INV-BA imbalances in the healthy range a constant challenge:

- They have different goals
- They are based on different determinants
- They face different constraints
- They are managed by different decision makers
- They are evaluated according to different efficiency criteria
- They respond differently to external change.

Given the systemic and persistent nature of this problem, researchers have suggested a variety of solutions over the years. These solutions fall into three categories: (1) make personnel management more flexible, (2) use information about community health as an input in manpower management, and (3) make manpower management more fiscally informed. After an unsuccessful attempt to implement the latter solution via granular programming, the Navy has settled on a fourth solution: buying extra billets to eliminate OOE.

Of these solutions, we chose to pursue fiscally informed manpower management. Specifically, we chose to revisit granular programming because it has the most potential to align the manpower and personnel management processes. Before moving to the paper exercise and its results, the next section elaborates on the potential benefits of granular programming and introduces our conceptual approach to setting granular rates.

Granular Programming To Minimize Supply-Demand Imbalances

The review of previous work on supply-demand imbalances revealed that a fundamental cause of imbalances is that supply (personnel) and demand (manpower) are managed with two linked, but essentially separate, systems. In particular, the groups that manage supply and the groups that determine demand have inherently different interests, including different goals and different constraints. Thus, one approach to minimizing supply-demand imbalances is to develop a mechanism that aligns these interests as efficiently as possible.

In this section, we discuss why granular programming could be that mechanism by introducing market incentives to guide the behavior of decentralized decision makers. Then we propose an approach to setting granular programming rates using estimated substitution patterns rather than costs.

Granular programming as a decentralized, market-based initiative

The costs and benefits of decentralized (instead of centralized) decision-making have been widely discussed in the civilian literature (see [22-28]). To explain why granular programming could work to align the interests of personnel and manpower management organizations, we briefly summarize some of the relevant discussion on decentralization.

The primary benefit of decentralization is access to superior information. Middle- and low-level managers often have better information than high-level executives about the parts of the organization they oversee. This information is valuable if it can help executives identify ways to increase productivity, lower costs, or engage in other innovations.[17] Understanding this argument, Navy leadership has expressed

[17] Additional potential benefits of decentralization include higher employee motivation [22].

interest in using decentralized decision-making to increase the efficiency of its manpower and personnel systems.[18]

Incorporating information from lower level managers into decision-making can also, however, have costs; the information given to senior managers from junior ones (either via suggestions or via direct decisions) may be influenced by two factors:

- The incentives to lower level managers may encourage them to make decisions that benefit them or their part of the organization at the cost of the organization as a whole[19]
- Lower level managers are likely to have worse (potentially substantially worse) information about which actions benefit the organization as a whole.

In both cases, the decisions made by lower level managers may benefit either the manager or the manager's part of the organization to the detriment of the organization as a whole.

Both cases are also relevant to the problem of supply-demand imbalances for Navy officers. In the first case, we can imagine a situation in which a manpower claimant is evaluated exclusively on the performance of the part of the Navy under his or her authority. Thus, the claimant's incentive is to request a paygrade mix that maximizes his or her organization's mission output, regardless of the potential impact on community health. In the second case, the claimant may not have enough information to be able to assess the impact of his or her request on community health.[20] A related issue is that the impact of any one group's request may not be large enough to seem like a problem. It is only when several such requests are aggregated to the Navy-wide level that the problem becomes visible.

Given that corporate decision-makers tend to be fairly knowledgeable, much of the focus in the civilian literature has been on addressing the first problem. Unfortunately, the most common solution is to link middle managers' pay to overall firm performance,[21] which is impractical for the Navy.

Another solution is a market-based policy. Here, prices and/or competition minimize the extent to which decentralized managers make decisions that benefit their

[18] See [29].

[19] This is known as the "principal-agent problem."

[20] This is the assumption underlying the "more information" solution discussed in the previous section.

[21] See especially the literature on executive compensation, a summary of which can be found in [30].

organizations to the detriment of the organization at large. The key to market-based policies is that prices, combined with binding budget constraints, can be set to induce decentralized managers to make locally optimal decisions that, when aggregated, also generate organizationally optimal results.

This is precisely the type of solution needed to align the interests of manpower and personnel organizations, without giving up too much of the information contained in manpower claimants' requests.

Calculating rates: costs versus substitution-based pricing

For granular programming to solve supply-demand imbalances, it is necessary to have paygrade-specific rates that induce manpower claimants to demand officer billets with structures that match the inventory structures the personnel system produces. Thus, the next question is how these prices should be determined. First, we consider two types of cost-based approaches:

- Average cost, which reflects how much the Navy spends on officers at each paygrade
- Marginal cost, which captures the increase in total costs associated with filling one additional billet

Then, we propose an alternative approach that takes into account current INV-BA imbalances and estimated substitution patterns across paygrades. We call this approach substitution-based pricing.

Cost-based rates

Average costs

The Navy's practice has been to set programming rates based on some version of average costs. The traditional (and current) programming rate is based on average MPN cost: the total officer MPN budget divided by officer endstrength. This approach ensures that the Navy can cover the officer MPN budget. When the Navy tried granular programming, the paygrade-specific rates were based on average MPN costs by paygrade. The benefits of this approach to granular programming are that it is conceptually straightforward, the rates are easy to calculate, and it still makes it easy to stay within the Navy's budget constraint.

MPN costs don't, however, capture all the costs of personnel. First, they don't include costs associated with medical and retirement benefits, which are substantial. Second, they don't include the costs of training and development. These are also a large budget item in the Navy's closed personnel system, which has to develop senior officers not only by accessing and retaining junior officers, but also by providing formal training and education as well as on-the-job training. Reference [20] also showed, however, that incorporating these costs into paygrade-specific rates is not straightforward because it's difficult to figure out how to apportion one-time development costs across paygrades.

Marginal costs

More generally, other research indicates that prices based on average costs don't drive economically efficient resource trade-offs. Instead, the efficient price for one division of an organization (e.g., the Navy personnel system) to charge another division (e.g., the Navy manpower system) for the acquisition of an internally produced good is marginal cost, or the change in cost to the supplying division of producing that good relative to the cost of not producing it.[22]

For many goods (e.g., airplane engines), the marginal cost of an extra unit is easy to calculate because it is very close to the cost of all of the inputs required to produce it. This is not true, however, for officer personnel in the Navy's closed system. Not only must marginal cost calculations take into account all the non-MPN costs that should go into average cost calculations, they must also consider the different ways to achieve the extra inventory. For example, there are numerous policies to affect retention, each of which has different costs that can vary over time and/or across paygrades. Thus, calculating marginal costs requires running scenarios for each policy option and finding the lowest cost approach.

Ultimately, a 1996 CNA research memorandum concluded that using marginal costs to calculate programming rates in the Navy system is infeasible:

> The only accurate way to calculate the [marginal] cost is to build a comprehensive simulation model that allows one to calculate the cost of the entire personnel system with and without the one additional billet. We probably don't understand the dynamics of the personnel system well enough to build this model. Even if we could, it is probably not practical to use such a model in real-time. [20]

[22] This is known as transfer pricing and has been widely studied. See reference [31].

Cost-based approaches and INV-BA imbalances

Regardless of which cost-based approach is used, if rates are based only on explicit budget outlays, they are not guaranteed to solve INV-BA imbalances. To see this, consider the effects of imbalances on marginal cost calculations associated with adding one new billet in a given paygrade.

If INV is greater than BA at the proposed billet's paygrade, the short-term marginal cost of the billet is zero because there is at least one excess officer who needs to be employed. If INV is less than or equal to BA at the billet's paygrade, the marginal cost of the billet is greater than zero because at least one additional officer must be introduced into the system. How to calculate the marginal cost in this case depends on the paygrade of the billet.

If the proposed billet is a very junior (i.e., an O1 or O2) billet, the additional officer needed to fill it can probably be acquired by bringing in one more officer accession. The extra cost is the cost of accessing, training, and paying that junior officer.

If the proposed new billet is more senior, the additional officer may be acquired by increasing retention (in the short run) or by increasing accessions (in the longer run). In either case, it is necessary to consider the effect on existing imbalances at more junior grades. For example, consider the current cases of JG OOE and CG OUE in the SW and SUB communities. In these cases, increasing JG INV to fill one more CG billet will exacerbate the existing JG OOE. Rates that are based only on personnel expenditures would not capture the costs of increasing this imbalance and are, therefore, not likely to resolve INV-BA imbalances.[23]

Substitution-based rates

Given these issues with cost-based rates, we propose a third option: substitution-based rates. Following this approach, instead of setting prices equal to marginal costs to achieve a billet structure that is efficient from a strict cost perspective,

[23] The discussion here is limited to programming rates designed to induce trade-offs among personnel of different paygrades. We note, however, that these issues are also relevant to designing programming rates to induce trade-offs between personnel and other inputs. For example, consider the potential effects of implementing labor-saving technology that reduces the need for lower level workers. While this clearly has the potential to save money for private-sector firms, its ability to save money for the military depends on whether the lower level workers displaced by machinery but required to support more senior-level positions can be used elsewhere in the organization. If not, the implementation of labor-saving technology may not result in cost savings.

prices are set to equate INV and BA based on the rates at which manpower claimants actually trade off junior and senior billets to achieve their missions.

The details of the substitution-based approach are described in the next section. Here we note two important benefits. First, because it is based on observed substitution patterns, it utilizes the revealed preferences of decentralized decision-makers' past choices in the calculation process. Second, it produces a type of efficiency that is appropriate for the closed personnel system: it ensures that all officers are employed and that they go to the commands where they are most highly valued.

Summary

As described in the previous section, the Navy's current manpower and personnel processes are decentralized across multiple types of decision-makers. As described in this section, economic theory identifies costs and benefits associated with this type of decentralization. On the benefits side, decentralized decision-makers often have better information about how work can be done most efficiently in their parts of the organization. On the cost side, what is locally best may not be best for the organization as a whole. When these costs arise, pricing solutions can be used to align the interests of decentralized decision-makers across an organization. Thus, in the Navy context, granular programming is a theoretically sound way to align the competing priorities of manpower and personnel.

There are, however, multiple ways to set granular programming rates. Here we showed that cost-based rates—rates based on either average or marginal personnel costs—are either infeasibly difficult to calculate or unlikely to resolve INV-BA imbalances, or both. Thus, we proposed using what we call a substitution-based approach that is explicitly designed for the purpose at hand.

Granular Programming: A Substitution-Based Approach To Setting Rates

In this section, we use a paper exercise to see if granular programming rates developed using substitution-based pricing could work to resolve INV-BA imbalances and to see what the market-clearing prices might look like—the flat rate that is currently in use, the granular programming rates that were used and abandoned, or something quite different. Specifically, we design a theoretical game to see if Navy can set prices that induce the BSOs to make officer billet requests that, in aggregate, map to existing officer inventories. This section first describes the game-theoretic framework in detail, highlighting the assumptions required to make the game work. Then it shows the results of the game, highlighting how the substitution-based rates differ from the cost-based rates that were actually used and identifying complementary policies that need to be in place for substitution-based granular programming rates to be effective.

The game-theoretic framework

The game has two sets of players—leaders and followers—and each set of players has (1) an objective, (2) a set of actions, and (3) constraints on the range of possible actions. The game is then designed to allow the leaders to achieve their objectives by exploiting the incentives of the followers.[24]

In the paper exercise, the leader's goal (and, thus, the overall goal of the game) is to generate a set of paygrade-specific billet prices to minimize INV-BA imbalances. The leader set has only one member: the Deputy Chief of Naval Operations (Manpower, Personnel, Training and Education) (CNO (N1)). As the leader, N1 acts as a centralized authority who runs the game and sets prices to achieve the goal.

[24] This is known as a Stackelberg game.

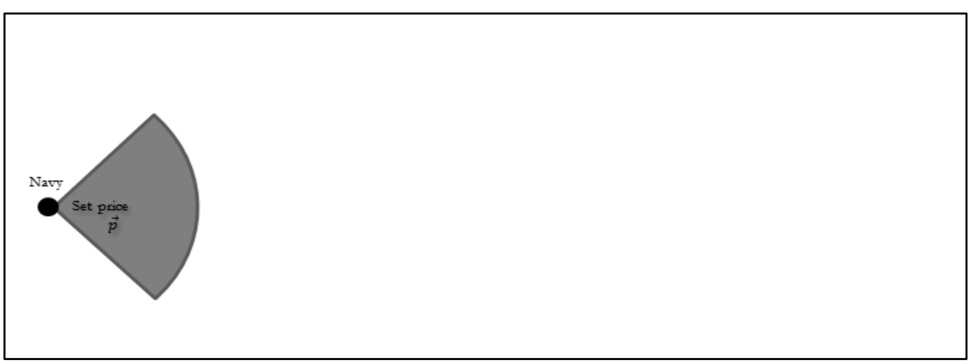
The second set of players has multiple members, each of which uses the paygrade-specific prices set by the central authority as inputs to its own constrained optimization problem. These players are Navy BSOs, which are seeking to buy officer billets in paygrade combinations that will maximize their production of mission output subject to budget constraints. Thus, the game can be summarized as follows:

	Player 1 N1	Player 2 Navy BSOs
Objective	Make BA match INV as closely as possible	Maximize mission output
Actions	Set price for each officer billet paygrade	Request billets of each officer billet paygrade
Constraints on actions	n/a	Total cost must not exceed budget

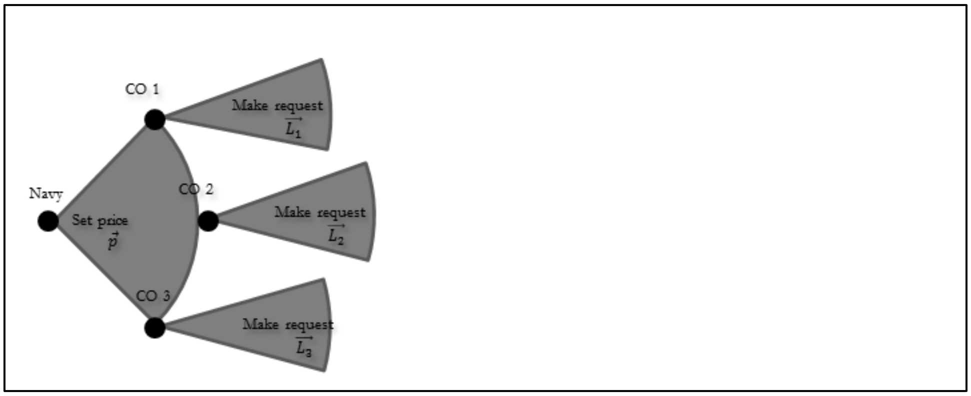
Fundamentally, this is a bi-level optimization problem that can be solved for the prices that will equate BA to INV at each paygrade. The principal challenge in solving this problem, and what makes it a complicated process, is that N1 must "charge" all BSOs the same price for a billet of a given paygrade even though the BSOs all have different missions and mission "production" processes, as well as different budget constraints. The details of solving this equation for the imbalance-eliminating prices are described in the appendix. Here, we provide an intuitive description, focusing on the structure of the game and the underlying assumptions and inputs that are required to solve the mathematical problem.

The structure of the game

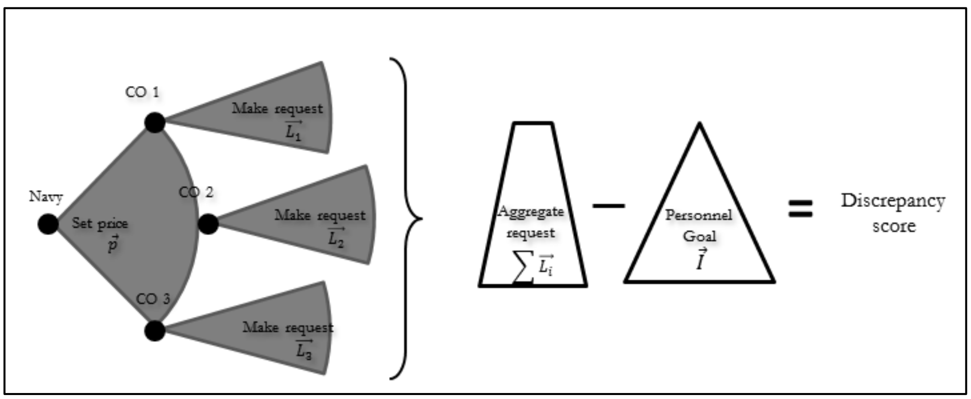
Let us identify officer paygrades by r = O1,..,O6 and the various BSOs by c = 1,..,C. The game begins with N1 offering paygrade-specific prices, or rates, for officer billets, p_r, which can be summarized as $\vec{p}$.



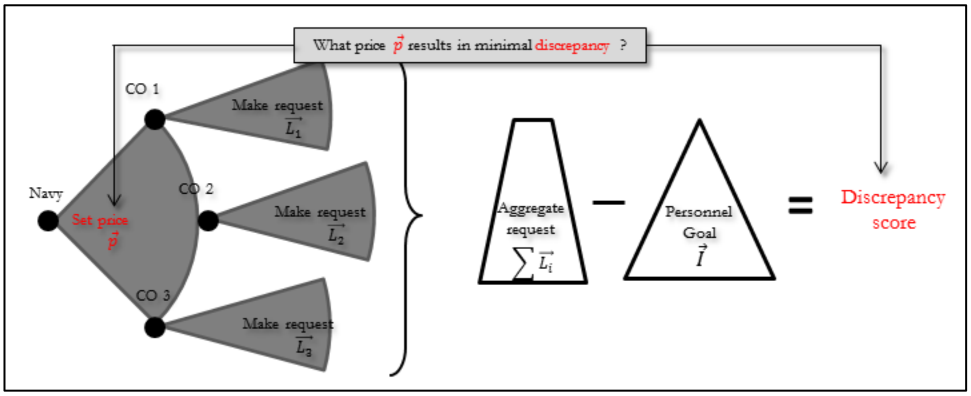
Next, each BSO responds to the price offering, $\vec{p}$, by making paygrade-specific billet requests, denoted by, L_{cr}, and summarized by, $\overrightarrow{L_c}$. Each BSO generates these requests by maximizing the mission output from its officer billets based on a specific production process and subject to a budget constraint.



After each BSO has made its best response, $\overrightarrow{L_c}$, all the requests are summed to generate Navy-wide billet requests, $\sum\overrightarrow{L_c}$. The aggregate requests are then compared against the target personnel inventory, $\vec{I}$, to produce a discrepancy score that captures INV-BA imbalances at each paygrade.



It is the discrepancy score that defines the Navy's overall problem: find the prices, $\vec{p}$, that minimize the discrepancy score. Solving the mathematical problem is equivalent to playing the game over and over again until the offered price achieves the goal.



Underlying assumptions

The game's structure is based on underlying assumptions about who should be playing the game, how the players behave, and what determines the production relationship between mission output and the paygrade mix of officer billets.

Players

The players in the game represent the key players in the relevant manpower and personnel management processes.

As the head of the MPT&E organization, N1 has policy-making authority for both manpower and personnel management. Thus, although N1 is no longer the single resource sponsor for manpower, it is still the most likely office to act as a central price-setting authority.

BSOs' role in the system is to develop billet authorizations at individual activities. Starting with activity-level billet requirements, BSOs submit requests to turn requirements into authorizations while remaining within budget constraints. Typically, budget constraints are binding so that not all requirements can be authorized. Although other organizations also have important manpower management roles (e.g., NAVMAC and the RSs), we chose BSOs as the players in our game because of their primary role in deciding which requirements to authorize and to maintain the decentralized feature of the game.

We do, however, limit our set of players to Navy-controlled BSOs, and we treat BA for BSOs controlled by other DOD organizations as fixed to mimic the burdens placed on the system by these "outside" requirements. See the appendix for a list of Navy- and DOD-controlled BSOs.

Behavior and goals

In addition to its policy-setting role, N1 also has responsibility to assess billet authorization requests in terms of their effects on the health and executability of Navy communities.[25] Thus, the game assumes that N1's goal is to eliminate the INV-BA imbalances that threaten both.

BSOs, in contrast, are seeking to maximize mission output while remaining within budget constraints. Within the context of the game, this entails making trade-offs between more and less experienced officers based on the relative prices and the relative mission contributions of billets in each paygrade. It is these trade-offs that the estimated substitution patterns are intended to capture.

Range of action

In addition to limiting the players in the game to Navy-controlled BSOs, we also limit the categories of billets over which they make their optimization decisions to "fleet" billets both at sea and on shore. We do not include student billets or billets for transients, patients, prisoners, and holdees (TPPHs) in the optimization problem. Based on these limits, we create two categories of billets: discretionary and non-discretionary. The former are included in the optimization problem, and the latter are not.

Mission production processes

Given the assumption that BSOs are trying to maximize mission output based on the paygrade mix of officer billets, it is necessary to specify a mathematical relationship between billets at each paygrade and the mission output that is produced. Following basic microeconomic theory, we specify this relationship according to the "production function" defined in equation 1.[26]

$$Mission\ output = \prod_{r=1}^{R} L_{cr}^{\alpha_{cr}} \tag{1}$$

[25] See references [31] and [9], which are, respectively, versions K and L of the OPNAV Instruction that specifies the Navy's Total Force Manpower Policies and Procedures. Note that the language changed slightly from version K [31] to version L [9]. Version K states: "CNO (N1) must *adjudicate* authorization requests accounting for the health and executability of Navy communities." Version L says that "(CNO (N1)) will *assess* military manpower authorization requests to account for the health and executability of Navy military communities."

[26] This is known as a Cobb-Douglas production function.

The coefficients on each billet input (α_{cr}) define the responsiveness of mission output to a change in the number of billets at each experience/grade level. These "productivity coefficients" are assumed to be constants that are determined by technology and other factors that affect how officer work is used to accomplish the mission. They are also assumed to be positive fractions (i.e., they take on values between 0 and 1) that sum to 1. This means that more of any billet increases mission performance, but at a decreasing rate, and that a BSO seeking to maximize performance subject to its budget constraint will substitute relatively cheaper billets for more expensive ones as the relative prices of billets at each paygrade change. Implicit in this substitution assumption is the notion that the cheaper billets being bought to replace more expensive ones embody productive work; they are not just placeholders for excess officers.

This production function was chosen primarily because it has properties that are consistent with two notable facts about actual billet authorizations: even when the prices of all officer billets are equal, BSOs request billets across a range of paygrades and the paygrade mix does change over time. This means that officers of different experience levels are neither perfect substitutes (such that BSOs would typically choose all of one type)[27] nor perfect complements (such that BSOs would always use officers in the same experience combinations). A second desirable property of this functional form is that it typically produces a unique solution to the constrained optimization problem. Thus, although it is a stylized representation of the potential relationship between officer experience and mission output, it is likely to generate a reasonably realistic outcome from the game.

To play the game, we further assume that each BSO has a separate production function for each of three main designator groups: the URL, the RL, and the non-medical Staff Corps.[28] Although the communities within these groups have distinct skills, the idea here is to account for the different personnel management models that create different INV-BA imbalances, as well as the fact that BSOs are, to some extent, aligned with designator-specific functions.

[27] To see this, note that, because the relationship between performance and officer billets is based on multiplication (rather than addition), it means that at least one billet in each paygrade is necessary for mission performance to be greater than zero.

[28] We exclude the Medical, Dental, Nurse, and Medical Service Corps because requirements for these communities are managed differently. In addition, the Medical and Dental Corps are not subject to the constraints of the grade table.

Inputs

Three inputs are needed to solve the mathematical problem the game creates. These are BSO-specific: (1) productivity coefficients for each paygrade and each skill type, (2) target inventories, and (3) budget constraints. The appendix provides BSO-level data for all the inputs, as well as detailed descriptions of how each input was defined and calculated. Here we provide basic summaries.

Estimated productivity coefficients

The game's optimization problem cannot be solved without actual values for the productivity coefficients in the BSOs' mission production functions. We do not have (there does not exist) a robust set of different granular programming rates and resulting billet authorizations, so we cannot estimate these productivity coefficients empirically.[29] Instead, we use a set of prices and actual BA under one year of granular programming to calculate what the productivity coefficients must have been to have maximized the mission performance of each BSO under that set of prices. Thus, we are effectively assuming that the BA for this year reflect the budget-constrained decisions that were based on the given granular rates and, at least to some extent, reflect how BSOs qualitized their billet authorizations.

At the suggestion of personnel from the Navy's Total Force Resource Management Division (OPNAV (N10)), we used FY10 because it is considered to be a relatively "clean" year. It was in the middle of both the granular programming and single manpower resource sponsor regimes, and the budget and endstrength constraints were relatively less binding than in other recent years.

To illustrate the range of values placed on different levels of experience, Table 4 shows the productivity coefficients for one BSO for each of the three designator groups. The high O6 URL coefficient for BSO 24 indicates that activities in that BSO place relatively high value on more-senior URL work.[30] For BSO 11, the relatively high O4 and O5 RL coefficients indicate that the bulk of the RL work in those activities requires less seniority. Finally, for BSO 25, the relatively high O3 and O4 non-medical Staff Corps coefficients indicate that much of the Staff Corps work in these activities is more junior.

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[29] If there were sufficient data to allow direct estimation of substitution patterns, we would not have to impose the structure of the Cobb-Douglas production function.

[30] The URL O1 productivity coefficient of 0.00 for BSO 24 reflects the fact that BSO 24 had no O1 BA in FY10.

Table 4. Examples of productivity coefficients: one BSO for each designator group

BSO	Designator group	Productivity coefficients for each paygrade					
		O1	O2	O3	O4	O5	O6
24: COMNAVSEASYSCOM	URL	0.00	0.01	0.14	0.15	0.27	0.43
11: OPNAV	RL	0.01	0.05	0.16	0.30	0.29	0.19
25: COMNAVFACENGCOM	Non-medical Staff Corps	0.07	0.11	0.25	0.28	0.18	0.11

Budget constraints

The budget constraints for each BSO were created by simply multiplying the actual BA for each paygrade by the actual paygrade-specific granular rates. This was intended to act as a rough estimate of the actual MPN budgets that are specified at the BSO level during the manpower authorization process.

FY10 granular programming rates

To calculate the productivity coefficients and the budget constraints, we used POM-10 strength-only rates for FY10 provided by N10 staff. They are shown in Table 5.

Table 5. FY10 granular programming rates by paygrade

	O1	O2	O3	O4	O5	O6
FY10 rates	$69,957	$90,569	$112,754	$135,224	$156,983	$187,200

Target inventory

The target inventories used in the game are the actual FY10 inventories for each designator group less the inventory required to fill designator-specific non-discretionary billets (i.e., inventory that we are treating as already obligated to DOD-controlled BSOs and student billets, and that are expected to be found in TPPH status). FY10 data were used to be consistent with the endstrength constraint that accompanied the budget constraint and to capture the actual imbalance between total inventory and total authorizations.

Results

Solutions to the optimization problem

BSO-specific results are provided in the appendix. Table 6 shows results aggregated by designator group, and for each group the table shows the following:

- *Actual FY10 INV.* This is the total INV on which the target inventory is based.
- *Initial conditions: The FY10 granular programming rates and the FY10 BA.* In the game's framework, the FY10 BA represent the BSOs' billet requests given the FY10 granular programming rates.
- *Optimization results: Calculated granular programming rates and calculated BA* The calculated granular programming rates are the rates that minimize the INV-BA discrepancies in the game, and the calculated BA are the billet requests associated with the calculated rates.

Discussion of these results follows.

Table 6. Initial conditions and optimization results by paygrade for the URL, RL, and non-medical Staff Corps

	Paygrade						
	O1	**O2**	**O3**	**O4**	**O5**	**O6**	**Total**
URL							
URL INV	4,609	3,906	7,936	4,188	3,117	1,448	25,204
FY10 rates[a]	$69,957	$90,569	$112,754	$135,224	$156,983	$187,200	M$2.052
FY10 URL BA	3,119	3,923	7,192	4,470	3,111	1,397	23,212
Calculated rates[a]	$26,271	$91,089	$100,437	$147,204	$156,576	$178,847	M$2.050
Calculated URL BA	4,609	3,902	7,931	4,181	3,116	1,445	25,184
RL							
RL INV	415	497	1,570	1,640	1,194	559	5,875
FY10 rates[a]	$69,957	$90,569	$112,754	$135,224	$156,983	$187,200	M$587
FY10 RL BA	394	472	1,804	1,811	1,247	522	6,250
Calculated rates[a]	$65,611	$84,923	$141,309	$155,651	$166,207	$171,241	M$585
Calculated RL BA	415	497	1,564	1,636	1,194	556	5,862
Non-medical Staff Corps							
Staff INV	438	608	1,713	1,202	829	410	5,200
FY10 rates[a]	$69,957	$90,569	$112,754	$135,224	$156,983	$187,200	M$533
FY10 Staff BA	467	454	1,802	1,254	863	407	5,247
Calculated rates[a]	$75,977	$65,256	$120,005	$142,697	$164,985	$185,503	M$530
Calculated Staff BA	436	605	1,706	1,198	819	409	5,173

[a] The values in the Total column for this row are total budgets in millions of dollars.

Discussion

INV-BA imbalances by designator group

The data in Table 7 compare the actual INV-BA discrepancies for FY10 with the minimized discrepancies that result from the game. The data show that, for all three designator groups, when using the calculated granular programming rates, the minimized discrepancies are near zero at every paygrade. Consequently, the imbalances at the designator-group level have been nearly eliminated. Thus, there are prices that "work" within the stylized framework of the game.

Table 7. Actual INV-BA discrepancies vs. minimized discrepancies for the URL, RL, and non-medical Staff Corps[a]

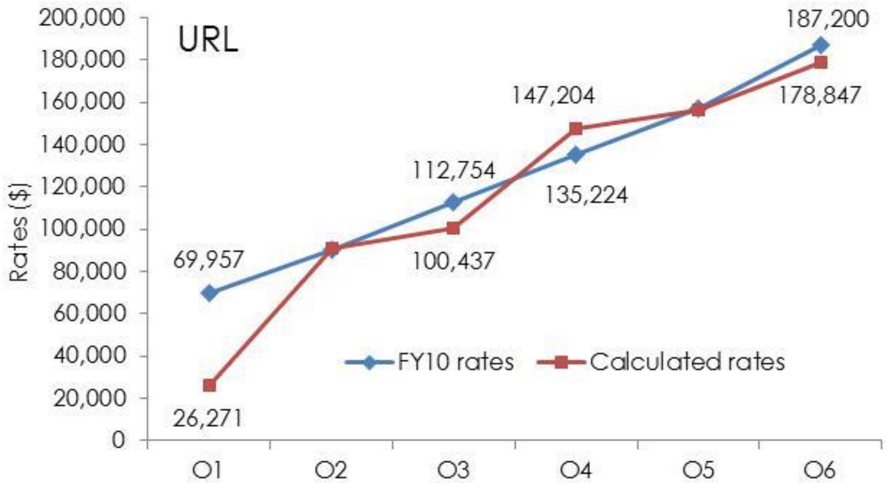
Discrepancy	Paygrade O1	O2	O3	O4	O5	O6	Total
URL							
Actual	1,490	-17	744	-282	6	51	1,992
Minimized	0	4	5	7	1	3	20
RL							
Actual	21	25	-234	-171	-53	37	-375
Minimized	0	0	6	4	0	3	13
Staff Corps							
Actual	-29	154	-89	-52	-34	3	-47
Minimized	2	3	7	4	10	1	27

[a.] For each designator group, the actual discrepancies = actual FY10 INV – actual FY10 BA, and the minimized discrepancies = actual FY10 INV – the calculated BA.

FY10 rates versus calculated rates

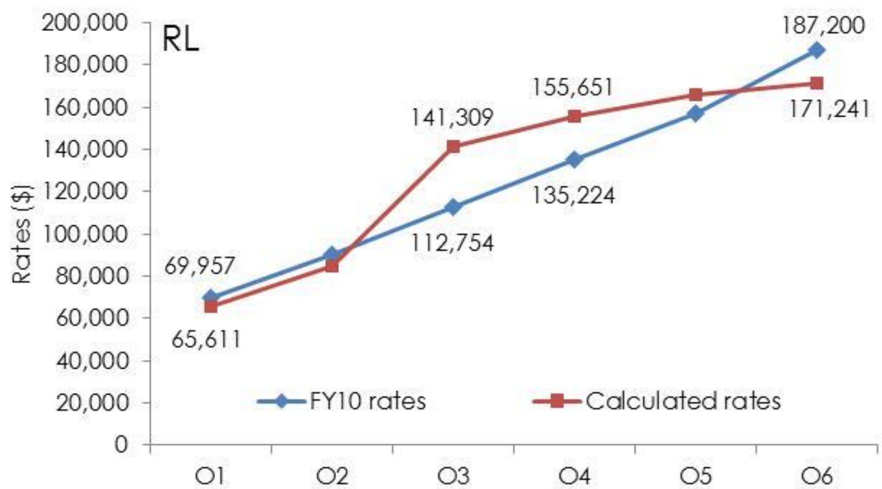
Figure 8, Figure 9, and Figure 10 compare the FY10 rates with the calculated rates. Each figure also includes ratios to show the differences in the spreads across paygrades for each set of rates (i.e., Ox/O1).

Figure 8. Actual FY10 granular programming rates versus calculated URL rates



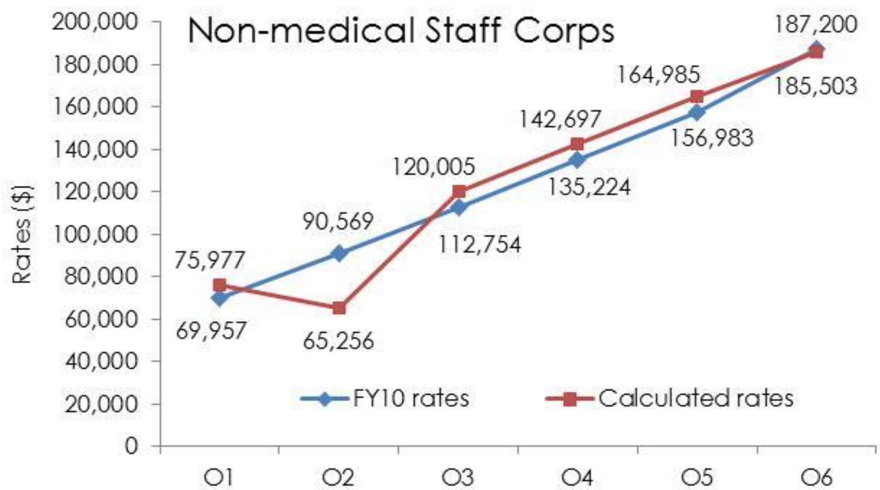
Ratios: Ox/O1	O1	O2	O3	O4	O5	O6
FY10 rate	1.00	1.29	1.61	1.93	2.24	2.68
Calculated rates	1.00	3.47	3.82	5.60	5.96	6.81

Figure 9. Actual FY10 granular programming rates versus calculated RL rates



Ratios: Ox/O1	O1	O2	O3	O4	O5	O6
FY10 rates	1.00	1.29	1.61	1.93	2.24	2.68
Calculated rates	1.00	1.29	2.15	2.37	2.53	2.61

Figure 10. Actual FY10 granular programming rates versus calculated non-medical Staff Corps rates



Ratios: Ox/O1	O1	O2	O3	O4	O5	O6
FY10 rates	1.00	1.29	1.61	1.93	2.24	2.68
Calculated rates	1.00	0.86	1.58	1.88	2.17	2.44

First, the figures show that, like the FY10 rates, the calculated rates are generally increasing with rank. The exception is that the calculated rate for O2 non-medical Staff Corps billets is less than the calculated rate for O1 billets. This is because of the initial INV-BA discrepancy: the non-medical Staff Corps was underexecuted at O1 and overexecuted at O2.

But, the figures also show that there are important differences between the FY10 rates and the calculated rates. Generally, the differences between the two sets of rates are a function of the size and direction of the imbalances to be eliminated. To see this, the data in Table 8 show, for each designator group and at each paygrade, the actual INV-BA discrepancies and the ratios of calculated rates to the FY10 rates.

The data show that, when imbalances are small, the calculated rates are close to the FY10 rates, but as the imbalances increase, so do the differences. Furthermore, for paygrades where INV was greater than BA (i.e., where there was excess supply), the calculated rates are lower than the FY10 rates to induce BSOs to buy more billets in those paygrades. Conversely, for paygrades where INV was less than BA (i.e., where there was excess demand), the calculated rates are higher than the FY10 rates to induce BSOs to buy fewer billets in those paygrades. Thus, the biggest differences between the calculated and FY10 rates correspond to the cases with the biggest imbalances: URL O1 and O3; RL O3 and O4; and Staff Corps O2.

Table 8. Actual INV-BA discrepancies and differences between the FY10 and calculated rates for the URL, RL, and non-medical Staff Corps

	Paygrade					
	O1	O2	O3	O4	O5	O6
URL						
Actual discrepancy	1,490	-17	744	-282	6	51
Calculated rate/FY10 rate	0.38	1.01	0.89	1.09	1.00	0.96
RL						
Actual discrepancy	21	25	-234	-171	-53	37
Calculated rate/FY10 rate	0.94	0.94	1.25	1.15	1.06	0.91
Non-medical Staff Corps						
Actual discrepancy	-29	154	-89	-52	-34	3
Calculated rate/FY10 rate	1.09	0.72	1.06	1.06	1.05	0.99

The differences between the calculated and FY10 rates indicate that the substitution-based programming rates have the potential to dramatically reduce, if not eliminate, INV-BA imbalances. The similarities between the calculated and FY10 rates also indicate, however, that, even if they are not optimal, the simple average-cost-based granular rates have the potential to reduce imbalances compared to using only one average rate for all paygrades.

Redistribution of BA across paygrades in response to substitution-based rates

The point of the game was to change both total BA and the paygrade structure of BA to minimize INV-BA imbalances at each level, and the game succeeded in attaining this goal. This success, however, highlights one of the complementary practices that reference [20] identified as necessary for effective implementation of granular programming: for manpower managers to respond to the incentives granular programming rates provide, they must be able to go outside the limits set by requirements.

Specifically, recall that Navy policy guidelines state that total BA may never exceed requirements and that BA must also equal requirements in terms of quality unless restricted by INV limitations or by legal limitations, such as the grade table. But, a key feature of the game is that it enables increases in total BA to occur within budget constraints by allowing claimants to shift their billet requests from more expensive to less expensive billets.

Table 9 provides data to show the extent to which the game's redistribution is likely to violate the current Navy policy. For each designator group and each paygrade, the data compare the percentage difference between the calculated BA and FY10 BA with the 2001-20015 average difference between BA and requirements.

Table 9. Percentage differences between calculated BA and FY10 BA vs. typical differences between BA and requirements

Difference between	Paygrade						Total
	O1	O2	O3	O4	O5	O6	
URL							
FY10 & calculated BA[a]	47.8%	-0.5%	10.3%	-6.5%	0.2%	3.4%	8.5%
BA & requirements[b]	2.7%	-0.8%	2.4%	-2.2%	-3.3%	-3.0%	0.0%
RL							
FY10 & calculated BA[a]	5.3%	5.3%	-13.3%	-9.7%	-4.3%	6.5%	-6.2%
BA & requirements[b]	4.8%	19.8%	-0.2%	-1.6%	-3.3%	-2.8%	0.0%
Non-medical Staff Corps							
FY10 & calculated BA[a]	-6.6%	33.3%	-5.3%	-4.5%	-5.1%	0.5%	-1.4%
BA & requirements[b]	0.2%	4.1%	3.9%	-2.6%	-4.4%	-4.9%	-0.1%

[a.] Percentage difference between calculated BA and actual FY10 BA.

[b.] Percentage difference between 2001-2015 average BA and 2001-2015 average requirement.

Starting with total differences, the data show that the increases in total URL and RL BA that result from the game are substantially greater than the historical differences between total BA and total requirements. Similarly, some of the differences by paygrade indicate that the game's redistribution of BA across paygrades results in shifts that are outside historical norms. The following percentage differences between calculated and FY10 BA stand out: O1 and O3 for the URL, O3 for the RL, and O2 for the non-medical Staff Corps. We note that, for all three designator groups, CG BA is historically less than CG requirements. We infer that this is because of constraints imposed by the grade table or by INV or both.

As a whole, the data in Table 9 indicate that implementing substitution-based granular programming rates without changing the current policy is likely to limit its effectiveness. There are two potential options. At minimum, the stipulations that BA must equal requirements in terms of quantity and quality need to be relaxed. A more extreme option would be to introduce some form of granular programming into the requirements process itself. We note that recent versions of MRD policy guidance have eliminated explicit reference to the "zero-based" concept under which multi-year manpower requirements were determined without consideration of funds or availability of personnel.[31]

[31] Compare the 1998 version the *Manual of Navy Total Force Manpower Policies and Procedures* to the 2007 and 2015 versions (references [9], [31], and [32], respectively).

Estimated productivity coefficients

In addition to redistributing BA to eliminate INV-BA imbalances within budget constraints, the game was also designed to maximize BSO-level output within not only budget constraints, but also INV constraints. The underlying assumption was that actual work could be redistributed based on the estimated substitution patterns in a way that would either increase output or minimize potential decreases in output. In particular, by reducing OUE, the game would reduce the likelihood of gapped billets, and by reducing OOE, it would facilitate the assignment of officers who have to be carried in INV to support the personnel pyramid anyway to activities where they would be most productive. In other words, the game was intended to increase the quality of BA as a demand signal.

Within this context, the actual success of a substitution-based granular programming approach clearly depends on the accuracy, or realism, of the estimated productivity coefficients that define the substitution patterns. We acknowledge that the estimated productivity coefficients used for the paper exercise aren't likely to be either accurate or realistic for at least two reasons. First, because we had only one year's worth of data, it was necessary to make strong assumptions about how billets at different paygrades are used to produce output or readiness. It is unlikely that these assumptions actually hold.[32] Second, given that BA isn't allowed to deviate much from requirements (as shown above), even though FY10 was the year deemed most likely to reflect behavioral responses to cost-based granular programming, it is likely that the effects are underestimated.

To see the latter point, recall that the BSO-specific estimated productivity coefficients were zero for any paygrades in which there was no FY10 BA. Thus, based on this feature of the production function, the game primarily solved OOE by adding billets where they already existed, and it solved OUE by taking billets away from where they already existed. This outcome is only different from the current practices of creating "OOE billets" and leaving billets gapped if activities are really able to rearrange work—either to make productive use of the excess officers assigned to them or to shift work to paygrades where INV exist to fill the billets.

In practice, this issue could be resolved by implementing granular programming long enough to generate several years' worth of data on which to estimate actual substitution patterns, rather than productivity coefficients for a prespecified production function. For this to work, however, activities would have to be able to rearrange actual work, not just billets.

[32] Specifically, it is unlikely that activities all produce readiness using a Cobb-Douglas type of production function with constant returns to scale.

Summary

The paper exercise to test the potential for substitution-based pricing to resolve INV-BA imbalances uses a game-theoretic approach that entails solving a bi-level optimization problem for the set of prices that equates BA to INV at each paygrade.Solving the mathematical problem requires three key inputs: paygrade-specific target inventories, BSO-level budget constraints, and estimated productivity coefficients that capture the rates at which junior and senior billets can be substituted at each BSO.

More fundamentally, the game rests on key assumptions about the goals and behavior of the two sets of players. Starting with assumptions about the behavior of the leader, the game's most important assumption is that minimizing INV-BA imbalances is a worthy objective. In addition, the game's structure assumes that the leader can both set paygrade-specific prices and impose binding budget constraints at the BSO level. Turning to the behavior of BSOs, the game assumes that BSOs can respond to changes in relative billet prices. Specifically, BSOs must understand their activities' production processes well enough to make output-maximizing trade-offs among billets of different paygrades, and they must have the authority to buy billets in those optimizing combinations.

The results of the game show that, within its stylized framework, substitution-based granular rates can be set to eliminate INV-BA imbalances. In particular, the calculated rates are sufficiently different from the actual FY10 granular programming rates to indicate that the substitution-based approach would be more effective than the cost-based approach at achieving this goal. The calculated rates and actual rates are sufficiently similar, however, to indicate that even the simple, cost-based granular rates are better than the one overall average rate that is currently being used.

Other results highlight the complementary policies that need to be in place for substitution-based granular programming to be effective. First, the differences between the actual FY10 BA and the BA calculated by the game are larger than historical differences between BA and requirements. This indicates that for granular programming to effectively eliminate INV-BA imbalances, BSOs must be able to request billet structures that deviate from the limits set by requirements, which would be a change in policy. Indeed, this conclusion holds regardless of whether the rates are set based on substitution patterns or costs.

Second, the estimated productivity coefficients used in the game are not likely to reflect actual substitution patterns. In actual practice, if granular programming were in place long enough, this problem could be addressed by directly estimating substitution patterns based on BSOs' real responses to changes in paygrade-specific rates. This would, however, require that BSOs can not only change their billet structures, but also rearrange the underlying work to maximize readiness.

Conclusion

The problem addressed in this study is INV-BA imbalances in the Navy's officer corps. Following from previous research, we started with the position that these imbalances should be resolved because they are costly—not just in money terms, but also in terms of readiness.

In the four main sections of this report, we did the following:

- Defined, described, and analyzed the INV-BA imbalances of current concern
- Reviewed the extant literature on the manpower and personnel management systems, focusing on features that cause the INV-BA imbalances and on previously suggested solutions
- Proposed revisiting granular programming for officer BA using a substitution-based, rather than a cost-based, approach to setting the rates
- Used a game-theoretic model to explore whether the proposed approach to granular programming could resolve INV-BA imbalances

In this conclusion, we summarize the main takeaways from each section and give recommendations for a path forward.

Takeaways

Supply-demand imbalances in the Navy's officer corps

The primary imbalance of current concern is JG OOE in the SW and SUB communities because their JG INV/BA ratios have gone increasingly out of the healthy range. Although OUE exists for the control grades of these communities, it is mainly in the healthy range when the flexibility of non-discrete billet allocation is taken into account. The exception here is the SUB community, which doesn't have enough CG inventory to fill its discrete CG BA.

Two factors contribute to INV-BA imbalances and make managing them a persistent challenge. First, some community management practices can increase the likelihood that imbalances will occur. For the SW and SUB communities, planning accessions to meet post-MSR work requirements contributes to the JG OOE they are experiencing. And, for the URL as a whole, the lateral transfer system drives a wedge between community requirements and accessions. Second, the personnel and manpower management systems allow for independent changes in BA and INV. This study focused on the latter.

Literature review

Although the Navy's manpower and personnel management processes are intended to function as two parts of one integrated system, they have at least six fundamental differences that make keeping INV-BA imbalances in the healthy range a constant challenge. In general, the issue is that decentralized manpower and personnel decision-makers have different priorities and constraints. Given this characterization of the problem, we focused on one of four previously proposed or attempted solutions: granular programming.

Granular programming to minimize supply-demand imbalances

Economic theory identifies costs and benefits associated with decentralization. On the benefits side, decentralized decision-makers often have better information about how work can be done most efficiently in their parts of the organization. On the cost side, what is locally best may not be best for the organization as a whole. When such costs arise, pricing solutions can be used to align the interests of decentralized decision-makers across an organization. Thus, in the Navy context, granular programming is a theoretically sound way to align the competing priorities of manpower and personnel.

There are, however, multiple ways to set granular programming rates. In the Navy's closed personnel system, cost-based rates—rates based on either average or marginal personnel costs—are either infeasibly difficult to calculate or unlikely to resolve INV-BA imbalances, or both. Thus, we proposed using what we call a substitution-based approach that is explicitly designed for the purpose at hand.

Granular programming: A substitution-based approach to setting rates

The results of the paper exercise showed that, within its stylized framework, substitution-based granular rates can be set to substantially reduce, if not eliminate, INV-BA imbalances. This means that granular programming has the potential to work in practice.

In particular, the calculated rates have two important features: Like the actual FY10 granular rates, they are increasing with paygrade, but unlike the FY10 granular rates they do not increase linearly with paygrade. Combined, these features suggest that cost-based granular rates, like those used in FY10, would be better than using one rate for all paygrades, but such rates aren't sufficiently targeted to eliminate either specific or very large imbalances.

Other aspects of the paper exercise highlight the complementary policies that need to be in place for substitution-based granular programming to be effective. First, the game's structure assumes N1, or some other centralized Navy authority, can both set paygrade-specific prices and impose binding budget constraints at the BSO level.

Second, BSOs must be able to respond to changes in relative billet prices. They must not only understand their activities' production processes well enough to make output-maximizing trade-offs among billets of different paygrades, but also have the authority to buy billets in those optimizing combinations. The game's results reinforce this point. For granular programming to eliminate, or substantially reduce, INV-BA imbalances, BSOs must be able to request billet structures that deviate from the limits set by requirements. This conclusion holds regardless of whether the rates are based on substitution patterns or costs.

Finally, the estimated productivity coefficients used in the game are not likely to reflect actual substitution patterns. In actual practice, if granular programming were in place long enough, this problem could be addressed by directly estimating substitution patterns based on BSOs' real responses to changes in paygrade-specific rates. This would, however, require that BSOs can not only change their billet structures, but also rearrange the underlying work to maximize readiness.

Path forward

The paper exercise was based on a very stylized representation of the billet authorization process. As such, it may have more value as the first steps on a path forward than as a ready solution. In particular, given the complexity of the entire

MPT&E system, more research could help to reveal the potential for unintended effects and additional complementary practices. We offer two possible approaches.

The first approach is to expand the game-theoretic model to capture some of the additional complexities of the MPT&E system. For example, given that INV-BA imbalances vary across communities, the model could easily be adapted to solve INV-BA imbalances for individual designators rather than designator groups. A more complicated extension would be to allow BSOs to substitute across designators as well as paygrades. Another option is to solve for a multi-year solution that would both capture the effects of a given year's pricing system on future inventories and allow the players in the game to learn from each previous round to make better decisions in the next round. This type of extension would require making assumptions about how inventory flows through the system from year to year.

The second approach is to actually re-implement granular programming using cost-based rates to collect data on actual substitution patterns. To accompany this approach, it would be valuable to study how, and to what extent, Navy activities actually redistribute work across paygrades. Do they simply do their own versions of billet roll-downs or do they fundamentally reorganize their work processes?

Whichever approach is taken, the most important thing to remember is that any effort to use granular programming to resolve INV-BA imbalances must include adopting the required complementary policies and practices. In particular, BA must be allowed to deviate from requirements, and the relevant IT systems must be adapted to accommodate granular rates.

Appendix A: BSOs

Table 10 lists the BSOs used in the game, identifying which are controlled by the Navy and which are controlled by other organizations within DOD. (See also [9].)

Table 10. BSOs used in the game

Navy-controlled BSOs
11: Office of the Chief of Naval Operations (OPNAV) (Assistant for Field Support Activity (FSA))
12: Department of the Navy/Assistant for Administration (DON/AA) (AAUSN)
14: Chief of Naval Research (CNR)
15: Naval Intelligence Activity (NIA) (ONI)
18: Chief, Bureau of Medicine and Surgery (BUMED)
19: Commander, Naval Air Systems Command (COMNAVAIRSYSCOM)
22: Bureau of Naval Personnel (BUPERS) (CHNAVPERS)
23: Commander, Naval Supply Systems Command (COMNAVSUPSYSCOM)
24: Commander, Naval Sea Systems Command (COMNAVSEASYSCOM)
25: Commander, Naval Facilities Engineering Command (COMNAVFACENGCOM)
27: Commandant of the Marine Corps (CMC)
30: Director, Strategic Systems Programs (DIRSSP) (CM3)
33: Commander, Military Sealift Command (COMSC)
39: Space and Naval Warfare Command (COMSPAWARSYSCOM)
52: Commander, Navy Installations Command (CNIC)
60: Commander, United States Fleet Forces Command (COMUSFLTFORCOM)
70: Commander, U.S. Pacific Fleet (COMPACFLT)
72: Commander, Navy Reserve Force (COMNAVRESFOR)
76: Naval Education and Training Command (NETC)
88: Commander, Naval Special Warfare Command (SPECWARCOM)
DOD-controlled BSOs
02 Central Operating Activity (COA)
20 Defense Finance and Accounting Service (DFAS)
28 Joint Chiefs of Staff (JCS)
29 Office, Secretary of Defense (OSD)
34 Defense Technology Security Agency (DTSA)
35 Missile Defense Agency (MDA)
36 Defense Advanced Research Projects Agency (DARPA)
40 Defense Contract Management Agency (DCMA)
42 Defense Threat Reduction Agency (DTRA)
43 Director, Defense Information Systems Agency (DISA)
44 Director, Defense Intelligence Agency (DIA)
45 National Security Agency (NSA)
47 Defense Inspector General (IG)
48 National Geospatial-Intelligence Agency (NGA)
51 Director, Defense Logistics Agency (DLA)
56 DoD Human Resources Agency (DoDHRA)
75 U.S. Transportation Command (USTRANSCOM

Appendix B: The Bi-Level Optimization Problem

Defining the problem

There are three key pieces to the problem.

(1) Each BSO's mission production function:

$$\text{Utility}_c = \prod_{r=1}^{R} L_{cr}^{\alpha_{cr}}$$

(2) Each BSO's optimization problem:

$$\max \left\{ \prod_{r=1}^{R} L_{cr}^{\alpha_{cr}} \right\}$$

$$\text{subject to: } \overrightarrow{L_c} \cdot \vec{p} \leq B_c$$

(3) N1's overall problem:

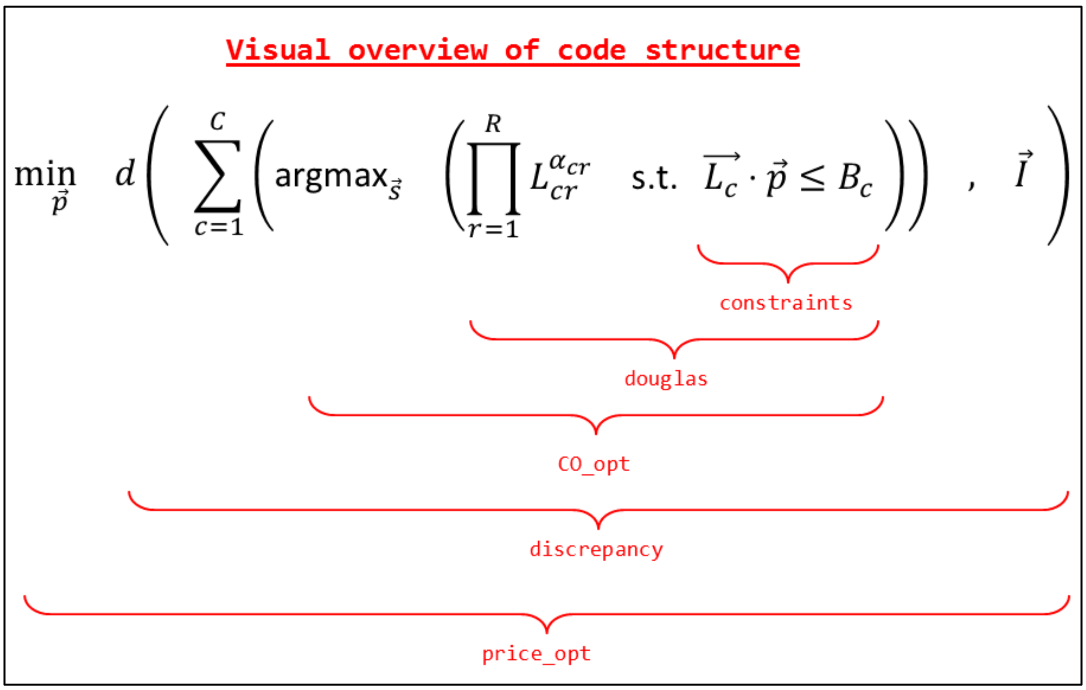
$$\min_{\vec{p}} \quad d\left(\sum_{c=1}^{C} \left(\underset{\text{s.t.} \quad \overrightarrow{L_c} \cdot \vec{p} \leq B_c}{\text{argmax}_{\vec{s}} \quad \prod_{r=1}^{R} L_{cr}^{\alpha_{cr}}} \right) \quad , \quad \vec{I} \right)$$

This is a bi-level optimization problem, a mathematical equation that can be solved for a unique $\vec{p}$, given any set of the following inputs:

- Inventory desired to be cleared, $\vec{I}$
- Budget for each BSO, B_c
- Productivity coefficients for each BSO, α_{cr}

Solving the problem

To solve each optimization, we use the limited-memory Broyden-Fletcher-Goldfarb-Shanno-Byrd algorithm (commonly referred to as the L-BFGS-B) to solve our bi-level optimization problem. The advantage of this algorithm is requiring no presumed knowledge of the structure of the function being optimized. Because our problem has many interactions that cannot be reduced to a simpler form, this algorithm is appropriate. The disadvantage of this algorithm is that its performance is considered subpar in comparison to other optimization algorithms, both in terms of speed and accuracy. See [33] for the details of this algorithm. A schematic diagram of the code's structure is provided in the figure below. The code is written in R and is available from the authors on request.



Appendix C: Game Inputs

FY10 BA data by BSO

The tables in this appendix show the FY10 BSO-specific BA data used in the game. The data are shown by category: (1) the sea and shore "fleet" billets for Navy-controlled BSOs used in the optimization problem, (2) the student and TPPH billets in Navy-controlled BSOs that were held constant, and (3) the billets in DOD-controlled BSOs that were also held constant.

URL

Table 11. URL discretionary and non-discretionary FY10 BA for Navy-controlled BSOs

BSO	O1	O2	O3	O4	O5	O6	Total
Discretionary BA							
11: OPNAV	0	4	114	257	254	173	802
12: AAUSN	1	2	24	25	50	44	146
14: CNR	0	0	13	3	10	8	34
15: ONI	0	3	46	8	6	7	70
18: BUMED	1	0	3	1	0	0	5
19: COMNAVAIRSYSCOM	2	0	133	72	79	37	323
22: CHNAVPERS	0	1	150	71	98	33	353
23: COMNAVSUPSYSCOM	0	0	1	0	0	0	1
24: COMNAVSEASYSCOM	0	3	28	24	39	51	145
27: CMC	0	0	43	18	11	0	72
30: DIRSSP	0	0	7	11	5	5	28
33: COMSC	0	0	22	22	16	16	76
39: COMSPAWARSYSCOM	0	0	31	14	15	20	80
52: CNI	0	7	140	62	82	77	368
60: CFFC	392	1,203	1,894	1,179	648	238	5,554
70: COMUSPACFLT	498	1,645	2,469	1,270	689	210	6,781
72: COMNAVRESFOR	0	6	24	6	4	1	41
76: NETC	2	9	659	225	198	135	1,228
88: COMNAVSPECWARCOM	0	97	266	197	106	37	703
Total	896	2,980	6,076	3,512	2,341	1,104	16,909
Non-discretionary BA							
70: COMUSPACFLT	1,107	490	111	51	26	1	1,786
76: NETC	867	299	715	258	127	21	2,287
Total	1,974	789	826	309	153	22	4,073

Table 12. URL non-discretionary FY10 BA for DOD-controlled BSOs

BSO	O1	O2	O3	O4	O5	O6	Total
02: COA	248	152	239	444	260	107	1,450
28: JCS	0	1	31	162	260	78	532
29: OSD	0	0	8	6	32	48	94
34: DTSA	0	0	0	0	3	0	3
35: MDA	0	0	0	9	9	2	20
36: DARPA	0	0	0	0	1	1	2
40: DCMA	0	0	6	10	1	0	17
42: DTRA	0	0	3	30	20	10	63
43: DISA	0	0	3	5	8	3	19
44: DIA	0	1	6	19	37	28	91
45: NSA	1	0	3	0	1	0	5
47: DIG	0	0	0	0	1	2	3
48: NGA	0	0	0	2	4	2	8
51: DLA	0	0	0	0	1	0	1
56: DODHRA	0	0	0	2	0	0	2
75: USTRANSCOM	0	0	0	7	10	2	19
Total	249	154	299	696	648	283	2,329

RL

Table 13. RL discretionary and non-discretionary FY10 BA for Navy-controlled BSOs

BSO	O1	O2	O3	O4	O5	O6	Total
Discretionary							
11: OPNAV	4	20	57	89	74	41	285
12: AAUSN	5	10	40	25	23	15	118
14: CNR	0	0	1	5	6	3	15
15: ONI	34	60	58	37	33	18	240
18: BUMED	0	0	0	0	0	1	1
19: COMNAVAIRSYSCOM	1	0	13	109	107	51	281
22: CHNAVPERS	0	1	75	54	43	18	191
23: COMNAVSUPSYSCOM	0	0	0	0	0	1	1
24: COMNAVSEASYSCOM	0	0	23	76	74	52	225
30: DIRSSP	0	0	1	11	11	8	31
33: COMSC	0	0	1	1	1	0	3
39: COMSPAWARSYSCOM	0	1	60	64	48	24	197
52: CNI	0	0	25	19	10	8	62
60: CFFC	147	158	455	462	280	81	1,583
70: COMUSPACFLT	59	71	238	239	140	40	787
72: COMNAVRESFOR	0	0	2	17	7	2	28
76: NETC	54	47	57	47	83	30	318
88: COMNAVSPECWARCOM	13	8	52	48	15	4	140
Total	317	376	1,158	1,303	955	397	4,506
Non-discretionary							
76: NETC	30	10	320	140	34	3	537

Table 14. RL non-discretionary FY10 BA for DoD-controlled BSOs

BSO	O1	O2	O3	O4	O5	O6	Total
02: COA	44	59	131	146	84	26	490
28: JCS	0	7	69	87	65	26	254
29: OSD	0	0	4	7	16	11	38
35: MDA	0	0	0	2	3	1	6
40: DCMA	0	0	5	13	5	7	30
42: DTRA	0	0	0	1	1	0	2
43: DISA	0	0	12	10	4	2	28
44: DIA	0	12	38	52	40	27	169
45: NSA	2	6	61	31	21	15	136
47: DIG	0	0	0	1	1	0	2
48: NGA	1	1	4	8	9	4	27
51: DLA	0	0	0	1	2	1	4
56: DODHRA	0	0	0	0	1	0	1
75: USTRANSCOM	0	1	2	9	6	2	20
Total	47	86	326	368	258	122	1,207

Non-medical Staff Corps

Table 15. Non-medical Staff Corps discretionary and non-discretionary FY10 BA for Navy-controlled BSOs

BSO	O1	O2	O3	O4	O5	O6	Total
Discretionary							
11: OPNAV	0	11	227	109	63	44	454
12: AAUSN	0	0	17	23	58	46	144
14: CNR	0	0	0	0	1	1	2
15: ONI	0	0	0	1	1	0	2
18: BUMED	0	19	48	26	20	6	119
19: COMNAVAIRSYSCOM	0	2	3	32	21	4	62
22: CHNAVPERS	0	1	9	19	5	3	37
23: COMNAVSUPSYSCOM	0	73	69	100	92	46	380
24: COMNAVSEASYSCOM	0	0	4	14	14	7	39
25: COMNAVFACENGCOM	73	86	155	144	82	42	582
27: CMC	1	11	163	76	65	28	344
30: DIRSSP	0	0	1	2	0	1	4
33: COMSC	0	4	15	5	13	2	39
39: COMSPAWARSYSCOM	0	1	1	10	6	2	20
52: CNI	1	13	87	66	41	21	229
60: CFFC	131	85	313	182	105	40	856
70: COMUSPACFLT	160	84	247	123	68	22	704
72: COMNAVRESFOR	0	0	0	0	2	2	4
76: NETC	0	6	61	36	25	10	138
88: COMNAVSPECWARCOM	0	1	53	25	19	1	99
Total	366	397	1,473	993	701	328	4,258
Non-discretionary							
76: NETC	76	9	209	54	16	1	365

Table 16. Non-medical Staff Corps non-discretionary BA in FY10 for DOD BSOs

BSO	O1	O2	O3	O4	O5	O6	Total
02: COA	25	28	77	87	45	17	279
20: DFAS	0	0	2	2	0	1	5
28: JCS	0	0	2	29	28	16	75
29: OSD	0	1	6	21	21	7	56
35: MDA	0	0	0	0	0	1	1
40: DCMA	0	7	11	12	6	8	44
42: DTRA	0	0	0	3	0	0	3
43: DISA	0	0	0	1	2	1	4
44: DIA	0	0	0	0	1	0	1
45: NSA	0	0	2	2	0	0	4
47: DIG	0	0	0	0	1	0	1
51: DLA	0	10	18	39	36	23	126
75: USTRANSCOM	0	2	2	11	6	4	25
Total	25	48	120	207	146	78	624

BSO-specific budget constraints

Table 17 shows BSO-specific budget constraints calculated by multiplying actual BA by the FY10 granular programming rate.

Table 17. Simulation budgets for discretionary billets

	Budgets in dollars		
BSO	URL	RL	Non-med. Staff Corps
11: OPNAV	120,228,082	39,845,064	59,457,562
12: AAUSN	22,423,741	15,564,844	22,743,184
14: CNR	4,938,904	2,292,372	344,183
15: ONI	8,792,481	27,905,737	292,207
18: BUMED	543,443	187,200	14,911,687
19: COMNAVAIRSYSCOM	44,200,381	42,619,556	8,892,011
22: CHNAVPERS	48,166,507	25,969,084	5,021,126
23: COMNAVSUPSYSCOM	112,754	187,200	50,967,599
24: COMNAVSEASYSCOM	22,343,732	34,221,508	5,852,314
25: COMNAVFACENGCOM	0	0	70,579,927
27: CMC	9,009,267	0	45,167,637
30: DIRSSP	3,997,657	4,824,631	570,402
33: COMSC	10,962,444	404,961	5,144,885
39: COMSPAWARSYSCOM	11,487,255	27,538,129	2,871,861
52: CNI	52,090,437	8,455,536	30,349,239
60: CFFC	655,641,407	197,488,579	100,736,717
70: COMUSPACFLT	781,421,984	99,177,470	78,076,950
72: COMNAVRESFOR	4,875,986	3,997,597	688,366
76: NETC	162,039,955	39,462,516	18,086,047
88: COMNAVSPECWARCOM	88,983,483	17,091,498	12,617,008

BSO-specific productivity coefficients

Recall the CO's optimization problem:

$$\max\left\{\prod_{r=1}^{R} L_{cr}^{\alpha_{cr}}\right\}$$

$$\text{subject to: } \overrightarrow{L_c} \cdot \vec{p} \le B_c$$

Using the billet authorizations from FY10, we reverse-engineer our desired quantities. Specifically, we can completely determine the productivity coefficients α and budgets B_c for each BSO if we assume the following:

- The 2010 requests were maximizing each BSO's output
- The 2010 requests completely exhausted each BSO's budget
- The prices in 2010 were the granular programming rates in FY2010.

More precisely, there is a unique set of productivity coefficients that would have produced their observed behavior in 2010, if it is assumed that their behavior was optimal. These coefficients are shown by designator group in Table 18, Table 19, and Table 20.

Table 18. Productivity coefficients for URL billets

BSO	O1	O2	O3	O4	O5	O6
11: OPNAV	0.00	0.00	0.11	0.29	0.33	0.27
12: AAUSN	0.00	0.01	0.12	0.15	0.35	0.37
14: CNR	0.00	0.00	0.30	0.08	0.32	0.30
15: ONI	0.00	0.03	0.59	0.12	0.11	0.15
18: BUMED	0.13	0.00	0.62	0.25	0.00	0.00
19: COMNAVAIRSYSCOM	0.00	0.00	0.34	0.22	0.28	0.16
22: CHNAVPERS	0.00	0.00	0.35	0.20	0.32	0.13
23: COMNAVSUPSYSCOM	0.00	0.00	1.00	0.00	0.00	0.00
24: COMNAVSEASYSCOM	0.00	0.01	0.14	0.15	0.27	0.43
27: CMC	0.00	0.00	0.54	0.27	0.19	0.00
30: DIRSSP	0.00	0.00	0.20	0.37	0.20	0.23
33: COMSC	0.00	0.00	0.23	0.27	0.23	0.27
39: COMSPAWARSYSCOM	0.00	0.00	0.30	0.16	0.20	0.33
52: CNI	0.00	0.01	0.30	0.16	0.25	0.28
60: CFFC	0.04	0.17	0.33	0.24	0.16	0.07
70: COMUSPACFLT	0.04	0.19	0.36	0.22	0.14	0.05
72: COMNAVRESFOR	0.00	0.11	0.55	0.17	0.13	0.04
76: NETC	0.00	0.01	0.46	0.19	0.19	0.16
88: COMNAVSPECWARCOM	0.00	0.10	0.34	0.30	0.19	0.08

Table 19. Productivity coefficients for RL billets

BSO	O1	O2	O3	O4	O5	O6
11: OPNAV	0.01	0.05	0.16	0.30	0.29	0.19
12: AAUSN	0.02	0.06	0.29	0.22	0.23	0.18
14: CNR	0.00	0.00	0.05	0.29	0.41	0.24
15: ONI	0.09	0.19	0.23	0.18	0.19	0.12
18: BUMED	0.00	0.00	0.00	0.00	0.00	1.00
19: COMNAVAIRSYSCOM	0.00	0.00	0.03	0.35	0.39	0.22
22: CHNAVPERS	0.00	0.00	0.33	0.28	0.26	0.13
23: COMNAVSUPSYSCOM	0.00	0.00	0.00	0.00	0.00	1.00
24: COMNAVSEASYSCOM	0.00	0.00	0.08	0.30	0.34	0.28
30: DIRSSP	0.00	0.00	0.02	0.31	0.36	0.31
33: COMSC	0.00	0.00	0.28	0.33	0.39	0.00
39: COMSPAWARSYSCOM	0.00	0.00	0.25	0.31	0.27	0.16
52: CNI	0.00	0.00	0.33	0.30	0.19	0.18
60: CFFC	0.05	0.07	0.26	0.32	0.22	0.08
70: COMUSPACFLT	0.04	0.06	0.27	0.33	0.22	0.08
72: COMNAVRESFOR	0.00	0.00	0.06	0.58	0.27	0.09
76: NETC	0.10	0.11	0.16	0.16	0.33	0.14
88: COMNAVSPECWARCOM	0.05	0.04	0.34	0.38	0.14	0.04

Table 20. Productivity coefficients for non-medical Staff Corps billets

BSO	O1	O2	O3	O4	O5	O6
11: OPNAV	0.00	0.02	0.43	0.25	0.17	0.14
12: AAUSN	0.00	0.00	0.08	0.14	0.40	0.38
14: CNR	0.00	0.00	0.00	0.00	0.46	0.54
15: ONI	0.00	0.00	0.00	0.46	0.54	0.00
18: BUMED	0.00	0.12	0.36	0.24	0.21	0.08
19: COMNAVAIRSYSCOM	0.00	0.02	0.04	0.49	0.37	0.08
22: CHNAVPERS	0.00	0.02	0.20	0.51	0.16	0.11
23: COMNAVSUPSYSCOM	0.00	0.13	0.15	0.27	0.28	0.17
24: COMNAVSEASYSCOM	0.00	0.00	0.08	0.32	0.38	0.22
25: COMNAVFACENGCOM	0.07	0.11	0.25	0.28	0.18	0.11
27: CMC	0.00	0.02	0.41	0.23	0.23	0.12
30: DIRSSP	0.00	0.00	0.20	0.47	0.00	0.33
33: COMSC	0.00	0.07	0.33	0.13	0.40	0.07
39: COMSPAWARSYSCOM	0.00	0.03	0.04	0.47	0.33	0.13
52: CNI	0.00	0.04	0.32	0.29	0.21	0.13
60: CFFC	0.09	0.08	0.35	0.24	0.16	0.07
70: COMUSPACFLT	0.14	0.10	0.36	0.21	0.14	0.05
72: COMNAVRESFOR	0.00	0.00	0.00	0.00	0.46	0.54
76: NETC	0.00	0.03	0.38	0.27	0.22	0.10
88: COMNAVSPECWARCOM	0.00	0.01	0.47	0.27	0.24	0.01

Target inventory

To determine the amount of inventory that N1 desires to match, we used the INV data from FY10, then subtracted out enough inventory to fill billets that were considered fixed in the game—billets requested by DOD-controlled BSOs as well as student and TPPH billets. The remaining inventory is the target inventory that N1 is seeking to match in the game.

This calculation is summarized in Tables 21, 22, and 23.

Table 21. Target inventory calculation for URL

	O1	O2	O3	O4	O5	O6	Total
Inventory	4,609	3,906	7,936	4,188	3,117	1,448	25,204
– Non-discretionary BA	2,223	943	1,125	1,005	801	305	6,402
Target inventory	2,386	2,963	6,811	3,183	2,316	1,143	18,802

Table 22. Target inventory calculation for RL

	O1	O2	O3	O4	O5	O6	Total
Inventory	415	497	1,570	1,640	1,194	559	5,875
– Non-discretionary BA	77	96	646	508	292	125	1,744
Target inventory	338	401	924	1,132	902	434	4,131

Table 23. Target inventory calculation for non-medical Staff Corps

	O1	O2	O3	O4	O5	O6	Total
Inventory	438	608	1,713	1,202	829	410	5,200
– Non-discretionary BA	101	57	329	261	162	79	989
Target inventory	337	551	1,384	941	667	331	4,211

Appendix D: BSO-Level Optimization Results

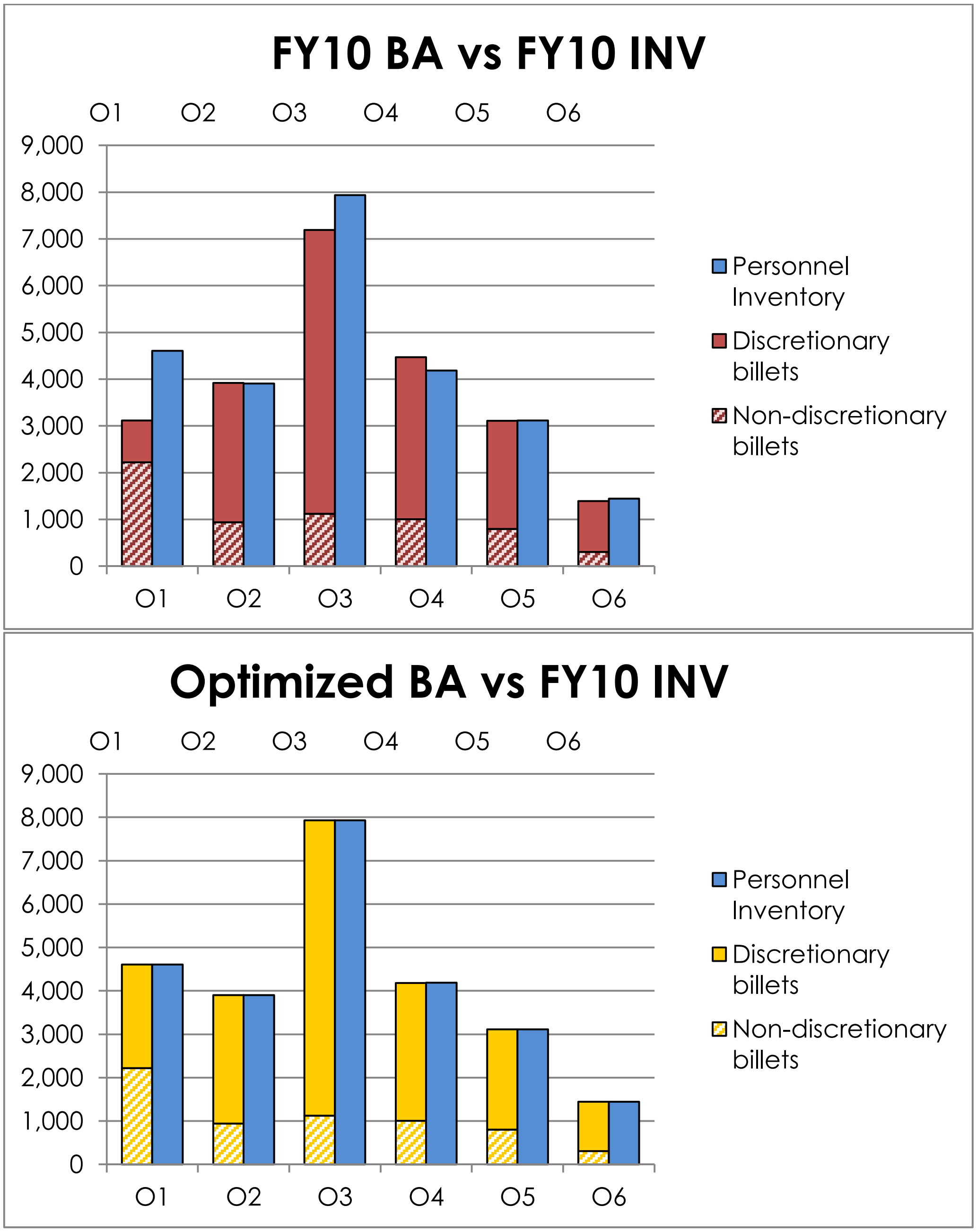
Optimized billet requests

URL

Table 24. URL billet requests under optimized prices

BSO	O1	O2	O3	O4	O5	O6
11: OPNAV	0	3	127	236	254	181
12: AAUSN	3	2	27	22	51	46
14: CNR	0	0	14	2	10	8
15: ONI	0	2	51	7	6	7
18: BUMED	3	0	4	0	0	0
19: COMNAVAIRSYSCOM	5	0	149	66	79	38
22: CHNAVPERS	0	0	168	65	98	34
23: COMNAVSUPSYSCOM	0	0	1	0	0	0
24: COMNAVSEASYSCOM	0	2	31	22	39	53
27: CMC	0	0	49	16	11	0
30: DIRSSP	0	0	7	10	5	5
33: COMSC	0	0	24	20	16	16
39: COMSPAWARSYSCOM	0	0	34	12	16	21
52: CNI	0	7	158	56	82	81
60: CFFC	1,043	1,196	2,126	1,083	649	249
70: COMUSPACFLT	1,326	1,636	2,772	1,167	691	219
72: COMNAVRESFOR	0	5	26	5	4	1
76: NETC	6	9	740	206	198	142
88: COMNAVSPECWARCOM	0	97	298	181	106	39

Figure 11. BA before and after optimal price changes for URL

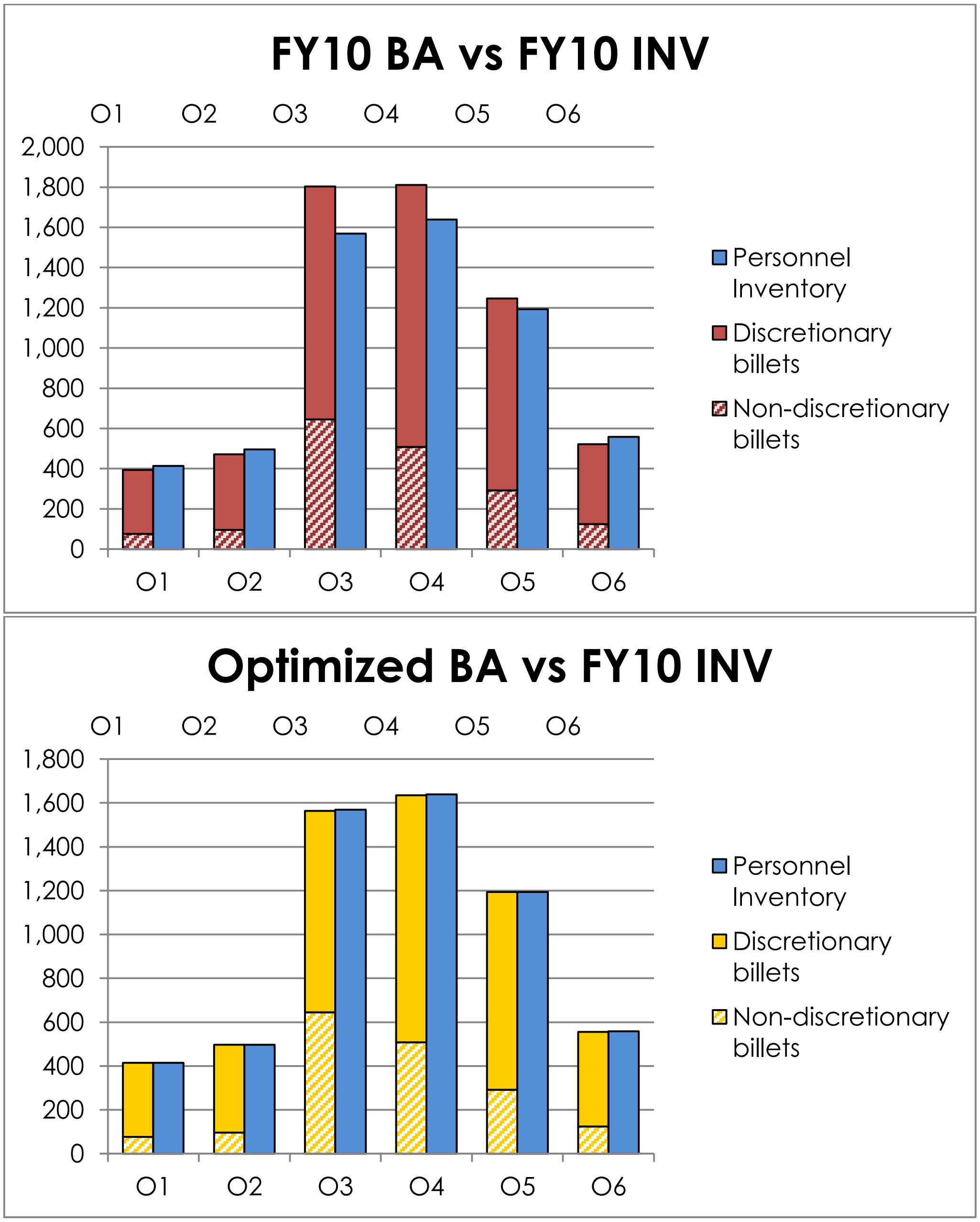


RL

Table 25. RL billet requests under optimized prices

BSO	O1	O2	O3	O4	O5	O6
11: OPNAV	5	22	46	78	69	44
12: AAUSN	6	11	31	21	22	17
14: CNR	0	0	0	5	6	3
15: ONI	36	63	46	32	31	19
18: BUMED	0	0	0	0	0	1
19: COMNAVAIRSYSCOM	1	0	10	94	101	55
22: CHNAVPERS	0	1	60	46	41	20
23: COMNAVSUPSYSCOM	0	0	0	0	0	1
24: COMNAVSEASYSCOM	0	0	18	66	70	57
30: DIRSSP	0	0	0	9	11	9
33: COMSC	0	0	1	1	0	0
39: COMSPAWARSYSCOM	0	1	47	55	45	26
52: CNI	0	0	19	16	10	9
60: CFFC	156	168	363	401	264	88
70: COMUSPACFLT	63	76	189	207	133	44
72: COMNAVRESFOR	0	0	1	15	7	2
76: NETC	58	51	46	41	78	32
88: COMNAVSPECWARCOM	13	8	41	41	14	4

Figure 12. BA before and after optimal price changes for RL

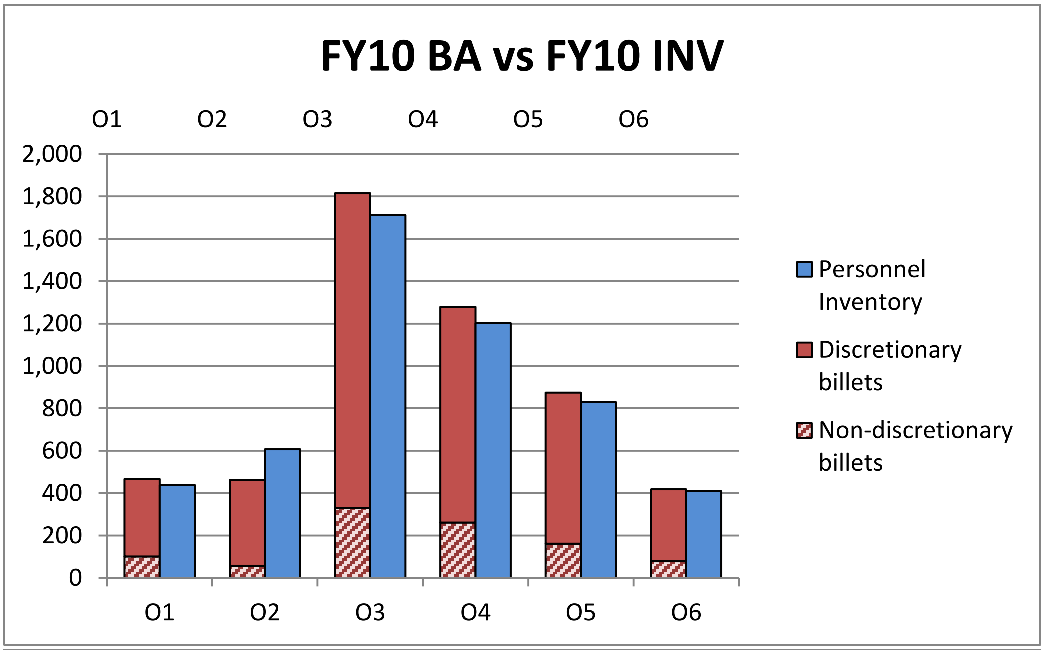


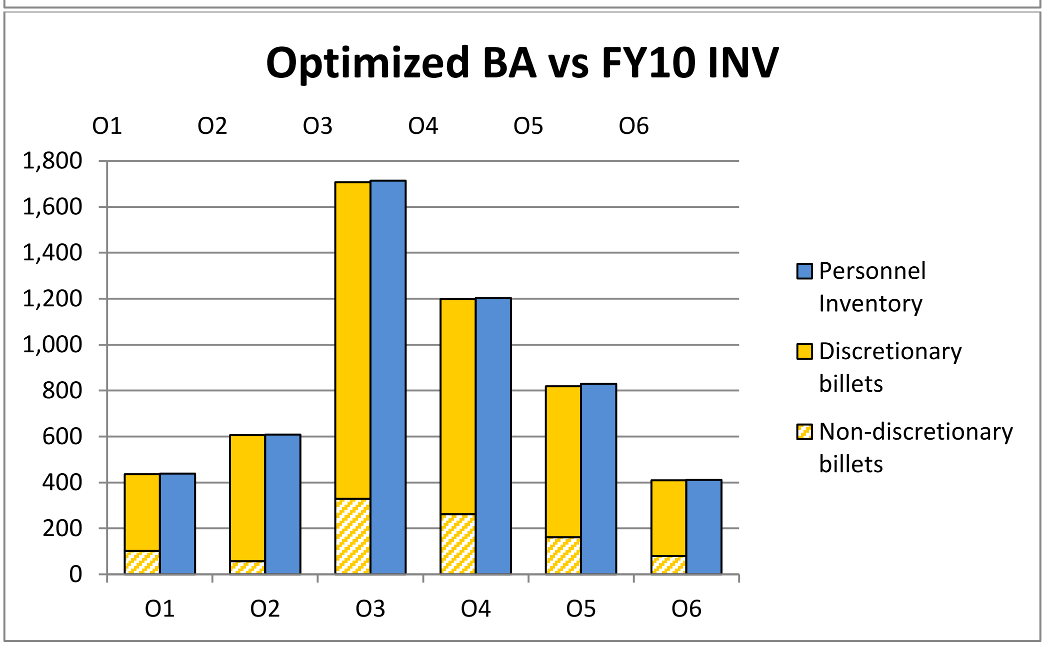
Staff Corps

Table 26. Non-medical Staff Corps billet requests under optimized prices

BSO	O1	O2	O3	O4	O5	O6
11: OPNAV	0	15	213	103	59	44
12: AAUSN	0	0	15	22	55	47
14: CNR	0	0	0	0	0	1
15: ONI	0	0	0	1	0	0
18: BUMED	0	26	45	24	19	6
19: COMNAVAIRSYSCOM	0	3	3	30	20	4
22: CHNAVPERS	0	1	8	18	4	3
23: COMNAVSUPSYSCOM	0	102	64	95	87	47
24: COMNAVSEASYSCOM	0	0	3	13	13	7
25: COMNAVFACENGCOM	67	119	145	136	78	42
27: CMC	0	15	153	72	61	28
30: DIRSSP	0	0	0	2	0	1
33: COMSC	0	5	14	4	12	2
39: COMSPAWARSYSCOM	0	1	0	9	5	2
52: CNI	0	18	81	62	39	21
60: CFFC	121	118	295	173	99	40
70: COMUSPACFLT	147	116	232	116	64	22
72: COMNAVRESFOR	0	0	0	0	1	2
76: NETC	0	8	57	34	23	10
88: COMNAVSPECWARCOM	0	1	49	23	18	1

Figure 13. BA before and after optimal price changes for non-medical Staff Corps





Implied changes in output

Using the productivity coefficients and the number of billets in each paygrade, we can calculate a notional output for each BSO under the actual FY10 BA and the optimized BA. The results of these calculations are shown in Table 27, Table 28, and Table 29.

Table 27. URL output associated with FY10 BA and optimized BA

BSO	Output based on		Absolute change	Percent-age change
	FY10 BA	Optimized BA		
11: OPNAV	210.38	210.25	-0.13	-0.06
12: AAUSN	38.11	38.82	0.71	1.85
14: CNR	9.19	9.10	-0.09	-1.02
15: ONI	20.70	21.39	0.69	3.32
18: BUMED	1.98	2.72	0.75	37.88
19: COMNAVAIRSYSCOM	81.84	83.81	1.97	2.40
22: CHNAVPERS	92.57	95.00	2.43	2.62
23: COMNAVSUPSYSCOM	1.00	1.00	0.00	0.00
24: COMNAVSEASYSCOM	37.87	38.39	0.52	1.38
27: CMC	26.23	27.27	1.04	3.95
30: DIRSSP	7.16	6.91	-0.25	-3.47
33: COMSC	18.76	18.65	-0.11	-0.57
39: COMSPAWARSYSCOM	19.74	20.38	0.64	3.26
52: CNI	88.26	91.32	3.07	3.48
60: CFFC	1,154.22	1,224.74	70.53	6.11
70: COMUSPACFLT	1,369.51	1,459.59	90.08	6.58
72: COMNAVRESFOR	11.36	11.28	-0.08	-0.70
76: NETC	339.13	354.61	15.49	4.57
88: COMNAVSPECWARCOM	166.63	169.55	2.93	1.76
URL total	3,694.64	3,884.80	190.16	5.15

Table 28. RL output associated with FY10 BA and optimized BA

BSO	Output based on FY10 BA	Output based on Optimized BA	Absolute change	Percent-age change
11: OPNAV	61.00	56.66	-4.34	-7.11
12: AAUSN	23.50	21.46	-2.04	-8.66
14: CNR	4.33	0.00	-4.33	-100.00
15: ONI	40.06	37.33	-2.72	-6.80
18: BUMED	1.00	1.00	0.00	0.00
19: COMNAVAIRSYSCOM	81.97	76.76	-5.20	-6.35
22: CHNAVPERS	49.17	43.73	-5.44	-11.06
23: COMNAVSUPSYSCOM	1.00	1.00	0.00	0.00
24: COMNAVSEASYSCOM	61.55	58.25	-3.30	-5.36
30: DIRSSP	9.50	0.00	-9.50	-100.00
33: COMSC	1.00	0.00	-1.00	-100.00
39: COMSPAWARSYSCOM	47.78	42.69	-5.09	-10.65
52: CNI	15.76	13.96	-1.79	-11.39
60: CFFC	314.12	283.35	-30.77	-9.80
70: COMUSPACFLT	161.72	145.37	-16.36	-10.11
72: COMNAVRESFOR	9.70	8.66	-1.05	-10.79
76: NETC	55.69	52.89	-2.79	-5.02
88: COMNAVSPECWARCOM	31.83	27.39	-4.44	-13.96
RL total	970.67	870.50	-100.16	-10.32

Table 29. Non-medical Staff Corps output associated with FY10 BA and optimized BA

BSO	Output based on BA	Output based on Optimized BA	Absolute change	Percent-age change
11: OPNAV	120.02	114.57	-5.45	-4.76
12: AAUSN	42.30	41.07	-1.22	-2.97
14: CNR	1.00	1.00	0.00	0.00
15: ONI	1.00	1.00	0.00	0.00
18: BUMED	27.15	26.73	-0.42	-1.57
19: COMNAVAIRSYSCOM	19.95	19.14	-0.81	-4.24
22: CHNAVPERS	10.17	9.32	-0.85	-9.07
23: COMNAVSUPSYSCOM	77.73	78.23	0.50	0.63
24: COMNAVSEASYSCOM	10.87	10.09	-0.78	-7.78
25: COMNAVFACENGCOM	104.28	103.04	-1.24	-1.20
27: CMC	89.34	85.25	-4.08	-4.79
30: DIRSSP	1.39	1.39	0.00	0.00
33: COMSC	9.72	9.08	-0.64	-7.06
39: COMSPAWARSYSCOM	5.83	5.23	-0.61	-11.59
52: CNI	50.52	48.61	-1.91	-3.92
60: CFFC	157.14	153.54	-3.61	-2.35
70: COMUSPACFLT	133.33	130.31	-3.02	-2.32
72: COMNAVRESFOR	2.00	1.45	-0.55	-37.55
76: NETC	33.85	32.17	-1.68	-5.22
88: COMNAVSPECWARCOM	31.24	29.06	-2.18	-7.51
Staff Corps total	928.83	900.28	-28.55	-3.17

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