Synthesis and analysis of future naval fleets*

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Philip C. Koenig, Peter M. Czapiewski and John C. Hootman

Future Concepts and Surface Ship Design Group, Naval Sea Systems Command, Washington Navy Yard, Washington, DC 20376, USA

Abstract: The Naval Sea Systems Command conducted an in-house, interdisciplinary study of alternative fleet architectures with a goal of addressing the high cost and extended duration of naval vessel design and construction. This paper describes the approach used and variables studied in the naval architectural and force architecture components of the study, that is, the fleet synthesis and analysis part. The methods and findings of other recent studies in this subject were reviewed, and an approach was developed that includes capabilities requirements, ship design and cost, and quantitative tracking of the long-term evolution of the fleet as ships are introduced and old ones are retired. It was found that procurement cost could be reduced by consolidating ship and system types; however, this initial result is conditioned by significant restrictions placed on the design space. It is recommended that future studies be pursued using this fleet synthesis method with fewer design constraints.

Key words: Naval ship design, concept design, preliminary design, fleet composition, fleet planning, force architecture.

INTRODUCTION

Designing and planning a future navy having the right composition at a supportable cost is a perennial problem, which has become particularly acute in recent years in the United States due to the "spiraling cost growth in naval vessels" (U.S. Congress 2005). Concern was heightened recently by a flurry of analyses prompted by the Secretary of the Navy's submittal in February 2006 of a report to Congress on the Navy's long-range plan for construction of naval vessels (U.S. Navy 2006). This document, referred to by many as the "30 Year Plan," laid out annual ship purchases and inventory counts for fiscal years 2007 through 2036. This report, and the effort that led to it, spawned numerous studies of future ship concepts and naval fleet mixes by analysts in a number of organizations including think tanks and Government offices.

The Naval Sea Systems Command (NAVSEA) is responsible for U.S. naval ship design and shipbuilding. In an effort to address the high cost of the Navy's shipbuilding plan, NAVSEA formulated and conducted an interdisciplinary Affordable Future Fleet Study (AFFS) during fiscal year 2006. The objective was to conceive and evaluate alternative concepts for the composition or "architecture" of the U.S. Navy over the period covered by the 30 Year Plan. Alternative architectures were conceived, explored, and evaluated using a process that included ship concept design work, cost estimating, and the formulation of build plans. The warfighting capabilities and warfare sufficiency of the alternative fleets were assessed. In addition, warfare systems architectures and alternative acquisition approaches were investigated. This paper focuses on the fleet synthesis and analysis work that was led by NAVSEA's Future Concepts and Surface Ship Design Group. For an overall view of the Affordable Future Fleet Study, including subjects not addressed in this paper; see Goddard *et al*. (2007).

The problem of high-naval shipbuilding costs can be studied from a number of angles, including acquisition strategy, industrial base issues, program management practices (GAO 2005), and others. This study was done from the perspective of ship and force architecture definition, which is a fundamental cost determinant regardless of how any other factors are modified. The scale and scope of this study was different from that of past ship concept design studies done in the Department of the Navy. The objective was not just to design ships, but to design the entire Navy

*This work was part of a multidisciplinary project carried out by several organizations in the Department of the Navy. This paper covers the portion led by Naval Sea Systems Command's Future Concepts and Surface Ship Design Group, and it concentrates on the ship design and fleet architecture elements.

Corresponding Author:
Philip C. Koenig
Future Concepts and Surface Ship Design Group
Naval Sea Systems Command, Washington Navy Yard
Washington, DC 20376, USA
Tel: +1 202 781-3439
Fax: +1 202 781–4572
Email: philip.koenig@navy.mil

and to program a ship-by-ship and year-by-year transition from the currently planned fleet to an alternative fleet. To do this, alternative architectures were backed by ship concept designs, cost estimates, and program plans that specify individual ship purchases, retirements, and inventories on an annual basis, that is, the same level of information that is presented in the 30 Year Plan. The result is that this study offers not only alternative future fleet mixes (as others have done) but also (1) populates them with naval architecturally valid ship concepts and (2) shows how the alternative architectures evolve over time from the existing baseline. This integration of surface ship fleet mixes, ship designs, and long-range evolutionary planning, is new.

Set of major assumptions

To answer specific questions posed by Navy leadership, this study was constrained by a set of major assumptions. Those having the largest impact were the following: (1) no impact to programs of record (existing ship acquisition programs are unchanged), (2) future aircraft carriers are CVN 78 design, (3) submarines remain nuclear powered, (4) all vessels are retained for their full-planned service life (no early retirements or major modernizations), and (5) the naval capabilities in the 30 Year Plan are approximately matched year by year.

THE 30 YEAR PLAN

Congressional legislation requires the Secretary of Defense to submit a 30 Year Plan with the defense budget on an annual basis. The official name of this plan is the *Annual Long-Range Plan for Construction of Naval Vessels*, and it is required to show (U.S. Navy 2006):

1. a detailed program for the construction of combatant and support vessels for the Navy over the next 30 fiscal years,
2. a description of the necessary naval vessel force structure to meet the requirements of the national security strategy of the United States or the most recent Quadrennial Defense Review (QDR), and
3. the estimated levels of annual funding necessary to carry out the program, together with a discussion of the procurement strategies on which such estimated levels of annual funding are based.

The following is excerpted from the fiscal year 2007 30 Year Plan, which was used as the baseline in this study (U.S. Navy 2006):

> Because of the complex configuration and size of naval vessels, design time can range from two to five years and construction time can range from two to seven years and acquisition costs can be substantial. Naval vessels are procured in relatively low rates and a naval vessel's estimated service life is comparatively long: 25 years for smaller ships and up to 45–50 years for ballistic missile submarines and nuclear aircraft carriers. As a result, 30–40 years are required to make a substantial change in the Navy's force structure. With this in mind, the Navy uses a planning methodology that incorporates three specific phases reflecting the appropriate focus of each time period. These are:
>
> *Near-Term*: This period includes the current budget year and future years defense plan (FYDP). During this phase, the Navy endeavors to minimize adjustments to the plan in order to balance the mix of ships, unit cost and resources available in the budget, while addressing industrial and vendor base concerns. Given known requirements and quantities the cost estimates are reasonably accurate.
>
> *Mid-Term*: This period is beyond the FYDP out to approximately 10 to 15 years. Requirements are based on Defense-wide planning scenarios and incorporate intelligence assessments of future threats and operating environments. Cost estimates are representative based on delivering ship classes started in the near-term.
>
> *Far-Term*: This period begins 15 or more years into the future. Because the requirements are not clear, the number and type of ships are estimated based on Joint and internal Navy analytical efforts. Cost estimates in this period are notional due to uncertainties in requirements, quantities, business conditions/costs and various other uncertainties associated with the shipbuilding industry and the needs of the Navy.

Figure 1 shows two views of the 30 Year Plan as contained in the fiscal year 2007 submission to Congress. These views indicate that there is a complex balance between ship acquisition/industrial base concerns and battle force inventory levels over time.

REVIEW OF RECENT GOVERNMENT STUDIES

Articles addressing various aspects of naval force planning appear regularly in the *Naval Institute Proceedings, Naval War College Review,* and elsewhere. Some articles concentrate on ideas for ship designs, others on historical lessons; there are other general approaches as well. Recently, there have been several government-commissioned studies on the synthesis of future fleets from a combined perspective incorporating views of ship concepts, fleet mixes, and costs. In late 2003, Congress

> . . . required the Secretary of Defense to provide for two independently performed studies on potential future fleet platform architectures (i.e., potential force structure plans) for the Navy. The two studies, which were conducted by the Center for Naval Analyses (CNA) and the Office of Force Transformation (OFT, a part of the Office of the Secretary of Defense), were submitted to the congressional defense committees in February 2005. (O'Rourke 2006)

O'Rourke (2006) provides a summary and discussion of three studies: OFT, CNA, and an additional report by Work (2005). Here, we review the Congressionally mandated work by CNA and OFT, plus a report by the Institute

30 Year Plan Purchase Plans

	Near Term					Mid Term									Far Term															
Type/Class	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
Aircraft Carrier		1				1				1					1				1				1					1		
Surface Combatants	2		1	1	2	1	2	1	2	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Littoral Combat Ships	2	3	6	6	6	6	5	6	6	5														1	3	2	3	6	6	6
Attack Submarines	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	2	1	2	1	2	1	2
Cruise Missile Submarines																														
Ballistic Missile Submarines																1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Expeditionary Warfare Ships	1	1		1								1			1	1	1	2	1	1	2	2	1	2	1	1	1			1
Combat Logistics Force	1	1										1		1	2	2	2	2	3	3	2	1								
Mine Warfare Ships																														
Maritime Prepo Force (Future)			2	2	4	2	1																							
Support Vessels			1	1	1	1	2	2	1	1					1	2	3	2		1	1		1	2						
Total New Construction Plan	7	7	11	12	14	13	12	11	11	10	4	6	4	5	9	10	11	11	10	10	10	8	7	10	8	8	8	12	10	11

Ref: FY 2007 Annual Long-Range Plan for the Construction of Naval Vessels, Report to Congress, January 31, 2006

30 Year Plan Battle Force Count

	Near Term					Mid Term									Far Term															
Type/Class	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
Aircraft Carrier	11	11	11	11	11	11	10	10	11	11	11	11	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
Surface Combatants	105	108	110	112	113	112	106	99	93	91	92	93	93	94	95	93	93	93	92	89	88	87	85	82	79	77	75	73	73	73
Littoral Combat Ships	1	4	6	9	15	21	27	33	38	44	50	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55
Attack Submarines	52	53	54	53	53	54	55	53	52	50	50	48	48	47	47	47	46	45	44	43	42	40	40	41	42	44	46	48	49	51
Cruise Missile Submarines	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	2	1	0	0	0	0	0	0	0	0
Ballistic Missile Submarines	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	13	12	11	12	13	12	12	12
Expeditionary Warfare Ships	34	33	33	33	33	33	32	32	31	31	31	31	31	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
Combat Logistics Force	32	35	35	33	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
Mine Warfare Ships	14	14	14	14	14	14	14	14	14	14	13	12	10	8	6	5	2	1	0	0	0	0	0	0	0	0	0	0	0	0
Maritime Prepo Force (Future)	0	0	0	0	0	2	4	7	10	11	11	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
Support Vessels	18	18	18	18	19	20	21	19	17	17	18	20	21	21	21	21	22	23	21	22	22	22	22	22	21	22	21	21	21	21
Total Naval Force Inventory	285	294	299	301	306	315	317	315	314	317	324	330	330	327	326	323	320	319	314	311	307	303	299	296	292	294	294	293	294	296

Ref: FY 2007 Annual Long-Range Plan for the Construction of Naval Vessels Report to Congress, January 31, 2006

Figure 1 30 Year plan representations.

for Defense Analyses (IDA; a Federally funded research and development center) along with an additional U.S. Government report from the Congressional Budget Office.

Institute for Defense Analyses study

Greer *et al*. (2005) at the Institute for Defense Analyses (IDA) addressed the question, "are there alternative architectures" that can preserve or improve naval capabilities under "budgetary and geopolitical constraints." Their work was an input to OFT. IDA's approach was (1) identification of an irreducible set of naval capabilities, (2) reflection on the general nature of the geopolitical situations that a future navy might encounter, (3) consideration of new technology, recently proposed ship designs, and shipbuilding costs to propose new platforms, (4) identification of several alternative architectures using these platforms, chosen as comparable in cost with the programmed fleet, (5) development of a set of quantitative metrics to compare capabilities among alternative fleets, and (6) assessment of alternative fleets relative to the current and programmed ones.

IDA focused on the year 2030 in which current and programmed fleets "could realistically be replaced entirely by a completely new design ship" and examines the finished product or "end state" of the fleets. They did not consider "intermediate stages of evolution from current to one of the alternatives, with mixed fleets over time." Force attributes used to select alternative architectures were those proposed by OFT: flexibility, adaptability, agility, speed, and information dominance through networking.

The methodology of the IDA study was of interest to the AFF study team, but the fleet designs and conclusions are not comparable for several reasons, chief among them being (1) Greer and coworkers were not constrained by programs of record nor by carrier and submarine designs and (2) their fleet architectures were point designs at year 2030 whereas a key feature of the AFF study was that it used evolutionary programming, covering the entire period of the 30 Year Plan. Relaxing the constraints on submarine options freed up IDA's design space considerably. For example, in all of IDA's alternative fleets, nuclear attack submarines in carrier strike groups were replaced by nonnuclear air-independent submarines estimated by IDA at one quarter the cost per boat. This provided a lot of cost leverage, but it was not applicable to the AFF study. Within their ship design and fleet architecture constraints and evaluation criteria, Greer and coworkers recommended that a larger fleet with smaller ships was the best solution.

Office of Force Transformation study

The OFT study was reported by Johnson and Cebrowski (2005) with a short summary by Holzer (2005). It presents intriguing alternative fleet architectures based on a design philosophy grounded in the following "rules": (1) capabilities of a fleet are decoupled from platforms, (2) power and survivability of a fleet have been decoupled from size, (3) information has been substituted for mass, (4) sensor proximity and persistence will drive the utility of weapons reach, (5) mass customization delivers greater value than mass production, and (6) networked components outperform integrated systems. From this, three alternative fleet architectures were formulated, all asserted to be at roughly the same cost as the currently programmed fleet. Key features are (1) the greater number of smaller ships with lower unit cost; (2) ships can carry different modules depending on mission; (3) combat aviation is carried on a large number of smaller carriers; (4) some nuclear attack submarines are replaced by air independent diesel submarines; and (5) unmanned vehicles are used for many surveillance, anti-submarine warfare, and mine warfare missions.

OFT maintains that its design philosophy is "on the right side of trends in technology" (Johnson and Cebrowski 2005). It is further asserted to confer numerous warfighting advantages such as scalability, adaptability, and so on. However, replacing nuclear-powered aircraft carriers with smaller aviation ships, introducing diesel submarines, and other innovations go beyond the bounds of the AFF study assumptions. Therefore, the AFF study group was not able to adopt OFT's force architecture concepts.

Center for Naval Analyses study

The Congressionally requested study done by CNA is reported in Gilmore (2005). This study considered future changes in the composition and size of the Navy compared to the projections in the 2001 Quadrennial Defense Review. The analysts restricted themselves to consideration of programs of record platforms and systems—no new ship designs are proposed. This highly restrictive assumption ruled out naval architectural innovation as a means to solve the Navy's cost problems. This approach is not useful for guiding a naval architectural study, but it provides a useful, documented boundary condition. On the other hand, CNA concentrated on military strategy and presence. Maintenance cycles, deployment lengths, crewing strategies, etc. were analyzed in a manner that is consistent with the presence calculations done in the fleet synthesis part of the AFF study.

Congressional Budget Office study

Labs (2003) examines the Navy's problem of planning a build-up to a fleet of over 300 ships while staying within achievable levels of ship acquisition (SCN) funding. Labs' approach takes account of the transition from today's fleet to the future fleet, and his general objective is rather similar to that of the AFF study. But the assumptions are different and the scope is restricted to surface combatants. Peacetime and wartime capability of fleet options were evaluated but without access to the campaign analysis models that the Navy uses to analyze the demand for ships during wartime. Three options are proposed; the first two do not meet key assumptions of the AFF study. The third option, "buy fewer next-generation ships by assigning multiple crews to new ship classes" invokes a sea-swap-like concept. Although this was found to have advantages in terms of peacetime capability, it has "a lower wartime capability, as multiple crews provide no extra benefit during war" (Labs 2003). The AFF study invoked sea-swap-like concepts for surface combatants and fleshed out the implications through a detailed analysis of required peacetime presence and wartime sufficiency.

Labs notes that the direction the Navy's force architecture takes after 2025 "will be determined largely by what the Navy decides to do with its Arleigh Burke class destroyers." He mentions that "historically, surface combatants become less effective in wartime operational environments well before the end of their notional 35-year service lives in the absence of midlife improvements to their combat systems." Consideration of these issues was outside the bounds of the AFF study; one of the major assumptions of which was that all ships were sustained for their full-service lives with no major modernization or early retirement. Congressional Budget Office (CBO) later broadened its scope of analysis to encompass the entire fleet including aircraft. This was reported in Labs (2006) in which "the main conclusion of CBO's analysis is that unless shipbuilding budgets increase significantly in real (inflation-adjusted) terms or the Navy designs and builds much cheaper ships, the size of the fleet will fall substantially. In some cases, however, the fleet's capability would not decline commensurately with the decrease in size."

Use of these studies

The AFFS team took the results of the studies and others into account when formulating fleet options and ship concept designs. Differences in assumptions and study goals made it impossible to directly incorporate future ship point designs from any of the other studies; still, they provided valuable insight, especially into operational and service life issues. For comparative purposes, it can be helpful to consider where a proposed future fleet architecture lies along the spectrum of innovation from constrained (conservative thinking, mild technological development, focus on one variable, minimal program impact, etc.) to unconstrained (speculative thinking, aggressive technology development, multivariate, rapid change of entire fleet, etc.). Location along this spectrum is largely a function of the variables that are to be isolated, which in turn drives the rules and assumptions imposed. The AFF study is located near the constrained end of this spectrum (Figure 2).

FLEET SYNTHESIS AND ANALYSIS WORKFLOW

Based on the literature search, discussions with planners in the Pentagon, and brainstorming, the team developed and evaluated fleets based on consideration of ship characteristics, ship concept designs, shipbuilding program planning, and overall programmed costs and mission sufficiency. The principal steps in the process or workflow are laid out in Figure 3.

Step 1: Define the baseline fleet architecture

Step 1 in the workflow was to define the architecture of the baseline fleet (i.e., the Navy's existing plan for shipbuilding) in terms of tactical groups, warfare system counts, and presence. Future naval capabilities were gauged by tactical

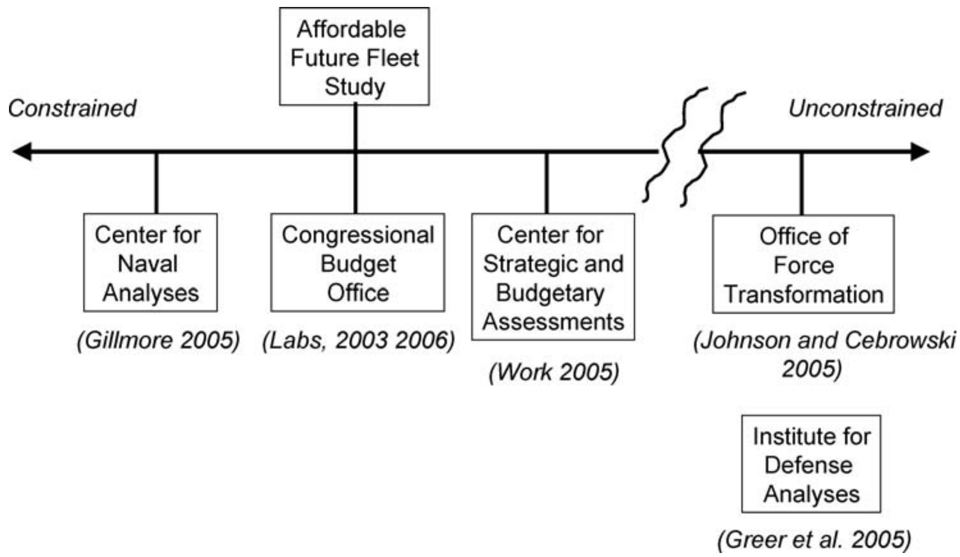

Figure 2 Recent fleet architecture studies: The spectrum of innovation.

groups, as this allowed individual ship class designs to vary within a design trade space, without having to make changes in military doctrine. The tactical groups used were the carrier strike group (CSG), expeditionary strike group (ESG), assured access group (AAG), theatre air and missile defense surface action group (TAMD SAG), and the maritime prepositioning squadron future (MPF(F)). For each tactical group, warfare systems and capacities were tabulated. For example, ESG capacities include troops carried, vehicle area, helicopter spots, and so forth; the CSG and TAMD SAG systems needed to include certain levels of radar performance, etc.

For carriers, amphibious assault ships, and support ships, the number of ships in the fleet was taken as a function of the number of tactical groups, for example, 11 carrier strike groups means 11 carriers. However, for surface combatants an additional requirement comes into play, and that is peacetime presence. A defined mix of ships is required on station at all times, at designated locations around the world. For each surface combatant required on station at a given location, a presence multiplier was derived to allow for back inventory needed due to operational availability, time in theatre, transit time, and other considerations of the sort that might be familiar to an operations manager in a large commercial shipping company. The presence multiplier is applied to the number of ships required to determine the number of ships needed in the fleet (by this criterion). The multiplier can be reduced by

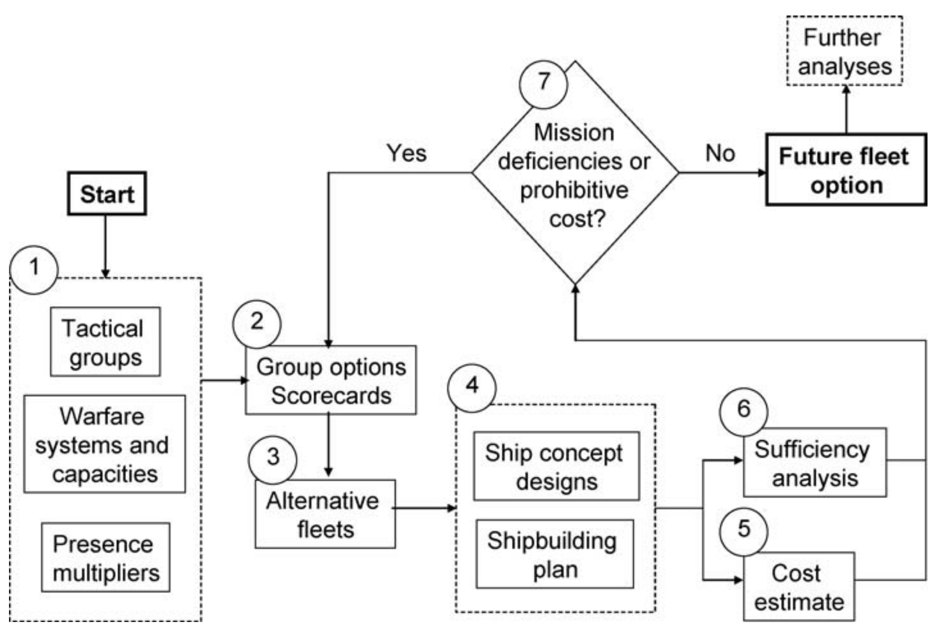

Figure 3 Essential steps in the fleet synthesis and analysis workflow.

forward basing, crew-swapping arrangements, and other means.

Step 2: Generate ship-type options

Four ship-type groups were studied in depth: surface combatants, amphibious assault ships, combat logistics vessels, and submarines. For each of these, brainstorming was used to conceive three to five options for combinations of these ships that were comparable in capacity to the baseline fleet but had the potential to have lower acquisition costs. Within the four ship-type groups, various approaches to new ship concepts were explored. As an initial cut, the sizes of the ship concepts were estimated parametrically. An initial assessment was done subjectively by the following criteria: (1) cost, (2) mission capability, (3) operational flexibility, (4) adaptability, (5) ability to transition beyond the program of record, (6) commonality, and (7) criteria specific to individual tactical groups.

Step 3: Assemble alternative fleets

By selecting from the options that received satisfactory scorecards in step 2, three alternate fleets were assembled under the design themes of (1) maximum reuse of existing designs, (2) minimum number of ship types, and (3) maximum use of modularity. These fleets were essentially evolutionary from the 30 Year Plan. Ideas for transformational fleet architectures had been considered early in the study; however, they were not pursued, as they were incompatible with the assumption that our alternative fleets would not cause changes in existing ship acquisition programs ("programs of record"). Each of the three alternate fleets used the CVN 78 as well as the program of record for MPF(F) and a common set of commercially based support ships.

Step 4: Establish technical and program characteristics of the alternative fleets

For the alternative fleets, ship concept designs were carried out and build plans were put together. In NAVSEA, ship concept designs are done to specified levels of effort. For this study, the Rough Order of Magnitude level was appropriate, that is, design information was defined at the one digit ship work breakdown structure (SWBS) level using ASSET (advanced ship and submarine evaluation tool) and other methods. The ship concept designs were assembled into working ship construction "build plans." A year-by-year running inventory resulted from a juggling of fleet need dates, acquisition lead times, service lives, and some rough shipyard loading considerations. A sample working build plan showing some surface ship elements from an intermediate stage of the study is shown in Figure 4. For each ship category shown in the chart, new concept designs as well as those already in the 30 Year Plan are indicated.

Steps 5 and 6: Ship acquisition cost estimates and sufficiency analysis

NAVSEA's cost engineering group provided acquisition cost estimates for each ship in the three themed fleets and developed an acquisition funding profile covering 2007 through 2036. The estimates were based on the concept designs and included nonrecurring engineering costs for detailed design as well as construction costs. Sufficiency analyses were done (by other team members) for the surface combatants in the three alternate fleets in both wartime and

	FY	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Amphibs (Option 5)	LPD-17 (30 Yr. Plan)	1		1														
	LHA-6 (30 Yr. Plan)		1															
	LHD-8															1		
	LPD-17													1			1	1
CLF (Option 2)	T-AKE (30 Yr. Plan)	1	1	1														
	T-AKE					1		1		1		1						
	T-AO(X)												1		1	2	2	2
Surface Combatants (Option 1A)	LCS (30 Yr. Plan)	3	2	3	6	6	6	6	5	6	6	5						
	DDG-1000 (30 Yr. Plan)		2		1	1	1	1	1									
	DDG-1000 (additional)										1	1	1	1	1	1		
	DDG-1000 (AAW variant)								1	1	2	2	3	2	3	2	3	2
	LCS(X)																	
Sea Basing	T-AKE(mod) (30 Yr. Plan)				1	1	1											
	LHA(R)(mod) (30 Yr. Plan)					1			1									
	LMSR(mod) (30 Yr. Plan)					1	1	1										
	MLP (30 Yr. Plan)				1		1	1										

	FY	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
Amphibs (Option 5)	LPD-17 (30 Yr. Plan)																		
	LHA-6 (30 Yr. Plan)																		
	LHD-8	1	1	1	1	1	1	1	1	1	1			1			1		
	LPD-17		1	1		1	1		1	1									
CLF (Option 2)	T-AKE (30 Yr. Plan)																		
	T-AKE																		
	T-AO(X)	2	3	3	2	1													
Surface Combatants (Option 1A)	LCS (30 Yr. Plan)																		
	DDG-1000 (30 Yr. Plan)																		
	DDG-1000 (additional)																		
	DDG-1000 (AAW variant)	3	2	3	2	3	2	3	2	3	2	3	2	3	2	3	2	3	2
	LCS(X)								1	3	2	3	6	6	6	6	5	6	6
Sea Basing	T-AKE(mod) (30 Yr. Plan)																		
	LHA(R)(mod) (30 Yr. Plan)																		
	LMSR(mod) (30 Yr. Plan)																		
	MLP (30 Yr. Plan)																		

Figure 4 Notional working build plan for some surface ship elements (not final).

Table 1 **Surface ship designs in the 30 year plan fleet, themed fleets, and end-state AFFS fleet**

	30 Year Plan	Theme 1: Design re-use	Theme 2: Fewer ship types	Theme 3: Modularity	AFFS fleet (least acquisition cost)
Carrier	CVN 78	CVN 78	CVN 78	CVN 78	CVN 78
Amphibious	LHD 8 LPD 17 LHD (X)	LHD 8 LPD 17	LH (X)	L(X)	L(X)
CLF	T-AO 187/201 AOE 6 T-AKE T-AO(X) T-AOE(X)	T-AKE T-AO(X)	T-AKE T-AO(X)	T-AKE T-AKO	T-AKE T-AO(X)
Surface combatant	DDG 1000 CG(X) DDG(X) LCS(X)	DDG 1000 DDG 1000 AAW LCS(X)	DDG 1000 DDG 1000 AAW Small focused	DDG 1000 Large Multi LCS(X)	DDG 1000 DDG 1000 AAW New cruiser variant Small focused

Ships in the 30 Year Plan are programs of record.

peacetime. Wartime analysis included examining warfighting scenarios to evaluate each fleet option's sufficiency to meet critical operational tasks. A sufficient alternative fleet was defined as one matching the capability of the 30 Year Plan fleet, year by year. The capability of the carriers and amphibious ships were assessed using the capacity counts defined in step 2, whereas surface combatants were examined in more detail using a spreadsheet-based sufficiency analysis.

Step 7: Check and iterate

The process was set up to allow additional iterations of the synthesis loop. If steps 5 and 6 resulted in alternate fleets that were less costly than the baseline and that had sufficient warfighting capability, then the final step was to pick the lowest acquisition cost option for each ship type grouping (amphibious, submarine, combat logistics force, surface, and combatant). Otherwise, the process could be iterated beginning again at step 2. A second iteration was not performed in this study because the final sufficiency analysis and cost estimates showed the AFF study fleet to be adequate with only minor changes in quantity of ships to improve warfighting capability and satisfy industrial base concerns.

RESULTS

Starting with the baseline 30 Year Plan fleet, the fleet synthesis and analysis workflow described above were applied subject to the set of major assumptions. Given the constrained design space (existing programs must be completed, capabilities of proposed fleets match those of the 30 Year Plan fleet, ships serve to their full service lives, no changes to carrier design, submarines are nuclear powered, etc.), it was inevitable that the resulting future fleet architectures were composed of evolutionary rather than revolutionary ship designs. Three future fleet

Table 2 **Surface ship designs in the AFFS fleet**

Ship concept	Type	Notes
CVN 78	Aircraft carrier	Program of record
L(X)	Amphibious assault	AFFS new concept design. The amphibious assault ship component of an AFFS fleet's expeditionary strike group is composed of three L(X) ships
T-AKE	Logistics (dry cargo)	Program of record
T-AO(X)	Logistics (oiler)	AFFS new concept design. T-AO(X) and T-AKE are the AFFS fleet's combat logistics force
DDG 1000	Surface combatant	Program of record
DDG 1000 AAW	Surface combatant	AFFS modified-repeat concept design; a DDG 1000 variant tuned for anti-air warfare
New Cruiser variant	Surface combatant	AFFS modified-repeat concept design; a surface combatant tuned for air and missile defense
Small Focused	Surface combatant	AFFS new concept design; smaller than DDG 51, larger than LCS

architectures were built from ship concepts motivated by three design themes: design reuse, fewer ship types, and modularity. Within the study constraints, none of these led to significant acquisition cost benefits. Therefore, a fleet was assembled by choosing the lowest acquisition cost bits from among the themed fleets. This AFFS fleet showed an estimated 4% reduction in procurement cost compared to the Navy's 30 Year Plan baseline. The composition of the surface ship component of the themed fleets and the AFFS fleet is shown in Table 1, and a general idea of what kinds of ships are included is given in Table 2.

The relatively marginal cost saving obtained by the least-cost fleet (AFFS fleet) is principally due to the conservative major assumptions, combined with the long life of naval ships. Greater savings are expected if the design space is opened further. The AFFS fleet is a conservative excursion from today's plan, and pre-AFFS fleet ships are not completely removed until 2036 due to their long service life. This suggests that, considering current capabilities needs, the existing fleet is reasonably positioned within the currently specified fleet architecture design space. Broadening the bounds of the design space would require relaxing major study assumptions, changing peacetime or wartime concepts of operations, or other changes. This is discussed below under "recommendations for future work."

CONCLUSIONS

With acquisition cost reduction in mind, a systematic, quantitative approach to synthesizing an alternative naval fleet was developed that takes account of the main drivers: naval architecture, shipboard warfare systems, ship service life, new construction program planning, and naval operations in peacetime and wartime. Two key features of this study were (1) explicit checking of ship designs and fleet architectures for peacetime presence and warfighting sufficiency and (2) tracking of the retirement of older ships and their replacement with future concepts. This highlighted the lag between initial ship design, and realization of a fleet in which that design is not only present, but is the dominant component in its type. These two features are absent from many other fleet architecture studies in the literature, and failure to consider them can encourage an inadequate appreciation of the magnitude of effort required to affect large changes in naval force architectures, given a large existing navy.

The lowest-cost alternative (the AFFS fleet) was estimated to have an acquisition cost 4% lower than that of the currently planned fleet. This relatively modest cost advantage is attributable to the major study assumptions that limited the design space. These assumptions were put in place, so that this initial study would transition smoothly from the existing naval ship inventory and acquisition programs; as in other techno-economic areas, smooth transition leads to gradual change. This was a reasonable strategy for this study, as radical future fleet architectures were already well documented in the recent literature.

Recommendations for future work

This initial study was limited by a relatively confining set of major study assumptions (constraints). These can be relaxed for future studies. One key major assumption called for changes in service life to be disallowed; this kept the scope of the study tractable within the allotted time and budget. The problem is that early retirement and the reverse (service life extension via modernization) are realistic scenarios that do happen. They have been cited in other fleet architecture studies, and furthermore they have a large impact on the year-by-year evolution of the future fleet. Including variable service lives in future fleet architecture studies is recommended (especially for surface combatants).

This study was a first attempt by NAVSEA ship designers to address long-term force structure issues. Our 30-year planning horizon is unique; the Secretary of the Navy recently remarked "how often does a customer lay out the broad outlines of his entire acquisition structure for the next 30 years?" (Winter 2007). Some challenges we faced, which are amenable to being addressed in future studies, are (1) accounting for capability attenuation as a function of time and technological advancement, (2) postulating future requirements, and (3) predicting how future fleets will operate and how future tactical groups will be organized.

The fleet synthesis and analysis workflow were developed and applied by a team led by ship concept designers supported by other disciplines, but the workflow is also suited to studies concentrating on exploring variables in other areas (operations, industrial policy, warfare systems engineering, technology forecasting, etc.) with support from ship concept designers. This workflow is well suited to synchronizing future analyses with planners in other naval offices.

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