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CONGRESSIONAL BUDGET OFFICE

CBO

An Analysis of the Navy's Fiscal Year 2017 Shipbuilding Plan

FEBRUARY 2017

Notes

Unless otherwise indicated, all years referred to in this document are federal fiscal years, which run from October 1 to September 30 and are designated by the calendar year in which they end, and all dollar amounts reflect budget authority in constant 2016 dollars.

Numbers in the text and tables may not add up to totals because of rounding.

The data underlying the figures in this report are posted along with the report on CBO's website.

On the cover:

Top left: Ohio class ballistic missile submarine USS *Wyoming* (SSBN-742). Photo by Mass Communication Specialist 1st Class Rex Nelson, U.S. Navy.

Top right: San Antonio class amphibious transport dock ship USS *Green Bay* (LPD-20). Photo by Mass Communication Specialist 3rd Class Christian Senyk, U.S. Navy.

Center: Nimitz class aircraft carrier USS *George Washington* (CVN-73). Photo by Petty Officer 3rd Class Dary M. Patten, U.S. Navy.

Bottom left: The lead ship of the current class of destroyers, USS *Zumwalt* (DDG-1000). U.S. Navy photo.

Bottom right: The lead ship of the current class of attack submarines, USS *Virginia* (SSN-774). Photo by Journalist 2nd Class Christina M. Shaw, U.S. Navy.

Contents

An Analysis of the Navy's Fiscal Year 2017 Shipbuilding Plan

Summary

The Department of Defense (DoD) submitted the Navy's 2017 shipbuilding plan, which covers fiscal years 2017 to 2046, to the Congress in July 2016.[1] The average annual cost of carrying out that plan over the next 30 years—about $21 billion in 2016 dollars, the Congressional Budget Office estimates—would be one-third more than the average amount of funding that the Navy has received for shipbuilding in recent decades. The Navy's 2017 shipbuilding plan is similar to its 2016 plan with respect to the goal for the total inventory of battle force ships, the number and types of ships that the Navy would purchase, and the funding proposed to implement its plans.

The Navy's 2017 Plan Aims to Expand the Fleet to 308 Battle Force Ships

In November 2016, the fleet numbered 272 battle force ships—aircraft carriers, submarines, surface combatants, amphibious ships, combat logistics ships, and some support ships. (Other support ships are not included in that number.) The Navy's goal (in military parlance, its requirement), as stated in its 2017 shipbuilding plan and reflecting its 2014 force structure assessment, was to maintain a fleet of 308 battle force ships. Toward that end, the Navy would buy a total of 254 ships over the 2017–2046 period: 209 combat ships and 45 combat logistics and support ships (see Table 1). If the Navy adhered to its current schedule for retiring ships, it would meet the goal of 308 ships under the 2017 plan by 2021, and it would be able to maintain its inventory at that level or higher through 2028. After that, however, the fleet would fall below 308 ships. By the 2030s, the fleet would number fewer than 300 ships.[2]

In mid-December 2016, the Navy released a new force structure assessment, which called for building a fleet of 355 ships.[3] This CBO report assesses the projected outcomes under the 2017 plan against the 308-ship goal set in the 2014 force structure assessment that was in effect when the plan was written, rather than against the larger December number.

The 2017 shipbuilding plan falls short of the 2014 force structure assessment's specific goals for some types of ships in some years. With the exception of small surface combatants, the shortfalls are slightly smaller than those in the plans for the previous two years, which also incorporated a goal of 308 ships. But when compared with the 355-ship target called for by the new 2016 force structure assessment, the current plan falls short of the specific goals for most types of ships by larger amounts.

1. Department of the Navy, *Report to Congress on the Annual Long-Range Plan for Construction of Naval Vessels for Fiscal Year 2017* (July 2016), https://news.usni.org/2016/07/12/20627.

2. Although most new ships are built to replace older ships as they retire (such as the new ballistic missile submarines that are proposed for the 2020s and 2030s), the Navy sometimes builds ships to fulfill a new mission or to satisfy a specific need. For example, several years ago, the Navy canceled the DDG-1000 destroyer program and restarted its DDG-51 destroyer line after assessing the need for different types of ships. The new Montford Point class of expeditionary transfer docks represents a new type of ship meeting a new need for the Navy.

3. Department of the Navy, *Executive Summary, 2016 Navy Force Structure Assessment (FSA)* (December 14, 2016), http://tinyurl.com/zgdk5o7.

Table 1.

The Navy's 2016 and 2017 Shipbuilding Plans

	2016 Plan (2016–2045)	2017 Plan (2017–2046)	Change From 2016 to 2017
		Number of Ships Purchased Over 30 Years	
Combat Ships			
Aircraft carriers	6	6	0
Ballistic missile submarines	12	12	0
Attack submarines	45	44	-1
Large surface combatants	65	66	1
Small surface combatants	67	58 [a]	-9
Amphibious warfare ships	23	23	0
Subtotal	218	209	-9
Combat Logistics and Support Ships	46	45	-1
Total	**264**	**254**	**-10**
		Costs of New-Ship Construction[b] (Billions of 2016 dollars)	
Total Cost Over 30 Years			
Navy's estimate	503	509	6
CBO's estimate	562	566	4
Average Annual Cost			
Navy's estimate	16.8	17.0	0.2
CBO's estimate	18.7	18.9	0.2
Average Cost per Ship			
Navy's estimate	1.9	2.0	0.1
CBO's estimate	2.1	2.2	0.1
Memorandum:			
Average Annual Costs of All Activities Typically Funded From Budget Account for Ship Construction			
Navy's estimate	18.6	18.8	0.2
CBO's estimate	20.5	20.7	0.2

Source: Congressional Budget Office, using data from the Department of the Navy.

a. Under the 2017 plan, the Navy would have 40 small surface combatants in service after 2029. However, because each of those ships is expected to be in service for 25 years, the Navy would begin buying replacements in 2029.

b. Amounts shown for new-ship construction exclude the costs of refueling nuclear-powered aircraft carriers and of other items funded by the Navy's shipbuilding account, including ship conversions, construction of ships that are not part of the Navy's battle force (such as oceanographic survey ships), training ships, and outfitting and postdelivery activities (which include the purchase of smaller tools and pieces of equipment that are needed to operate a ship but that are not necessarily provided by the manufacturing shipyard as part of ship construction). The costs of the mission packages for littoral combat ships, which are not funded by the Navy's shipbuilding account, are also excluded.

The size of the Navy does not depend on ship construction alone; the length of time that particular ships remain in the fleet also affects the force structure. The Navy often shows flexibility in its approach to retiring ships: A ship may be retired before the end of its service life to save money or kept beyond it to maintain a desired force level. Generally, the Navy's estimates of expected service life align with historical experience. However, in its current plan, the Navy assumes a 35- or 40-year service life for its large surface combatants despite the fact that, in the past, few of those ships remained in the fleet for longer than 30 years. (See Table 2 for the composition of the fleet and the planned service life of the major types of ships.) If those surface combatants were to have a shorter service life than projected in the Navy's plan, then the shortfalls in the number of those ships would be larger than those shown in the 2017 plan.

Table 2.

The Navy's Inventory of Ships and Their Expected Service Life, by Major Ship Type, as of November 2016

	Inventory	Service Life (Years)
Aircraft Carriers	10	50
Ballistic Missile Submarines	14	42
Guided Missile Submarines	4	42
Attack Submarines	52	33
Large Surface Combatants	85	35–40
Small Surface Combatants and Mine Countermeasures Ships	19	25–30
Amphibious Warfare Ships	31	40
Combat Logistics and Support Ships	57	30–45
Total	**272**	

Source: Congressional Budget Office, using data from the Department of the Navy.

CBO Estimates That Spending for New Ships in the Navy's Plan Would Average $18.9 Billion per Year

The Navy estimates that buying the new ships specified in the 2017 plan would cost $509 billion (in 2016 dollars) over 30 years, or an average of $17.0 billion per year—slightly more than the amount that the Navy estimated the construction of new ships would be under its 2016 plan. Using its own models and assumptions, CBO estimates that those new ships would cost a total of $566 billion (in 2016 dollars) over 30 years, or an average of $18.9 billion per year.

CBO's estimates are higher because its estimating methods and assumptions regarding future ships' design and capabilities differ from those that the Navy uses and because its treatment of growth in the costs of labor and materials for building ships is different from the Navy's. CBO's constant-dollar estimate is 2 percent higher than the Navy's for the first 5 years covered in the plan, 6 percent higher for the next 5 years, and 15 percent higher for the final 20 years (see Figure 1).[4] The difference widens over time in part because the Navy's method of developing constant-dollar estimates does not account for the faster growth in the costs of labor and materials in the shipbuilding industry than in the economy as a whole and thus does not reflect the increase in the real (inflation-adjusted) costs of ships with today's capabilities that would be anticipated if such ships were purchased in the future.

The Navy's shipbuilding plan reports only the costs of new-ship construction. It excludes other activities typically funded from the Navy's budget account for ship construction—such as refueling nuclear-powered aircraft carriers or outfitting new ships with various small pieces of equipment after they are built and delivered—that would, by CBO's estimate, add $1.8 billion to the Navy's average annual shipbuilding costs under the 2017 plan. (From 2011 to 2016, the cost of those other activities averaged $2.0 billion per year.) CBO estimates that with those extra costs included, the average annual cost of the Navy's 2017 plan would be $20.7 billion per year—10 percent greater than the Navy's estimate with those additional costs added in.

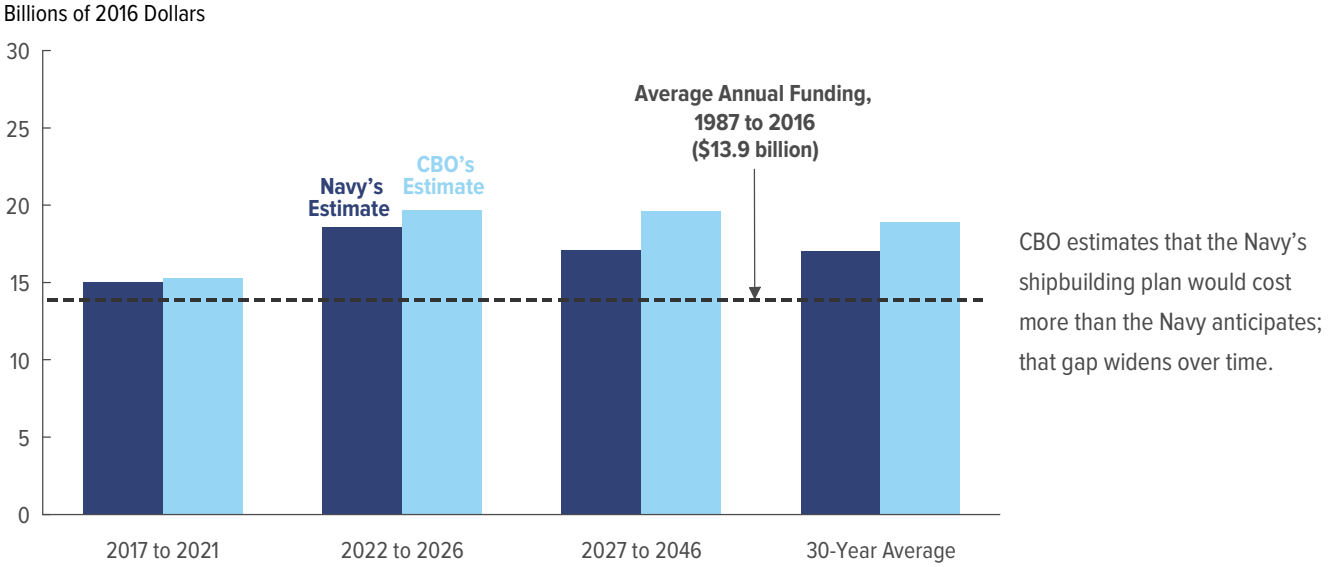
The Navy's Shipbuilding Plan for the Next 30 Years Would Cost Almost One-Third More Than It Has Spent Over the Past 30 Years

If the Navy received the same average annual amount of funding (in constant dollars) for ship construction in each of the next 30 years that it received over the past three decades, the service would not be able to afford its 2017 plan. CBO's estimate of $18.9 billion per year for new-ship construction under the Navy's 2017 shipbuilding plan is 36 percent more than the historical average of $13.9 billion (in 2016 dollars) in annual funding for new-ship construction. CBO's estimate of $20.7 billion per year for the full cost of the plan is 30 percent higher than the $15.9 billion the Navy has spent annually, on average, over the past 30 years for all activities funded by its shipbuilding account. If funding continued at its 30-year average, under one possible approach to ship construction, the Navy would be able to build about 74 fewer battle force ships than it currently plans, CBO estimates. Conversely, a notional fleet of 350 ships, which some policymakers have called for and which is similar in size to the goals articulated by the Navy in its December 2016 force structure assessment, could cost $25 billion per year, or 60 percent above the historical average.

4. The Navy restructured the time frames in its shipbuilding plan this year. Whereas in the past the Navy divided the plan by decade, the 2017 plan defines the near term as the first 5 years (the same period as the Department of Defense's Future Years Defense Program), the midterm as the second 5 years, and the far term as the final 20 years.

Figure 1.

Average Annual Costs of New-Ship Construction Under the Navy's 2017 Plan



Source: Congressional Budget Office, using data from the Department of the Navy.

Amounts shown exclude the costs of refueling nuclear-powered aircraft carriers and of other items funded by the Navy's shipbuilding account, including ship conversions, construction of ships that are not part of the Navy's battle force (such as oceanographic survey ships), training ships, and outfitting and postdelivery activities (which include the purchase of smaller tools and pieces of equipment that are needed to operate a ship but that are not necessarily provided by the manufacturing shipyard as part of ship construction). The costs of the mission packages for littoral combat ships, which are not funded by the Navy's shipbuilding account, are also excluded.

Implementing the Navy's Shipbuilding Plan Might Be Difficult Under Current Law

For 2017 through 2021, the Navy's shipbuilding plan incorporates the assumption that total discretionary funding for DoD will accord with the President's 2017 budget submission and the associated 2017 Future Years Defense Program (FYDP; a five-year funding plan that DoD updates annually). However, the funding proposed in the 2017 FYDP exceeds the amounts available to DoD under current law: The Budget Control Act of 2011 (BCA) placed caps on both defense and nondefense discretionary spending that remain in effect through 2021. (The BCA does not address specific budget accounts such as the one for shipbuilding.)

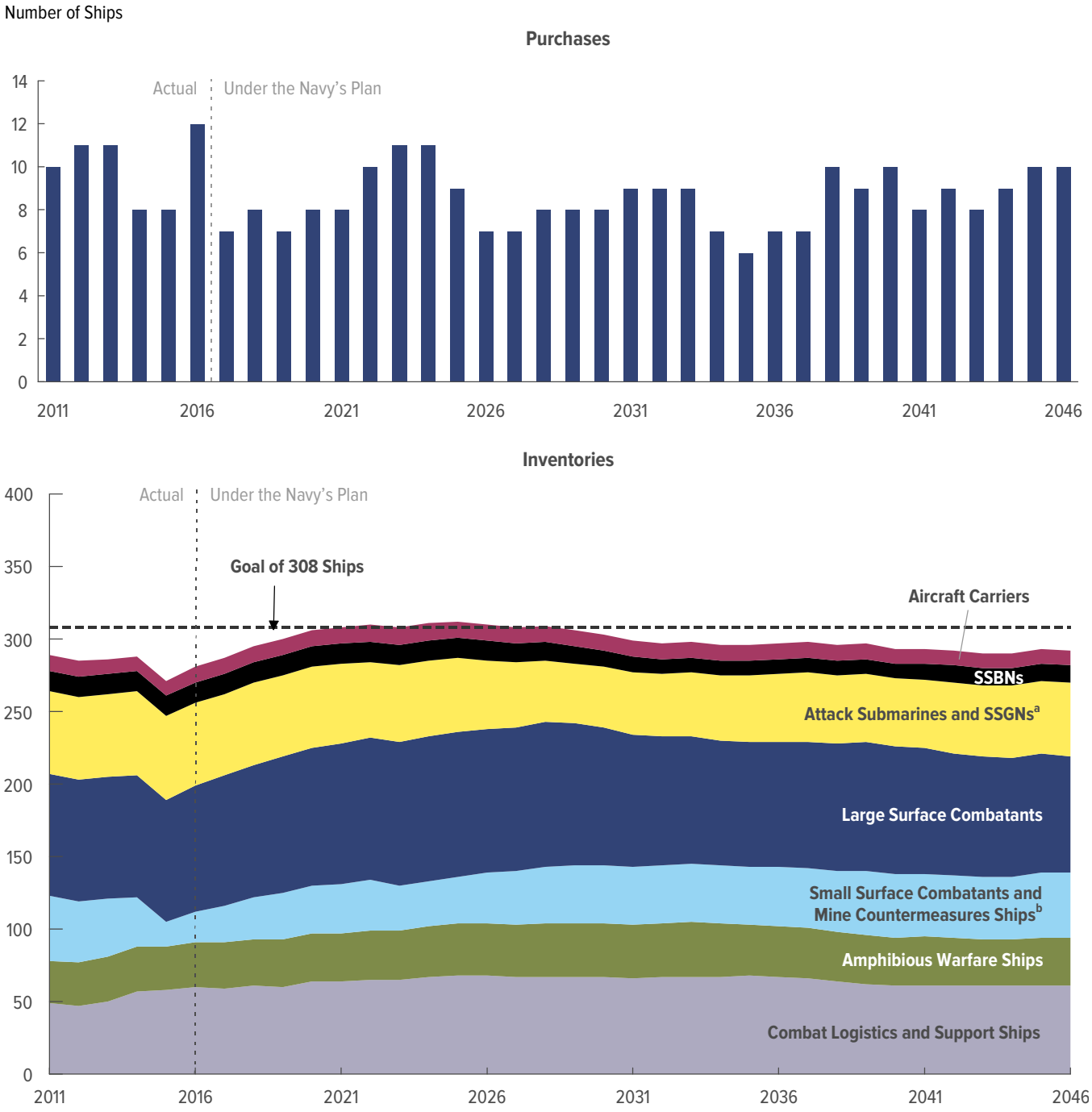
If, under the BCA's caps, the Navy received the same portion of DoD's budget and devoted the same percentage of its budget to ship construction over the 2017–2021 period that it has over the past 15 years, the annual shipbuilding budget would fall 20 percent short of CBO's estimate of the amount required to execute the Navy's 2017 plan over that period. If all shipbuilding programs were cut proportionately, a reduction of that magnitude would require the Navy to purchase 9 fewer ships than the 38 it plans to purchase over that period. Consequently, under current law, policymakers face a choice between implementing the Navy's 2017 shipbuilding plan and cutting costs elsewhere in the Navy's budget (or in DoD's budget more broadly), scaling back the 2017 plan, or taking some combination of those actions. Facing similar constraints, in setting the appropriations for each year from 2013 through 2016, the Congress added $1 billion to $2 billion to the Administration's request for shipbuilding.

Ship Purchases and Inventories Under the 2017 Plan

The Navy's 2017 shipbuilding plan, which the Department of Defense submitted to the Congress on July 9, 2016, reflects the inventory goal of 308 battle force ships that the service set forth in its 2014 update to its 2012 force structure assessment. The Navy intends to buy 7 ships in 2017 and a total of 38 ships between 2017 and 2021—the period covered by DoD's 2017 FYDP (see Figures 2 and 3). From 2022 through 2046, the Navy would buy an additional 216 ships, for a total of 254 ships over 30 years, or an average of about 8.5 ships per year. The pace of shipbuilding would be slower, on

Figure 2.

Annual Ship Purchases and Inventories Under the Navy's 2017 Plan



Source: Congressional Budget Office, using data from the Department of the Navy.

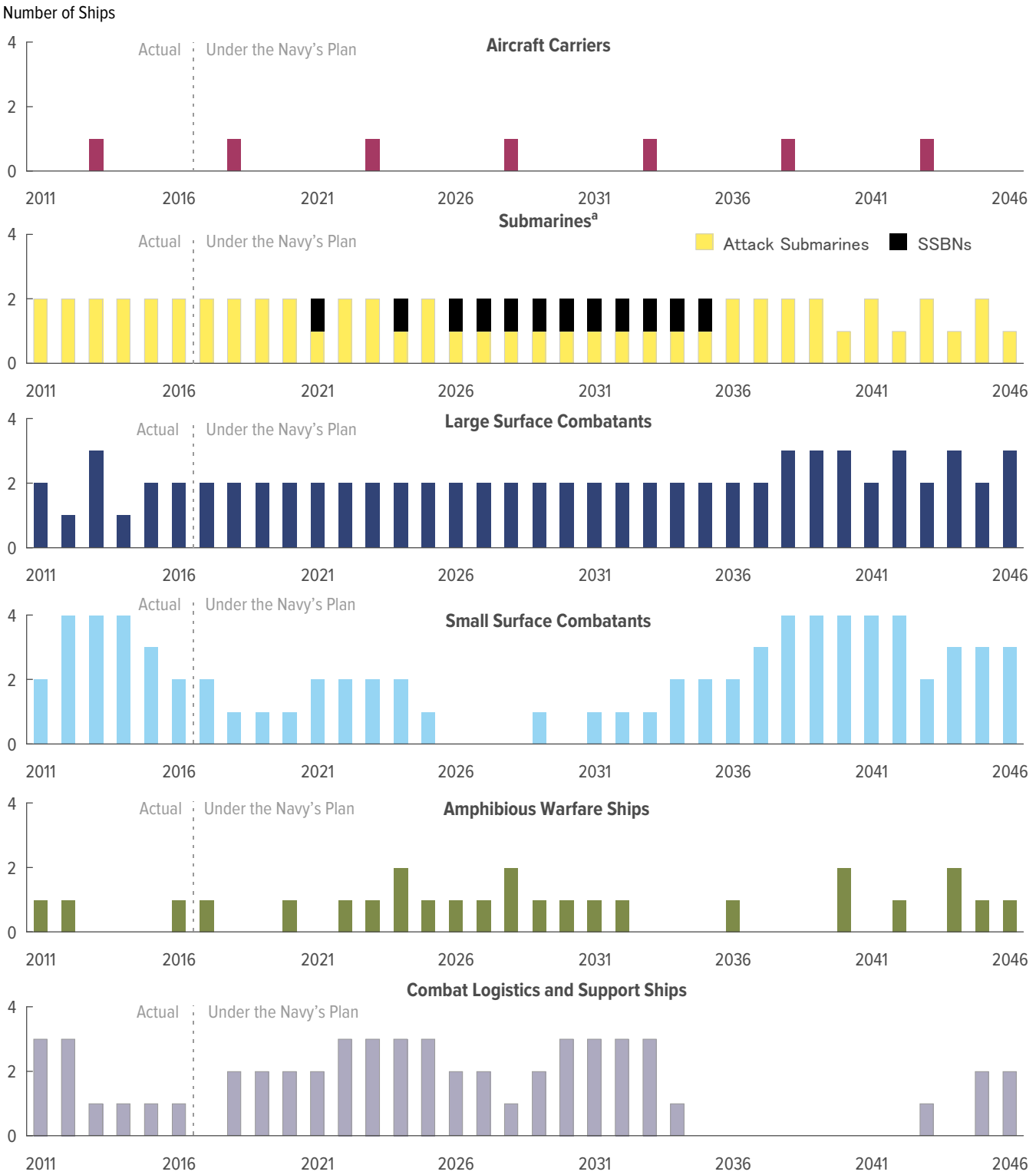
SSBNs = ballistic missile submarines; SSGNs = guided missile submarines.

a. Although the Navy does not plan to build more SSGNs, 4 will be in service through the mid-2020s.

b. Includes littoral combat ships, Oliver Hazard Perry FFG-7 frigates, future frigates, and Avenger class mine countermeasures ships.

Figure 3.

Annual Ship Purchases Under the Navy's 2017 Plan, by Category



Source: Congressional Budget Office, using data from the Department of the Navy.

SSBNs = ballistic missile submarines.

a. Although guided missile submarines are included in the Navy's inventory, the service does not plan to build more of them.

Table 3.

The Navy's Inventory Goals, as Stated in Its Most Recent Force Structure Assessments

	2005 Force Structure Assessment	2010 Force Structure Assessment	2012 Force Structure Assessment	2014 Update to the 2012 Force Structure Assessment[a]	2016 Force Structure Assessment
Aircraft Carriers	11	11	11	11	12
Submarines					
Ballistic missile	14	12	12	12	12
Attack	48	48	48	48	66
Guided missile	4	4	0	0	0
Large Surface Combatants	88	94	88	88	104
Small Surface Combatants and Mine Countermeasures Ships[b]	55	55	52	52	52
Amphibious Warfare Ships	31	33	33	34	38
Maritime Prepositioning Force (Future) Ships	12	0	0	0	0
Combat Logistics Ships	30	30	29	29	32
Support Ships					
Expeditionary fast transports (Formerly joint high-speed vessels)	3	10	10	10	10
Other[c]	17	16	23	24	29
Total	**313**	**313**	**306**	**308**	**355**

Source: Congressional Budget Office, using data from the Department of the Navy.

a. The Navy's 2017 shipbuilding plan is based in part on achieving its goal of a 308-ship fleet, as stated in the 2014 update to its 2012 force structure assessment.

b. Includes littoral combat ships, Oliver Hazard Perry FFG-7 frigates, future frigates, and Avenger class mine countermeasures ships.

c. Includes command ships, salvage ships, ocean tugs, ocean surveillance ships, and tenders.

average, in the near term than later on. The Navy plans to purchase ships at an average annual rate of 7.6 ships from 2017 to 2021, 9.6 ships from 2022 to 2026, and 8.4 ships from 2027 to 2046.

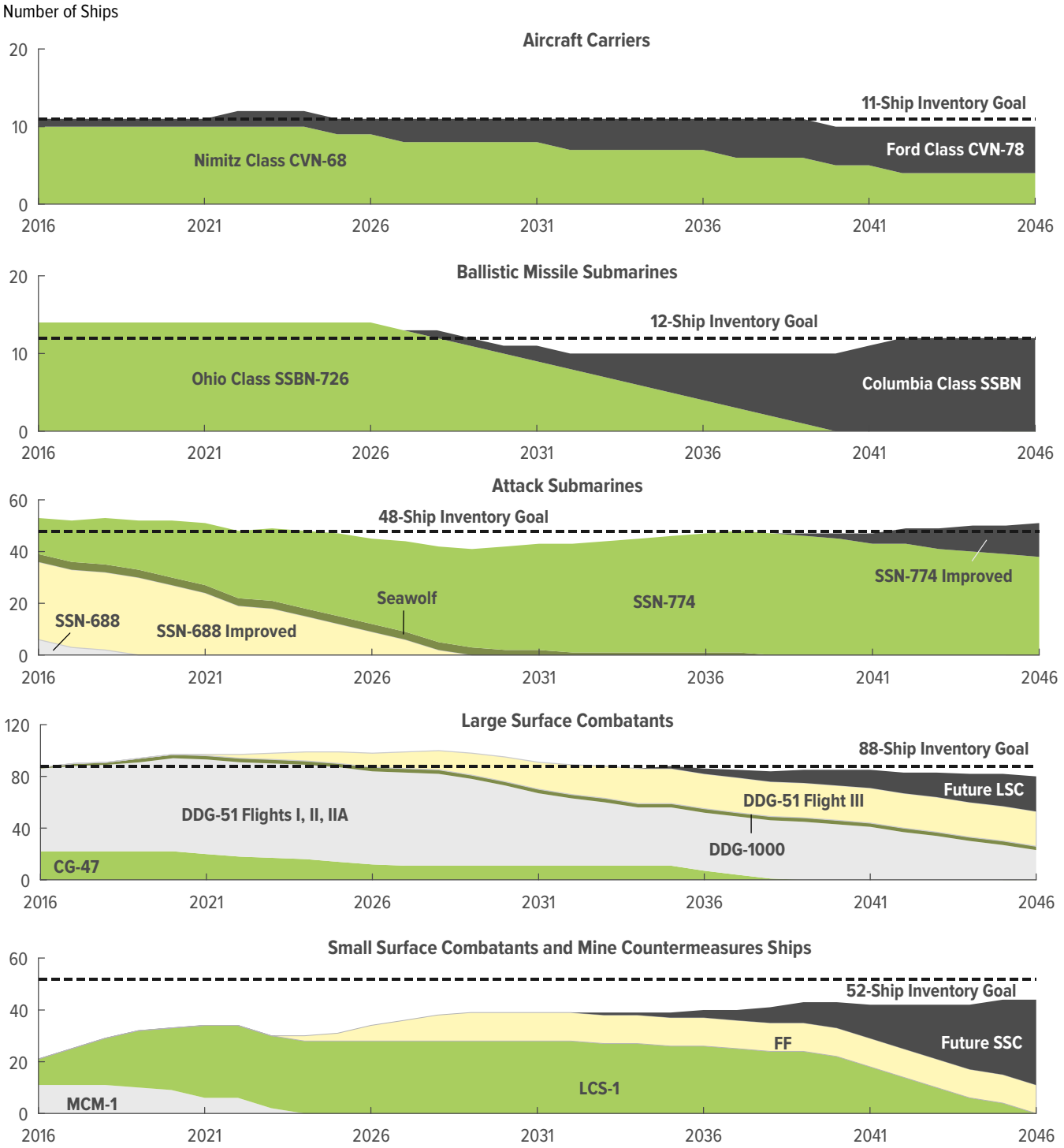
With those purchases, the Navy projects that it will have 287 ships in the fleet at the end of 2017. Under its current ship-counting rules, the Navy would not reach its goal of 308 ships until 2021. The service would meet that goal for only 8 of the 30 years covered by the plan, and from 2031 through 2046, the fleet would number less than 300 ships (see the bottom panel of Figure 2). The Navy would achieve its force structure goal at about the same time under the 2017 plan as it would have under its 2016 plan, although under this year's plan, the Navy would meet its force goal for fewer years. All told, the 2017 plan calls for the Navy to buy 10 fewer ships over 30 years than the 2016 plan.

In December 2016, the Navy released a new force structure assessment, in which it increased its force goal to 355 ships. (For a comparison of the goals established in the five most recent force structure assessments, see Table 3).[5] This report assesses the projected outcomes under the 2017 plan against the 308-ship goal set in the

5. Department of the Navy, *Executive Summary, 2016 Navy Force Structure Assessment (FSA)* (December 14, 2016), http://tinyurl.com/zgdk5o7. For a more extensive discussion of the history of the Navy's force structure goals, see Ronald O'Rourke, *Navy Force Structure and Shipbuilding Plans: Background and Issues for Congress,* Report for Congress RL32665 (Congressional Research Service, February 2, 2017).

Figure 4.

Annual Inventories Under the Navy's 2017 Plan Versus Goals for Selected Categories of Ships



Source: Congressional Budget Office.

CG = guided missile cruiser; CVN = nuclear-powered aircraft carrier; DDG = guided missile destroyer; FF = frigate; LCS = littoral combat ship; LSC = large surface combatant; MCM = mine countermeasures ship; SSBN = ballistic missile submarine; SSC = small surface combatant; SSN = attack submarine.

2014 force structure assessment that was in effect when the plan was written, rather than against the larger December number. CBO did not evaluate the validity of the Navy's goals or the fleet's ability to fulfill its missions in the national military strategy. Rather, this report presents CBO's assessment of the costs of implementing the 2017 plan, its effects on the force structure, and the extent to which it would satisfy the Navy's specific goals for major components of the U.S. fleet. (The major types of ships in the fleet and their basic missions are described in Box 1.)[6]

Combat Ships

Over the next 30 years, the Navy envisions buying 209 combat ships—aircraft carriers, submarines, large and small surface combatants, and amphibious warfare ships—9 fewer than the total number of purchases called for in its 2016 plan. Those purchases would leave the Navy short of its inventory objectives for ballistic missile submarines, attack submarines, large surface combatants, and small surface combatants for significant segments of the 2017–2046 period (see Figure 4). The Navy would, however, generally meet its objectives for amphibious warfare ships.

Aircraft Carriers. Under its 2017 shipbuilding plan, the Navy would purchase 6 aircraft carriers between 2017 and 2046 at a rate of 1 every 5 years. That plan would allow the Navy to maintain a force of 11 aircraft carriers through 2039. However, given that the carriers have a 50-year expected service life, the force would fall to 10 carriers in 2040 and remain at that number through the end of the 30-year period. (To maintain a force of 11 carriers, the Navy would need to purchase 1 ship every 4 years through 2046—rather than 1 every 5 years as the Navy's current plan calls for—and 1 ship every 4½ years over the very long run.)

Ballistic Missile Submarines. The 2017 shipbuilding plan calls for buying the first Columbia class ballistic missile submarine (SSBN) to begin replacing the current Ohio class submarines in 2021 and for purchasing 11 more by 2036. The Columbia class SSBNs would begin to enter the fleet in 2028. (The Navy estimates that the lead submarine will take about seven years to build and two to three additional years to test before it can be placed into regular operation.) However, because the Ohio class submarines will be retired at the end of their 42-year service life, the Navy's inventory of SSBNs would fall at least 1 ship short of its goal of 12 SSBNs between 2030 and 2041. From 2032 to 2040, the Navy would have only 10 SSBNs.

Attack Submarines. Under the 2017 plan, the Navy would purchase 44 attack submarines (SSNs) through 2046, 1 less than under the 2016 plan. That would not be enough to keep the force at the inventory goal of 48 SSNs for all of the next 30 years. The number of attack submarines would decline from 48 in 2024 to a low of 41 in 2029. The force would not return to 48 SSNs until 2042, but it would remain at or above that number through 2046. The decline is the result of the retirement, beginning in 2014, of Los Angeles class attack submarines (SSN-688s). Those ships, which were generally built at a rate of 3 or 4 per year during the 1970s and 1980s, are reaching the end of their 33-year service life. The Navy would replace them with Virginia class attack submarines (SSN-774s) and their successors at a rate of 1 or 2 per year.

Large Surface Combatants. The 2017 shipbuilding plan calls for buying 66 destroyers based on the existing Arleigh Burke class destroyer (DDG-51) design—1 more than the 2016 plan. Those purchases, along with the Navy's plan to modernize its cruiser force, would allow the Navy to meet or exceed its inventory goal of 88 large surface combatants (LSCs) through 2033. The fleet would decline thereafter, falling to 80 ships by 2046.

The Navy's assumptions about the service life of large surface combatants have not changed for several years. All 34 Arleigh Burke class destroyers commissioned after 2000 are assumed to have a service life of 40 years, and the 28 destroyers commissioned earlier, a service life of 35 years. Historically, however, very few cruisers or destroyers have served longer than 30 years.[7] If the Navy's large surface combatants served for only 30 years instead of their longer intended life and the Navy acquired them at the pace called for in the 2017 plan, the number of LSCs in the fleet would fall substantially short of the Navy's goal of 88 such ships.[8]

6. See also, Congressional Budget Office, *The U.S. Military's Force Structure: A Primer* (July 2016), www.cbo.gov/publication/51535.

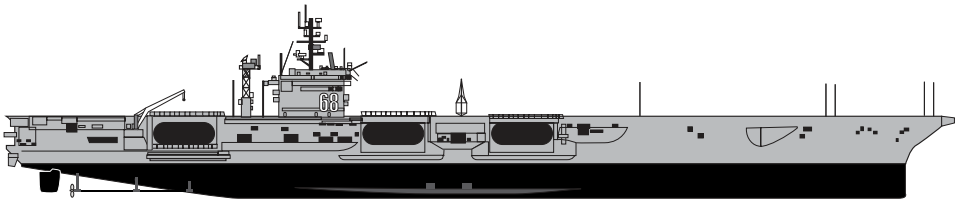
7. See Congressional Budget Office, *Resource Implications of the Navy's Fiscal Year 2009 Shipbuilding Plan* (attachment to a letter to the Honorable Gene Taylor, June 9, 2008), p. 25, www.cbo.gov/publication/41703.

8. See Congressional Budget Office, *An Analysis of the Navy's Fiscal Year 2014 Shipbuilding Plan* (October 2013), p. 26, www.cbo.gov/publication/44655.

Box 1.

Major Types of Ships in the Navy's Fleet

Nimitz Class Aircraft Carrier



The Navy's 10 **aircraft carriers** are the heart of the battle force. Each carries an air wing of about 60 aircraft, which can attack hundreds of targets per day for up to a month before needing to rest. Carriers are the largest ships in the fleet, with a displacement of about 100,000 tons. (A ship's displacement is the weight of water that it displaces when floating or, in the case of a submarine, when submerged.) All 10 of the current carriers belong to the Nimitz class. The Navy will commission the first of a new class, the *Gerald R. Ford*, in 2017.

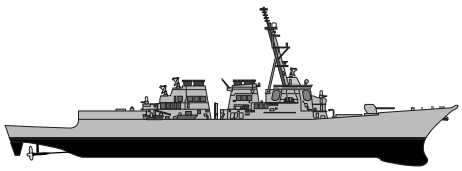
Ohio Class Ballistic Missile Submarine

Strategic ballistic missile submarines are one component of the U.S. nuclear triad. Each submarine carries up to 24 Trident missiles armed with one to eight nuclear warheads apiece. The Navy has 14 Ohio class ballistic missile submarines, each of which displaces about 19,000 tons when submerged. The service has 4 other submarines of that class that it converted to a conventional guided missile (SSGN) configuration. Those SSGNs carry up to 154 Tomahawk missiles as well as special operations forces.

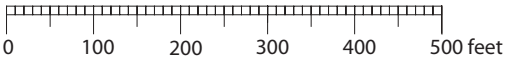
Los Angeles Class Attack Submarine

Attack submarines are the Navy's premier undersea warfare and antisubmarine weapons. Since the end of the Cold War, however, they have mainly been used for covert intelligence gathering. They can also launch Tomahawk missiles at inland targets in the early stages of a conflict. Of the Navy's 51 attack submarines, 36 belong to the Los Angeles class. Displacing 7,000 tons when submerged, they are less than half the size of ballistic missile submarines.

Arleigh Burke Class Destroyer



Large surface combatants, which include cruisers and destroyers, are the workhorses of the fleet. They provide ballistic missile defense for the fleet and for overseas regions. They defend aircraft carriers and amphibious warfare ships against other surface ships, aircraft, and submarines, and they perform such day-to-day missions as patrolling sea lanes, providing an overseas presence, and conducting exercises with allies. They can also launch Tomahawk missiles to strike land targets. Most of the Navy's surface combatants displace about 9,000 to 10,000 tons.



Continued

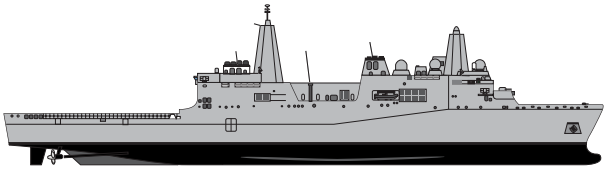
Box 1. Continued

Major Types of Ships in the Navy's Fleet

Freedom Class Littoral Combat Ship

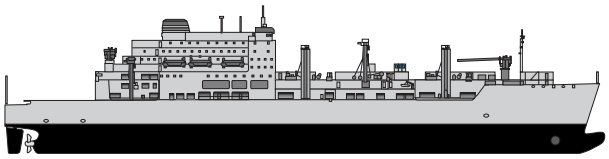
Small surface combatants include littoral combat ships (LCSs) and frigates. LCSs are intended to counter mines, small boats, and diesel-electric submarines in the world's coastal regions. The Navy's new frigates, which are based on the LCS but have enhanced capabilities, will perform similar missions but also include antiship capabilities. More routinely, LCSs and frigates—like their counterparts, the large surface combatants—patrol sea lanes, provide an overseas presence, and conduct exercises with allies. They range in size from 3,000 to 4,000 tons. The Navy retired all of its Oliver Hazard Perry frigates in 2015.

San Antonio Class Amphibious Transport Dock



The Navy has five classes of **amphibious warfare ships**. The two classes referred to as amphibious assault ships (also known as large-deck amphibious ships or helicopter carriers) are the second-largest types of ships in the fleet, displacing between 40,000 and 45,000 tons. With capacity for about half the troops and equipment of a Marine expeditionary unit, the amphibious assault ship is the centerpiece of the amphibious ready group. In addition to troops, each ship can carry as many as 30 helicopters and 6 fixed-wing Harrier jump jets, or up to 20 Harriers or short takeoff and landing versions of the Joint Strike Fighter. The other three classes are divided into two types: amphibious transport docks and dock landing ships. Two of those ships together provide the remaining transport capacity for a Marine expeditionary unit in an amphibious ready group. They range in size from 16,000 to 25,000 tons.

Lewis and Clark Class Dry Cargo/Ammunition Ship



The many **combat logistics and support ships** in the Navy's fleet provide the means to resupply, repair, salvage, or tow combat ships. The most prominent of those vessels are fast combat support ships, which resupply carrier strike groups with fuel, dry cargo (such as food), and ammunition. Logistics and support ships can be as small as 2,000 tons for an oceangoing tug or as large as 50,000 tons for a fully loaded fast combat support ship.

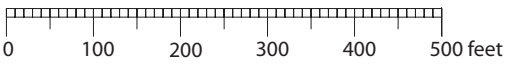


Table 4.

Average Annual Shipbuilding Costs Under the Navy's 2017 Plan

	Near Term (2017–2021)	Midterm (2022–2026)	Far Term (2027–2046)	All Three Periods (2017–2046)
		Navy's Estimates (Billions of 2016 dollars)		
New-Ship Construction	15.0	18.6	17.1	17.0
New-Ship Construction and Refueling of Nuclear-Powered Aircraft Carriers[a]	16.5	19.6	18.0	18.0
New-Ship Construction, Refueling of Nuclear-Powered Aircraft Carriers, and Other Items[b,c]	17.6	20.6	18.6	18.8
		CBO's Estimates (Billions of 2016 dollars)		
New-Ship Construction	15.3	19.7	19.6	18.9
New-Ship Construction and Refueling of Nuclear-Powered Aircraft Carriers	16.7	20.8	20.5	19.9
New-Ship Construction, Refueling of Nuclear-Powered Aircraft Carriers, and Other Items[b]	17.9	21.7	21.3	20.7
		Percentage Difference Between the Navy's and CBO's Estimates		
New-Ship Construction	2	6	15	11
New-Ship Construction and Refueling of Nuclear-Powered Aircraft Carriers	2	6	14	11
New-Ship Construction, Refueling of Nuclear-Powered Aircraft Carriers, and Other Items[b]	2	5	14	10

Source: Congressional Budget Office, using data from the Department of the Navy.

Actual costs for all items funded by the Navy's shipbuilding account over the past 30 years averaged $15.9 billion per year.

a. Amounts are the sum of the Navy's estimates for new-ship construction and CBO's estimates for the refueling of nuclear-powered aircraft carriers.

b. "Other Items" includes ship conversions, construction of ships that are not part of the Navy's battle force (such as oceanographic survey ships), training ships, and outfitting and postdelivery activities (which include the purchase of smaller tools and pieces of equipment that are needed to operate a ship but that are not necessarily provided by the manufacturing shipyard as part of ship construction).

c. Amounts are the sum of the Navy's estimates both for new-ship construction and for the cost to complete for ships purchased in prior years and CBO's estimates for the refueling of nuclear-powered aircraft carriers and for other items.

Small Surface Combatants. For small surface combatants (SSCs), the Navy plans to replace its retired Oliver Hazard Perry frigates and mine countermeasures ships with littoral combat ships (LCSs) and frigates, which are LCSs with improved survivability features and combat capabilities. In December 2015, the Secretary of Defense directed the Navy to purchase 12 fewer SSCs than it had planned to purchase and to redirect the money saved to other naval priorities. As a consequence, at no time through 2046 would the Navy reach its objective of having 52 small surface combatants in the fleet.

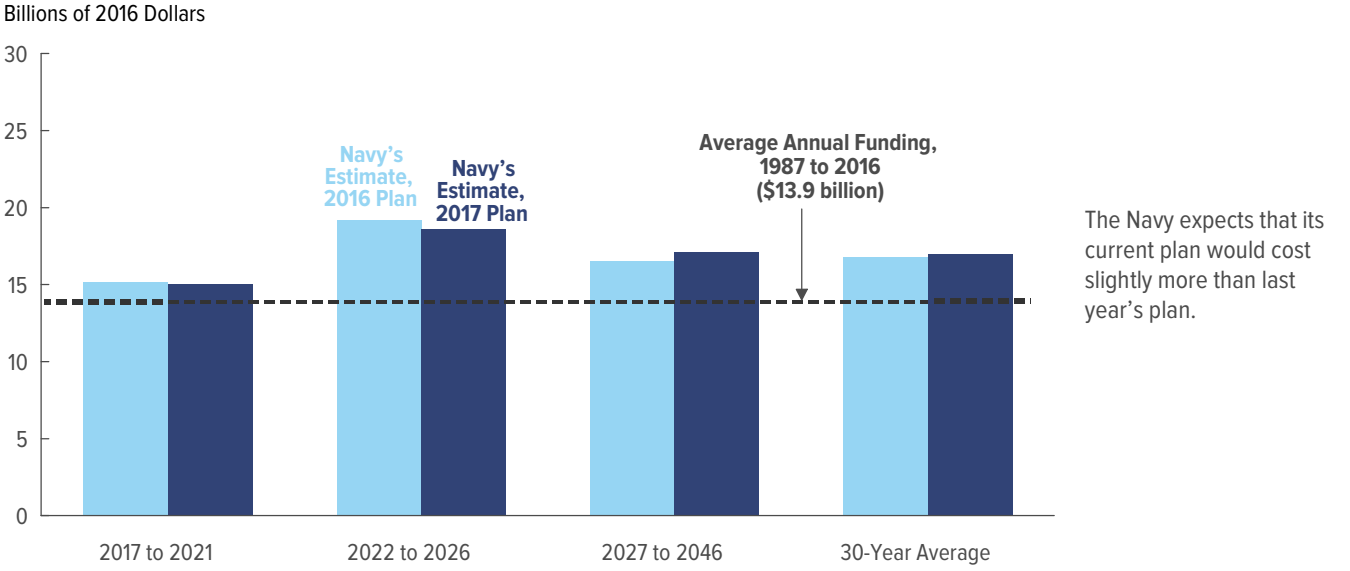
Amphibious Warfare Ships. The Navy's 2017 plan calls for buying 23 amphibious warfare ships through 2046—the same number as specified in the 2016 plan—and increasing the amphibious force from the current 30 ships to 34 by 2022. The force would stay at that size or increase through 2039 and then fall 1 or 2 ships short of the goal in the 2040s. The Navy assumes that it will keep its LHD class amphibious assault ships in the fleet for 43 to 45 years, although their expected service life is just 40 years.

Combat Logistics and Support Ships

Under the 2017 plan, the Navy would buy 45 combat logistics and support ships in the next three decades—1 less than under the 2016 plan. Combat logistics ships include T-AKE dry cargo ships, T-AO oilers, and AOE

Figure 5.

The Navy's Estimates of the Average Annual Costs of New-Ship Construction Under Its 2016 and 2017 Plans



Source: Congressional Budget Office, using data from the Department of the Navy.

Amounts shown exclude the costs of refueling nuclear-powered aircraft carriers and of other items funded by the Navy's shipbuilding account, including ship conversions, construction of ships that are not part of the Navy's battle force (such as oceanographic survey ships), training ships, and outfitting and postdelivery activities (which include the purchase of smaller tools and pieces of equipment that are needed to operate a ship but that are not necessarily provided by the manufacturing shipyard as part of ship construction). The costs of the mission packages for littoral combat ships, which are not funded by the Navy's shipbuilding account, are also excluded.

fast combat support ships; they operate with or directly resupply combat ships that are on deployment. The plan calls for purchasing 16 new oilers (which provide fuel and other supplies to ships at sea) at a rate of 1 per year from 2018 through 2033 and 5 replacements for T-AKE dry cargo and ammunition ships from 2043 to 2046. Under the plan, the Navy would also purchase the following other support ships: 10 expeditionary fast transports (formerly called joint high-speed vessels), 7 salvage/fleet tug ships, 5 surveillance ships, and 2 tenders.

The current plan leaves in place the early retirement of 2 salvage ships and 2 fleet tugs scheduled for 2017 that was presented in the 2016 plan. Those retirements had been moved up as a cost-saving measure by nine and four years, respectively, under the 2015 plan. That would leave the Navy with 2 fleet tugs and 2 salvage ships in its inventory until 2020 and 2023, respectively, when replacements are scheduled to enter the fleet. The decision to retire the ships early (even though they are less expensive to operate than many other ship types) and the consequent gaps in the inventory raise the question of whether the Navy needs 4 ships of each type to support fleet operations. In the 2015 plan, the Navy stated that it would use leased vessels "if [the] mission workload requires additional ships."[9] In addition, the Navy delayed the retirement of 4 T-AGOS ocean surveillance ships by three or four years and the purchase of their replacements by one year.

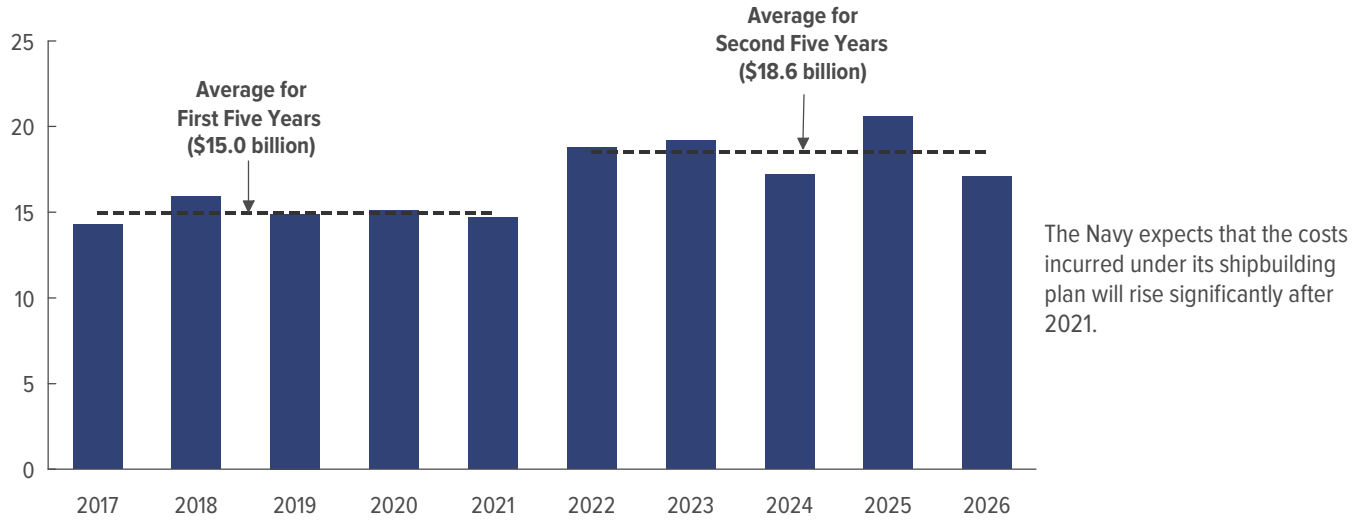
Shipbuilding Costs Under the 2017 Plan

According to the Navy's estimates, its planned purchases of new ships would cost an average of $17.0 billion per year (in 2016 dollars) through 2046 (see Table 4)—1 percent more than the $16.8 billion average per year that the service estimated it would spend to carry out its 2016 plan (see Figure 5). In making its estimates, the Navy divided the time frame of the 2017 plan into three periods: the near term (2017 to 2021), the midterm (2022 to 2026), and the far term (2027 to 2046). That represents a substantial change from the time frames that the Navy used in most of its previous shipbuilding plans. Whereas in those plans the Navy had divided the 30-year period into three decades, in the 2017 plan, it defined the

9. Department of the Navy, *Report to Congress on the Annual Long-Range Plan for Construction of Naval Vessels for FY2015* (June 2014), p. 13, http://go.usa.gov/FYZR (PDF, 3.4 MB).

Figure 6.

The Navy's Estimates of the Costs of New-Ship Construction, 2017 to 2026



Source: Congressional Budget Office, using data from the Department of the Navy.

Amounts shown exclude the costs of refueling nuclear-powered aircraft carriers and of other items funded by the Navy's shipbuilding account, including ship conversions, construction of ships that are not part of the Navy's battle force (such as oceanographic survey ships), training ships, and outfitting and postdelivery activities (which include the purchase of smaller tools and pieces of equipment that are needed to operate a ship but that are not necessarily provided by the manufacturing shipyard as part of ship construction). The costs of the mission packages for littoral combat ships, which are not funded by the Navy's shipbuilding account, are also excluded.

near term to coincide with the FYDP, the midterm to include the next 5 years, and the far term to comprise the remaining 20 years. CBO has restructured its analysis to comport with the Navy's approach.

CBO also estimated the costs of the Navy's 2017 plan; it used its own cost models and assumptions, which are explained in detail later in this report, to price the ships. All told, CBO's estimates of the cost of ship construction are an average of $1.9 billion (or 11 percent) higher per year than the Navy's for the 30-year period. The differences in CBO's and the Navy's estimates increase over time: They are smallest for the near term and largest for the far term. When the other activities that the Navy would need to fund from its budget account for ship construction are included, they add an additional $1.8 billion per year to the Navy's estimates and $1.9 billion to CBO's estimates, bringing the total estimated annual cost for ship construction to $18.8 billion (based on the Navy's estimates for new-ship construction) or $20.7 billion (based on CBO's estimates).

The Navy's Estimates

The Navy's 2017 report is a relatively brief document that includes a short discussion of future shipbuilding procurements, retirements, and inventory projections. Detailed cost projections are provided in Appendix 3 of the report, a limited distribution that the Navy made available to CBO. In the main report, the Navy addresses the issue of costs sparingly, stating that the President's budget and associated FYDP provide sufficient resources to implement the plan but adding that "in order to procure these vessels without impacting remaining procurement plans, the Navy will continue to need additional resources for ship construction beyond the FYDP, not unlike those that occurred during construction of the Ohio class in the 1980's."[10]

10. Department of the Navy, *Report to Congress on the Annual Long-Range Plan for Construction of Naval Vessels for Fiscal Year 2017* (July 2016), p. 5, https://news.usni.org/2016/07/12/20627. For a discussion of historical funding for ballistic missile submarines, see Eric J. Labs, "Finding Funding for the New Boomer," *Proceedings* (U.S. Naval Institute, February 2015), pp. 63–67, http://tinyurl.com/jfqh3nx.

New-Ship Construction Costs. According to the Navy's estimates for its 2017 plan, over the near term, new-ship construction would cost an average of $15.0 billion per year. That amount excludes about $430 million in funding to cover cost overruns and to restore cuts resulting from the 2013 sequestration (that is, automatic spending reductions) that will be needed to complete the construction of ships funded before 2017; that sum would be spent from 2017 through 2020.

The Navy estimates that the average annual cost for new-ship construction would rise from $15.0 billion in the near term to $18.6 billion in the midterm (see Figure 6). The costs for the far term, which includes 8 years in which the Navy plans to purchase Columbia class ballistic missile submarines and 12 more years at the end of the planning period, would average $17.1 billion per year—23 percent more than the $13.9 billion the Navy has received, on average, over the past 30 years.

Total Shipbuilding Costs. As in previous shipbuilding plans, the Navy's 2017 estimates exclude the following costs, which it would need to cover with funds from its budget account for ship construction:

- The cost of refueling nuclear-powered aircraft carriers midway through their 50-year service life, which CBO estimates would add $1 billion per year to the Navy's estimate of the cost of implementing the 2017 plan, bringing the average cost to $18.0 billion a year through 2046;[11] and
- The costs of ship conversions, construction of ships that are not part of the Navy's battle force (oceanographic survey ships, for instance), moored training ships, outfitting and postdelivery activities (including the purchase of many smaller tools and pieces of equipment that are needed to operate a ship but that are not necessarily provided by the shipyard when the ship is built), and smaller items. Together, those items would boost the Navy's estimate by $0.8 billion per year through 2046.

Adding those costs, plus the $430 million in cost-to-complete funding that will be spent from 2017 through 2020, to the estimated cost of new-ship construction would boost the Navy's estimate for the 30-year cost of the 2017 shipbuilding plan to an average of $18.8 billion per year—$1.8 billion more than its estimate for new-ship construction alone. That amount is 18 percent greater than the average funding of $15.9 billion per year that the Navy has received for shipbuilding over the past three decades.

CBO's Estimates

In CBO's estimation, the full cost of the 2017 shipbuilding plan (including construction, refueling of nuclear-powered aircraft carriers, and other items) would average $20.7 billion per year in constant 2016 dollars over the 2017–2046 period (see Table 4). That amount is 29 percent greater than the average annual funding that the Navy has received over the past three decades. The estimated costs vary from year to year but generally trend upward for the first two decades of the plan (see Figure 7). CBO makes the following estimates for the 30-year period as a whole:

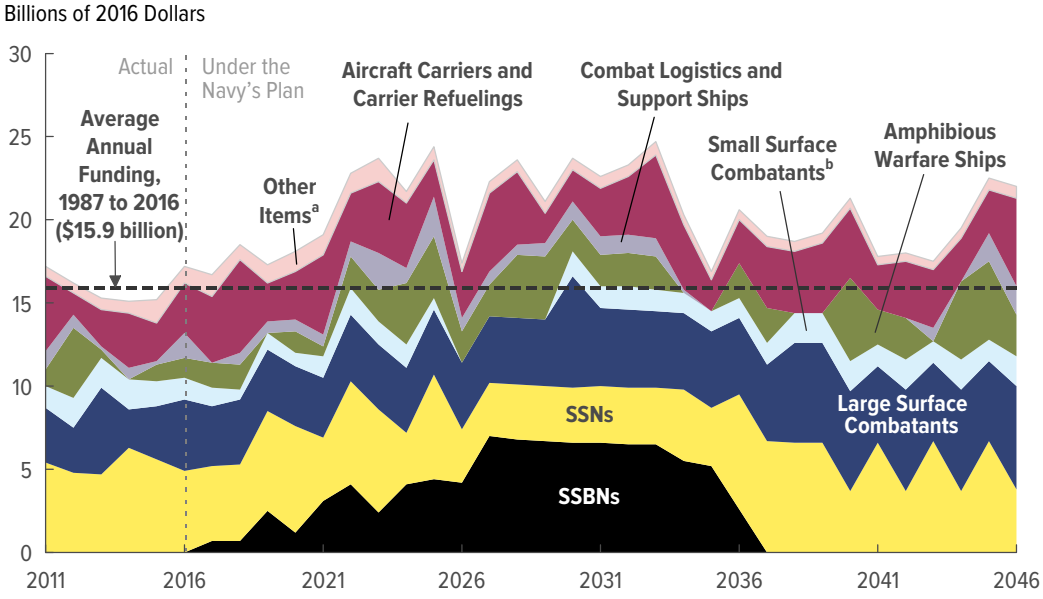
- New-ship construction would cost an average of $18.9 billion per year, 11 percent more than the Navy's estimate of $17.0 billion;
- New-ship construction plus refueling of nuclear-powered aircraft carriers would cost an average of $19.9 billion per year, 11 percent more than the estimate of $18.0 billion that is based on the Navy's projection of new-ship construction costs; and
- All other items would add annual costs of about $800 million, raising CBO's estimate to an average of $20.7 billion per year through 2046, 10 percent more than the estimate of $18.8 billion that is based on the Navy's projection of new-ship construction costs.

CBO's estimates of the full cost of the plan are only 2 percent higher than the Navy's for the near term, which coincides with DoD's FYDP, but 15 percent higher for the far term. The two sets of estimates are similar for the near term because most of the ships that the Navy plans to buy are already under construction and their costs are reasonably well known. But CBO and the Navy made different assumptions about the size and capabilities of future ships that contributed to different cost estimates for the midterm and far term. Generally, CBO estimates

11. In 2010, the Navy transferred funding for refueling nuclear-powered submarines from its Shipbuilding and Conversion account to three other accounts (Other Procurement, Operation and Maintenance, and Weapons Procurement) that are not used to purchase ships. Therefore, CBO did not include the refueling costs for submarines in its estimates of future shipbuilding costs.

Figure 7.

CBO's Estimates of Annual Shipbuilding Costs Under the Navy's 2017 Plan



Over the next two decades, CBO estimates, the new SSBN program will push the Navy's annual shipbuilding costs above the historical average.

Source: Congressional Budget Office, using data from the Department of the Navy.

SSBNs = ballistic missile submarines; SSNs = attack submarines.

a. Includes ship conversions, construction of ships that are not part of the Navy's battle force (such as oceanographic survey ships), training ships, and outfitting and postdelivery activities (which include the purchase of smaller tools and pieces of equipment that are needed to operate a ship but that are not necessarily provided by the manufacturing shipyard as part of ship construction).

b. The costs of the mission packages for littoral combat ships, which are not funded by the Navy's shipbuilding account, are excluded.

the cost of a future ship on the basis of the relationship between the weight and cost of analogous existing ships. The resulting amount is then adjusted for factors such as production efficiencies that occur as more ships of the same type are built simultaneously at a given shipyard and additional efficiencies that occur as more ships are built over the duration of a production run.

CBO also incorporated into its estimates (which are in constant 2016 dollars) a projection that labor and materials costs would probably continue to grow faster in the naval shipbuilding industry than in the economy as a whole, as they have for the past several decades. (For more information on CBO's methods for estimating the cost of new ships, see Appendix A.) The Navy's constant-dollar estimates do not reflect that faster growth, although its nominal-dollar estimates under the FYDP do (see Box 2). The Navy states that if it does not receive additional funding to account for the higher inflation in the shipbuilding industry, it would probably be unable to afford all of the ships in its plan.

Illustrative Alternatives to the Navy's Plan

CBO examined three alternatives to the Navy's plan and estimated the costs that the Navy would incur and the ship inventories that it would be able to maintain under those alternatives. Under the first alternative, the Navy would receive the same amount of funding (adjusted for inflation) over the next 30 years that it received over the past 30 years. Under the second, the Navy would buy enough ships to meet its stated force goals for all ships, except for ballistic missile submarines. Under the third, the Navy would build a larger fleet of about 350 ships (see Table 5). Those three alternatives were chosen for illustrative purposes because variations of all of them have been suggested by policymakers or discussed during Congressional hearings on the Navy's budget and shipbuilding plan; they are not recommendations by CBO.

Limit Funding for Shipbuilding to Its Historical Average

CBO's estimate of $20.7 billion per year for the full cost of the Navy's 2017 shipbuilding plan is 30 percent higher

Box 2.

Inflation in the Cost of Naval Shipbuilding

The costs of building ships in the future will depend not just on their size and capabilities but also on the evolution of production costs. The differences between the Navy's and the Congressional Budget Office's estimates of the cost of the Navy's shipbuilding plans arise in part from their different methods of estimating production costs that will be incurred years or decades from now in constant 2016 dollars (that is, the amounts have been adjusted to remove the effects of inflation).

When estimating the cost of building a ship in the future that is identical to a ship that has already been produced, the Navy reports the future cost of capabilities purchased as being the same as the cost today. By contrast, CBO projects the cost to build the same ship in the future by accounting for the rising cost of shipbuilding labor and materials relative to the rising costs of other goods and services in the economy. CBO regards that difference between shipbuilding inflation and overall inflation as growth in the constant-dollar cost of building naval ships. The agency's constant-dollar estimates incorporate the increased costs of a future ship of any given size and capability relative to the average increase in costs for other goods and services that might be purchased with the same funds.

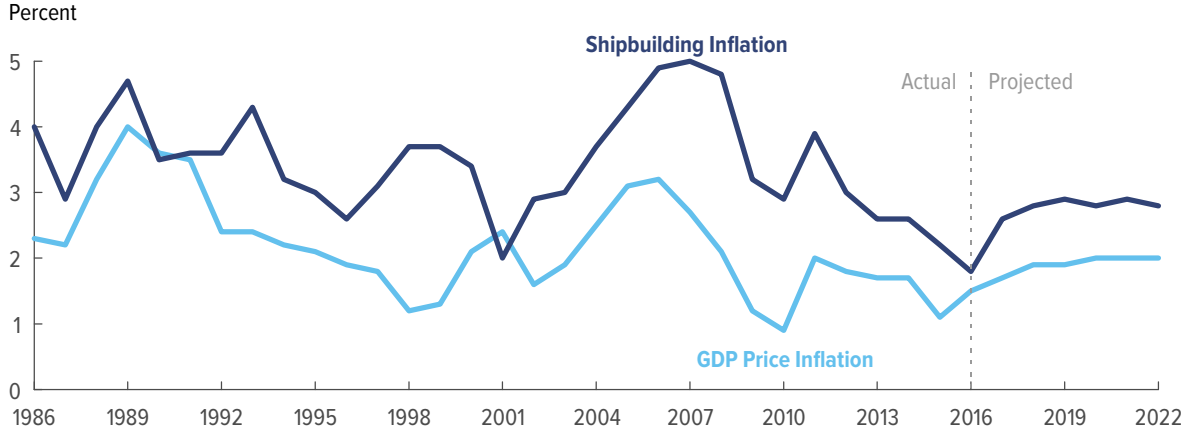
The Navy provided CBO with a naval shipbuilding cost index that measures growth in the costs of labor and materials from 1960 to 2015. To project increases for 2016 through 2020, the Navy constructed a shipbuilding cost index by extrapolating from the historical cost data and incorporating other information—derived from advance-pricing agreements, vendor surveys, and forecasts of the labor market—into its projections. For the 2016–2020 period, the Navy projects, shipbuilding costs will rise at an average annual rate of 2.8 percent.

The Navy incorporated that projection into its budget request for 2017 and into the associated Future Years Defense Program; both documents express costs in nominal dollars. In projecting the constant-dollar costs for its 2017 shipbuilding plan, the Navy converted nominal dollars to constant 2016 dollars by discounting the nominal dollar amounts; it used the same shipbuilding cost index that it used to construct the future-year estimates. Thus, the Navy's constant-dollar estimates are essentially a measure of the amount of ship capability purchased: If a ship costs $2.5 billion to build in 2016, the Navy's projected cost (in 2016 dollars) of building an identical ship in 2035 will be the same amount—$2.5 billion.

In contrast, CBO used the gross domestic product (GDP) price index, which measures the prices of all final goods and services produced in the economy, to convert shipbuilding costs from nominal to constant dollars. CBO anticipates an average annual rate of increase in that measure of 1.9 percent for the 2016–2020 period. CBO's estimates of the cost of building a given ship (as projected from the Navy's shipbuilding cost index) show a rate of increase over the period that is an average of 0.9 percentage points faster per year than the rate of inflation it projects for the overall economy. (CBO identified a slightly higher rate of real annual growth in its analysis of the Navy's 2016 plan.)

Since 1986, the average difference between the rate of increase in the Navy's shipbuilding cost index and that in the GDP price index has been about 1.2 percentage points per year (see the figure). Cost growth in the shipbuilding industry has exceeded general inflation for most of the past three decades, and CBO lacks an analytical basis for determining when or to what extent the difference between the two growth rates might narrow. The agency therefore projects that shipbuilding inflation will outpace GDP price inflation by 0.9 percentage points per year between 2016 and 2020 and by about 1.2 percentage points per year—matching the 30-year historical average—thereafter. As a result, CBO estimates that a ship that costs $2.5 billion to build in 2016 would cost $3.2 billion (in 2016 dollars) in 2035. (However, shipbuilding costs cannot continue to grow faster than the costs of goods and services in the economy as a whole indefinitely. If that occurred, the price of ships would eventually outstrip the Navy's ability to pay for even a small number of them.)

Annual Rates of Shipbuilding Inflation and GDP Price Inflation



Sources: Congressional Budget Office; Department of the Navy.

GDP = gross domestic product.

Table 5.

Ship Purchases, Costs, and Inventories Under Illustrative Alternatives to the Navy's Plan, by Major Ship Type

	Limit Funding for Shipbuilding to Its Historical Average	Meet Nearly All Inventory Goals in Each Year	Build a Fleet of 350 Ships	Memorandum: Navy's 2017 Plan	
				Navy's Estimates	CBO's Estimates
	Total Ship Purchases, 2017–2046 (Number of ships)				
Aircraft Carriers	6	8	10	6	6
Ballistic Missile Submarines	12	12	12	12	12
Attack Submarines	30	44	52	44	44
Large Surface Combatants	44	74	92	66	66
Small Surface Combatants	39	67	75	58	58
Amphibious Warfare Ships	15	25	29	23	23
Combat Logistics and Support Ships	34	45	51	45	45
Total	**180**	**275**	**321**	**254**	**254**
	Average Annual New-Ship Construction Costs, 2017–2046 (Billions of 2016 dollars)				
Aircraft Carriers	2.4	3.0	3.9	2.3	2.4
Ballistic Missile Submarines	2.9	2.9	2.9	2.6	2.9
Attack Submarines	3.2	4.7	5.5	4.6	4.8
Large Surface Combatants	2.8	5.0	5.6	4.0	4.6
Small Surface Combatants	1.0	1.6	1.7	1.1	1.4
Amphibious Warfare Ships	1.3	2.2	2.5	1.7	1.9
Combat Logistics and Support Ships	0.5	0.7	0.9	0.6	0.7
Total	**14.2**	**20.1**	**23.0**	**17.0**	**18.9**
	Inventory in 2046 (Number of ships)				
Aircraft Carriers	10	11	12	10	10
Ballistic Missile Submarines	12	12	12	12	12
Attack Submarines	39	51	58	51	51
Large Surface Combatants	63	88	106	80	80
Small Surface Combatants	29	52	62	45	45
Amphibious Warfare Ships	26	34	38	33	33
Combat Logistics and Support Ships	52	61	65	61	61
Total	**231**	**309**	**353**	**292**	**292**

Source: Congressional Budget Office, using data from the Department of the Navy.

than the $15.9 billion (in 2016 dollars) that the Navy has spent annually, on average, for all activities funded from its shipbuilding account over the past 30 years. If the Navy's future funding for shipbuilding was in line with the past, the Navy would need to purchase significantly fewer ships than called for in its 2017 plan.[12]

To illustrate how much smaller the fleet of battle force ships might be under that scenario, CBO constructed an alternative shipbuilding plan that met two criteria. First, the number of specific types of ships purchased, with the exception of ballistic missile submarines and aircraft carriers, would be reduced in rough proportion to the number of such ships called for under the 2017 plan.[13]

12. For a broader discussion of historical cost trends in Navy shipbuilding, see testimony of Eric J. Labs, Senior Analyst for Naval Forces and Weapons, Congressional Budget Office, before the Subcommittee on Seapower and Expeditionary Forces of the House Committee on Armed Services, *The Long-Term Outlook for the U.S. Navy's Fleet* (January 20, 2010), www.cbo.gov/publication/41886.

13. In a report accompanying the 2014 defense authorization act, the House Committee on Armed Services directed the Navy to provide the Congress with a similar illustration of a shipbuilding plan (starting in 2015) that conformed to historical funding levels. The Navy has not responded to that Congressional directive.

The Navy's most senior officials have described replacing the current Ohio class submarines as the service's top priority; CBO therefore assumed that the Navy would purchase all 12 submarines included in its 2017 plan. The Congress has mandated that the Navy maintain a fleet of 11 aircraft carriers, so in this illustrative scenario, CBO did not make cuts to that category. The second criterion was that spending be kept fairly similar (in real dollars) during the near term, midterm, and far term.

Under that illustrative 30-year plan, the Navy would purchase 180 ships instead of the 254 ships called for under the Navy's plan. In 2023, the battle force fleet would be about the same size as in the Navy's plan, but by 2046, it would be significantly smaller, numbering 231 ships rather than 292.

Other approaches to limiting funding for shipbuilding to its historical levels would produce different results. If the Navy built fewer larger, more expensive ships than the number specified in the illustrative plan, the fleet would be larger overall. Conversely, if it preserved the more expensive programs and purchased fewer of the less expensive ships than called for under the illustrative plan, the fleet would be smaller overall. Ultimately, decisions about which ships to build would depend on policymakers' priorities for certain naval missions in relation to others.[14]

Meet Nearly All Inventory Goals in Each Year

Under its 2017 shipbuilding plan, the Navy would not meet its inventory goal of 308 battle force ships until 2021. The Navy's inventory of several types of ships—namely ballistic missile submarines, attack submarines, large and small surface combatants, and, in the far term, aircraft carriers—would fall below its specific goals for ships of a given type (see Figure 4). This illustrative plan aims to meet and maintain the Navy's inventory goals for most types of ships as soon as practical in light of the capacity of the shipbuilding industrial base. The only exception, which is explained below, is for ballistic missile submarines. If the Navy purchased additional ships to meet all of its specific goals (except for those for ballistic missile submarines), the average annual cost of ship construction would rise from $18.9 billion under the Navy's current plan to $20.1 billion, CBO estimates.

The Navy does not believe that it can prevent a shortfall in its inventory of ballistic missile submarines. Extending the service life of the existing Ohio class submarines is not possible because of specific characteristics of the design of those submarines and the extent of their past and current operations.[15] Nor is building the new class of ballistic missile submarines faster an option, according to the Navy, because doing so would introduce technical risks that outweigh the risk of having only 10—rather than the preferred 12—deployable SSBNs for a decade.

Other shortfalls could be reduced or avoided altogether by accelerating certain shipbuilding programs or purchasing more ships than specified in the Navy's 2017 shipbuilding plan. Most of the Navy's specific goals could be met as follows:

- To prevent the force from falling below the inventory goal of 48 attack submarines, the Navy could purchase 7 of the submarines that it currently plans to purchase between 2025 and 2034 over the 2018–2024 period instead, thus increasing the production rate to 3 submarines per year for most years in that earlier period. The Navy would be able to maintain the desired inventory through 2046—but an average of only 1 new attack submarine per year would be built over the 2026–2046 period. However, it might be difficult for the shipbuilding industry to increase production that quickly and to produce submarines as efficiently after 2025 as it does today.

- To prevent the carrier force from declining to 10 ships in the 2040s—1 ship short of its inventory goal of 11—the Navy could accelerate purchases of carriers after 2018 to 1 every four years, rather than 1 every five years.

- To meet its goal of 88 large surface combatants in the final years of the plan, the Navy could purchase 8 additional destroyers between 2031 and 2041, increasing the production rate to 3 ships per year for eight more years.

14. For an illustration of such an analysis, see Congressional Budget Office, *Options for the Navy's Future Fleet* (May 2006), www.cbo.gov/publication/17802.

15. Although many factors determine the service life of a submarine, the two main factors are the condition of its hull and the energy in its reactor. The number of times a submarine can "cycle"—submerge and surface—before it must be retired is limited, as is the reactor's capacity to produce energy. Some nuclear submarines can be refueled if their hulls have life remaining, but those with "life of the ship" reactor plants cannot be refueled.

- To reach its goal of 52 small surface combatants, the Navy could add back to its plan for the 2020s the 12 LCSs and frigates that DoD ordered it to cut. By acquiring those additional ships then, the Navy would be able to purchase 4 fewer small surface combatants in the 2030s and 2040s than specified under its current plan.

Other approaches to preventing the Navy from falling short of its goals could have different costs. For example, if the Navy was able to extend the service life of some existing ships, it would need fewer new ones. Procurement costs would be reduced, but operation and maintenance costs might increase because older ships tend to be more expensive to operate than newer ships of the same class. Furthermore, such an approach would not be effective in preventing a shortfall of all types of ships. Destroyers, in particular, probably cannot serve longer than the Navy currently expects them to, CBO estimates. Although historically very few destroyers have served longer than 30 years, the Navy's current plan reflects the assumption that most of them will be in service for 40 years. By contrast, extending the service life of amphibious warfare ships seems more plausible because some of those ships have already served for 40 years and the Navy expects some of them to remain in service even longer. Thus, the Navy could prevent the minor shortfalls in amphibious warfare ships after 2040 by not retiring existing ships and extending their service life—in many cases, by a few years.

Build a Fleet of 350 Ships

CBO also examined a shipbuilding plan that would produce a fleet of about 350 ships by 2046 to illustrate the costs of building a larger fleet and the rates at which ships could reasonably be expected to be produced given the existing industrial base.[16] (This notional fleet is somewhat different from one based on the Navy's 2016 force structure assessment. CBO will assess the Navy's 355-ship force goal in a future report.) Under this alternative, the Navy would increase ship production so that it had a fleet of 353 ships by 2046. To meet that goal, the service would purchase 321 ships over the next 30 years at an average cost of $23.0 billion per year. When all shipbuilding activities are included, the average annual cost would be $25.0 billion.

Specifically, the Navy would acquire aircraft carriers at a rate of 1 every three years instead of 1 every five years, as specified under its current plan. Inventory goals for attack submarines and surface combatants would increase by 20 percent. The goal for amphibious ships would increase from 34, which the Navy and Marine Corps describe as "fiscally constrained," to the services' preferred number of 38.[17] To support the larger fleet, the Navy would also increase the number of selected combat logistics and support ships that it purchased. Only the goal for ballistic missile submarines, which was set in accordance with national strategic requirements, would remain unchanged.

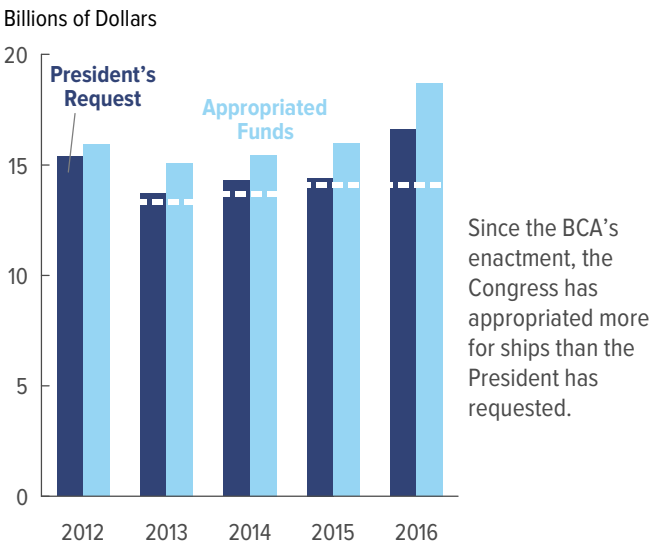
Under this alternative, the fleet would be expanded solely by building new ships. Thus, it would take many years before the goal of 350 could be achieved. A larger fleet could be attained more quickly by delaying the

16. The independent panel that reviewed DoD's 2010 Quadrennial Defense Review for the Congress proposed a fleet of 346 ships, and some independent organizations and Members of Congress have endorsed that proposal. See Stephen J. Hadley and others, *The QDR in Perspective: Meeting America's National Security Needs in the 21st Century, The Final Report of the Quadrennial Defense Review Independent Panel* (United States Institute of Peace, 2010), http://tinyurl.com/3yf5q9f; and Ronald O'Rourke, *Navy Force Structure: A Bigger Fleet? Background and Issues for Congress*, Report for Congress R44635 (Congressional Research Service, November 9, 2016).

17. Joint statement of the Honorable Sean J. Stackley, Assistant Secretary of the Navy, Research, Development, and Acquisition; Vice Admiral Joseph P. Mulloy, Deputy Chief of Naval Operations, Integration of Capabilities and Resources; and Lieutenant General Kenneth J. Glueck Jr., Deputy Commandant, Combat Development and Integration, and Commanding General, Marine Corps Combat Development Command, before the Subcommittee on Seapower and Projection Forces of the House Committee on Armed Services (February 25, 2015), p. 12, http://go.usa.gov/x9Q24. See also Ronald O'Rourke, *Navy LX(R) Amphibious Ship Program: Background and Issues for Congress*, Report for Congress R43543 (Congressional Research Service, June 8, 2016); Maren Leed, *Amphibious Shipping Shortfalls: Risks and Opportunities to Bridge the Gap* (Center for Strategic and International Studies, September 2014), http://tinyurl.com/hpmybxr; and Congressional Budget Office, *An Analysis of the Navy's Amphibious Warfare Ships for Deploying Marines Overseas* (November 2011), www.cbo.gov/publication/42716.

Figure 8.

Requested and Appropriated Shipbuilding Budgets Under the Budget Control Act of 2011



Source: Congressional Budget Office, using data from various volumes of the Department of the Navy's *Highlights of the Department of the Navy Budget*.

The dashed lines indicate CBO's estimate of what the shipbuilding budget would have been under the Budget Control Act of 2011 (as that law stood at the time of each year's budget submission) if it had equaled its historical share of the Department of Defense's base budget.

retirement of some existing ships and upgrading their physical condition and combat capabilities. The Navy could also build ships faster than assumed in this illustration, but doing so would increase costs in the near term and midterm. Such an approach could be less expensive overall than the alternative described here, but it might not provide the Navy the capabilities that advocates of a larger fleet have in mind.

Shipbuilding Under the Budget Control Act of 2011

The Budget Control Act of 2011, as amended by the American Taxpayer Relief Act of 2012 and the Bipartisan Budget Acts of 2013 and 2015, established caps on discretionary defense funding that took effect in 2013 and are scheduled to continue through 2021. Those caps apply to DoD's base budget but not to the costs of overseas contingency operations, including U.S. military activities in Afghanistan, Iraq, and Syria as well as nonroutine military activities elsewhere. The caps limit funding, in real terms, to amounts that are substantially smaller than what DoD received in 2010 when its inflation-adjusted base budget peaked.

In the first three years in which the BCA was in effect, the Congress provided more funding for shipbuilding than the amounts requested by the President, which roughly aligned with the shares that, on the basis of past appropriations, the service would have expected to receive under the law. (For the past 15 years, the Navy has received about 30 percent of DoD's base budget and has devoted about 10 percent of its funding to shipbuilding.) Between 2013 and 2016, the President's budget requests included an average of about $14.7 billion per year in nominal dollars for shipbuilding. The Congress appropriated about 10 percent more, bringing the average to $16.3 billion per year (see Figure 8). Nevertheless, the Navy bought substantially fewer ships between 2013 and 2016 than it had planned to purchase in its 2012 shipbuilding plan, which it had prepared before the BCA took effect. In all, that plan called for the purchase of 45 ships from 2013 to 2016. The Administration proposed purchasing a total of 34 ships in its budgets for those years, and the Congress added funding for 5 additional ships along with partial funding for several more.

In 2016, DoD's real base budget fell to about the same amount that it received in 2008. Under the BCA's caps, funding (in real terms) would essentially remain at that level through 2021. Consequently, under current law, policymakers face a choice: They can implement the Navy's 2017 shipbuilding plan and cut costs elsewhere in the Navy's budget (or in DoD's budget more broadly), scale back the 2017 shipbuilding plan, or take some combination of those actions.

Specifically, if in the coming years the Navy received the same share of DoD's base budget and devoted the same percentage of its budget to ship construction that it has historically, the annual shipbuilding budget would be about $14 billion (in 2016 dollars) from 2017 through 2021. By comparison, the Navy's 2017 plan would require spending a little less than $18 billion per year on all shipbuilding over the same period, CBO estimates. The $14 billion amount would fall by about $4 billion per year—or 22 percent—short of the amount that CBO estimates would be necessary to execute the Navy's 2017 plan over the 2017–2021 period. If all shipbuilding programs were cut proportionately, a reduction of that magnitude would require the Navy to purchase 9 fewer ships than the 38 it currently plans to purchase over that period.

Table 6.

Comparison of the Navy's and CBO's Estimates for the Construction of Major New Ships Under the Navy's 2017 Plan

Billions of 2016 Dollars

	Number of New Ships Purchased Under the 2017 Plan	Total Costs per Class Over the 2017–2046 Period		Average Costs per Ship Over the 2017–2046 Period		Memorandum: Average Costs per Ship Under the 2016 Plan	
		Navy's Estimates	CBO's Estimates	Navy's Estimates	CBO's Estimates	Navy's Estimates	CBO's Estimates
CVN-78 Gerald R. Ford Class Aircraft Carriers	6	70 [a]	73 [a]	11.4 [a]	12.3 [a]	11.6	12.4
Columbia Class Ballistic Missile Submarines	12	77	87	6.4	7.3	6.3	7.5
SSN-774 Virginia Class Attack Submarines	24	70	74	2.9	3.1	2.9	3.0
Improved Virginia Class Attack Submarines (Replacements for Virginia class)	20	69	70	3.4	3.5	3.1	3.2
DDG-51 Flight III Arleigh Burke Class Destroyers	26	44	49	1.7	1.9	1.7	2.0
Future Large Surface Combatants	40	75	90	1.9	2.2	1.9	2.3
Frigates (Modified LCSs)	11	7	7	0.6	0.7	0.6	0.6
Future Small Surface Combatants	44	25	34	0.6	0.8	0.5	0.5
LHA-6 America Class Amphibious Assault Ships	7	24	27	3.4	3.9	3.7	4.1
LX(R)s (Replacements for amphibious dock landing ships)	11	16	18	1.5	1.7	1.6	1.9
LPD-17 Replacements	5	11	13	2.2	2.6	2.0	2.8
T-AO-205 John Lewis Class Oilers	16	8	10	0.5	0.6	0.5	0.6

Source: Congressional Budget Office, using data from the Department of the Navy.

Amounts shown in this table exclude funding for research and development.

For brevity, this table excludes 3 littoral combat ships and 29 support ships of various types that are included in Table 1.

CVN = nuclear-powered aircraft carrier; DDG = guided missile destroyer; LCS = littoral combat ship; LHA = amphibious assault ship; LPD = amphibious transport dock; SSN = attack submarine; T-AO = oiler.

a. In CBO's and the Navy's estimates for aircraft carriers, total costs per class include remaining funding for the CVN-79 but exclude some funding for the carrier that the Navy plans to purchase in 2048 because that money would not be budgeted until 2046 or later. CBO's and the Navy's estimates of the average cost per ship exclude the remaining funding for the CVN-79 but include all funding for the 2043 carrier.

Outlook for Specific Ship Programs

To estimate the costs of implementing the Navy's 2017 shipbuilding plan, CBO calculated the cost of each of the 254 ships that the Navy intends to purchase between 2017 and 2046 (see Appendix A). For ships under construction, the estimates were based in part on data for actual costs from the Navy. For ships yet to be built, the estimates were based primarily on information about the cost-to-weight ratio of similar ships from the past. Specifically, CBO used the cost per thousand tons of lightship displacement—which is the weight of the water that the ship displaces without its crew, stores, ammunition, or fuel or other liquids. CBO then adjusted its estimates to incorporate the effects of *rate* (the reduction in average overhead costs that occurs as a shipyard builds multiple ships of the same type simultaneously) and *learning* (the efficiencies that shipyards gain as they produce additional units of a given type of ship). The effects of rate and learning were applied to the estimated cost of the first ship of a class (the lead ship) to determine the estimated costs for all subsequent ships of that class. Thus, CBO's estimate of the cost of the lead ship of a class drove its estimate of the costs of subsequent ships of that class. For ships for which the Navy has not yet developed designs,

CBO had to make assumptions about their size and capabilities. All cost estimates for specific ships exclude outfitting and postdelivery costs, which typically add at least 3 percent to a ship's cost.

Aircraft Carriers

The 2017 shipbuilding plan states that the Navy's goal is to have 11 aircraft carriers—the number mandated by the Congress. The Navy intends to buy 6 CVN-78 Gerald R. Ford class aircraft carriers over the 2017–2046 period (see Table 6).

The Navy's current estimate of the total cost of the lead ship of the CVN-78 class is $12.9 billion in nominal dollars appropriated over the period from 2001 to 2016, an amount that is equal to the cost cap set in law. CBO used the Navy's inflation index for naval shipbuilding to convert that figure to $14.9 billion (in 2016 dollars), or 23 percent more than the President requested in his budget proposal when the ship was first authorized in 2008.[18] The Navy's estimate does not include $4.8 billion in research and development costs that apply to the entire class.

Because construction of the lead ship is nearly finished, CBO used the Navy's estimate for that ship to estimate the cost of successive ships in the class. That does not, however, mean that all of the cost risk has been eliminated. In particular, the ship's power systems and its advanced arresting gear (that is, the system used to recover aircraft landing on the ship) are not yet working properly. It is not clear how much money will be required to fix those problems, and CBO does not have enough information to make an estimate.[19]

The next carrier after the CVN-78 will be the CVN-79, the *John F. Kennedy*. Funding for that ship began in 2007, the Congress officially authorized its construction in 2013, and appropriations for it are expected to be complete by 2018. The Navy estimates that the ship will cost $11.4 billion in nominal dollars (or $11.1 billion in 2016 dollars). The Navy's selected acquisition report on the CVN-79 states that "the Navy and shipbuilder have made fundamental changes in the manner in which the CVN 79 will be built to incorporate lessons learned from CVN 78 and eliminate the key contributors to cost performance challenges realized in the construction of CVN 78."[20] Although CBO expects the Navy to achieve a considerable cost reduction in the CVN-79 compared with the CVN-78, the agency's estimates are somewhat higher than the Navy's. Specifically, CBO estimates that the ship will cost $11.8 billion in nominal dollars (or $11.5 billion in 2016 dollars), about 4 percent more than the Navy's estimate.[21]

The Navy estimates an average cost of $11.4 billion for the 6 carriers in the 2017 shipbuilding plan (the CVN-80 through the CVN-85). CBO's estimate is $12.3 billion per ship. Both estimates are essentially the same for the 2017 plan as they were for the 2016 plan. The Navy's current estimate incorporates the effects of efforts to reduce costs for the CVN-79 and subsequent ships in the class. CBO's estimate is based on the Navy's estimate for the final cost of the CVN-78. Its estimate is still greater than the Navy's, however, because CBO projects smaller reductions in price than the Navy expects and because CBO anticipates real cost growth in the naval shipbuilding industry.

Submarines

Under the 2017 shipbuilding plan, submarines would consume the lion's share of shipbuilding funds over the next 20 years (see Table 7). The Navy currently operates 14 Ohio class ballistic missile submarines, 4 Ohio class guided missile submarines (SSGNs) modified from the SSBN version, and 51 attack submarines of several classes. Over the next three decades, the Navy plans to buy 12 new SSBNs, the first of which it would purchase in 2021. It also plans to buy 44 new SSNs, including 24 Virginia class submarines and 20 submarines that are based on a redesigned and improved Virginia class. (Production of those ships is set to begin in 2034.)

18. For more on the calculation of the cost cap, see Congressional Budget Office, *Inflation in the Costs of Building Aircraft Carriers* (April 2016), www.cbo.gov/publication/51469.

19. See, for example, Anthony Capaccio, "Navy's $12.9 Billion Carrier Isn't Ready for Warfare, Memo Says," *Bloomberg* (July 20, 2016), http://tinyurl.com/z7q3xxh.

20. Defense Acquisition Management Information Retrieval, *Selected Acquisition Report (SAR): CVN 78 Gerald R. Ford Class Nuclear Aircraft Carrier, as of FY 2016 President's Budget* (Department of the Navy, December 2014), p. 29.

21. DoD's Cost Assessment and Program Evaluation (CAPE) office estimates that the CVN-79 will cost $11.9 billion in nominal dollars. See Tony Capaccio, "Aircraft Carrier $370 Million Over Congressional Cost Cap," *Bloomberg* (May 19, 2015), http://tinyurl.com/hlh5vue.

Table 7.

Total Shipbuilding Costs, by Major Category, 1987 to 2046

	Historical, 1987–2016	CBO's Estimates Under the Navy's 2017 Plan, 2017–2046
	Average Annual Costs (Billions of 2016 dollars)	
New-Ship Construction[a]		
Aircraft carriers	1.9	2.4
Submarines	4.1	7.7
Surface combatants	5.4	6.1
Amphibious warfare ships	1.5	1.9
Combat logistics and support ships	0.9	0.7
Subtotal	13.9	18.9
Refueling of Nuclear-Powered Carriers and Submarines[b]	0.9	1.0
Other Items	1.0	0.8
Total	15.9	20.7
	Percentage of Average Annual Costs	
New-Ship Construction[a]		
Aircraft carriers	14	12
Submarines	30	37
Surface combatants	39	29
Amphibious warfare ships	11	9
Combat logistics and support ships	6	3
Subtotal	88	91
Refueling of Nuclear-Powered Carriers and Submarines[b]	6	5
Other Items	6	4
Total	100	100

Source: Congressional Budget Office.

a. Amounts shown exclude the costs of refueling nuclear-powered aircraft carriers and of other items funded by the Navy's shipbuilding account, including ship conversions, construction of ships that are not part of the Navy's battle force (such as oceanographic survey ships), training ships, and outfitting and postdelivery activities (which include the purchase of smaller tools and pieces of equipment that are needed to operate a ship but that are not necessarily provided by the manufacturing shipyard as part of ship construction). The costs of the mission packages for littoral combat ships, which are not funded by the Navy's shipbuilding account, are also excluded.

b. CBO's estimates under the Navy's 2017 plan reflect only the costs of refueling aircraft carriers. Historically, the refueling of nuclear-powered submarines was also included in the Navy's shipbuilding accounts, but in 2010, the Navy transferred that funding to other accounts.

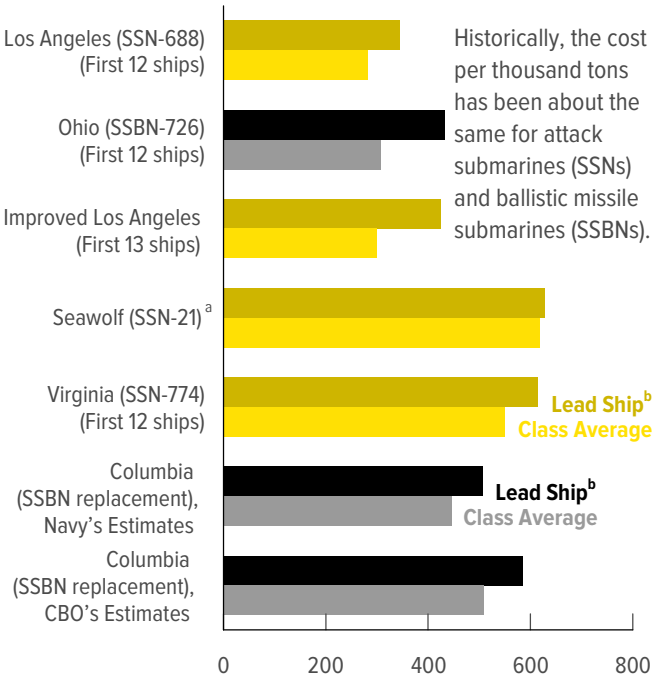
The Navy does not plan to replace the 4 SSGNs that it will retire in the mid-to-late 2020s.

Ballistic Missile Submarines. SSBNs, which carry Trident ballistic missiles, constitute the sea-based component of the United States' strategic nuclear triad. (The other two components are land-based intercontinental ballistic missiles and manned strategic bombers.) The design, cost, and capabilities of the 12 Columbia class submarines included in the 2017 shipbuilding plan are among the most significant uncertainties in the Navy's and CBO's analyses of the cost of shipbuilding in the future. Under the 2017 plan, the first Columbia would be purchased in 2021, although advance procurement funding would be needed starting in 2017 for items with long lead times. The Navy would purchase a second Columbia class submarine in 2024 and then 1 per year from 2026 to 2035 (see Figure 3).[22]

22. For additional information, see Ronald O'Rourke, *Navy Columbia Class (Ohio Replacement) Ballistic Missile Submarine Program (SSBN[X]): Background and Issues for Congress,* Report for Congress R41129 (Congressional Research Service, October 25, 2016). See also the testimony of Eric J. Labs, Senior Analyst for Naval Forces and Weapons, Congressional Budget Office, before the Subcommittee on Seapower and Expeditionary Forces of the House Committee on Armed Services, *The Long-Term Outlook for the U.S. Navy's Fleet* (January 20, 2010), www.cbo.gov/publication/41886.

Figure 9.

Cost per Thousand Tons for Various Classes of Submarine, Lead Ship and Class Average



Source: Congressional Budget Office, using data from the Department of the Navy.

Cost per thousand tons of Condition A-1 weight, which is analogous to lightship displacement (the weight of the ship without its crew, stores, ammunition, or fuel or other liquids) for surface ships.

SSBN = ballistic missile submarine; SSN = attack submarine.

a. Although 29 Seawolf class submarines were planned, only 3 were built before the program was canceled.

b. Data exclude the nonrecurring costs of engineering and detailed design.

The Navy currently estimates that the first Columbia will cost $12.2 billion in 2016 dollars and that the subsequent ships will have an average cost of $5.9 billion. (The Navy has stated that it aims to reduce that cost to $5.7 billion.)[23] The implied total cost for the 12 submarines is $77 billion, or an average cost of $6.4 billion for each ship (see Table 6). The Navy estimates that research and development costs will amount to $13 billion, bringing the total acquisition cost to $90 billion. (See Box 3 for a discussion of how the costs in the Navy's shipbuilding plan compare with the costs in the recently released Columbia class Milestone B acquisition decision memorandum.)

According to the Navy's estimate, the cost per thousand tons for the first Columbia will be 17 percent less than that of the first Virginia class attack submarine—an improvement that would affect costs for the entire new class of ballistic missile submarines. The Navy anticipates lower costs by weight for the Columbia because it plans to recycle, to the extent possible, the design, technology, and components used for the Virginia class. Furthermore, because ballistic missile submarines (such as the Columbia class) tend to be larger and less densely built ships than attack submarines (like the Virginia class), they will be easier to build and thus less expensive per thousand tons, the Navy asserts. The Navy has stated, however, that there is a greater than 50 percent probability that the cost of the first Columbia and of subsequent ships of the class will exceed its estimates.

The costs of lead ships of new classes of submarines built in the 1970s and 1980s provide little evidence that ballistic missile submarines are cheaper by weight to build than attack submarines (see Figure 9). The first Ohio class submarine was more expensive to build than the lead ships of the two classes of attack submarines built during the same period—the Los Angeles and the Improved Los Angeles. (The design of the Improved Los Angeles included the addition of 12 vertical-launch system cells.) In addition, the average cost-to-weight ratio of the first 12 or 13 ships of the class was virtually identical for the Ohio, Los Angeles, and Improved Los Angeles classes.

By the 1990s, although the cost by weight of lead ships for submarines had grown substantially, there was still little evidence that size makes a difference in the cost per thousand tons of submarines. The first Virginia class submarine, which was ordered in 1998, cost about the same by weight as the first Seawolf submarine even though the Seawolf is 20 percent larger and was built nine years earlier.

Using data from the Virginia class submarine program, CBO estimates that the first Columbia class submarine will cost $13.3 billion in 2016 dollars. (The Navy

23. That objective was stated in a briefing by the Navy to the staff of the House Committee on Armed Services, CBO, and the Congressional Research Service on February 28, 2011. The Navy's estimate, expressed in 2010 dollars, was that each Columbia class submarine produced after the lead ship would cost $5.6 billion, on average, and the service hoped to reduce that cost to $4.9 billion.

Box 3.

The Navy's New Estimates for the Columbia Class Ballistic Missile Submarine

On January 4, 2017, the Department of Defense (DoD) approved the Columbia class ballistic missile submarine for production. Specifically, the Under Secretary of Defense for Acquisition signed the acquisition decision memorandum (ADM) that launched the program into engineering and manufacturing development—known as Milestone B in DoD's complex acquisition process. That development is notable for several reasons, but the ADM is particularly significant because it included an updated cost estimate for the 12-ship program. Although the new ADM estimate appears to be significantly higher than the costs estimated in the Navy's 2017 shipbuilding plan, the Navy states that the real (inflation-adjusted) costs in the ADM are actually similar. The Congressional Budget Office did not include the new ADM estimates in presenting the Navy's estimates of the 2017 plan because detailed information is not yet available; the updated estimates in the ADM would not affect CBO's projections of the costs of the plan.

In the ADM, the Navy estimates that the 12 submarines will cost an average of $7.1 billion each *in 2017 dollars* ($7.3 billion including outfitting and postdelivery costs). To compare that estimate with those in the Navy's 2017 shipbuilding plan, CBO adjusted the amounts to 2016 dollars to match the dollars reported in that plan. The result is that the average cost per vessel for the 12-ship program under the Navy's new estimate—excluding outfitting and postdelivery costs—would be $6.8 billion *in 2016 dollars* (see the table). That amount is about $400 million more than what the Navy reported in its 2017 shipbuilding plan and closer to CBO's estimates of $7.3 billion.

According to the information about DoD's new Milestone B cost estimate that is available to CBO, most of the difference between the Navy's estimates should not be interpreted as a change in the underlying cost of the program; rather, it is the result of the two different methods that the Navy used to convert its constant-dollar estimates for the Columbia class program from the 2010 dollars in which they were expressed at Milestone A into 2016 dollars for the 2017 shipbuilding plan and 2017 dollars for the estimates in the ADM. The Navy used an inflation index based specifically on the Columbia class program to adjust its estimates for the ADM, whereas it had used the broader naval shipbuilding cost index discussed in Box 2 to prepare its estimates for the 2017 shipbuilding plan. The Navy's method for preparing the estimates in the ADM accounts for the fact that inflation in the submarine shipbuilding industry has been greater than gross domestic product price inflation. It is similar to the method that CBO used throughout its analysis, which is discussed in more detail in Box 2, and explains why the Navy's estimate in the ADM is much closer to CBO's estimate for the Columbia class than its estimate in the 2017 shipbuilding plan.

In addition, the Navy's estimate in the ADM is higher than its estimate in the 2017 shipbuilding plan for another reason: The ADM represents the Navy's most current estimate of the costs of the submarines, whereas for the 2017 shipbuilding plan, the Navy based its estimates on its cost target for the ships, which is lower.

The ADM also includes an "affordability cap" of $8.0 billion per ship, essentially allowing for the possibility of cost growth of as much as 10 percent above the Navy's estimate of $7.3 billion. According to Navy officials, all major acquisition programs at Milestone B must include an affordability cap or growth margin. If a program's costs exceed its cap, DoD will review the program to determine whether major changes or other corrective actions are needed.

The Navy's Estimates for Columbia Class Submarines at Milestone B

Billions of Dollars

	2010 Dollars	2016 Dollars[a]	2017 Dollars
Cost of Lead Ship			
Plans	4.2	5.0	5.1
Construction	6.2	7.3	7.5
Other costs	0.5	0.6	0.6
Total	11.0	12.9	13.3
Average Cost of 11 Follow-on Ships	5.0	6.3	6.5
Average Cost of All 12 Submarines	5.4	6.8	7.1
Outfitting and Postdelivery Costs	n.a.	0.2	0.2
Average Cost, Including Outfitting and Postdelivery Activities	n.a.	7.0	7.3
Affordability Cap	n.a.	7.7	8.0
Total Procurement Cost for 12 Ships	66	82	85

Source: Congressional Budget Office, using data from the Department of the Navy.

n.a. = not applicable.

a. CBO converted the estimate in the Navy's acquisition decision memorandum for the Columbia class program, which is in 2017 dollars, into 2016 dollars.

estimates that it will cost $12.2 billion.) Estimating the cost of the lead ship of a class with a new design is particularly difficult because of uncertainty about how much the Navy will spend on nonrecurring engineering and detailed design. CBO estimates that, all told, 12 Columbia class submarines would cost $87 billion, or an average of $7.3 billion each—$0.9 billion more per submarine than the Navy estimates. That average is based on the $13.3 billion estimated cost of the lead submarine and an average cost of $6.7 billion estimated for the 2nd through 12th submarines. Research and development will cost between $13 billion and $17 billion, CBO estimates, for a total program cost of $100 billion to $104 billion.

Overall, the Navy expects a 19 percent improvement in the cost-to-weight ratio of the Columbia class compared with the first 12 submarines in the Virginia class. Given the history of submarine construction, however, CBO is less optimistic than the Navy. It estimates that the Navy will realize an 8 percent improvement, stemming in part from the projected savings attributable to the concurrent production of the Columbia and Virginia class submarines.

The costs for the Columbia class submarines could be lower than the Navy and CBO project, depending on the acquisition strategy. The savings could be considerable if, for example, lawmakers authorized the Navy to use a block-buy strategy—an approach that it has used with other types of ships—to purchase a group of submarines over a specified period (effectively lowering the price of the ships by promising a steady stream of work for the shipyard) and allowed the service to purchase components and materials for the submarines in optimal amounts that minimize costs (known as economic order quantities).[24] However, some benefits of a block-buy strategy are already incorporated into the Navy's and CBO's estimates because they are based in part on the costs of the Virginia class, the first few ships of which the Navy purchased using a block-buy strategy. Similarly, if the Congress funded the purchase of the Columbia class submarines through the National Sea-Based Deterrence Fund, which was established in the Carl Levin and Howard P. "Buck" McKeon National Defense Authorization Act for Fiscal Year 2015, the Navy could potentially save several hundred million dollars per submarine by purchasing components and materials for several submarines, and possibly for other ships, at the same time.[25] One disadvantage of such an acquisition strategy is that if lawmakers later decided not to build all the submarines for which the Navy purchased materials, the materials that were to be used for them might go unused. A second disadvantage is that under a block-buy strategy, if the Congress did not approve of how the program was progressing, it might have less flexibility to change procurement plans or to purchase fewer submarines.

Costs for the Columbia class submarines could, however, exceed both the Navy's and CBO's estimates. The new SSBN will be the largest submarine that the United States has ever built. It will reuse technology and components from the Virginia class submarine, but it will also include many new elements, such as a new missile compartment and a nuclear reactor designed to last the entire 42-year service life of the submarine.

Attack Submarines. The 2017 shipbuilding plan calls for the Navy to buy 24 Virginia class attack submarines. Between 2017 and 2033, it would purchase 1 or 2 such ships per year. In 2034, the Navy would begin purchasing the ship's successor—the Improved Virginia class submarine—at the same rate.

The Navy's and CBO's estimates of the cost of purchasing all the Virginia class submarines included in the 2017 shipbuilding plan are similar. The Navy estimates that the 24 submarines scheduled to be purchased between 2017 and 2033 would cost a total of about $70 billion. CBO estimates that cost to be $74 billion.

The Navy expects to purchase the first Improved Virginia class submarine in 2034. The service's recent shipbuilding plans have called for continually changing the current design to create a new class of submarine that

24. For more information on block-buy and multiyear procurement authority acquisition strategies, see Ronald O'Rourke and Moshe Schwartz, *Multiyear Procurement (MYP) and Block Buy Contracting in Defense Acquisition: Background and Issues for Congress,* Report to Congress R41909 (Congressional Research Service, July 25, 2016). The potential cost savings from block buys and purchasing materials in economic order quantities are not included in either the Navy's or CBO's estimates.

25. That fund, like the National Sealift Defense Fund, would probably operate outside of many of DoD's acquisition regulations, and it would allow the Navy to make a single purchase of components and materials for a group of submarines. The potential cost savings are not included in either the Navy's or CBO's estimates.

incorporates significant technological upgrades in systems and capabilities. CBO therefore assumed that the Improved Virginias would incorporate changes that were substantial enough to make the submarines a new class, although that class would not have a wholly new design. On the basis of that assumption, CBO arrived at estimates similar to the Navy's: It estimated that the average Improved Virginia class attack submarine would cost $3.5 billion, slightly more than the Navy's estimate of $3.4 billion.

Although its shipbuilding plan does not include purchasing submarines to replace the 4 existing Ohio class guided missile submarines when they are retired in the 2020s, the Navy expects to lengthen the hull of future Virginia class submarines to insert the Virginia payload module (VPM). The VPM would contain four large-diameter payload tubes, each of which could carry 7 Tomahawk missiles. That modification would increase the submerged displacement of the submarine by nearly 30 percent and would increase the number of the Virginia class submarine's vertical-launch weapons from 12 to 40. (The submarines are armed with approximately 25 additional weapons in the torpedo room.) The Navy estimates that 20 Virginia class submarines equipped with the additional payload modules would provide a "near equivalent" to the strike capability of the existing force of 4 SSGNs. In the 2017 budget, the Administration proposed spending $700 million between 2015 and 2019 for research and development on the VPM and for modifying the design of the Virginia class submarine. The Navy's 2017 plan calls for including the VPM on all new Virginia class submarines starting in 2019 (a total of 20 ships), whereas the 2016 plan called for only 15 Virginias with the VPM. Both the Navy's and CBO's estimates of costs reflect that change.

Large Surface Combatants

Under its 2017 plan, the Navy would purchase the same types of destroyers it would have under the 2016 plan. The service restarted production of DDG-51 Flight IIA destroyers in 2010 and purchased 11 of them through 2016. (The fleet already has 62 DDG-51s, including 34 Flight IIAs, which were purchased before production ceased in 2005.) The Navy may use funds appropriated for 2016 to acquire 1 more DDG-51 Flight IIA if the Congress appropriates enough money in 2017 for the service to complete the purchase.[26] Between 2017 and 2029, the Navy plans to build 26 DDG-51s with an upgraded design, a configuration known as Flight III (see Table 6). The first ship in that new flight was authorized in 2016. In 2030, the Navy would buy the first of 40 large surface combatants of a new class, which is intended to replace the DDG-51 class. Although those new ships were designated as destroyers in the past, the Navy does not offer any description or designation of the class in its 2017 plan.

The Navy is pursuing two other strategies to boost its inventory of large surface combatants. One is to modernize 11 of its 22 Ticonderoga class cruisers and thereby extend their service in the fleet through 2038. (The other 11 would remain in the fleet through the end of their service life but would not require as much modernization to remain effective.) If the Navy does not modernize those ships, all of its cruisers will be retired by 2028. The other critical strategy is to keep all DDG-51 Flight IIAs and subsequent destroyers serving in the fleet for 40 years. The class was originally designed to serve for 30 years, but the Navy has gradually increased the planned service life of Flight IIA and Flight III ships—first to 35 years and then, in the 2009 shipbuilding plan, to 40 years. However, 12 of the last 13 classes of destroyers and cruisers have been retired after serving for 30 years or less. Indeed, in recent years, Spruance class destroyers and some Ticonderoga class cruisers have been retired after serving 25 years or less. The Navy retired all of those ships for various reasons: They had reached the end of their useful service life, they became too expensive to maintain, or they no longer had the combat capabilities needed to meet existing threats and modernization was not considered cost-effective.[27] If the DDG-51 class met the same fate, the Navy would need to purchase additional ships to achieve its inventory goal.

DDG-51 Flight III Destroyers. The Navy's strategy for meeting the combatant commanders' goal of improving ballistic missile defense capabilities so that in the future

26. In the 2016 appropriation, the Congress provided all of the funding necessary to acquire 2 destroyers. In addition, it appropriated $1 billion more than the President requested in fiscal year 2016 to fund the purchase of a third destroyer. However, the Navy is unwilling to award a construction contract for the ship until it has the remaining funds of about $430 million from future appropriations that it needs to complete construction of the ship.

27. See the testimony of Eric J. Labs, Senior Analyst, Congressional Budget Office, before the Subcommittee on Seapower and Expeditionary Forces of the House Committee on Armed Services, *The Navy's Surface Combatant Programs* (July 31, 2008), www.cbo.gov/publication/20065.

they exceed those provided by existing DDG-51s—and for replacing 11 Ticonderoga class cruisers when they are retired in the 2020s—is to substantially modify the design of the DDG-51 Flight IIA destroyer to create a Flight III configuration.[28] That modification would incorporate the new Air and Missile Defense Radar (AMDR), now under development, which will be larger and more capable than the radar on current DDG-51s. The effective operation of the AMDR in the new Flight III configuration, however, will require an increase in the ships' capacity to generate electrical power and their ability to cool major systems.[29]

With those improvements incorporated into the design of the Flight III and the associated increases in the ships' displacement, CBO expects that the average cost per ship over the entire production run would be $1.9 billion in 2016 dollars—about 15 percent more than the Navy's estimate of $1.7 billion. Costs could be higher or lower than CBO's estimate, however, depending on the eventual cost and complexity of the AMDR and the associated changes to the ship's design to integrate the new radar.

Future Large Surface Combatants. Like the Navy's 2016 shipbuilding plan, the current plan includes a future class of LSCs that is intended to replace the DDG-51 Flight I and II ships when they are retired in the late 2020s and 2030s.[30] Unlike the 2016 plan, however, the 2017 plan does not specify whether that new ship would be a cruiser or destroyer or something else entirely. The Navy's report does not describe the ship at all, although the 2016 plan described it as a "mid-sized future surface combatant."[31]

Under the 2017 plan, production of the future class of large surface combatants would start in 2030. The Navy says that it would buy 40 of the new LSCs through 2046 at an average cost of $1.9 billion—about $200 million more than the average cost of a DDG-51 Flight III ship. That estimate implies that the new LSC will be either a destroyer-sized ship with capabilities that represent only a modest improvement over the DDG-51 Flight III or a smaller ship with significantly improved capabilities.

The Navy appears to base its estimate of the cost of the future class of LSCs on a modified version of the existing DDG-51. In contrast, CBO expects that the new LSC will have a largely new design but be about the same size as the DDG-51 Flight III, which would make it consistent with the concept of a large surface combatant. A new design is likely to be more expensive to build than a modified version of an existing ship. Thus, CBO projects that the average future LSC will cost $2.2 billion, roughly 20 percent more than the Navy's projection. Over the 2017–2046 period, CBO estimates, the Navy would have to spend $90 billion for the future LSC portion of the shipbuilding program—$15 billion more than the Navy's estimate of $75 billion. That amount represents almost one-quarter of the overall difference of $57 billion between the Navy's and CBO's estimates of the total cost of the 2017 shipbuilding plan (see Appendix B). The great uncertainty about the ultimate size and capabilities of the future class of LSCs suggests that the true cost could be substantially different from both the Navy's and CBO's estimates.

Small Surface Combatants

Under the 2017 plan, the Navy envisions building 40 small surface combatants—littoral combat ships and frigates—by 2025. In December 2015, the Secretary of Defense directed the Navy to reduce the number of LCSs and frigates that it planned to purchase from 52 to 40 and to invest the money it would have spent on those canceled ships in other areas. In the 2017 plan, the Navy's stated goal for small surface combatants remains at 52.

28. Combatant commanders—the four-star generals or admirals who head the regional commands—oversee all U.S. military operations within their areas of geographic responsibility.

29. See Ronald O'Rourke, *Navy Aegis Ballistic Missile Defense (BMD) Program: Background and Issues for Congress,* Report for Congress RL33745 (Congressional Research Service, October 25, 2016), and *Navy DDG-51 and DDG-1000 Destroyer Programs: Background and Issues for Congress,* Report for Congress RL32109 (Congressional Research Service, October 19, 2016). Press reports indicate that some Navy officials do not agree with the DDG-51 Flight III strategy and would prefer to build Flight IIAs a little longer while designing an entirely new destroyer that would allow for new, more capable, potentially larger weapons and increased capabilities in the future. See Christopher P. Cavas, "U.S. Navy Weighs Halving LCS Order," *Defense News* (March 17, 2013).

30. Those retirement dates are based on the Navy's assumption that all DDG-51 Flight IIAs will be modernized midway through their 40-year service life.

31. Department of the Navy, *Report to Congress on the Annual Long-Range Plan for Construction of Naval Vessels for Fiscal Year 2016* (March 2015), http://tinyurl.com/ocrqtfc.That description also appeared in the 2015 plan but not in prior shipbuilding plans.

The first LCS was authorized in 2005, and the Navy currently has 26—split evenly between two designs built by competing contractors—either already in its fleet or currently under construction. Because those ships are assumed to have a service life of 25 years, the Navy would need to begin procuring their replacements in 2029. The service plans to purchase 3 more LCSs through 2018 and then 11 frigates between 2019 and 2025 to complete a force of 40 ships. (The Navy says that, if possible, it will order the first of the new frigates in 2018—and buy 1 less LCS—thus bringing the total number to be acquired to 12.) In 2030, the Navy would begin purchasing 44 next-generation ships, which it currently refers to simply as future small surface combatants, to replace the first-generation LCSs and frigates as they retire.

When it was first conceived, the LCS differed from other past and present U.S. warships in that its production program was divided into two components—the sea frame (the ship itself) and mission packages (the main combat systems). The sea frame was originally designed and built so that mission packages with one of three capabilities—antisubmarine, antisurface warfare, or countermine—could be switched onto or off of a given ship over time as its mission changed. But in a recent review of the LCS program, the Navy's leadership decided that in the future one particular mission package would be installed on each ship indefinitely. Thus, although it will still be possible to switch the mission package of a given ship, the Navy would probably not make such a change because the operating concept, maintenance, and training for the class will be designed around the new approach. The new policy will bring the LCSs more in line with frigates, which will not feature interchangeable mission packages but will instead have most of the antisubmarine and antisurface warfare equipment, along with some other items, permanently installed. It is not clear at this point how many mission packages the Navy would buy for its LCS force.[32]

32. See Ronald O'Rourke, *Navy Littoral Combat Ship (LCS)/Frigate Program: Background and Issues for Congress*, Report for Congress RL33741 (Congressional Research Service, October 19, 2016); and Justin Doubleday, "Navy Will Base Independence-Variant LCSs on West Coast, Freedom-Variant Ships on East Coast," *Inside Defense* (September 8, 2016), http://tinyurl.com/zkafvys.

The Navy currently estimates that, on average, each of the frigates will cost $625 million, although the ships' final design and capabilities have not yet been determined. Based on all publicly available information, CBO estimates that the frigates will cost an average of $655 million per ship. The uncertainty surrounding the frigate design, however, makes those estimates subject to change.

Under the 2017 plan, the Navy would also purchase 44 future small surface combatants beginning in 2029. In light of the many changes encountered by the LCS program and its continuing evolution, it is not clear how large the new SSC will be, what capabilities it will have, or what its full range of missions will be. The Navy estimates that each of the new SSCs will cost an average of $560 million; it is not clear whether that estimate includes a mission package. On the basis of that estimated cost, it appears that the Navy assumed that the new SSC would be similar to the LCS in size and capabilities.

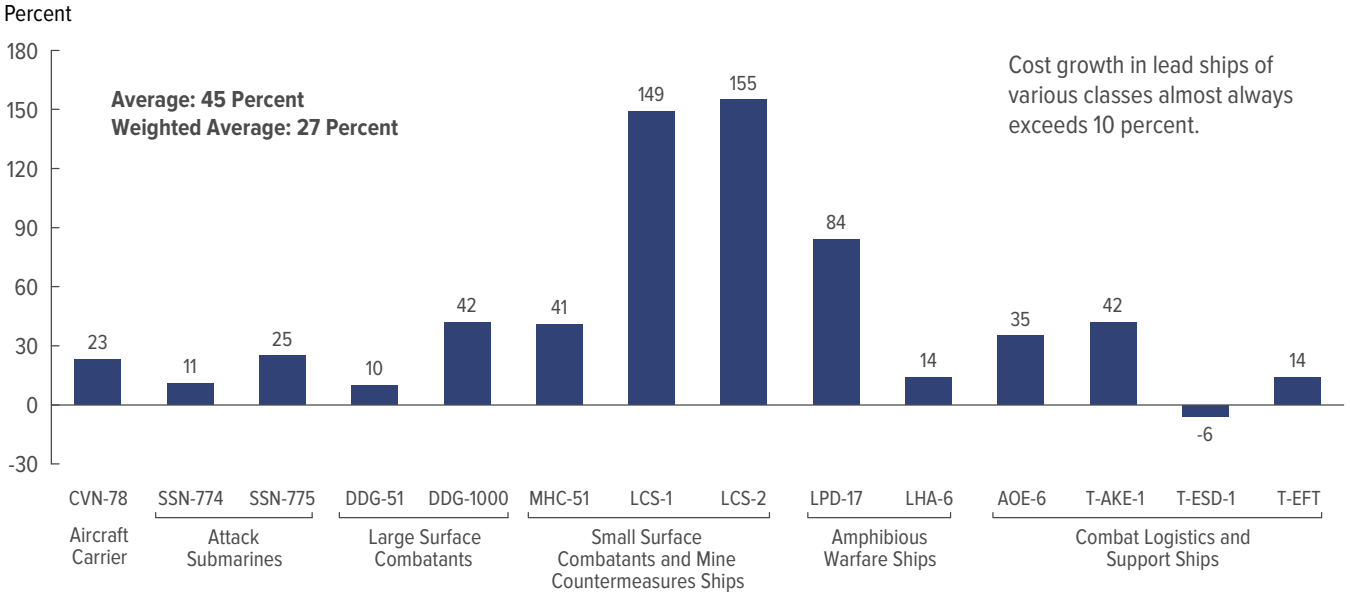
In contrast, CBO assumed that the new class of small surface combatants would be larger than the currently planned frigates and more in line with the recently retired class of Oliver Hazard Perry frigates. CBO estimates that new SSCs will cost $770 million each. That estimate reflects real cost growth in the naval shipbuilding industry as well as the assumption that the new small surface combatant will be a more capable ship than what the Navy plans.

Amphibious Warfare Ships

The Navy's inventory goal for amphibious warfare ships is 34. That proposed force would consist of 11 LHA or LHD amphibious assault ships, 12 LPD amphibious transport docks, and 11 replacements for the Navy's LSD dock landing ships. The 2017 plan calls for buying 7 LHA-6s, at a rate of 1 every four or seven years, to replace LHD-1 class amphibious assault ships as they are retired. It also calls for purchasing 11 LX(R)s (the replacements for dock landing ships)—the first in 2020, and then 1 per year between 2022 and 2031—to replace existing LSD-41s and LSD-49s. Under the plan, the Navy would also start replacing the LPD-17 class with a new class in 2040 and would buy 5 of the new ships by 2046.

Figure 10.

Cost Growth in Lead Ships, 1985 to 2015



Source: Congressional Budget Office, using data from the Department of the Navy.

For most ships, CBO calculated cost growth using the first and last mentions of a ship in the books that accompany each year's budget: *Justification of Estimates, Shipbuilding and Conversion, Navy*. For AOE-6, MHC-51, T-EFT (formerly JHSV), and DDG-51, CBO relied on information papers provided by the Navy for the final estimates and on the Budget Appendixes for the years those ships were authorized.

AOE = fast combat support ship; CVN = nuclear-powered aircraft carrier; DDG = guided missile destroyer; LCS = littoral combat ship; LHA = amphibious assault ship; LPD = amphibious transport dock; MHC = coastal mine hunter; SSN = attack submarine; T-AKE = ammunition cargo ship; T-EFT = expeditionary fast transport (formerly joint high-speed vessel); T-ESD = expeditionary transfer dock (formerly mobile landing platform).

The Navy intends to keep the existing class of LHD-1 amphibious assault ships in service for 43 to 45 years. That expectation, which the service has stated in its four most recent shipbuilding plans, differs from the 40-year service life that the Navy generally estimates for amphibious warfare ships and that it identified for the LHD-1 class in its 2012 plan.

The Navy estimates that the LHA-6 class amphibious assault ships will cost $3.4 billion each—$400 million less per ship than the estimate provided in the 2016 plan. It is not clear why the Navy's estimate fell by more than 10 percent. CBO's estimate is higher than the Navy's and remains the same as it was last year—$3.9 billion per ship. Both CBO and the Navy assumed that the LHA-6 class ship authorized for 2017 and all subsequent amphibious assault ships would have well decks, which would necessitate some redesign of the LHA-6 class and therefore impose additional costs; those costs are reflected in both the Navy's and CBO's estimates. (A well deck is a large floodable area in the stern of an amphibious warfare ship that allows direct launching of amphibious vehicles and craft.)

The Navy estimates that each LX(R) will cost $1.5 billion, on average, and that the lead ship will cost $1.6 billion. The design of the LX(R) is to be based on the hull of the LPD-17, which is much larger than existing LSDs. The Navy estimates that a modified LPD-17—designed to reduce both capability and cost—would cost about $1.8 billion if ordered today. Thus, the Navy's estimate for the first LX(R) appears optimistic in light of the growth in the costs of lead ships that has occurred over the past 30 years (see Figure 10). To achieve its cost goal for the LX(R), the Navy plans to alter the design of those ships further and to change the manner in which it buys them. First, the LX(R) variant of the LPD-17 will have substantially less capability than the LPD-17 class. Second, the Navy plans to use a competitive process for procurement, which would probably include asking the Congress to give it multiyear authority or block-buy authority to purchase ships—or at least the materials for them—in batches of 5 to 10.[33] Such authority would be similar to that provided for the Arleigh Burke class destroyers, Virginia class attack submarines, and LCSs. The shipyards competing to build the LX(R) would almost certainly incorporate the cost-saving benefits of such contracts into their bids.

On the basis of the limited information available, CBO estimates that the LX(R) class will cost an average of $1.7 billion per ship. The agency used the existing LPD-17 hull as the starting point for its estimate and then adjusted the ship's size to reflect the reduced capability it expects for the LX(R). CBO's estimate reflects the assumption that the Navy would use multiyear or block-buy procurement authority to purchase the ships and that it would do so in a competitive environment.

In the final six years covered by its current shipbuilding plan, the Navy would purchase 5 replacements for the LPD-17 class amphibious ships. CBO assumed that the replacement for the LPD-17 would be the same size and have roughly the same capabilities as the existing class—an assumption that the Navy also appears to have made in its 2017 plan. CBO estimates that the average cost of those ships will be $2.6 billion. That estimate is higher than the Navy's estimate of $2.2 billion largely because CBO factors real growth in the costs of labor and materials in the shipbuilding industry into its constant-dollar estimates and the Navy does not.

33. Although multiyear procurement and block-buy authority are broadly similar acquisition strategies, there are differences between them. Block-buy authority is not regulated by statute, and it is more flexible (in that it is subject to less Congressional oversight) and less likely to carry cancellation penalties than multiyear procurement authority. But multiyear procurement authority allows the Navy to buy materials in large quantities for all ships covered under a given contract (and thus purchase materials in economic order quantities), whereas block-buy authority requires separate authorizations to purchase materials for more than one ship at a time.

Appendix A: How CBO Estimates the Cost of New Ships

For this report, the Congressional Budget Office projected the costs of building the new ships that the Navy has proposed to purchase in its 2017 shipbuilding plan by first analyzing the cost per thousand tons for analogous ships that have already been built. The resulting amounts were then adjusted to account for the percentage of the cost attributable to *rate*, the production efficiencies that are made possible when several ships of the same type are built simultaneously at a given shipyard, and those that arise from *learning*, the gains in efficiency that accrue over the duration of a ship's production as shipyard workers gain familiarity with a particular ship model. CBO also accounted for the effect of the Navy's acquisition strategy for purchasing new ships—specifically, whether the service can reduce spending by purchasing in quantity. Finally, CBO's estimates (all in constant 2016 dollars) reflect the expectation that the costs of labor and materials in the naval shipbuilding industry will continue to grow faster than prices in the economy as a whole, as they have for the past several decades.

Projecting the Size of Future Ships

To estimate the cost of a future ship, CBO first uses data from the Navy to estimate the ship's size, which is traditionally measured as displacement—the weight of the water it displaces. At this step, CBO determines the size by *full-load displacement* for surface ships and by *submerged displacement* for submarines, both of which measure the weight displaced by the ships with their contents—crew, stores, ammunition, and fuel and other liquids. If such data are not available (perhaps because the ship is projected to be built in 20 years and the Navy does not specify ship designs that far in advance), CBO makes its estimate based on the sizes of existing ships of the same type that perform the same missions.

For example, the Navy has described the DDG(X), a guided missile destroyer, as a future "midsized" surface combatant, although it has not yet designed the ship. The Navy estimates that the cost of a DDG(X) will be close to that of a large surface combatant—in this case, a modified version of the DDG-51 Flight III destroyer. A fully loaded midsized surface combatant displaces between 6,000 and 9,000 tons; the Navy's current large surface combatants displace 9,000 to 10,000 tons each. (The new Zumwalt class DDG-1000 destroyer, which is currently in production, displaces 15,000 tons.) CBO's estimate of the cost of the DDG(X) incorporates the assumption that, like the current DDG-51 Flight III, the new ship would displace 10,000 tons.

Once the size of the ship when fully loaded is determined, CBO estimates the weight of the ship when it is mostly empty—the *lightship displacement* for surface ships or the *Condition A-1 weight* for submarines, both of which are reasonable measures of the weight of a vessel without a crew, stores, ammunition, or fuel or other liquids.

The Relationship Between Weight and Cost

After estimating a ship's size, CBO uses historical data from an analogous class or classes of ship to calculate the ship's cost per thousand tons (see Table A-1). A primary advantage of CBO's using analogous ships and cost-to-weight comparisons to develop its estimates is that doing so is more straightforward than projecting costs on the basis of supposition; similar ships have already been built and their cost-to-weight ratios are already documented. The primary disadvantage of that approach is that, because the data are historical, they will not capture potential improvements in manufacturing or other efficiencies that come with new approaches to ship construction or changes in technology that could lower a ship's cost per thousand tons. (However, that disadvantage may not have much practical effect: CBO has not identified any examples of new-generation ships that cost less per ton than earlier ships of the same type.) Another

Table A-1.

Ship Analogues for Estimating Cost-to-Weight Ratios

Ship Type	Analogous Ship Class
Aircraft Carriers	Ford (CVN-78)
Ballistic Missile Submarines	Virginia (SSN-774)
Attack Submarines	Virginia (SSN-774)
Large Surface Combatants	Arleigh Burke (DDG-51)
Small Surface Combatants	Freedom (LCS-1) Independence (LCS-2)
Large Amphibious Warfare Ships	America (LHA-6)
Small Amphibious Warfare Ships	San Antonio (LPD-17)

Source: Congressional Budget Office.

disadvantage is that sometimes there is no good historical analogue, recent or distant, to use as the basis of a cost projection for a new ship with an innovative design. In rare instances, CBO may start with the Navy's estimate and then apply a more generic factor to account for the likely increase in cost above the amount in the Navy's current plan. The object of applying such factors, which are derived empirically from historical data, is to track cost growth as the shipbuilding program evolves.[1]

As a rule, CBO tries to find the most recent comparable ship as a model for its cost-to-weight estimates. It would not be appropriate or useful to use an aircraft carrier as the analogue for a submarine: They are different vessels with different missions and designs, so their cost-to-weight ratios are not comparable.

For example, CBO identified the current Virginia class attack submarine as the most logical analogue for the new Columbia class ballistic missile submarine. Specifically, CBO used the cost per thousand tons of A-1 weight of the Virginia class submarine to estimate the cost of the Columbia class submarine as though it would be built in 2016. On the basis of the Navy's estimate that the new submarine would be about two and a half times the size of the current Virginia class submarine, CBO estimated that the total cost of the new vessel would be about two and a half times that of a Virginia class submarine at this point in the cost-estimating process. The agency did not use the historical cost of the original Ohio class ballistic missile submarine as the basis of its estimate because the Ohio was first built in the 1970s, too long ago to be useful. Even if adjusted for inflation, that basis would yield a cost for the Columbia that is only slightly higher than the cost of the Virginia today, despite the large difference in size.

Adjusting for Rate, Learning, and Acquisition Strategy

After establishing its preliminary estimate of how much a new ship would cost in 2016, CBO applies factors associated with rate, learning, and, as appropriate, the Navy's acquisition strategy to the entire proposed shipbuilding program. Although described here separately, those factors are applied simultaneously in the cost-estimating process. The result is an estimate of the cost of building new ships without any adjustment to account for future economic conditions in the industry.

When more than one ship is purchased in a given year, the cost per ship is less than it would be for a single ship, largely because the fixed overhead costs of ship construction at a shipyard are shared by more ships. That difference is the rate effect: It is less expensive per ship to produce two ships than it is to produce one, and cheaper still to build four ships than to build two—as long as the shipyard has the production facilities and workforce to accommodate the larger volume of work. Historically, the rate effect varies by type of ship. For example, building 2 attack submarines rather than 1 in a year reduces the cost of both by 10 percent; for surface combatants, the rate effect is closer to 20 percent.

Occurring simultaneously with the rate effect is the learning effect. As more ships of the same type are built in sequence, the shipyard learns how to build those ships more and more efficiently. The cost of the second ship in a production run is less than the first, the fifth ship is less expensive than the second, and the ninth ship is even

1. Several researchers have examined the historical cost growth of weapon systems. See, for example, David L. McNicol and Linda Wu, *Evidence on the Effect of DoD Acquisition Policy and Process on Cost Growth of Major Defense Acquisition Programs*, IDA Paper P-5126 (Institute for Defense Analyses, September 2014), www.acq.osd.mil/parca/docs/ida-p5126.pdf (826 KB); Obaid Younossi and others, *Is Weapon System Cost Growth Increasing? A Quantitative Assessment of Completed and Ongoing Programs* (prepared by the RAND Corporation for the United States Air Force, 2007), www.rand.org/pubs/monographs/MG588.html; and Mark V. Arena and others, *Historical Cost Growth of Completed Weapon System Programs* (prepared by the RAND Corporation for the United States Air Force, 2006), www.rand.org/pubs/technical_reports/TR343.html.

cheaper to build than the fifth. That effect represents the learning curve in production, and based on historical evidence, the slope of that learning curve varies by ship type. Whereas the rate effect continues to reduce costs as the number of ships built simultaneously in the same shipyard increases, the reduction in cost that comes from learning tapers off as more and more ships are built. Eventually, learning becomes effectively exhausted. Generally, the effects of the learning curve have the smallest influence of all factors in CBO's methods for estimating shipbuilding costs.

CBO's cost estimates also incorporate the effects of the ship acquisition strategy, when applicable. For example, DDG-51 Arleigh Burke class destroyers are usually purchased under a multiyear procurement contract. Such a contract commits the government to purchase a certain number of ships in exchange for a price that is less than it would be if those ships were purchased under a series of individual contracts because the shipyard can better plan its labor force and its purchases of inputs over a longer period. If the government does not purchase the agreed number of ships in the multiyear contract, it must pay a substantial penalty to the shipbuilder.

Adjusting for Cost Growth in the Naval Shipbuilding Industry

In the final step of the process, CBO adjusts the estimate to account for the consistently faster growth in prices paid for labor and materials in the shipbuilding industry than in the rest of the U.S. economy. The earlier part of the process establishes how much a ship would cost to build today, given current economic conditions and including adjustments for rate, learning, and acquisition strategy. But because the ship will be built in the future, CBO adjusts its constant-dollar estimates of the costs of new ships by applying a factor that is derived from the difference between historical inflation in the shipbuilding industry and general inflation in the economy as a whole. CBO regards that difference as real cost growth in the shipbuilding industry—that is, the cost growth in the industry after the effects of inflation in the general economy have been removed. (For more discussion, see Box 2 in the main text.)

An Example: Projecting the Cost of Virginia Class Attack Submarines

Between 2017 and 2033, the Navy plans to purchase 24 Virginia class attack submarines at a rate of 2 per year in most years through 2025 and then at a rate of 1 per year for the rest of the period. Using the methods described above, CBO estimated that those submarines would cost a total of $74 billion (in 2016 dollars), or about $3.1 billion each. (The Navy's estimate was slightly lower: a total cost of $70 billion, or about $2.9 billion each.)

To estimate the cost of those future submarines, CBO used data for the ships' closest analogue—the Virginia class submarines that have already been built. Since production of the class began in 1998, the Navy has purchased 22 Virginia submarines: 12 currently serve in the fleet, and 10 more are in various stages of construction. To arrive at its cost projections, CBO started with the actual cost of $6.0 billion for the first Virginia class submarine. The agency then subtracted from that total the $2.3 billion that the Navy spent for nonrecurring engineering and detailed design—onetime expenses that are reflected solely in the cost of building the first submarine and that do not carry over to subsequent vessels.

On the basis of cost data for that lead ship and for 21 additional submarines that have been completed or authorized thus far, CBO estimated a learning effect of 95 percent: As successive ships are built, the cost of a ship twice as far in the production sequence is 95 percent of that of the ship to which it is being compared. So, for example, costs drop by 5 percent from the second ship to the fourth, by another 5 percent from the fourth to the eighth, and so on. Learning tends to level out because the distance to the next doubling is always increasing: 8 more ships must be built to reach the 16th ship and thus to achieve an additional 5 percent decline in costs. CBO applied the 95 percent learning effect going forward from the 24th submarine (which was recently authorized) so that the next 5 percent reduction would occur when the Navy purchased the 24th submarine in its shipbuilding plan—the 48th in the Virginia class. CBO estimated the cost of that submarine, without an adjustment to account for the rate effect, to be $2.8 billion.

At the same time that CBO applied the learning effect to the estimates for Virginia class submarines, it applied the rate effect where appropriate. When submarines are purchased at a rate of 2 per year (a practice that began in 2011 and that is anticipated to continue in most years through 2025 under the Navy's plan), the cost per submarine is reduced by 10 percent; that reduction is added to the reduction attributable to the learning effect.

In addition, in 2019 the Navy will start including what is called the Virginia payload module in most of its new Virginia class submarines. To account for the cost of redesign, CBO added about 10 percent, starting in 2019, to the estimated cost of most submarines. The 2 ships planned for 2025 would be the 39th and 40th in the class, and both would include the new payload module. The 40th ship's position in the production sequence is not quite double that of the 24th, so the learning effect was set at 3.7 percent rather than a full 5 percent.[2] Applying a 3.7 percent learning effect, a 10 percent rate effect, and a 10 percent add-on for the payload module to the 40th submarine, CBO arrived at an estimate of $2.8 billion in constant 2016 dollars for that ship.

In the final step, CBO applied a factor to account for the difference between general inflation in the U.S. economy and inflation specific to the shipbuilding industry. That real growth would increase the cost of submarines purchased in 2025 by 12 percent. After making all of those adjustments, CBO estimates that the 40th Virginia class submarine would cost $3.2 billion.

2. For more on procedures for estimating and applying learning curves, see Matthew S. Goldberg and Anduin E. Touw, *Statistical Methods for Learning Curves and Cost Analysis* (Institute for Operations Research and the Management Sciences, 2003).

Appendix B: The Difference Between the Navy's and CBO's Estimates for the Cost of New Ships

Each year, the Navy provides estimates of the costs of building each class of ship in its 30-year shipbuilding plan. The Congressional Budget Office also produces annual estimates. Table B-1 compares the two sets of estimates for the six most recent 30-year plans. For the 2017 plan, three classes of ships account for about 60 percent of the $57 billion difference between CBO's estimate (in 2016 dollars) of the total cost of the plan and the Navy's estimate: future large surface combatants, Columbia class ballistic missile submarines, and future small surface combatants.

Table B-1.

Share of the Difference Between the Navy's and CBO's Estimates of Shipbuilding Costs, by Program

Percent

	2012 Plan	2013 Plan	2014 Plan	2015 Plan	2016 Plan	2017 Plan
CVN-78 Gerald R. Ford Class Aircraft Carriers	18	13	3	3	9	5
Columbia Class Ballistic Missile Submarines	15	13	12	20	22	18
SSN-774 Virginia Class Attack Submarines	1	1	-1	3	3	7
Improved Virginia Class Attack Submarines (Replacements for Virginia class)	3	4	-3	8	2	2
DDG-51 Flight III Arleigh Burke Class Destroyers	-7	11	7	11	12	9
Future Large Surface Combatants	41	34	58	38	29	26
Littoral Combat Ships	1	3	4	5	2	0
Frigates (Modified LCSs)	n.a.	n.a.	n.a.	n.a.	0	0
Future Small Surface Combatants	5	4	7	0	5	16
LHA-6 America Class Amphibious Assault Ships	7	5	5	3	3	5
LX(R)s (Replacements for amphibious dock landing ships)	5	4	4	5	3	4
LPD-17 Replacements	n.a.	n.a.	n.a.	n.a.	5	4
T-AO-205 John Lewis Class Oilers	0	0	1	1	3	4
Other	8	7	4	4	2	2
Total	100	100	100	100	100	100
Memorandum:						
Difference in Billions of Dollars[a]	74	94	76	66	58	57

Source: Congressional Budget Office.

Numbers reflect the percentage that each ship program contributes to the total difference in costs between the Navy's and CBO's estimates for each plan. Positive values indicate instances in which CBO's estimate is higher, and negative values, instances in which the Navy's estimate is higher.

CVN = nuclear-powered aircraft carrier; DDG = guided missile destroyer; LCS = littoral combat ship; LHA = amphibious assault ship; LPD = amphibious transport dock; SSN = attack submarine; T-AO = oiler; n.a. = not applicable.

a. For each plan, the difference is expressed as a percentage in constant dollars from the preceding year. For example, the difference for the 2012 plan is calculated in 2011 dollars, and the difference for the 2016 plan is calculated in 2015 dollars.s

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About This Document

This Congressional Budget Office report was prepared as required by the National Defense Authorization Act for Fiscal Year 2012 (Public Law 112-81). In accordance with CBO's mandate to provide objective, impartial analysis, the report makes no recommendations.

Eric J. Labs of CBO's National Security Division prepared the report with guidance from Matthew Goldberg (formerly of CBO) and David Mosher. Raymond Hall of CBO's Budget Analysis Division produced the cost estimates with guidance from Sarah Jennings. Bernard Kempinski created the ship illustrations. Carla Tighe Murray of CBO provided comments on the report, as did Mandy Smithberger of the Project on Government Oversight, Scott Truver of Gryphon Technologies, and Dakota Wood of the Heritage Foundation. (Assistance from external reviewers implies no responsibility for the final product, which rests solely with CBO.)

Jeffrey Kling, John Skeen, and Robert Sunshine reviewed the report. Bo Peery edited it, Jeanine Rees (formerly of CBO) and Gabe Waggoner prepared it for publication, and Maureen Costantino (formerly of CBO) designed the cover. An electronic version is available on CBO's website (www.cbo.gov/publication/52324).

Keith Hall
Director

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