Naval Shipbuilding Expansion: The World War II Surface Combatant Experience

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From the demise of the Soviet Union in 1991 to the present day, the U.S. Navy has exercised uncontested control of the high seas. In the absence of peer naval competition, the surface combatant force was re-oriented towards land attack and near-shore operations in support of power projection. This historically unprecedented strategic situation appears to be nearing its end with the rapid growth and reach of the new 21st century Chinese navy and the reinvigoration of the Russian fleet. In response, U.S. Navy strategic planning has been re-balanced towards naval warfare against growing peer competitors, and the naval shipbuilding program is being ramped up. The last time this took place was in the run-up to World War II. What can we learn from that experience, so that the currently planned buildup can be as effective as possible? This paper offers an introductory examination of how the U.S. planned, designed, and built the surface combatant fleet during the interwar period (1920-1941), with a focus on destroyers. After accounting for differences in warship complexity and the industrial and shipbuilding capabilities of the United States of the 1930's and 1940's as compared to today, lessons for today's surface combatant designers and program managers are identified and discussed. Recommendations are made for further work.

KEY WORDS

World War II; modularity; adaptability; destroyer; acquisition

INTRODUCTION

The sudden and unpredicted end of the Cold War over 25 years ago left the U.S. Navy exercising uncontested control of the high seas. Lacking a realistic high-end naval threat, naval shipbuilding (and other defense spending) was reduced during the 1990s. A peace dividend was envisioned as resources were shifted to other uses in the economy. With the rapid decay of the ex-Soviet fleet, the U.S. Navy's principal role in the post-Cold War era was re-oriented towards projecting influence and power ashore. Naval ship production rates were cut back, with roughly ten warships of all types procured annually from seven shipyards in recent years. There was no call to seriously consider what would be required to mobilize the shipbuilding industry in response to aggression from enemy naval forces potentially capable of inflicting severe losses at sea.

The situation changed in the mid- to late-2010s. The geopolitical environment has become characterized by "overt challenges to the free and open international order and the re-emergence of long-term, strategic competition between nations" (Department of Defense, 2018). The peace dividend is no more, and the prospect of non-nuclear, industrial-scale war can no longer be dismissed. If such a war were to break out against a peer-level enemy or against an alliance of multiple peer-level enemies, demands on the U.S. Navy will escalate in short order. Shipyard production rates will have to increase drastically to offset early losses, repair war-damaged ships, and build the new warships and merchant ships needed to win.

The most recent major mobilization of the shipbuilding industry occurred prior to and during World War II. The World War II shipbuilding effort encompassed every type of naval and merchant ship, plus emergent types that were not envisioned prior to hostilities. What problems were faced then, how were they overcome, and what lessons can be applied today, to avoid wasteful duplication of lessons that should have been learned?

In this paper, we discuss the surface combatant shipbuilding experience, and we focus specifically on destroyers. Because the composition of a fleet depends on acquisitions over a long time period, we identify four distinct time spans where different considerations impacted the design and acquisition of the warships that served in World War II:

1. World War I era (up to 1922)
2. Treaty period (1922-1936)
3. Pre-war (1937-1941)
4. World War II (1941-1945)

Based on an analysis of these four eras in which the World War II fleet was designed and built, we derive specific lessons and recommendations for our current Navy as it faces the renewed prospect of long-term international strategic competition.

WORLD WAR I ERA (up to 1922)

At the height of World War I in Europe, the U.S. passed the Shipping Act of 1916, which among other provisions, created the United States Shipping Board and its Emergency Fleet Corporation. With the U.S. entry into the war, those agencies were assigned responsibility for the construction of merchant ships (United States Shipping Board, 1918). An unprecedented shipbuilding effort was quickly ramped up, but it was not quick enough and most of the ships were delivered post-war (Pettavino 1989).

The picture was similar on the naval side, where production of destroyers was massively accelerated but the ramp-up did not start soon enough. Prior to the U.S. entry into World War I, the Navy had commissioned 68 destroyers, all of which served during that war and one of which would serve in World War II. In response to entry into World War I, the U.S. Navy procured 273 destroyers (nicknamed flush-deckers) of the *Caldwell*, *Wickes*, and *Clemson* classes. But only 41 had been commissioned by the end of hostilities; the remainder entered service by 1922. By the U.S entry into World War II, 12 had been lost and 93 were scrapped under the London Naval Treaty of 1930 (see below); the remainder served in World War II (Silverstone 1965).

The World War I experience provided a cautionary lesson for World War II and is relevant to today's planning because:

1. A significant proportion of the World War II fleet had been designed and built to World War I requirements. This highlights that ships are long-lived; those designed for one era's conflict need to have the flexibility to remain valuable in the future.
2. Ship design and production was quickly and successfully accelerated, but the start date was too late.

TREATY PERIOD (1922-1935)

In 1921-22 the major powers met to hammer out an agreement with an objective of curtailing a potential post-World War I naval shipbuilding arms race. The result was the 1922 Washington Naval Treaty. Among its provisions was a set ratio of warship tonnage which allowed the United States and Great Britain 500,000 tons each, Japan 300,000 tons, and France and Italy each 175,000 tons. The five signatories would stop building capital ships and would reduce their naval fleets by scrapping older ships. The status quo of U.S., British, and Japanese bases in the Pacific was recognized but their expansion was outlawed. (Jordan 2011, Department of State, n.d.).

The subsequent 1930 London Naval Treaty limited the size and number of capital warships, cruisers, and destroyers. Specifically, it limited 84 percent of destroyers to not exceed 1,500 tons standard displacement (full load minus fuel and reserve boiler feed water) and to carry guns with a maximum 5.1-inch bore diameter.

The U.S. Navy had a large inventory of destroyers constructed during the World War I era. In compliance with treaty provisions, 93 were scrapped (Silverstone 1965) and no new destroyers were acquired until 1932. Instead, during the 1920s the Navy focused on a plan to maximize fleet efficiency. As described by Kuehn (2008) this plan included:

"1. the modernization of the battleships retained under the treaty,
2. the development and construction of all allowable aircraft carriers, cruisers, and submarines and,
3. the construction of a mobile base force with an extensive logistics train (the "fleet train") for use upon the outbreak of war."

Logistics became critically important because the Washington Naval Treaty prohibited the U.S. from establishing new fortifications and naval bases in the Western Pacific. Underway replenishment was perfected, and many coal burning ships were converted to burn fuel oil. In at least one case, the battleship *USS Texas*, the conversion from coal to oil resulted in nearly doubling the endurance range. (Kuehn 2008)

By the 1930's changes in technology and characteristics needed to support the fleet under treaty restrictions called for the development of new destroyers with increased endurance, better seakeeping, and improved anti-aircraft protection. To meet these evolving needs, sixty-one destroyers in seven classes were constructed under treaty restrictions.

During the treaty period, torpedo tubes and 5-inch guns were considered the primary weapon systems of a destroyer. There was considerable discussion within the Navy as to the proper number of torpedo tubes and 5-inch guns a destroyer should have. Many advocated that the torpedo tubes should be prioritized over the guns. Dual purpose guns (for both anti-air defense and anti-surface warfare) were incorporated to reflect the increasing threat of aircraft, particularly torpedo planes, while still being able to conduct shore-bombardment. Anti-submarine warfare (ASW) equipment, such as depth charge racks, were not included in the initial designs of these ship classes. The ASW equipment may have been omitted to achieve treaty limitations with the understanding that in time of war depth charge racks could be readily added (Friedman 2004).

While a second London Naval Treaty was signed in 1936, it did not include restrictions on the displacement of destroyers.

PRE-WAR (1936-1941)

1936 was marked by two ship design/production milestones. The first was the Merchant Marine Act of 1936 which created the U.S. Maritime Commission, the agency that carried out America's spectacularly successful World War II merchant ship production campaign.

The second milestone of 1936 occurred on December 31, with the expiration of the (first) London Naval Treaty. This removed a significant constraint on destroyer design. Authorized in 1937, the *Sims* class of destroyers were the first to be unconstrained by treaty. In recognition of the ASW threat, these ships were outfitted with depth charge racks. Long range accuracy against air and surface targets was materially improved with the introduction of the MK 37 fire control system, with its radar and optical director and analog fire control computer. Special Treatment Steel (STS) was also employed in key locations to enhance ballistic protection.

By January 1939, the threat of war compelled Congress to invest in strengthening the military as a means to guarantee national security. There was still a strong desire to keep the U.S. out of war both in the Atlantic and Pacific theaters.

The Educational Orders Act of 1939 authorized expending $2 million ($36 million in 2018 dollars) per year for five years to prepare key industrial factories to mass produce armaments should mobilization be required (Janeway 1951). While conceptually sound, the small amount of funds authorized limited the effectiveness of the initiative.

In some cases, foreign military sales were having a bigger impact on the defense industry. The administration viewed these positively since the cost of development and tooling would be paid for by others, reducing the cost to the U.S. Treasury should the U.S. mobilize. The sale of military equipment was not without controversy. In 1938, France was willing to spend $65 million on 1,000 planes for delivery by July 1, 1939. Incredibly, the U.S. Army opposed the sale on the basis that it would interfere with its own production plans, even though the Army did not then have funding authorization for sufficient aircraft orders to keep these airplane plants functioning (Janeway 1951).

In June 1939 Congress passed a law authorizing $25 million for stockpiling key strategic imports such as rubber.

Although war raged throughout Europe and China during the election year of 1940, the predominant sentiment of much of the American population remained to keep the United States out of war. Even though President Roosevelt appeared to have been convinced that the U.S. should enter the war, his campaign reflected the views of the electorate and did not suggest U.S. involvement in either the European or Pacific theaters (Beard 1948).

In March 1941, the Lend-Lease Act enabled allies such as the United Kingdom to procure warships and other munitions from the United States. As part of Lend-Lease, the British Destroyer Escort (BDE) was designed by Gibbs and Cox as a convoy escort with a lower speed than the fleet destroyers. The BDE was based on concept designs developed by the U.S. Navy but not put into production up to that point. Once the U.S. entered the war, most destroyer escorts built in American shipyards were commissioned into the U.S. Navy.

By 1941 destroyers were being modified to increase splinter protection and light anti-aircraft guns. Performing anti-submarine warfare in the Atlantic required additional depth charge capability. To compensate for the additional weight, in-service ships had to give up some capability in the form of a gun mount, a torpedo director, and searchlights. (Friedman 2004).

The first ships of the *Fletcher* class were authorized in 1941. While the three previous classes of ships (*Sims, Gleaves,* and *Benson*) were not constrained by treaty, their designs were based on incremental changes to the previous treaty-constrained classes. The *Fletcher* class was the first clean-sheet design destroyer without a direct lineage to the treaty designs. These large destroyers (2,500 tons full load) initially incorporated five 5-inch guns with the associated MK 37 fire control system, ten torpedo tubes, a quadruple 1.1-inch director-controlled machine cannon, four .50 caliber machine guns, four depth charge projectors, and two depth charge racks. Before December 1941, the number of depth charge projectors was increased to six (Friedman 2004).

Fig. 1. USS *Fletcher* (DD 445) underway off New York, 18 July 1942 (www.history.navy.mil – 19-N-31245)

Altogether, 182 destroyers in four classes were authorized in the pre-war period. Of these, 39 would be in commission when the U.S. entered the war.

WORLD WAR II (1941-1945)

Fig. 2. depicts the number of destroyers in commission by time period of authorization for five dates spanning the U.S. involvement in World War II. On Dec. 7, 1941, over three quarters of the destroyer fleet was composed of ships from the WWI era and the treaty period. At the end of the war, more than half the destroyers in commission had been authorized prior to U.S. entry into the war; over 90 percent of the destroyers in commission were authorized before July 1, 1942. Decisions made early had a significant impact on the fleet composition throughout the war.

Few of the destroyers authorized in fiscal year 1943 (July 1, 1942 to June 30, 1943) or later were commissioned prior to the end of the war.

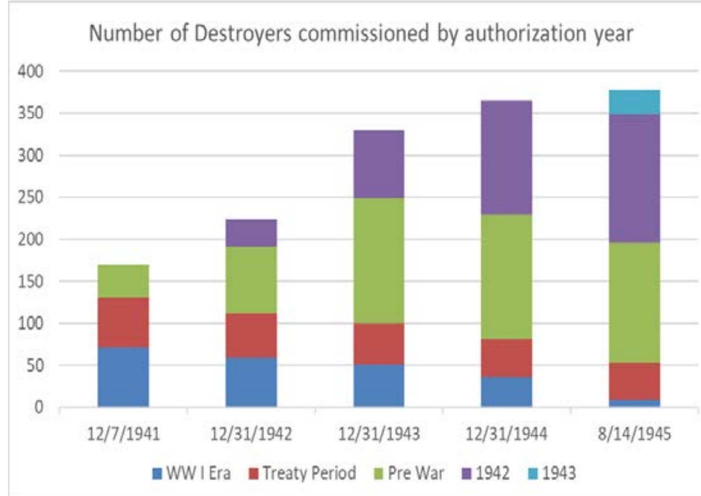

Fig. 2. Number of destroyers commissioned by authorization year. (Data: Fahey (1939, 1941, 1942, 1944, 1945, 1950), Janes (1992), Friedman (2004), Navy Department (1921), en.wikipedia.org, www.history.navy.mil and destroyerhistory.org)

During the war, destroyer armaments evolved as the nature of the war changed and the effectiveness or lack of effectiveness of different systems became apparent in combat. Soon after the attack on Pearl Harbor, the quadruple 1.1-inch machine cannons were replaced with twin 40 mm Bofors and .50 caliber machine guns were replaced with 20 mm Oerlikon cannons. As the war progressed, additional 40 mm and 20 mm guns were installed on the ships (see Figs. 3-4). In late 1942 and 1943, many of the *Fletcher* class and other pre-war destroyers were modified to incorporate a combat information center (CIC) for coordinating the employment of the weapons and sensors. In contrast to the prewar belief that the torpedo tubes were the primary weapon of the destroyer, in 1945 many ships of the *Fletcher* class had their forward torpedo tubes replaced with two twin Bofors and seven single mount Oerlikons replaced by six twin-mount Oerlikons to respond to the increased threat of *kamikaze* attacks (Friedman 2004).

Fig 3. USS *Fletcher* (DD 445) at Mare Island Navy Yard on 13 August 1943. Circles mark alternations including the addition of Bofors twin mounts. (www.history.navy.mil – 19-N-50812)

For maintenance and modernization, destroyers were typically taken offline for only brief periods of time by modern standards. For example, the modernization shown in Fig. 3 was completed in such a short time that the USS *Fletcher* was out of the combat theater for only slightly more than three months.

Fig. 4. 20 mm Oerlikon gun and 40 mm Bofors on USS *Halford* (DD 480) during World War II.
(U.S. Navy Photo: 80-G-K-1629)

In general, the ships designed during the war were not commissioned in time for combat or were cancelled. Examples include: *Midway* class aircraft carriers (CVB 41), *Montana* class battleships, *Des Moines* class cruisers (CA 134), *Oregon City* class cruisers (CA 122), *Worcester* class cruisers (CL 144), and *Fargo* class cruisers (CL 106). The notable exceptions were the tank landing ships; the LSTs. While the design of the LST began in November 1941, one month prior to U.S. entry into the war, much of the design work was conducted in early 1942. Over 1,000 LSTs were produced during World War II. The first LST began construction in June 1942 with 23 in commission by the end of 1942. LSTs were produced in many non-traditional shipyards; the largest builders were Missouri Valley Bridge and Iron Co. of Evansville, Indiana and Chicago Bridge and Iron of Seneca, Illinois. By the end of the war, construction time was down to two months.

The ascendency of the aircraft carrier over the battleship did not occur immediately after the attack on Pearl Harbor on December 7, 1941. Indeed, as long as Japan had battleships of its own and prior to the arrival of fast (*Iowa* class) battleships in the U.S. fleet, “the dilemma facing U.S. commanders before fast battleships arrived in the Central Pacific in 1943 was whether to pursue a Japanese force with aircraft carriers and risk running into Japanese battleships or cruisers” (McBride 2000). The ability to produce aircraft carriers faster than battleships may also have contributed to the dominance of the aircraft carriers. *Essex*-class carriers could be built in five shipyards in roughly 18 months. By the end of the war, 18 *Essex*-class carriers were commissioned. In contrast, the four *Iowa* class battleships were produced in two shipyards and took from two to over three years to construct.

The construction rate of battleships was limited by the production capacity of armor which had atrophied due to reduced orders resulting from the Washington and London naval treaties (Furer 1959). While efforts to increase armor production capacity were met with some success, the allocation of armor to a single battleship would deprive armor to many other warships. Hence, even had the battleship been in higher demand than the aircraft carrier, the ability to produce more aircraft carriers faster meant that the fleet would be dominated by aircraft carriers.

This is a reminder that industrial base production capacity is closely related to the tactics that an armed force employs; a fact that is sometimes overlooked. Donald Rumsfeld remarked in 2004, "As you know, you go to war with the army you have. They're not the army you might want or wish to have at a later time" (Kristol, 2004).

Although production of the *Fletcher* class had only commenced earlier in the year, by late 1941 the need for increased air defense became apparent. The resulting *Sumner* class (Fig. 5), based on the *Fletcher* design, replaced the five single 5-inch gun mounts with three twin mount 5-inch guns and additional Bofors. Ships of the *Sumner* class would not see combat until 1944. The *Gearing* class was a stretched version of the *Sumner* class; the extra 14 feet of length provided tankage for additional endurance range. The first ships of the class were commissioned in mid-1945.

Fig. 5. USS *Compton* (DD 705) off New York, 25 October 1944. (www.history.navy.mil – 80-G-288078)

The destroyer escort program highlighted the need for flexibility in requirements setting and in design, both of which were not just influenced but actually dictated by industrial base considerations. The ships were required for a variety of missions, including replacing the World War I flush-deckers in North Atlantic service (Silverstone 1965).

Shortages of propulsion equipment resulted in incorporating various propulsion plants based on availability of propulsion equipment. Propulsion plants ranged from diesel electric, to steam turbo-electric, diesel reduction gear and steam turbine reduction gear. Variations in hull and propulsion resulted in the production of six distinct classes (Friedman, 2004). 1,005 DE's were ordered by 1943, however only 563 were completed and "in order to get them to sea, 254 were completed with only half the designed horsepower (*Edsall*, *Cannon*, and *Evarts* classes), resulting in a speed of only 21 knots instead of the designed 24" (Silverstone 1965).

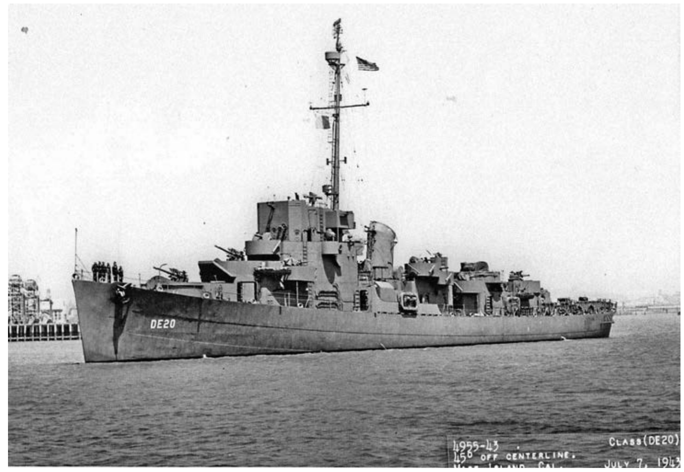

Fig. 6. USS *LeHardy* (DE 20) in the Mare Island Channel, 1943. (http://www.navsource.org/archives/06/images/020/0602016.jpg accessed 28 May 2018). This ship is of the *Evarts* class, which was fitted with diesel-electric drive of half the originally designed shaft horsepower (Silverstone 1965).

As newer destroyers and destroyer escorts entered the fleet, many of the older WW 1 era destroyers demonstrated their intrinsic flexibility through conversions to other roles such as minesweepers (DMS), mine layers (DM), seaplane tenders (AVD and AVP), high speed transports (APD), and miscellaneous auxiliaries (AG). Some of the seaplane tenders were reclassified as destroyers in 1943 (Silverstone 1965).

The U.S. Navy lost 71 destroyers in World War II as shown in Fig. 7. The heaviest losses were in the first year of the war and all of those ships were from the pre-war or earlier periods. Many pre-war ideas of how sea warfare would be conducted were found to be inadequate, resulting in a period of learning and adjustment in tactics. As observed by Gray (2006), "All warfare is a race between belligerents to correct the consequences of the mistaken beliefs with which they entered combat."

Of the 20 destroyers lost between November 1944 and the end of the war, 14 were lost due to Japanese tactical innovation in the form of *kamikaze* attacks, three sank during a typhoon in December 1944, one was sunk by gunfire, one by torpedo attack, and one by mine. As mentioned earlier, *kamikaze* tactics caused the U.S. Navy to remove torpedo tubes in order to install additional anti-aircraft guns.

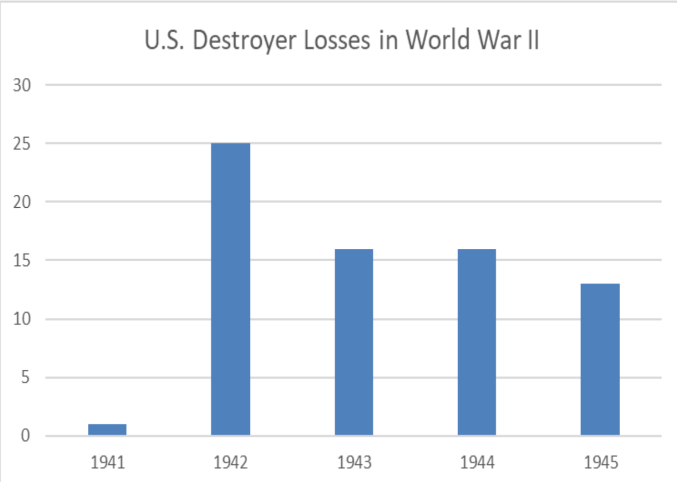

Fig. 7. U.S. destroyer losses in World War II.
Does not include destroyer escorts or destroyers that had been converted to other roles at the time they were lost.
(Data: Friedman 2004 and Fahey 1945.)

LESSONS FOR TODAY

Should the U.S. ever have to quickly expand its fleet in response to aggression from a peer or near-peer navy, key lessons to be learned from the World War II experience include:

1. Much of the fighting will be done by the ships in the fleet at the start of hostilities.
2. With few exceptions, ships designed during wartime will not enter the fleet in numbers prior to the end of the fighting. “Only equipment in production can pass into mass production” (Friedman 2004).
3. High volume production will not happen without expansion in industrial capacity, both in the shipyards and in their supply chains. This will delay high rates of ship delivery.
4. Shortages of key components and materiel will likely require rapid design modifications. Flexible relaxation of key performance parameters will likely be necessary in order to incorporate substitutions.
5. Speed of construction and battle damage repair will in large part determine fleet composition and thus the tactics that can be employed.
6. Useful ships that can be procured fast and then promptly sent to sea, will have more relevance than exquisitely capable vessels requiring a protracted design-build-testing effort.
7. Ships, weapons, and tactics will evolve rapidly and unexpectedly once the bloodshed starts. Speed of adaptability is of the essence.
8. Modernization of a ship class is time consuming. Ships in modernization are not available for combat; hence upgrades must be phased in over time (not done in blocks) to enable enough ships to remain in the fight.

U.S. DESTROYER ACQUISTION TODAY

The U.S. Navy currently has DDG 51 Flight IIA variants in serial production at two shipyards: Ingalls Shipbuilding and Bath Iron Works (BIW). Both have won contracts for constructing DDG 51 Flight III variants. BIW is also completing the third and final DDG 1000 class destroyer.

During ship construction, the period between the keel date and when the ship is launched is dominated by the construction of ship assemblies, pre-outfitting, and integration of the assemblies into the final ship. After launch and prior to delivery, work centers on system integration, any remaining outfitting, and testing.

For the most recent six DDG 51 class ships delivered to the Navy from BIW, the average time from the keel date to launch was 1.2 years and from keel date to delivery was 2.1 years. For Ingalls Shipbuilding the average times were 1.4 years and 3.0 years respectively (data from www.nvr.navy.mil).

In addition to the DDG 51 and DDG 1000 classes, two variants of the Littoral Combat Ship (LCS) class are in serial production. They are designed to embark modular mission packages that enable rapid reconfiguration for different missions. Mission packages are being developed for anti-submarine warfare, anti-surface warfare, and mine warfare.

For the second through fifth ships of the *Freedom* variant, the average time from the keel date to launch was 1.9 years and from keel date to delivery was 3.8 years. For the *Independence* variant, the average times for the second through seventh were 1.1 years and 2.9 years respectively. (data from www.nvr.navy.mil)

SHIPYARD CAPACITY

As reported by O'Rourke (2018), John P. Casey, Executive Vice President - Marine Systems, General Dynamics testified to Congress on May 24, 2017:

"Bath Iron Works is well positioned to support the Administration's announced goal of increasing the size of the Navy fleet to 355 ships. For BIW that would mean increasing the total current procurement rate of two DDG 51s per year to as many as four DDGs per year, allocated equally between BIW and HII. This is the same rate that the surface combatant industrial base sustained over the first decade of full rate production of the DDG 51 Class (1989-1999). No significant capital investment in new facilities is required to accommodate delivering two DDGs per year. However, additional funding will be required to train future shipbuilders and maintain equipment. Current hiring and training processes support the projected need and have proven to be successful in the recent past. BIW has invested significantly in its training programs since 2014 with the restart of the DDG 51 program and given these investments and the current market in Maine, there is little concern of meeting the increase in resources required under the projected plans."

With a larger workforce and capital investment, Ingalls Shipbuilding would likely be able to support additional destroyer production. The limit on destroyer production depends on the type and number of other ships produced in its yard. Between 1975 and 1980, Ingalls, with much of the same facilities as it has today, delivered thirty *Spruance*-class (DD 963) destroyers to the Navy, averaging five destroyers a year. During 1978, the peak year, Ingalls delivered eight destroyers. (www.nvr.navy.mil)

DESTROYER MAINTENANCE AND MODERNIZATION TODAY

Since 2014, the Optimized Fleet Response Plan (OFRP) has defined the operational framework for ships in the U.S. Navy. This framework has four phases: maintenance, basic, integrated or advanced, and sustainment. Major shipyard or depot-level repairs, upgrades, force reconstitution, and platform modernization occur during the maintenance phase. The basic phase and the integrated or advanced phase concentrate on preparing the crew to successfully operate their ship either independently or as part of a larger force structure. Ships are available for tasking or deployment during the sustainment phase (OPNAVINST 3000.15A)

As described by Yardley et al. (2016), surface combatants are transitioning to a 36-month OFRP cycle as shown in Fig. 8. In that figure, the Selected Restricted Availability (SRA) corresponds to the maintenance phased of the OFRP. As expected, most modernization efforts are concentrated during this period. Ideally, crews will train on the equipment they will use during the sustainment phase. The sustainment phase also typically includes a deployment of roughly eight months.

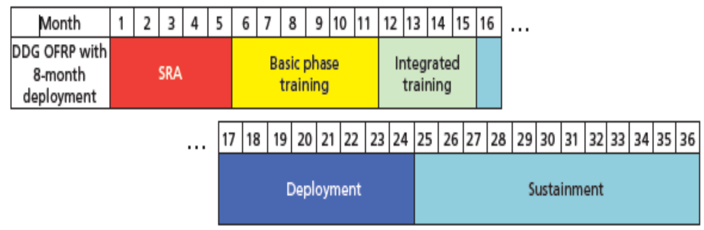

Fig. 8. 36-month operation cycle for surface combatants (Yardley et al., 2016)

A 36-month operation cycle implies that under normal conditions, the fastest that an upgrade or new equipment can be implemented fleetwide is three years. Normally however, budgetary constraints force longer implementation schedules.

IMPLICATIONS ON MOBILIZATION

If a future conflict with a peer or near-peer competitor is analogous to World War II, the first year of conflict may see very intense combat, high losses, rapid learning, and the need for fast adaptation of ships and tactics. During the first year, the U.S. Navy may experience destroyer losses on the order of two ships a month as it did in 1942. This loss rate may fall off in the following years as ships and tactics evolve.

The need to replace losses as well as to build up the Navy to dominate the enemy requires an order of magnitude increase in the destroyer production rate. Instead of producing two to four destroyers a year, our shipyards may be called upon to deliver forty destroyers a year for the duration of the conflict.

More production will be required than dictated by force structure needs, because destroyer losses are likely to be heavy early in the conflict. Based on the U.S. Navy's World War II experience, over 25 percent of the preconflict destroyer fleet may be lost in the first year of combat.[1] Additional destroyers will likely be lost in the subsequent years. Starting the ramp up of ship deliveries two or three years after the conflict begins will not be adequate. If possible, the ship construction ramp up and the expansion of shipyard and supply chain production facilities should start prior to the start of hostilities, as was done in World War II.

RECOMMENDATIONS

The following recommendations are provided to facilitate an order of magnitude increase in the rate of warship production, and a significantly reduced construction time:

1. Use modern digital modeling and simulation for ship design. Maintain digital models of all ships.
2. Build digital simulation models of the industrial base and use them to evaluate product designs, bottlenecks, and capital improvements in the shipyards and in the critical supply chain production facilities.
3. Run the digital ship preliminary designs through the digital industrial base simulation models prior to freezing the key performance parameters.
4. Implement rigorous design-for-production and link it to industrial base modeling and simulation, to ensure that the designs are producible.
5. Configure the ship designs to enable substitution of key components that may have limited availability.
6. Provide for integration of the combat systems in a facility other than the shipyard. Dis-aggregate the payload from the hull, mechanical, and electrical (platform) work.
7. Incorporate modularity and adaptability in warship designs.
8. Take advantage of modularity and adaptability to incorporate major changes in ship weapon systems.
9. Incrementally modify the ship design to reflect feedback from the fleet.
10. Design warships to be survivable; to preserve the force structure in the face of enemy action.

Digital Model of Warships

Designing a warship in a digital environment and maintaining that digital model through the life of the ship will become critically important during a future war for several reasons including:

1. The design of the ship can be quickly adjusted to react to shortages of materiel and components during the ship's construction.
2. Managing the configuration of each warship. The employment of modularity and flexibility may result in many ships of the same class having different mission systems. At the onset of peer-level naval combat, commonality will assume a low priority in the interest of getting ships out to sea quickly using whatever is available. This reflects the difference between peacetime naval procurement and operations, and wartime. (For more on the difference between peacetime and wartime naval force structure planning, see (for example) Koenig et al 2008.)
3. Changes that are contemplated during the war to counter enemy capabilities can be thoroughly investigated and properly designed prior to the ship entering a modernization availability.
4. In response to battle damage, analysis of the digital model can inform damage control and salvage decisions, to minimize the loss of life and possibly preventing loss of the ship.

Digital Model of Shipyards

Accelerating shipyard throughput quickly and effectively requires overcoming current bottlenecks and also a set of judicious capital improvements to move beyond that point. This can be done in the quickest and most reliable manner, avoiding guesswork and trial-and-error, by building and using a digital shipyard simulation model.

Work on modeling shipyard processes ramped up in earnest with a seminal U.S./South Korea effort funded by the Office of Naval Research International Field Office (Asia) in the early 2000s (Lamb et al 2006). Progress has been steady since then, notably in South Korea whose researchers have published a string of papers on this subject in the *Journal of Ship Production and Design* and elsewhere. Examples include Woo et al (2016), Back et

[1] In just the first six months of that war, five of 13 destroyers in the U.S. Asiatic Fleet were lost to enemy action.

al (2016), Lee et al (2014), Oh et al (2012), and Woo et al (2010).

Modular Adaptable Warships

Modular, adaptable designs are often part of a design strategy for ensuring warships remain militarily relevant over a service life where the requirements could change significantly, often in an unknown way (Schank et. al 2016; Doerry and Koenig 2017A). Many technologies are available for implementing modularity and adaptability. In Doerry and Koenig (2017B), we list the following:

- Service life allowances
- Planned access routes
- Mission packages
- Standard interfaces
- Mission bays
- Weapon modules
- Aperture stations
- Off-board vehicles
- Flexible infrastructure
- Modular hull ships

Many of these can facilitate increased production by decoupling the ship platform from its mission systems or payload as described by Greenert (2012). Since many of the needed adjustments in the ship design to counter enemy advancements will likely be required on the payload, the mass production of the platform can occur independently of the evolving payload. The definition of a payload can be delayed as long as possible to ensure the ship will be militarily relevant in the fight. Modularity enables concurrency of the design and production of the mission systems with the production of the ship (platform).

Different Facilities for Payloads and Platforms.

By decoupling the mission systems from the ship hull, mechanical and electrical systems, the shipyards can concentrate on high-volume production. Ideally, the mission systems for a specific ship would be integrated ashore for testing prior to the arrival of the ship at the module installation facility. With the shore testing completed, the equipment would be rapidly installed onboard ship with minimal additional testing. This approach, proposed by Lawson (1977) as part of the SEAMOD concept, would minimize the time between launch and delivery because of the reduction of payload integration work. In addition, creating or modifying facilities to integrate the mission systems into the platforms may require less work and time than greatly increasing the production capacity of the shipyards. This is an example of an industrial strategy question that can be quantitatively assessed using a (future) digital simulation model of the industrial base.

Incremental Improvement

The acquisition community should actively seek feedback from the crews that engaged in combat. Improvements that contribute to the ship's effectiveness and survivability should be incorporated into the ship design if production is not delayed. Particularly early in a major war, increasing the number of effective ships at sea is of high priority. Hence it is important to not only increase the rate of production and reduce production time, but also to reduce combat losses, while still achieving military objectives.

Modernize Using Modularity and Adaptability

As the war progresses, changes to the ship's mission systems will likely be required to counter tactical adaptations and innovations of the adversary. Modularity and adaptability features will facilitate the upgrading the combat capability of ships in the shortest duration modernization period possible, to quickly returning modernized, updated warships back to wartime deployment.

Key Component Substitution

In ramping up production of warships, shortages of key materiel are likely to occur. As was done with the destroyer escort program in World War II, the acquisition program should proactively provide options for substitutions of key components such as engines and transmissions. This may require larger intakes and uptakes and less densely packed machinery rooms.

The design process and contracting process should be sufficiently agile to quickly react to key component shortages. Digitally modeling both the ship and the shipyard will facilitate rapid substitution of key components.

CONCLUSIONS

Today's naval ship acquisition processes have evolved during nearly three decades of a post-Cold War era marked by the absence of a threat of peer-level naval combat. The naval mission, ship requirements setting process, ship design approaches, and industrial base policy and management have until very recently been geared to suit the needs of a peacetime force and power projection missions. Reorientation towards meeting the challenges of potential peer level, non-nuclear, industrial-scale war requires new thinking. In some key respects, the new geopolitical/naval strategic environment confronting the U.S. Navy more closely resembles that of the pre-World War II era than the more recent post-Cold War era.

RECOMMENDATIONS FOR FURTHER WORK

This article is intended to provoke discussion and the development of a research agenda for further work. It is an initial exploration of a relevant era of ship design and acquisition through the lens of one ship type and one navy. There is much more to be learned by more thoroughly mining this subject, and by broadening the coverage to include other ship types and the experiences of other navies.

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